VEGETATION RECOVERY FOLLOWING POLLUTION CONTROL AT TRAIL, BRITISH COLUMBIA

by

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ABSTRACT

This research has examined the nature and extent of the vegetation recovery at Trail, B.C. following pollution control. Sulphur dioxide emissions from the heavy metal smelter reached a peak in the late 1920's. By this date serious destruction of the natural vegetation had occurred. The recommendations of a tribunal set up to investigate the problem of air pollution were implemented by 1940. Hence, air qualities suitable for the re-establishment of the vegetation have prevailed for some 30 years.

The smelter fumes were restricted to the Columbia Valley, resulting in a pollution gradient upstream and downstream from the smelter. A stratified random sampling design based on distance from Trail was adopted to determine whether the present spatial variation in the vegetation cover reflected pollution conditions. Such variation was postulated to be the result of one or more of the following processes:

a) Differing periods of time since release from the toxic fumigations of the main pollution period.

b) Differing degrees of former vegetation destruction.

c) Occasional toxic fumigations during the recovery period.

d) Environmental controls unrelated to fumigation patterns.

Analysis-of-variance and linear correlations were conducted on selected climatic, edaphic, and pollution data to ascertain if macro-environmental conditions were uniform throughout the study area. The results indicated that significant spatial variation occurred in these variables. The preliminary analysis of the vegetation data was carried out by linear correlation to determine whether the variation in the cover could be related to distance from the pollution source. Apart from a decrease in the number of species present as the smelter was approached, only the density and standing crop of the coniferous species reflected the pollution gradient with some conifers having survived the period of pollution. However, few coniferous seedlings were found in the area which suggested that minimal seed input had occurred. Similarly, no evidence of successful seed germination was noted for birch or aspen, and it was concluded that regrowth in these species had probably developed from remnant rootstocks. Some of the patterning in the microclimatic and micro-edaphic variables was related to distance from Trail.

Multiple regression analysis was subsequently used to determine those factors which most affected the recovery of the vegetation. In the majority of cases the presence of older individuals of a species was integral to its continued establishment. For the conifers, this suggested the need for mature seed bearing individuals; in the case of the deciduous species this reflected the success of asexual reproductive methods. Similar analyses were conducted on the micro-environmental variables to determine the principal factors which brought about autogenic modification.

It was concluded that a shortage of seed had been the most restrictive factor to the re-establishment of the former cover, a condition which most seriously affected the conifers. The present cover appeared to be closely linked to the degree of former destruction, although variation in the macro-environment, particularly precipitation, also accounted for some of the patterning in the vegetation.

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Chapter 1

THE NATURE OF THE STUDY

Introduction

The expansion of industrial activity has been accompanied by a sustained increase in atmospheric pollution (Lamb, 1962; Landsberg, 1970; Mitchell, 1970; Plass, 1959). The adverse effects on vegetation of such pollution have long been recognised, with much of the early work conducted in Europe (Cohen and Rushton, 1912; Rushton, 1921; Toumey, 1921; see also Holmes et al., 1917, pp. 506-520, and Scurfield, 1960, p. 339). This, and subsequent research, concentrated on assessing damage to agricultural and forest crops. Consequently, an extensive literature has been compiled on the effects of specific pollutants on plants of economic importance (Adams, 1956; Adams et al., 1952; Brandt and Heck, 1968; Haggestad, 1968; Hepting, 1964, 1966, 1968; Katz and McCallum, 1952; Linzon, 1966, 1971; Metcalfe, 1953; Middleton, 1956, 1961; Middleton et al., 1950; Miller et al., 1963; Shaw et al., 1951), and on the manner in which they act (Bobrov, 1952; Darley and Middleton, 1966; Dugger et al., 1966; Hull and Went, 1952; Katz, 1949; Katz and Shore, 1955; Setterstrom and Zimmerman, 1939; Thomas and Hendricks, 1956; Thomas et al., 1950, Wood, 1968).

Since the early 1900's several North American studies have been concerned specifically with the effects of smelter fumes on vegetation. These were undertaken primarily in response to legal actions brought against certain smelting companies. For example, Widstoe (1903) investigated the detrimental effects of smoke from the copper smelters near Bingham, Utah; Haywood (1905, 1910) carried out surveys in the vicinity of the copper smelter near Redding, California, and in the area around the Washoe and Anaconda smelters, Montana (see also Hedgecock, 1912), and Hedgecock (1914) worked in Tennessee. Holmes et al. (1917) carried out an intensive survey for the suit brought against the Selby smelter, also in California. General accounts of the problem of atmospheric pollution by industrial wastes are given by Swain (1923) and Wells (1917), with experimental work on the toxicity of smoke to plants undertaken by Knight and Crocker (1913), and Rushton (1921): later work by Bleasdale (1952) confirmed their conclusions. In 1929 the National Research Council of Canada, in response to a request from the United States Government, began investigating the problem of damage to vegetation in Stevens County, Washington, allegedly caused by sulphur dioxide fumes emitted from the smelter at Trail, B.C. The results of this comprehensive research, published in 1939 (Katz et al., 1939), showed conclusively that the smelter effluent was an important factor limiting vegetation growth and reproduction in the region. Scheffer and Hedgecock (1955) reported on the effects of sulphur dioxide on vegetation both in the vicinity of the Anaconda smelter in Montana and in the Trail, B.C. region. This provides a useful supplement to the findings of the N.R.C. of Canada study. More recent investigations carried out around smelters include those by Dreisinger (1959), Dreisinger and McGovern (1970), and McCallum (1959) in the Sudbury, Ontario area, the study by Gorham and Gordon (1960) near Falconbridge, Ontario, and the work by Gordon and Gorham (1963) at Wawa, Ontario.

These, in common with the earlier research, dealt primarily with the destruction of the vegetation.

Objectives of the Study

The present research has been concerned with the natural revegetation of an area around an industrial site following the implementation of pollution controls. The area selected was in the vicinity of Trail, B.C. where the Consolidated Mining and Smelting Company of Canada (Cominco) established a large non-ferrous smelter designed specifically to treat the ores and concentrates of lead and zinc. Due to the nature of the smelting process many tons of sulphur dioxide are released to the atmosphere each month: in the past this had a serious detrimental effect on the vegetation of the adjacent area. However, since the early 1940's, levels of emission have been drastically reduced as a result of strictly enforced control measures. Consequently, a major restraint inhibiting plant growth was removed and the recolonization of the area has been proceeding.

Several advantages accrued from the choice of Trail as the study area. First, it had a well documented history of vegetation destruction with respect to smelter fumes, fire, and logging (Katz et al., 1939; McBride, 1937; Scheffer and Hedgecock, 1955). Secondly, the dates of improvements in the ore refining processes were available (King, 1950) together with sulphur dioxide emission data since 1940. Thirdly, comprehensive air photo coverage existed for the area since 1939. In that year a flight was made down the Columbia Valley followed in 1952, 1957, 1959, and 1969 by vertical coverage for the Columbia Valley and much of the surrounding region. In 1971 a further flight was made down the valley giving oblique coverage for the region (see Fig. 1). From such sources it was possible to delineate those areas which were affected by smelter fumes, to determine the date when sulphur dioxide emissions were reduced to levels tolerable to the native species, and to demonstrate that the vegetation in the area had been in a state of recovery.

Previous workers in the Trail area (Katz et al., 1939; Scheffer and Hedgecock, 1955) concentrated on the destruction of the plant life and the associated deterioration of the environment rather than the recovery of the fume damaged vegetation. The main object of the N.R.C. study of 1939 (Katz et al., 1939) was to determine the nature and extent of the damage to that part of the State of Washington subjected to smelter fumes in order that compensation could be arranged. An ancillary study was similarly conducted by the United States Government (Fisher et al., 1936) with reports being submitted to an Arbitral tribunal. Initially this work was carried out by field studies, but later the projects were extended to include experimental work on the fumigation of crop plants and coniferous species. Scheffer and Hedgecock's (1955) work was chiefly concerned with ascertaining the relative susceptibility of the native tree species to injury from sulphur dioxide fumigations, and in determining the effect of smelter fumes on timber reproduction in the affected parts of Washington State in the late 1940's.

Although high concentrations of sulphur dioxide appeared most responsible for the destruction of the vegetation in the Trail area, it could not be assumed that a reduction in emission was all that was required to ensure revegetation. Sawyer (1951, p. 2687) referring to

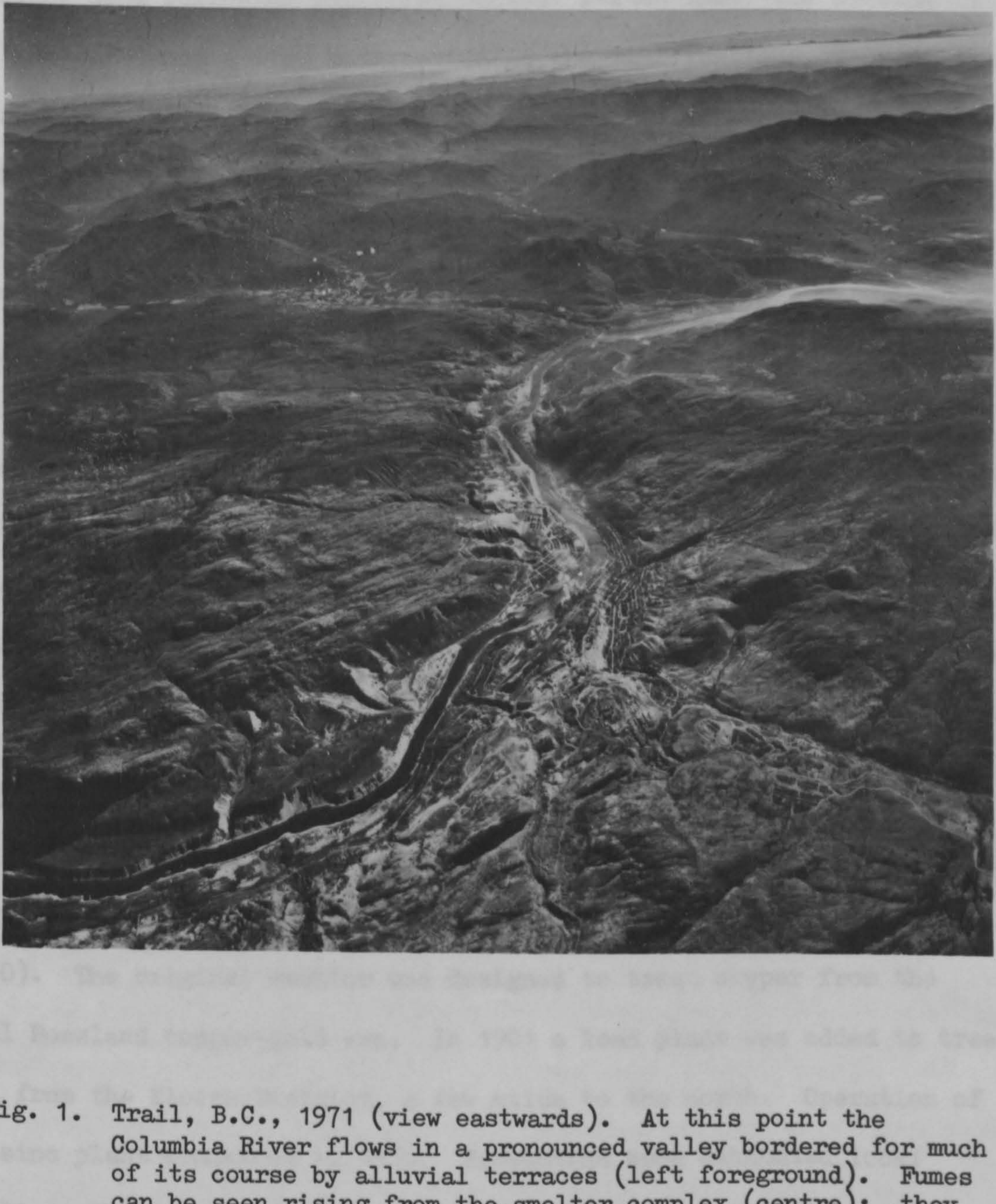

Fig. 1. Trail, B.C., 1971 (view eastwards). At this point the Columbia River flows in a pronounced valley bordered for much of its course by alluvial terraces (left foreground). Fumes can be seen rising from the smelter complex (centre): they are often confined by the valley, and drift upstream or downstream according to the direction of the prevailing wind

the Trail area following pollution control states that "the problem is now licked." Such a view underestimated the ramifications of vegetation destruction. Removal of the plant cover resulted in the concomitant deterioration of the physical environment; this required modification before the vegetation could be restored to its original condition. The manner in which the environment was altered and the extent to which amelioration had enabled regrowth to proceed in the area formed a basic part of the current research. This study was therefore concerned with secondary succession in the Trail area initiated by the destruction of the former vegetation and environment by smelter fumes. It concentrated on determining the nature of the present regrowth in the area, on assessing the possible factors which led to its present composition and distribution, and on tentatively predicting the future of this vegetation.

Industrial History of the Trail Area

The development of the industrial complex at Trail since its inception in 1896 is well documented by Katz et al. (1939), and King (1950). The original smelter was designed to treat copper from the local Rossland copper-gold ore. In 1901 a lead plant was added to treat ores from the Slocan District, a few miles to the north. Operation of the zinc plant commenced in 1916. Production soon exhausted local supplies; thus a considerable tonnage of ores and concentrates from neighbouring regions was also treated. Although the general trend indicated an increase in production as improved smelting methods were developed, fluctuations occurred reflecting market conditions, particularly during the depression of 1931-33. Annual production data for lead and zinc and associated sulphur emissions are shown in Fig. 2.

For the period 1900-1904 the amount of sulphur released from the Trail plant was in the order of 1,000 tons per month.[1] A steady increase in sulphur emission occurred until by 1919 the amount entering the atmosphere exceeded 5,000 tons per month. Much of this increase resulted from the opening of the zinc roasters in 1916. Because of a substantial increase in production, emission was doubled so that during the period 1926-1930 the amount of sulphur released to the atmosphere was between 9,000 and 10,000 tons per month. It was in 1926 that a claim for smoke damage was filed by the United States Government, and the following year an International Joint Commission was appointed to investigate the alleged damage to vegetation in Stevens County, Washington. The reduction in gas emission commenced in the late 1930's following the instigation of improved control methods. By 1941 emission was considered to be at a level tolerable to the native vegetation (Wadey, 1970). At present, sulphur released to the atmosphere totals about 1,000 tons per month.

A second smelter, located at Northport, Washington, was also in operation until the early 1920's. This was used intermittently from 1896 until 1908 during which time open roasting was practised with some 2,100 tons of sulphur being released per month. From 1916 to 1921 it was in continuous operation with sulphur emissions estimated at about 900 tons per month. This undoubtedly caused severe damage to the

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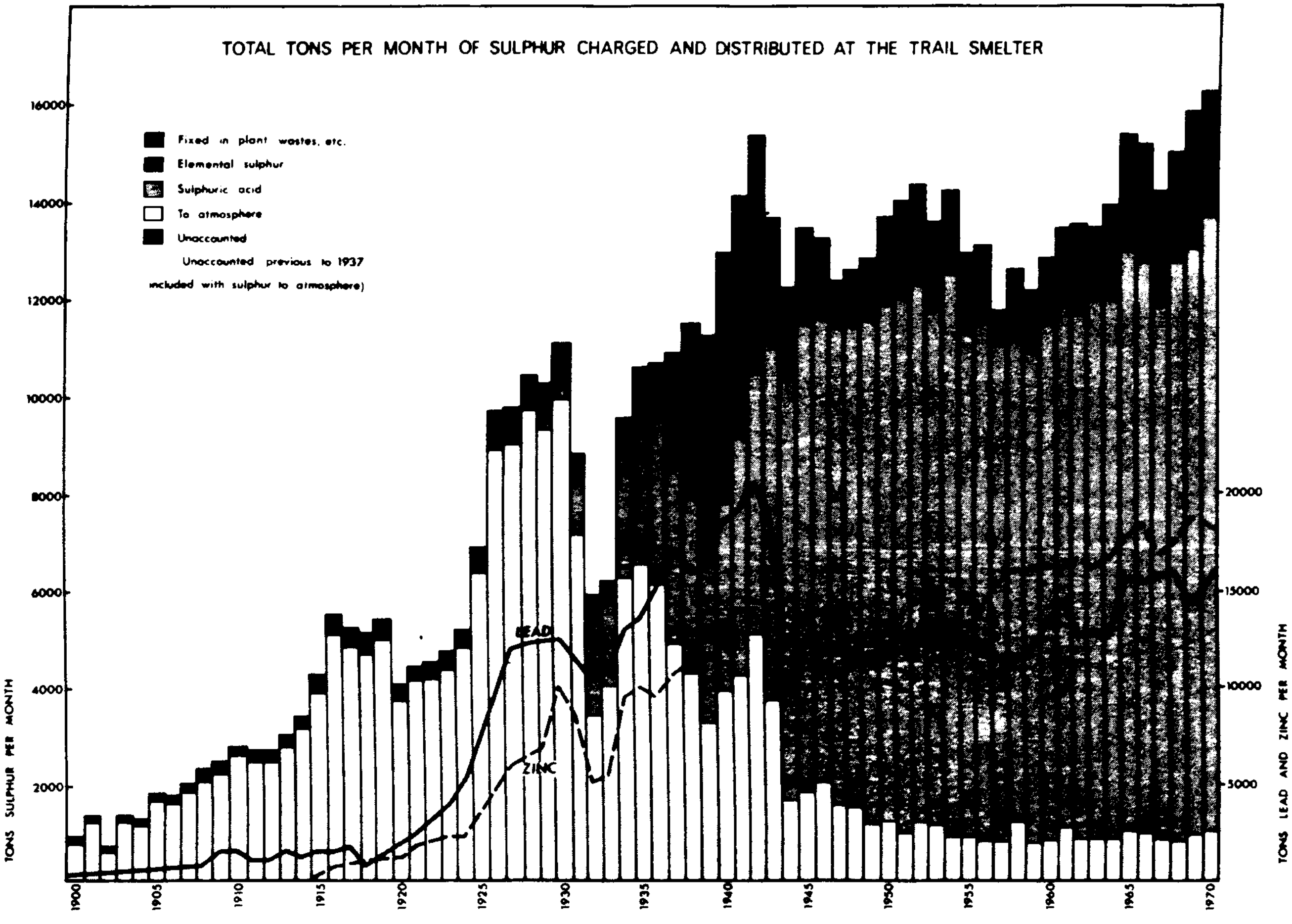
[1] One ton of sulphur is equivalent to approximately two tons of sulphur dioxide.



(Courtesy Cominco Ltd)

Fig. 2. Production data for lead and zinc and associated sulphur output from the Trail smelter for the period 1900-1970

surrounding vegetation. However, Scheffer and Hedgecock (1955) suggest that the area affected by fumigations from this smelter was rather restricted.

The Implementation of Control Methods

The control of sulphur dioxide emission at Trail was achieved through a combination of improved technology (King, 1950), and more careful supervision of waste disposal with respect to meteorological conditions (Hewson, 1944). The methods can be summarized as follows:

1) High stacks. The construction of high stacks provides one of the simplest yet most effective methods of diluting effluent gases to non-injurious concentrations (Bosanquet and Pearson, 1936; Dean, 1937; O'Gara, 1917). The first tall stack, exceeding 130 m in height, came into operation at Trail in November, 1925; the second in March, 1927. In addition, the temperature of the effluent gases is maintained at optimum levels for dispersion.

2) Sulphuric acid and fertilizer plant. The company constructed three sulphuric acid plants and various ancillary fertiliser plants in which the acid could be used. These came into full operation early in 1932, with the annual output of fertiliser now exceeding 1 million tons. As a result of the various treatments in operation throughout the metal and fertiliser production processes, the sulphur dioxide content of the tail gas now averages about 0.07 per cent.

3) Meteorological aspects. The company adopted the policy proposed by the tribunal of controlling the quantity of sulphur dioxide

emitted at any particular time according to the prevailing weather conditions. The sulphur dioxide concentration in the atmosphere is recorded continuously on instruments at Birchbank, 10 km north of Trail, Columbia Gardens, and Northport, 9 km and 30 km respectively to the south; readings are relayed automatically to the waste control office which also collects meteorological data. The operating régime requires that the smelter be run at a reduced rate or, in extreme cases, be shut down completely when prevailing weather conditions would otherwise permit the gas to build up to injurious concentrations. Data from the recorders for the period since 1940 are given in Appendix E2. Two main points were apparent. First, there was a noticeable decrease in the number of fumigations with distance from Trail, and secondly, there had been a remarkable reduction in the number of hours during which high levels of sulphur dioxide were recorded; this illustrated the effects of the remedial measures undertaken by Cominco.

Sulphur Dioxide and Plant Growth

Sulphur dioxide is possibly the most widespread pollutant in the atmosphere. Its presence can be detected by numerous techniques (Mueller et al., 1971) several of which have been incorporated in continuous monitoring apparatus thereby permitting detailed records of ambient conditions to be made. The mechanism of sulphur dioxide injury is described by Thomas et al. (1950). The gas enters the leaves by absorption through the stomata and, being very soluble, readily dissolves on the moist surfaces of the mesophyll cells. Its subsequent effect depends on the rate at which the gas enters the system. If the rate of entry is slow, the gas may be oxidised to sulphate and rapidly neutralized by the organic bases in the leaf. Such absorption, oxidisation, and neutralisation can continue over long periods of time without adverse effect to the plant until the buffering capacity of the leaves is approached. The leaves then become chlorotic, cease to function, and are abcissed. Thomas et al. (1950, p. 2233) state that if the rate of this process does not exceed appreciably the rate at which the plant can grow new leaves there is little or no deleterious effect. However, this process may cause a serious reduction in vigour in species such as the conifers which cannot quickly grow new replacement leaves. Conversely, in sulphur deficient environments the growth of plants might be stimulated by a slow accumulation of sulphate (Thomas et al., 1950).

If sulphur dioxide is absorbed by the leaves at a greater rate than it can be oxidised and neutralised, then an accumulation of sulphite occurs which can cause injury to cells at much lower concentrations than the saturation sulphate level. Experimental work (Thomas et al., 1950) suggests that the plasmolysis associated with rapid uptake is partly caused by the local concentrations of sulphurous acid in the mesophyll cells: the toxicity of the sulphite is further manifest by the alteration of respiration rates and enzyme systems, and by the inactivation of iron in the chloroplasts.

The gas produces two main types of injury to vegetation, acute or chronic, depending on concentration, length of exposure, and sensitivity of the plant (Daines, 1969; Thomas and Hendricks, 1956). Acute injury is characterised by necrosis in sharply defined marginal or intercostal areas and results from the rapid absorption of a toxic dose of sulphur dioxide. These areas exhibit a dull water-soaked appearance which, with subsequent drying, usually become bleached to an ivory colour, although some species, notably the conifers, assume a brown or reddish brown colouration due to the formation of anthocyanins. The leaf area surrounding acutely injured areas appears to function normally.

Chronic or chlorotic markings result either from the absorption of sulphur dioxide at concentrations somewhat lower than those that produce acute injury, or by continued exposure to sublethal concentrations causing a shattering of the mesophyll and palisade cells or the rupturing of the chloroplasts. Such injury has been shown to cause a reduction of up to 50 per cent in the photosynthetic activity of certain plants (Thomas and Hendricks, 1956). Chronically injured leaves typically exhibit white or brownish red turgid areas between the veins. Such leaves are usually shed prematurely (Daines, 1969).

Conifers were widespread in the Columbia Valley in the pre-smelter days. However, needle bearing species are particularly susceptible to injury because their needles remain on the tree for several years which greatly extends their exposure time. In addition, the age of the needles affects susceptibility: the first year needles are the most sensitive because of their ability to accumulate sulphur from the atmosphere more rapidly than the older foliage (Katz et al., 1939). Sulphur dioxide, like winter and drought injury, typically results in the desiccated appearance of the foliage. However, certain diagnostic symptoms can be used to distinguish between such injuries in the needle bearing species, as shown in Table 1. No conifers were encountered during the present study which exhibited any symptoms of injury.

TABLE 1. SOME DISTINGUISHING FEATURES OF SULPHUR DIOXIDE, WINTER, AND DROUGHT INJURY TO NEEDLE-BEARING TREES (after Scheffer and Hedgecock, 1955, p. 19)

Diagnostic Feature	Type of Injury		
	Sulphur Dioxide	Winter	Drought
Needle discolouration	Reddish or brownish when strongly affected	Reddish or brownish but typically less than by SO_2	Reddish or brownish but typically less than by SO_2
Extent of discolouration of individual needles	Often incomplete in the form of bands	Needles entirely discoloured	Needles entirely discoloured
Seasonal occurrence of discolouration	Any time in mild weather	Spring	Late summer to early winter
Maturity of affected needles	Middle-aged and older needles affected first	Older needles affected first	Youngest needles affected first
Maturity of affected trees	Excepting seedlings, older trees affected most	Young trees affected most	Young trees affected most
Character of injury to branches	Branches die from base of tree upwards; needles from base of branches to ends	Lower branches are not injured if protected by snow	Branches die from top of tree to base; needles from branch tips inwards
Killed trees	Dying typically slow with a deficiency of needles at death	Dying rapid with normal number of needles at death	Dying rapid with normal number of needles at death
Geographic distribution of injury	Severity of injury is related to distance from smelter and to relief features which confine the gas	Injury tends to be distributed in bands roughly paralleling contour lines	Injury typically occurs where soil and topography are unsuited for the retention of water

It has been established experimentally that the stomata provide the principal entrance for sulphur dioxide into the leaf (Mansfield and Majernik, 1970). Plants which close their stomata at night become highly resistant during the period of darkness, whereas others whose stomata remain open retain their sensitivity (Daines, 1969; Zimmerman and Crocker, 1934). Similarly, wilted plants show a greater degree of resistance than plants in a turgid condition: Zimmerman and Crocker (1934) again attribute this to the condition of the stomata. The influence of a number of environmental factors on the susceptibility of plants to sulphur dioxide can be summarised as follows:

a) Plants tend to be more resistant to sulphur dioxide at temperatures of 4.4°C and below (Setterstrom and Zimmerman, 1939; Swain, 1923; Wells, 1917). Resistance again increases at temperatures above 40°C. At Trail there were few times during the growing season when resistance would have been naturally high, although winter temperatures might have favoured the increased resistance of the coniferous species.

b) Low humidity reduces the stomatal openings and consequently decreases sulphur dioxide absorption (Katz, 1936b; Wells, 1917; Widstoe, 1903). Such increased resistance could have been operative at Trail since the growing season coincided with the period of low precipitation and low relative humidity.

c) High soil moisture increases the susceptibility of plants to sulphur dioxide (Katz, 1936b; Setterstrom and Zimmerman, 1939). Conversely, wilted plants show a high degree of resistance (Zimmerman and Crocker, 1934). The porous nature of the sandy soil at Trail, although possibly deficient in water for optimum growth, might have provided some beneficial effects to the plants.

d) Soil nutrient status has an important effect on resistance (Setterstrom and Zimmerman, 1934), with plants grown on poor soil being more susceptible to injury. This might have been an important factor in the Trail area since the sandy soils were susceptible to leaching.

e) Sensitivity to sulphur dioxide is much lower for plants during well lighted conditions than during shady periods (Setterstrom and Zimmerman, 1934). The sunny conditions experienced for much of the growing season at Trail might have increased the resistance of the vegetation, particularly the overstory.

The History of the Vegetation at Trail

General descriptions of the history of the vegetation of the Trail region are given by McBride (1937) and Wadey (1970). More detailed surveys concerned with the susceptibility of the native species to sulphur dioxide and the effects of the gas on vegetation appearance and performance are given in Katz et al. (1939), Katz and McCallum (1936), Lathe and McCallum (1936), McCallum (1936a, 1936b, 1937), and Scheffer and Hedgecock (1955). Recently, Hodson (1971) has outlined the natural recovery of the vegetation in the Trail region and has evaluated the success of Cominco's attempts at artificial re-establishment.

In the late nineteenth century, prior to smelting activities, the vegetation cover of the Columbia Valley at Trail was essentially coniferous in character (Wadey, 1970). Current descriptive works of the natural vegetation of the adjacent region have been used to infer the composition of these mixed stands. Rowe (1972) includes the Trail region within the Ponderosa Pine and Douglas-fir Section of the Montane Forest Region, and suggests that this type of forest has developed in response to the prevailing dry climate.[1] He recognises two different zones in the vicinity of Trail. At lower elevations a "parkland" of open grown ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and occasional interior Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) might have been found interspersed with bunchgrass prairie or weedy vegetation depending on its grazing history. Above about 1,100 m, interior Douglas-fir was probably found mixed with trembling aspen (*Populus tremuloides* Michx.) and lodgepole pine (*Pinus contorta* Dougl. ex Lourd.). However, Rowe (1972) suggests that environmental features such as soil texture, aspect, and exposure may critically influence species distributions in this region. This has been investigated in some detail by Krajina (1965, 1969) and Bell (1965).

According to Krajina (1965, 1969) the Trail region is located within the Interior Douglas-fir Zone in which the major coniferous species should include Douglas-fir and ponderosa pine together with lodgepole pine, western white pine (*Pinus monticola* Dougl. ex D. Don), grand fir (*Abies grandis* (Dougl.) Lindl.), larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmanii* Parry ex Engelm.), white spruce (*Picea glauca* (Moench) Voss), and cedar (*Thuja plicata* Donn). Under natural conditions ponderosa pine, lodgepole pine, and larch are regarded by Krajina (1965, 1969) as the pioneer tree species of this region, with the ponderosa pine favouring the drier sites. The other coniferous species common to the region are all shade tolerant species which develop best under a well established canopy. However, differences in site

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[1] The climate of the area is discussed on pages 77-85.

conditions resulting from variations in precipitation, physiography etc. (see Chapter 3) will further affect the distribution of the native species. Associated deciduous trees should include trembling aspen, black cottonwood (*Populus trichocarpa* Torr. & Gray ex Hook.), birch (*Betula papyrifera* Marsh.), and mountain maple (*Acer glabrum* Torr.). Bell (1965) recognises a number of secondary succession stages in this area leading to the climax forest of shade tolerant conifers. These can be summarised as:

1) Deforested land to young regeneration with small trees, shrubs and herbs generally dominant in the upper most stratum.

2) Hardwood-pioneer forest with hardwoods prominent in the crown canopy.

3) Conifer pioneer forest with shade intolerant conifers dominant in the tree stratum.

Early reports (McBride, 1937) show that much of the region was logged for cordwood and local sawmills in the early 1900's long before the smelter smoke could have killed the mature vegetation. Successive fires[1] and disease have similarly contributed to the decline of the forest vegetation (see Fig. 3), although the presence of sulphur dioxide may have acted indirectly by producing plants sufficiently moribund to be susceptible to attacks by these agents. Scheffer and Hedgecock (1955, pp. 19-20) show that bark beetles (*Dendroctus* spp.), engraver

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[1] The two most widespread fires occurred in 1919 and 1926. Practically all of the study area had been burned once, some areas several times. Hence fire must be considered as a major factor in the decline of the vegetation although the slow restocking of the area probably reflected the subsequent effect of sulphur dioxide fumes..

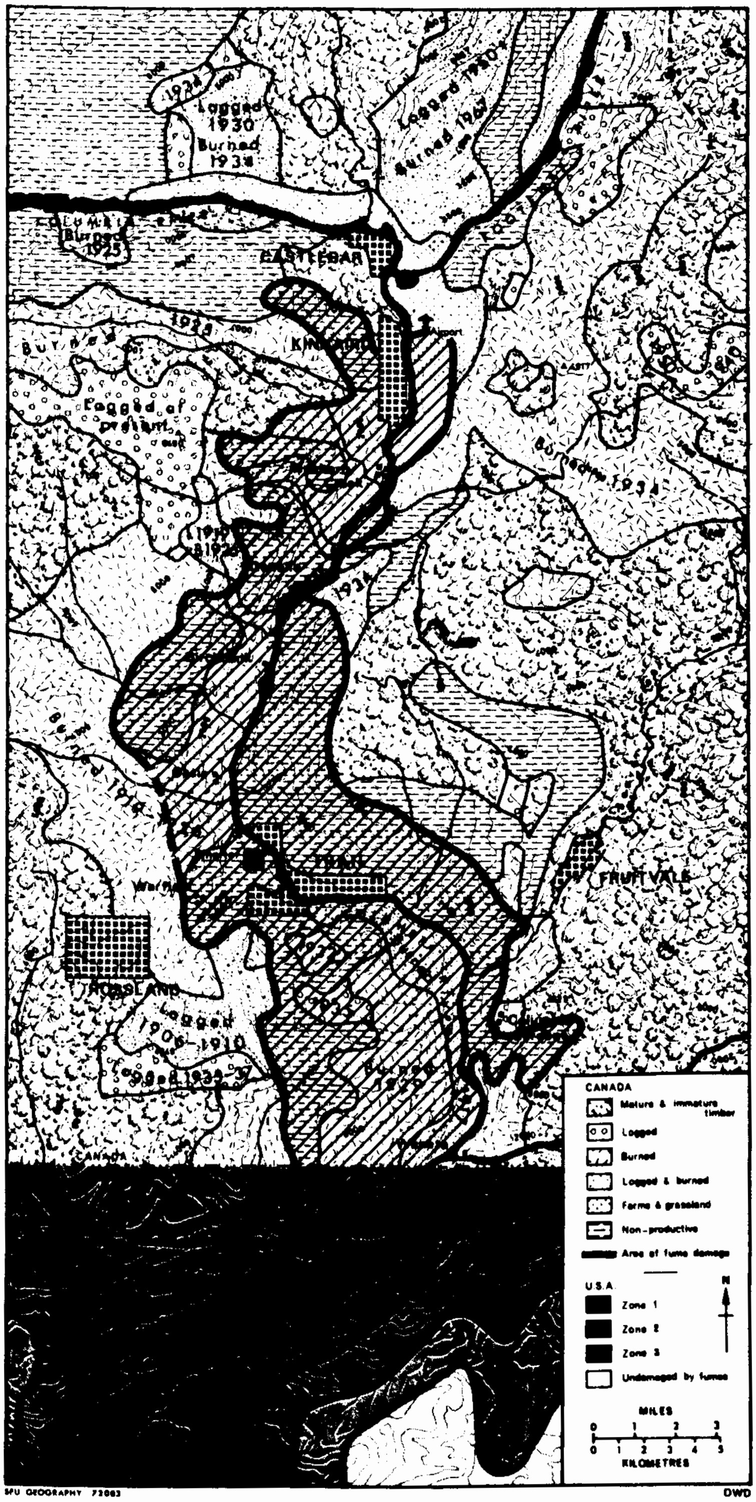
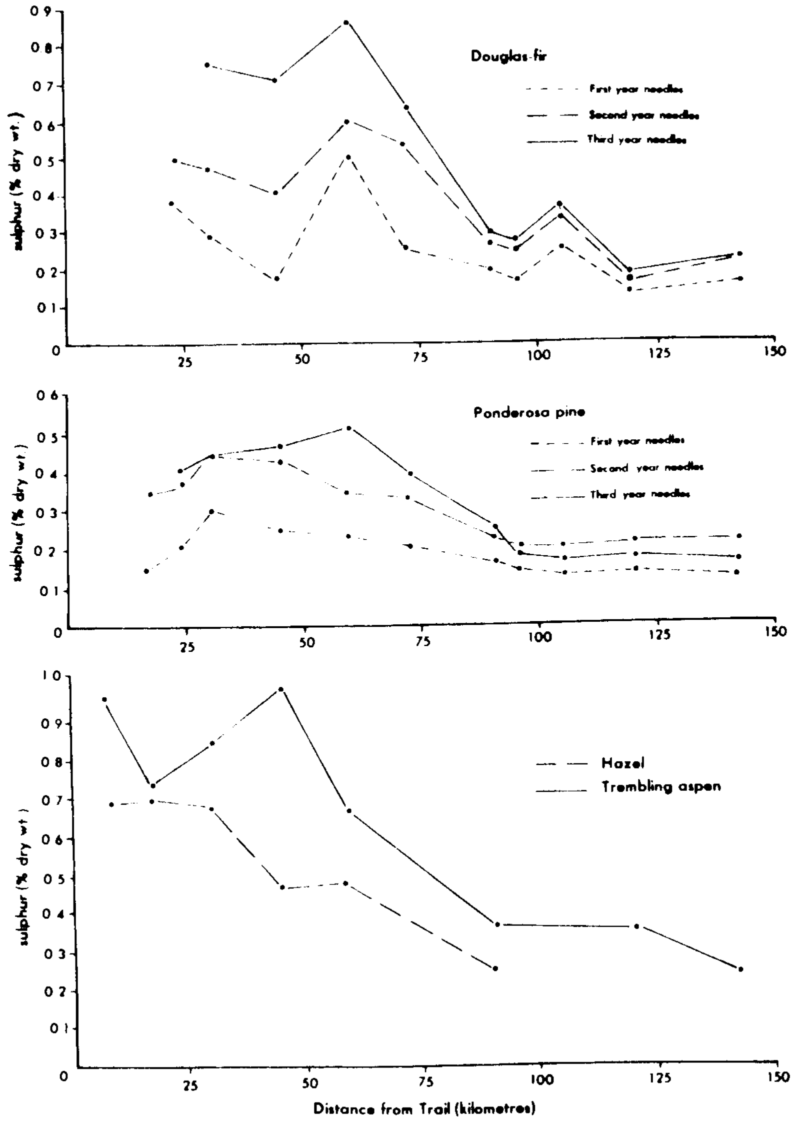


Fig. 3. The history of the vegetation of the study area (after McBride, 1937 and Scheffer and Hedgecock, 1955)

beetles (Ips spp.), and pine root fungus (Armillaria mellea) were more prevalent inside the region of sulphur dioxide injury, although most parasitic fungi were no more abundant in this region than elsewhere, and several appeared to be retarded by the presence of sulphur dioxide. However, the striking contrast today between the Columbia Valley and adjacent valleys of similar physical appearance which were subjected to similar logging operations, and which were equally susceptible to natural destructive forces, suggested that the smelter had unquestionably had a catastrophic effect on the natural vegetation.

At the peak of pollution, from 1926 to 1930, the area affected by fumes extended some 23 km upstream and approximately 95 km downstream from the smelter. Subsequent measurements of the sulphur dioxide content of the atmosphere (Katz, 1936a, 1949) showed that a noticeable decrease occurred both in the number and intensity of fumigations with distance from Trail. Such spatial variation was well illustrated by the analyses of the sulphur content of the vegetation (Katz, 1936b): in all of the species analysed there was a pronounced decrease in sulphur content with increasing distance from the smelter (see Fig. 4). The dispersion pattern of the sulphur dioxide therefore resulted in the more severe damage to the vegetation occurring close to Trail. A comparable pollution gradient of lower intensity may still prevail today and this was postulated as an important factor affecting the re-establishment of vegetation in these areas (see pages 29-30).

By the early 1930's the cover of the area exposed to fumes was extremely sparse (see Fig. 3). Between Trail and Castlegar, some 25 km to the north, the fume damaged areas supported a limited growth of aspen



(after Katz 1949)

Fig. 4. The sulphur content of selected tree species of the study area for the period 1930-1931 in relation to distance from Trail

and willow (Salix scouleriana Barratt) with some brush[1] (McBride, 1937). Much of the region was barren with few coniferous saplings, although some coniferous regrowth occurred at higher elevations (above 1,000 m) where fumes had not severely affected the vegetation. Between Trail and the International Border, some 17 km by river to the south, excessive devastation by fumes led to the almost total eradication of the vegetation and pronounced soil erosion occurred which resulted in the formation of drifting sand dunes on the terraces adjacent to the river. Little or no reproduction was found on the higher land (McBride, 1937).

The relative susceptibility of the native species to injury by sulphur dioxide was determined by previous workers following field observations and fumigation experiments conducted at Summerland, B.C. (Katz et al., 1939; Katz and McCallum, 1936). Douglas-fir and ponderosa pine were quite resistant to acute injury, but they commonly exhibited chronic symptoms induced by the gradual accumulation of sulphur over a period of years. Larch was very susceptible, particularly during the early part of the growing season, but became progressively more resistant later in the year. Injury to this species appeared to be confined to May; after this time the possibility of injury was remote. Fumigations in June, July, or August could result in the marking of the foliage but were never known to kill the larches. Other coniferous species, such as lodgepole pine and cedar, appeared to be injured only at points very close to the smelter. Birch was the most frequently marked broadleaf

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[1] No details regarding the composition of the brush were given but the term was thought to refer to buckbrush (Coeanothus sanguineus Pursh) which was still common in the region.

species, with aspen and mountain alder (Alnus tenuifolia Nutt.) exhibiting a slightly higher resistance. The deciduous species, although often showing signs of sulphur dioxide damage in an area within 25 km of the smelter, appeared to be much more resistant to killing than the conifers.

Scheffer and Hedgecock (1955) similarly list coniferous and deciduous tree species according to resistance. Several discrepancies occur between the two sources, for example, the latter authors list cedar, hemlock, and Douglas-fir as some of the most susceptible coniferous species while larch is shown to be somewhat more resistant. Likewise aspen and black cottonwood are regarded as fairly resistant to sulphur dioxide with alder given as the most sensitive broadleaf species. Full listings of the susceptibility of the native tree species as stated in Katz et al. (1939, pp. 99-101) and Scheffer and Hedgecock (1955, pp. 25-26) are given in Appendix A2.

Areas in which trees were killed or in which there was pronounced foliar damage similarly exhibited a marked reduction in timber reproduction. Scheffer and Hedgecock (1955), working in the Columbia Valley south of the International Border, conclude that this resulted both from a reduction in cone crops and from the death of any seedlings that might have become established. They subdivided the region into three zones according to the degree of devastation and the condition of the existing vegetation (see Fig. 3). It was within zone 1 that destruction was most widespread (60-100%), with much of the terrain being devoid of all but the most resistant species; within zone 2 intermediate damage (30-60%) was reported, and within zone 3 slight damage (1-30%) occurred. The detrimental effects of sulphur dioxide are well illustrated by the results of the cone production and seedling transplant studies shown in Table 2.

One of the main outcomes of the N.R.C. of Canada study (Katz et al., 1939) was that the maximum concentration of sulphur dioxide allowed to persist at Columbia Gardens, 9 km south of the smelter, before remedial action must be taken would be 0.3 ppm for 40 minutes in summer and 0.5 ppm for 60 minutes in winter. This represented a drastic reduction in fumigation levels compared with earlier emissions. By 1941 these recommendations had been implemented, and since that date revegetation has been in progress. By 1949 regrowth was well established on the hillsides and moister parts of the valley with the first reseeding of conifers occurring throughout the main Columbia Valley in 1950. These grew well, and by 1956 they were found within 3 km of the smelter with birch, aspen, and willow spreading from the tributary valleys and creek bottoms to the benches above the river (Wadey, 1970). The sequence of air photographs (see Fig. 5) for the Columbia Valley just north of Trail clearly illustrates the extent of the regrowth since 1939. Scheffer and Hedgecock (1955, p. 45) conclude that the re-established stands are likely to be comparable to the original ones in species representation. However, they note that in some areas larch had become locally important due to the capacity of the remnant parent trees and seedlings to survive exposure to sulphur dioxide.

Succession Theory—a general account

The idea of vegetation change over time has long been recognised (see Clements, 1928, pp. 8-32), with the first comprehensive account in

TABLE 2

A: CONE PRODUCTION BY PONDEROSA PINE OF BEARING AGE IN 1936* (after Scheffer and Hedgecock, 1955, p. 28)

Zone	No. trees examined	% trees with no cones	% trees with few cones	% trees with many cones
1	7670	81	13	6
2	5274	46	20	34
3	5142	27	17	56
Outside area of fume damage	7742	16	17	67

*average monthly rates of sulphur discharge during the period of maturation were 6,200 tons in 1934, 6,500 tons in 1935, and 6,100 tons in 1936

B: INJURY TO 1 AND 2 YEAR OLD TREES TRANSPLANTED IN THE DIFFERENT ZONES (after Scheffer and Hedgecock, 1955, p. 29)

Year and Zone		Ponderosa Pine		Douglas-fir	
		No. trees	% injured or killed	No. trees	% injured or killed
1932	1	77	90	489	84
	2	13	31	139	14
	3	*	*	171	0
	Outside area of fume damage	*	*	136	0
1933	1	984	98	486	78
	2	45	45	76	37
	3	24	0	9	0
	Outside area of fume damage	63	0	33	0

*plots damaged by rodents

Fig. 5(i). Vertical air photo coverage for the north-central part of the study area taken in 1939

Fig. 5(ii). Vertical air photo coverage for the north-central part of the study area taken in 1952

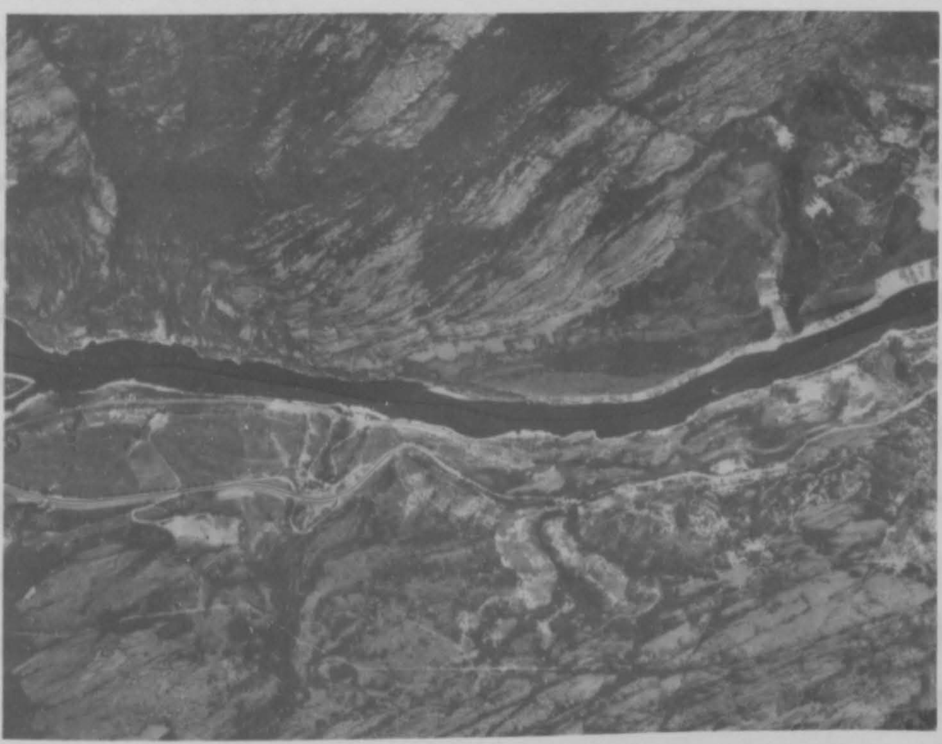

Fig. 5(iii). Vertical air photo coverage for the north-central part of the study area taken in 1969. The area shown is located between about 6.0 km and 4.0 km north of Trail. The river at this point flows almost due south: north is at the left margin of the photos. A general increase in the abundance of the vegetation is apparent from this sequence of photographs. This is well exemplified in the following places:

(a) On the terrace extending from the centre of the photos southwards along the east bank

(b) Along the creeks in the lower centre and lower left parts of the photos

(c) On the rock outcrop in the upper centre of the photos

North America being published by Cowles (1899). Since this early treatment, the concept of succession has undergone amendment and elaboration, notably by Clements (1916). Clements (1916) regards succession as a series of invasions by plant populations that are characterised by a change from lower to higher life forms: he introduced the term 'sere' to describe such developmental sequences. This progressive development ceases when a state of equilibrium is reached.[1]

Tansley (1920, 1935) modified Clements' (1916) basic postulates by distinguishing between autogenic and allogenic successions. Autogenic succession refers to normal progressive vegetation development which results from the modification of the environment by the plants themselves. In allogenic succession vegetation change is brought about by external agencies. Other viewpoints (Cooper, 1926) have stressed that any directional change in vegetation should be considered as succession, whether it be due to the reaction of the plants on their environment, or whether it be due to changes in external factors.

The seral communities as originally postulated by Clements (1916) are regarded as distinct entities which replace one another in a regular and predictable sequence leading to the climax community. Such a viewpoint receives strong support from Phillips (1934, 1935a, 1935b). Current interpretations conclude that succession appears to be a less orderly process than that envisaged by Clements and his adherents (Kellman, 1969;

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[1] Clements (1916) lists six stages in succession: nudation—the removal of soil, migration—the input of species, ecesis—the establishment of species, competition—the struggle between individuals for growing space, reaction—the modifying effect of plants on their environment, stabilisation—self perpetuation through adequate reproduction.

Whittaker, 1957; Yarranton, 1967).

At a functional level, contention has arisen regarding the causes of observed changes in vegetation covers, and whether these have resulted from variations in the maturation rates and life spans of the initial species complement, or whether they have been brought about through the successive invasion and subsequent germination and establishment of species previously excluded from an area due to unfavourable environmental conditions. Such confusion, according to Fosberg (1967), results from the failure to distinguish between primary and secondary succession.

The major difference between primary and secondary succession is the presence of a residual flora in a secondary situation, either in the form of living plants, or as buried viable propagules (Kellman, 1970a). The importance of such remnant floras has been discussed by Egler (1954). Kellman (1970b), Livingstone and Allessio (1968), Major and Pyott (1965), and Oosting and Humphreys (1940). Similarly, some micro-environmental[1] alteration will persist from the previous cover. The abundance of viable propagules and the extent of the environmental modification will be dependent upon the type and degree of disturbance. When a disturbance has been severe many of the effects of the previous vegetation are eliminated (Sartz, 1953). After a less severe disturbance many of the products and processes of reaction may remain. Subsequent alteration in the secondary cover will be dependent upon the competitive ability of the

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[1] For the purposes of this study, macro-environment refers to those external conditions which affect a plant's performance but remain unaffected by the vegetation: micro-environment refers to elements in a plant's habitat which reflect the type and stage of development of the vegetation (see de Vries, 1963, p. 6).

composite species, and therefore the processes involved clearly resemble those active in primary vegetation development. Secondary succession is terminated when no new species are introduced and when no species are lost because of their inability to reproduce in situ. Although the first communities to develop in a secondary area may not be typical of a primary succession, the later stages, and the processes by which they are produced, are similar to those associated with primary situations. The state of a secondary stand therefore reflects the nature, degree, and extent of the disturbance, the size and vigour of the residual flora, and the time elapsed since the disturbance occurred (Kellman, 1970a). It was these factors which were of direct relevance to the present study.

The Investigation of Secondary Succession in the Trail Area

It was evident from preliminary observations that noticeable differences occurred in the vegetation cover of the area: such variation appeared to be related to distance from the smelter. This variation was postulated to be a secondary successional sequence which reflected one or more of the following factors: progressive pollution abatement, differing degrees of former destruction, or the retardation of regrowth as a result of toxic fumigations subsequent to general pollution control. A stratified random sampling design, based on distance from the smelter, was adopted to examine the vegetation and the role of these three factors (see pages 42-46).

If pollution abatement resulted in a progressive, rather than a sudden decline in sulphur dioxide levels, it could be hypothesised that the spatial variation in the vegetation reflected a developmental sequence related to the gradual improvement in air quality. Under such conditions, the vegetation furthest from Trail would have been released from toxic fumigations earlier than that closer to the smelter. The more advanced stages of the recovery process should therefore have been represented by the more distant stands.

Alternatively, the spatial variation in the present cover might have reflected differing degrees of destruction of the former vegetation. Assuming that regrowth started at approximately the same time throughout the area, it was hypothesised that the vegetation would have been less advanced in areas of high former destruction. Areas of excessive disturbance would probably have been poor in remnant plant propagules since the eradication of the vegetation for several years prior to recovery might have prevented the in situ production and storage of viable material. Similarly, such areas would probably have exhibited strongly altered micro-environments which could have been inhospitable to all but a few pioneer species. Conversely, areas which were not subjected to severe sulphur dioxide levels should have contained a richer species complement and have provided a more varied range of micro-habitats for invading species. If the present appearance of the vegetation was related to the degree of former destruction, then theoretically the stands furthest from the smelter should have been less severely affected than those nearer to the pollution source.

Further, if significant fluctuations in the quantity of gas emitted to the atmosphere had occurred since major emission controls were instituted, it was possible that the revegetation of some areas might have been retarded by toxic outbreaks subsequent to the major period of destruction. For the majority of instances it was thought that outbreaks would have been temporary and hence should not have caused excessive damage to the regrowth. However, any prolonged occurrences of high sulphur dioxide levels might have resulted in the elimination of some of the less tolerant components of the cover. If such fluctuations in gas emissions have occurred during the revegetation process, then they presumably would have retarded regrowth at the stands closer to Trail.

In the event that the vegetation patterns did not show significant correlations with distance from Trail, these might most logically be attributed to spatial variation in the macro-environment of the area, unrelated to conditions of fumigation. Consequently, it was hypothesised that differences in the macro-environment might be reflected in the vegetation through variations in the ecological amplitudes of the representative species. This might have resulted either in the exclusion of some species, or in the retardation of regrowth in some locations. The importance of such non-distance related factors was determined by examining correlations between the vegetation and macro-environmental conditions.

With the exception of the macro-environmental controls, the explanation of the recovery patterns as put forward in the alternative research hypotheses could all have been substantiated by significant correlations between the vegetation characteristics and distance from the smelter. However, it was possible to distinguish between these hypotheses by considering the age of the plant cover.

One method of dating the sampled areas was to use the date at which the sulphur dioxide emissions were reduced to non-toxic levels.

This would have given a 'potential' age for all parts of the area from which one would necessarily have concluded that differences in the present cover simply reflected the degree of former destruction. However, this would not have taken into consideration the possibility that fluctuations in the sulphur dioxide levels might have delayed revegetation in some areas or might have subsequently retarded regrowth. As an alternative method of assessing the age of the cover, tree ring counts were made for the birch, trembling aspen, and coniferous species found at the sample plots. Because conditions for plant growth have theoretically been improving since the instigation of control measures, it was assumed that for each of the major tree species present in the area, the age of the oldest individual at each sample plot should have reflected the time elapsed since that species initially became established. Hence, tree ring analysis provided a suitable means of establishing a relative time scale which could be used in the interpretation of the recovery sequence.

The year 1941 was taken as the start of the 'post-pollution' period (Wadey, 1970). Individuals older than 30 years would therefore have been part of the remnant cover; those less than 30 years old would have represented regrowth. This provided a means of distinguishing between the effects of a gradual decline in pollution levels and the degree of former destruction, since plots which were less severely affected should have contained individuals over 30 years of age. Further, investigation into age class distributions at each sample plot enabled one to detect any subsequent suppression of regrowth, the assumption being that a period of suppression would have been reflected by the paucity or absence of individuals of certain ages. The more advanced stages of recovery should have been represented by the presence of tree species exhibiting a wide and continuous range in their age class distributions. Conversely, the early stages in the redevelopment of the vegetation should have contained tree species represented only by the youngest individuals.

In order to determine the exact nature of the controls to vegetation recovery it was therefore necessary to determine the nature of the variation in the vegetation cover and to examine macro-environmental conditions in the study area. In addition stand micro-environments were assessed since these too were regarded as further controls to the continued development of the vegetation cover. From the analysis of such data it was expected to formulate a secondary succession sequence which accounted for the pattern and process of revegetation in the Trail area.

Chapter 2

METHODOLOGICAL CONSIDERATIONS UNDERLYING THE FIELD WORK

Delineation of the Study Area

Trail (49° 05'N, $117^{\circ}44$'W) is located in the relatively narrow valley of the Columbia River in the mountainous terrain of southern British Columbia. At this point the river is some 120 m in width and is bordered for most of its course through the study region by a series of horizontal terraces which range in width from 800 m to over 5 km. Where present, these rise in progression to form level benchlands at approximately 65, 135 and 200 m above the river. Each level is separated from the preceding one by a steeply angled face. The elevation of the highest terrace is approximately 700 m A.S.L. Above this the valley sides rise steeply to elevations exceeding 1,300 m with peaks some 2,300 m in height only a short distance beyond (see Fig. 1). In general, the valley is narrow and deep, and constitutes a natural channel for the smelter gases which are released into it. The terrain therefore provided innumerable micro-habitats which might have affected the course of revegetation. Superimposed upon these were variations in the extent and intensity of past fumigation damage.

Such environmental heterogeneity necessarily affected the nature of the survey. All such variation could have been included in an extensive study in which the full range of conditions present in the area were sampled. Alternatively, an intensive survey could have been conducted in selected environments. Because of the limited time and equipment the former method would require that data be collected at a fairly generalised level. An intensive survey in a selected physiographic type would permit more detailed measurements of the vegetation and environmental factors. The latter approach was adopted in the present research, sampling being restricted to the terraces bordering the Columbia River. These terraces correspond to Hodson's (1971) landtype category 2(a) "Valley benches composed of sand and gravel." Such a procedure removed much of the inherent variation within the region since these terraces were thought to be composed of uniform parent material, were of similar elevation, and were approximately level.

The actual field area, could be delimited as follows. The east-west limit was determined by the width of the terrace material adjacent to the Columbia River, and avoided the inaccessible hard-rock exposures. The most northerly point to which fumigations reached, according to B.C. Forest Service records (McBride, 1937), was in the vicinity of Castlegar (see Fig. 3). This was taken as the northern limit of the main sampling area, a distance of 23 km by river from Trail. To the south, the effects of the sulphur dioxide reached some 95 km from the smelter (Katz, 1936a). However, sulphur dioxide concentration showed a marked decrease in the vicinity of Northport 30 km south. Because this study was concerned with revegetation following pollution control, it was thought that vegetation recovery would be most marked in the zone of intense fumigation; hence sampling was restricted to the terraces of this zone. Preliminary studies of climatic data showed that a marked decrease in precipitation occurred as one moved south into the United States. This too was considered in delimiting the southern boundary in the vicinity of Northport. In addition, a control area was set up on the terraces bordering the Kootenay River, 40 km north of Trail (see Fig. 7). This was at the same elevation and was of similar physiography to the main sample area but was some 17 km beyond the zone affected by sulphur dioxide. Because of the marked decrease in precipitation, no control site could be found which was representative of conditions to the south of the fumigation zone.

The study area, as defined above, consisted of a relatively narrow strip of land bordering the Columbia River, 45 km in length with a maximum width of only 2.5 km. At the outset, no significant variation was expected within the area with respect to physiography, climate, or edaphic factors, and its logging and fire histories were thought to be fairly uniform (McBride, 1937). Theoretically then, any floristic and environmental differences within the area should be due to the effects of the smelter effluent.

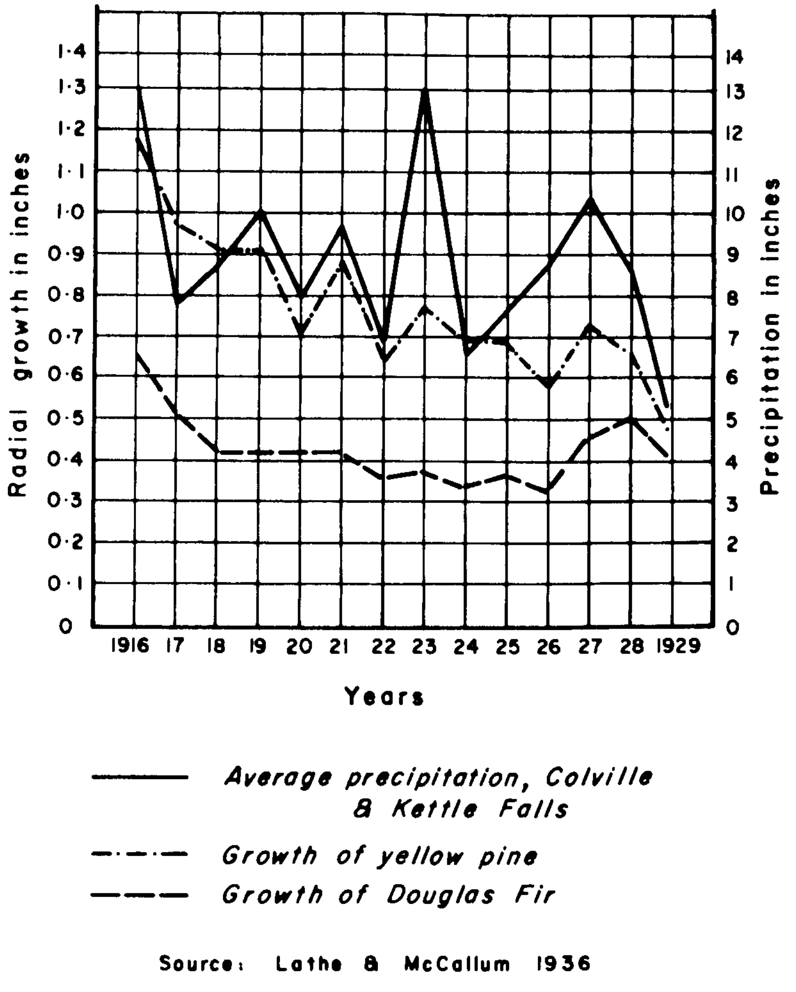
Macro-environmental Homogeneity of the Study Area

By restricting the field work to the terraces it was assumed that any variation in the present cover resulting from diverse macro-environmental conditions would be minimised. However, certain variables that were unaffected by the revegetation process might vary within this physiographic type: the most important of these included the edaphic factors, the macro-climatic factors, and the pollution factors.

Soil texture influences a range of soil properties and hence, indirectly, is of great importance to plants. The physical properties of infiltration, rate of movement, and retention of water within a soil, soil aeration, and soil temperature are controlled to a large extent by texture; so too is fertility and root penetration. Variation in soil texture might therefore be an important factor in determining the nature of the regrowth. Similarly, variation in soil moisture at depth might affect the vegetation of the area by inhibiting plant growth in excessively moist locations, or conversely, by stimulating development in locations where ground water might offset otherwise dry conditions. Also, variability in the chemical status of the parent material might be reflected in the present state of the cover.

The influence of climate on vegetation is widely accepted and typically affects the range and response of a species. In addition, it has previously been shown that susceptibility to sulphur dioxide is also related to climatic factors (see page 14). Uncontrolled macro-climatic variation within the study area might therefore be an important factor affecting the nature of the regrowth vegetation. Past research (Lathe and McCallum, 1936) further indicates that fluctuations in climate, notably precipitation, have affected tree growth in the Trail region (see Fig. 6). It was therefore essential to ascertain if such fluctuations had been uniform throughout the area, since retardation in establishment and growth might be reflected in the present spatial distribution of the vegetation.

The importance of sulphur dioxide as a factor affecting plant response has been discussed earlier (see pages 10-15). Any fluctuation in the duration or intensity of current fumigations might result in the suppression of regrowth in certain areas. Additional pollution variables included soil lead and zinc levels, since particulate forms of both of these heavy metals have been present in the flue gas. The possibility that lead might affect plant growth has received much attention in connection with mining spoil (Bradshaw, 1952, 1970; Bradshaw et al., 1965; Gregory and Bradshaw, 1965; Jowett, 1959, 1964; Smith and Bradshaw,



Source: Lathe & McCallum 1936

Fig. 6. The relationship between precipitation and the radial growth of yellow pine (ponderosa pine) and Douglas-fir

1970; Wilkins, 1957). Although zinc is an essential nutrient for plant growth (Russell, 1961), it has also been shown to be toxic in high concentrations (Gregory and Bradshaw, 1965; Mortvedt et al., 1972). Because unfavourable concentrations of the metal might have built up in the soil as a result of industrial activity, it too was considered as a pollution variable. Although no information was available regarding the tolerance of the native species to high lead and zinc levels, it was possible that spatial variation in the availability of these metals might affect the regrowth patterns exhibited by the vegetation. A high lead or zinc content in the soils close to Trail might preclude the germination and growth of many of the less tolerant species, these being found at plots where either the initial heavy metal content was low, or where subsequent removal had occurred.

Such considerations gave rise to the following null hypotheses regarding the macro-environmental conditions. For the selected edaphic variables, it was hypothesised that uniform soil texture, uniform soil moisture at depth, and uniform status of the parent material existed throughout the study area. In the case of the present macro-climatic conditions, it was hypothesised that maximum and minimum temperatures, maximum and minimum relative humidities, and precipitation were uniform within the field area; further, uniformity in precipitation régimes during the period of pollution control had also prevailed. With regards to the pollution variables, it was hypothesised that no significant spatial variation occurred in the present sulphur dioxide levels, nor in the present levels of available lead and zinc in the soil. In the event that these hypotheses were disproven, the macro-environmental factors would be incorporated as possible sources of variation which could be related to the patterning exhibited by the vegetation. The results of the investigation into macro-environmental variation within the study area are presented in Chapter 3; the data collection methods are described below (see pages 46-53).

Spatial Variation in the Vegetation Cover of the Study Area

The nature of the spatial variation exhibited by the vegetation cover was ascertained by sampling floristic composition, species abundance, and standing crop. These variables were considered in relation to the following hypotheses. First, areas representing the more advanced stages of recovery would exhibit richer floras and larger standing crops than areas representing the earlier stages. Secondly, species representative of the earlier stages of recovery would be more abundant in the younger areas whereas those associated with the later stages would be more abundant in the older areas. However, the latter hypothesis might be complicated by the existence of residual species and by the effects of vegetation suppression as a result of subsequent sulphur dioxide fumigations. Consequently, the assessment of age class structures was integral to this problem. The present reproductive status of the plant populations would form an important aspect of a study concerned with the recolonisation of an area following a disturbance. An investigation into the variation in seed production throughout the study area was therefore conducted on the assumption that seed production would be more prolific in areas representing the advanced stages of recovery. The methods used in assessing the spatial variation in the vegetation cover are given below (see pages 53-63); the results are discussed in Chapter 4.

Spatial Variation in the Micro-environment of the Study Area

In order to detect any autogenic modification of the environment during the course of succession it was essential to carry out accurate determinations at a micro-level. Such information could be used in comparing the degree of recovery of the various stands, and could be further incorporated as factors which might determine the direction and rate of the future regrowth. Because of the marked contrast in the density of the vegetation at different parts of the study area (see pages 94-104), it was postulated that significant differences in the micro-environment would be detectable. Measurements were therefore made of various micro-climatic and micro-edaphic variables according to the following hypotheses.

For micro-climate it was hypothesised that significant increases in shade, and in maximum and minimum relative humidity occurred beneath the cover as vegetation recovery proceeded. In addition, maximum air temperatures at ground level were lowered and minimum air temperatures at ground level were increased as regrowth became established. Regions devoid of vegetation typically possess drier, warmer soils resulting in an environment that may be inhibitive to successful seed germination. Modification of soil moisture and soil temperature would therefore reflect the state of the vegetation with soil moisture being increased and soil temperature being lowered as vegetation recovery proceeded. In many successional studies it has been possible to demonstrate the effect of vegetation development upon soil chemical properties (Crocker and Major, 1955; Olson, 1958). It was impossible to carry out full chemical tests on the soils, and analyses were limited to acidity, percent carbon, and the macro-nutrients, sodium, potassium, calcium, and magnesium. The resulting hypotheses were that soil acidity was lower in the more advanced plots, that percent carbon increased as vegetation recovery proceeded, and that the nutrient status of the surface soil increased as the cover established. The methods used in assessing the extent of the autogenic modification of the environment are presented below (see pages 63-65); the results are given in Chapter 5.

Sampling Design

A stratified sampling technique was adopted in which distance from the smelter was incorporated as the prime criterion of stratification. Twenty suitable sample plots were selected, nineteen of which were in the main Columbia Valley with an additional one located in the control area (see Fig. 7). The proposed interval of 1.5 km between plots had to be modified because of the lack of terraces at certain points in the valley or because access to suitable terraces was difficult. For example, to the north of plot 3, much of the land had been built upon. Between plots 4 and 6, a distance of 6 km, only one suitable location could be found because solid bedrock was exposed at the surface, although certain areas on the east bank would have been suitable had they been accessible. To the south of Trail, between plot 18 and the International Border, much of the area had been recently burnt and no suitable terraces could be found on the east bank. Plots

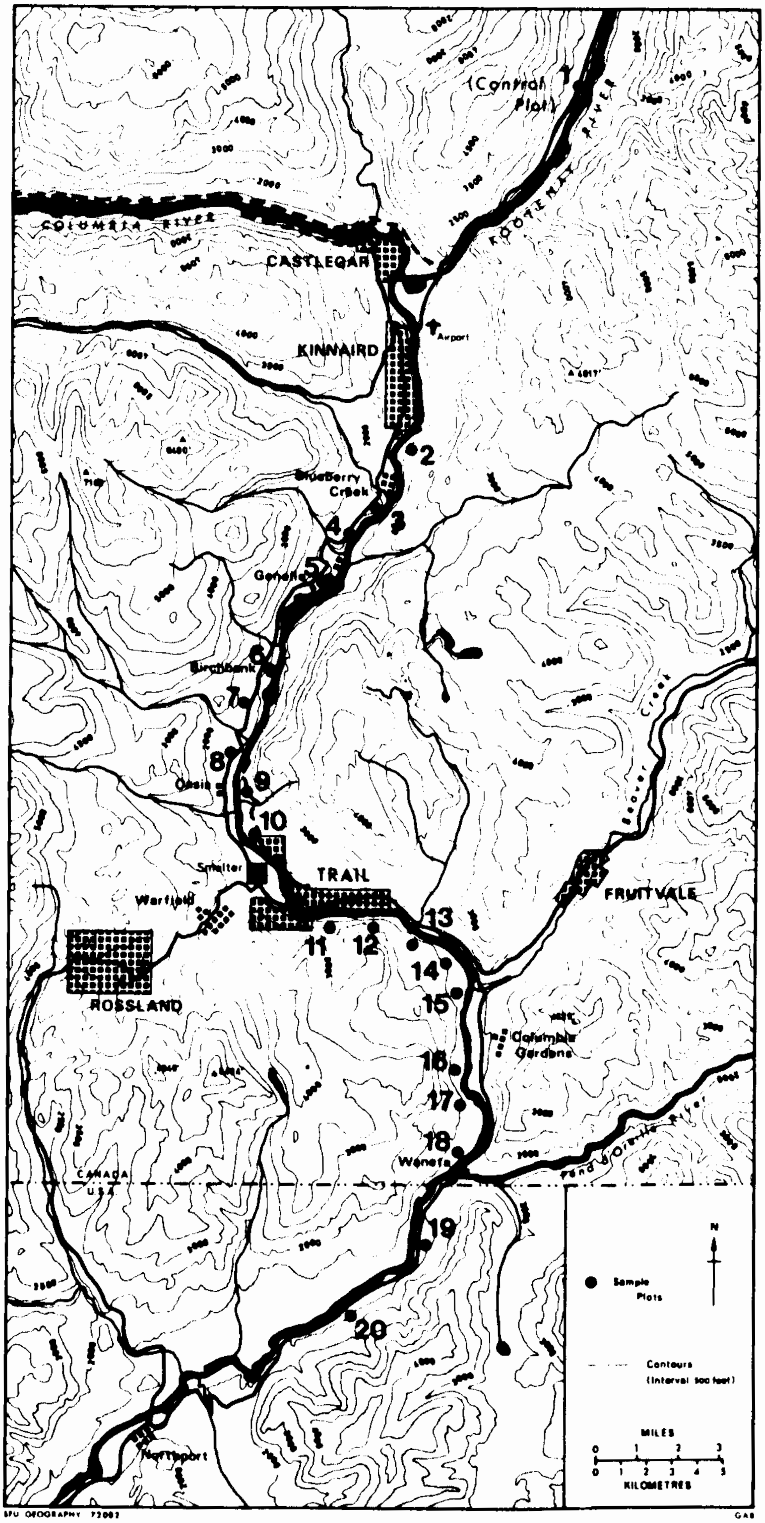


Fig. 7. The location of the sample plots.

were excluded from this area because it was thought that the fire might have destroyed part of the vegetation cover. Further deviations from the proposed sampling design resulted from the fact that power lines and their access roads had disturbed otherwise suitable terrain such that the remaining stands of vegetation were of insufficient dimensions to warrant the surveying of a sample plot. This was typical of the area between 6.0 and 10.0 km north of Trail. Consequently, slight variations in the proposed interval of 1.5 km between sample plots had to be imposed. Physiographic conditions similarly caused some variation in this proposed interval. For example, at a distance of 4.5 km north of Trail a tributary stream had cut a deep, steep-sided valley into the terrace. A suitable location for this plot (number 9) was found at 4.75 km north. These systematically spaced plots were rectangular in shape with dimensions of 50 x 100 m.

Randomisation of sampling within this stratification was achieved by subdividing each sample plot into a series of 10 x 10 m quadrats. A table of random numbers (Fisher and Yates, 1957) was used to select five of these quadrats which were later used in evaluating the variation in the tree cover. Those selected were further subdivided into one hundred 1 x 1 m quadrats. Five of these smaller quadrats were similarly chosen from each 10 x 10 m quadrat and subsequently used in assessing the variations in the ground vegetation and the micro-environment. Because some trampling occurred along the edges of the 10 x 10 m quadrats during the surveying procedures, the marginally located 1 x 1 m quadrats were excluded from the samples. The sampling design followed is shown in Fig. 8. The final sample size for the main Columbia Valley totalled

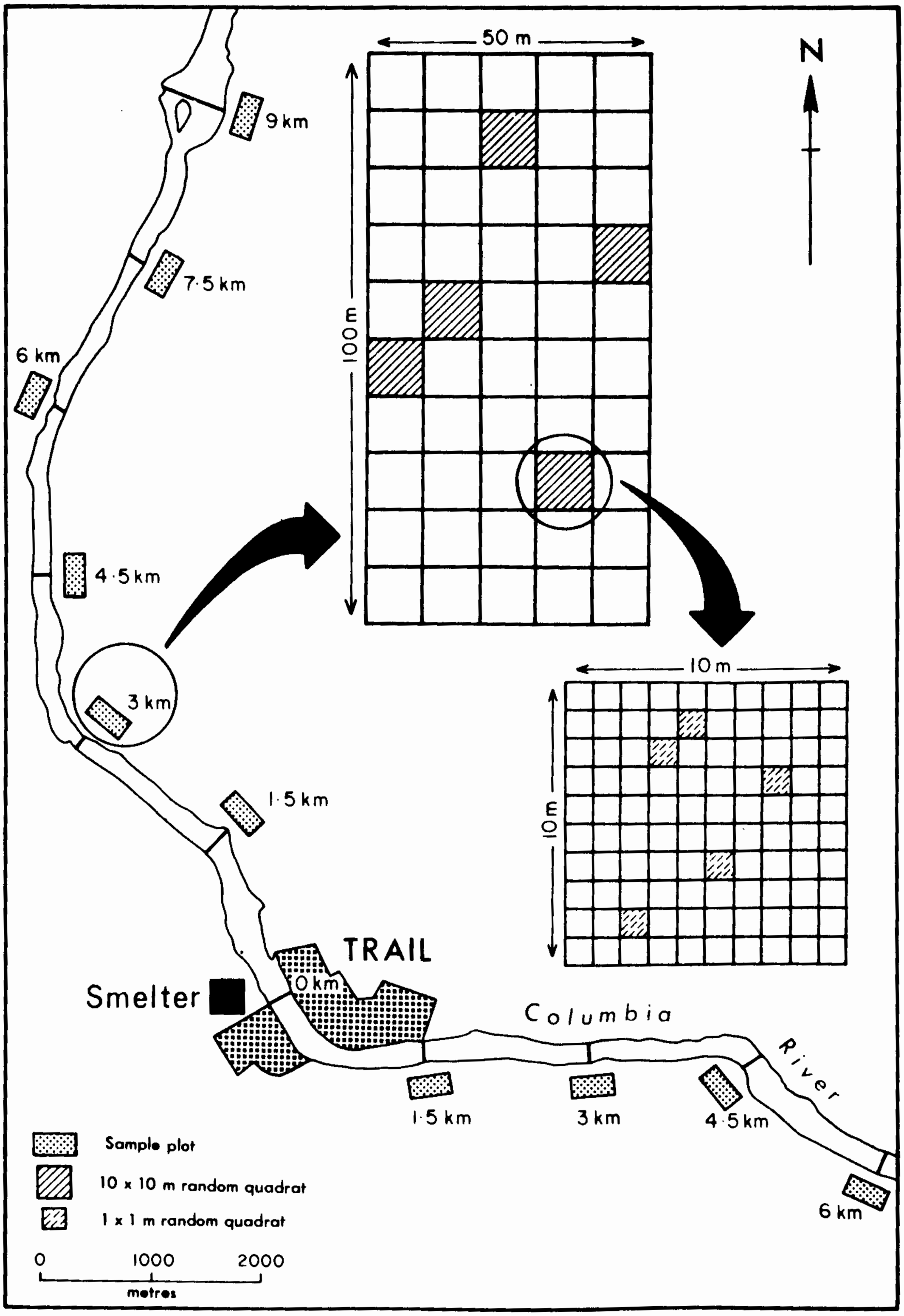


Fig. 8. The sampling design adopted for the study

ninety five 10 x 10 m quadrats and four hundred and seventy five 1 x 1 m quadrats, with five 10 x 10 m quadrats and twenty five 1 x 1 m quadrats located at the control site. Details of the vegetation and environmental data collected are listed in Table 3: the sampling procedures used and the methods adopted are described below.

Data Collection Procedures

The data collected could be grouped into three main classes, macro-environmental data, including edaphic variables, climatic variables, and pollution variables; vegetation data; and micro-environmental data.

1) Macro-environmental data

i) Edaphic variables

a. Soil profile descriptions. Full profile descriptions were made at sample plots 1, 5, 10, 15, and 20 according to the procedures outlined in the Soil Survey Staff (1951) field manual.

b. Soil texture. Textural analyses were conducted on material taken from plots 1, 5, 10, 15, and 20 at depths of 5, 15, 30, and 60 cm. Such a sampling procedure was adequate to detect the general trends. The analysis was performed by the hydrometer method as described by Bouyoucos (1936) and is outlined in Appendix D1.

c. Soil moisture at depth. The variability of soil moisture at depth was assessed electrically using fibreglass blocks embedded in the soil at 60 cm. The apparatus used is shown in Fig. 9. At each sample plot one 1 x 1 m quadrat was selected at random, the resistance block installed in an augered hole, and the soil repacked to the approximate bulk density of the undisturbed material. Thermistors

TABLE 3. DATA COLLECTION LOCATIONS

Variables Measured	Sample Plots																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1) Macro-environmental Data																				
i) Edaphic Variables																				
Soil profile descriptions	x				x					x					x					x
Soil texture at 5,15,30,60 cm	x				x					x					x					x
Soil moisture at 60 cm.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil chemical status at 30 cm	x				x	x			x	x			x		x	x		x		x
Soil chemical status at 60 cm	x				x					x										x
ii) Climatic Variables																				
Long term climatic data	Special locations: Crescent Valley, 55 km N of Trail; Columbia Gardens, 9 km S; Northport, Wn., 30 km S.																			
Daily weather data	Special locations: Castlegar Airport, 24 km N of Trail; Trail (Warfield), 1 km S; Waneta, 18 km S.																			
iii) Pollution Variables																				
Atmospheric sulphur dioxide levels	x	x	x		x	x		x		x	x		x		x	x		x		x
Available lead & zinc at 5,15 cm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Available lead & zinc at 30 cm	x				x	x			x	x			x		x	x		x		x
Available lead & zinc at 60 cm	x				x					x										x
2) Vegetation Data																				
Floristic composition	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Species abundance	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Standing crop	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Basal area of tree species	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Age of tree species	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Seed production	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3) Micro-environmental Data																				
Micro-climatic variables	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil moisture at 10,30 cm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil temperature at 10,30,60 cm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil chemical status at 5,15 cm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

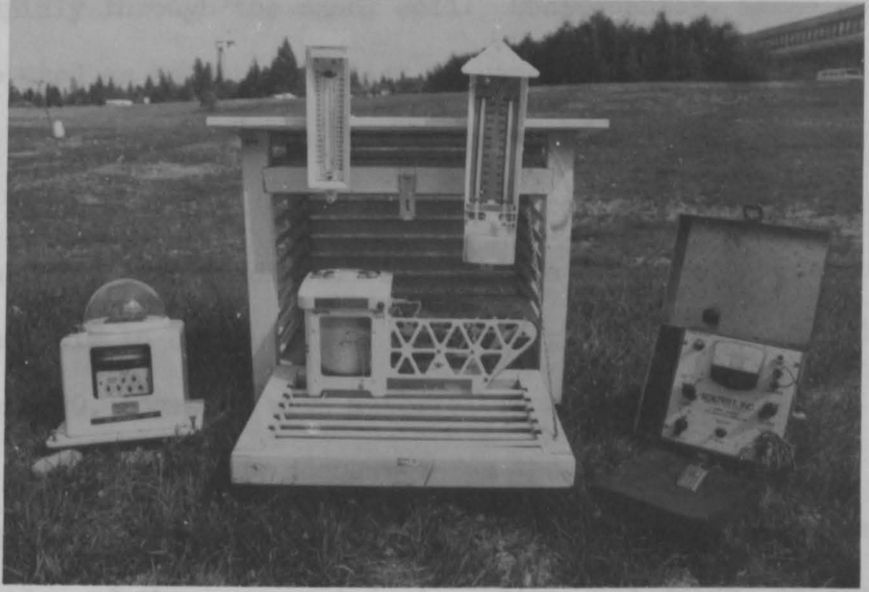


Fig. 9. The equipment used to measure the micro-environmental conditions. The instrumentation for recording soil moisture and soil temperature is shown to the right of the photograph. The small, metal encased fibreglass block was left embedded in the soil and was connected to the battery operated meter. The recording solarimeter (left) was used to determine shade conditions beneath the stands and the apparatus housed in the instrument shelter (centre) included a wet and dry bulb thermometer, a maximum and minimum thermometer, and a recording thermohygrograph

within the resistance blocks enabled soil temperatures to be measured simultaneously. Readings were taken at weekly intervals for the period May 31-September 27, and were subsequently corrected for temperature. The data collection took approximately eight hours; hence discrepancies might have occurred on days with intermittent rain since the water percolated rapidly through the sandy soil. Consequently, these data could only be used as an approximation of conditions in the area.

d. Chemical status of the parent material. Composite samples were taken at depths of 30 and 60 cm from pits dug at the centres of the 10 x 10 m quadrats. Prohibitive laboratory costs restricted analysis to samples from 30 cm for plots 1, 5, 6, 9, 10, 13, 15, 16, 18, and 20, together with material from 60 cm for plots 1, 5, 10, and 20. Such a selection accounted for the parent materials beneath the extreme vegetation cover types. The data collected included the concentration of the macro-nutrients sodium, potassium, calcium, and magnesium, percent carbon, soil acidity, and cation exchange capacity. The methods used in the analyses are presented in Appendix D2.

ii) Climatic variables

a. Long term climatic data. These data were used in assessing the uniformity of climatic conditions throughout the study area during the period of revegetation. Precipitation data for the period 1940-1970 were compiled for Crescent Valley, Columbia Gardens, and Northport, Wn. Average annual temperature and precipitation data were compiled for the government stations within the study area for the period 1960-1970; unfortunately many of these data were missing. The locations of the weather stations are shown in Fig. 10.

b. Daily weather data. These data provided a detailed record of the climatic variation within the study area during the growing season. Records of daily maximum and minimum temperatures and humidities, and daily precipitation were kept for the period June 1-September 30, 1971. Data were compiled for the Castlegar Airport and Trail (Warfield) stations, and for a temporary weather station that was set up on the terrace near Waneta (see Fig. 10).

iii) Pollution variables

a. Atmospheric sulphur dioxide levels. Present sulphur dioxide levels were assessed by the lead dioxide method designed by Huey (1968). The apparatus is shown in Fig. 11. Because of prohibitive costs, not all plots could be sampled; hence plots 1, 2, 3, 5, 6, 8, 10, 11, 13, 15, 16, 18, and 20 were selected in order to provide a well spaced network of recording points. Values for the remaining plots were interpolated by regression analysis. Each plate was left exposed for a period of thirty days: the results therefore indicated ambient sulphur dioxide levels during this period since no determinations of the duration or intensity of specific fumigations could be made.[1] The sulphur dioxide measurements were thus useful only as a guide in establishing the present day pollution levels. The analytical techniques are outlined in Appendix E1.

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[1] Using this technique, results for a thirty day period of continuous low intensity fumigations would be the same as those recorded for a period in which only a few strong fumigations occurred. However, the effects on the plant life might be less catastrophic under the former conditions.

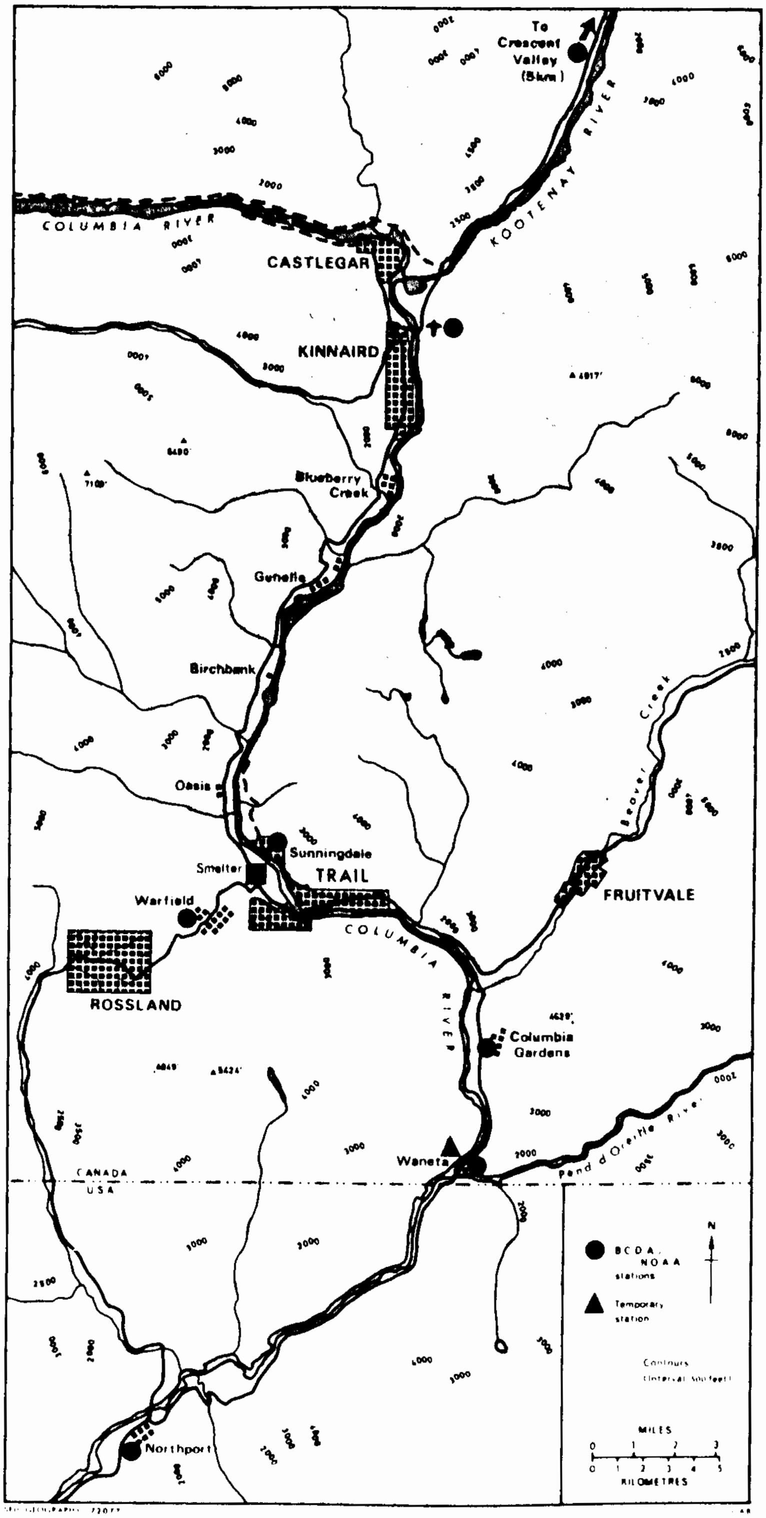

Fig. 10. The locations of the weather stations in the study area

Fig. 11. The lead dioxide sulphation plates used in the estimation of current sulphur dioxide levels in the study area. The upper plate is the standard 'Huey' equipment mounted with the lead paste facing downwards; the lower plate, facing upwards, is in a modified 'Cominco' holder

b. Available lead and zinc in the soil. Available lead and zinc were assessed for the composite soil samples from depths of 5 and 15 cm for all of the sample plots. In addition, material from 30 and 60 cm was analysed for the plots selected for the assessment of the chemical status of the parent material (see page 49). The laboratory methods are given in Appendix D2.

2) Vegetation data

a. Floristic composition. Lists of the species present were compiled for all of the sample plots. The tree species were recorded from the 10 x 10 m quadrats, and the 1 x 1 m quadrats were used for collecting the tree sapling[1] and ground vegetation data. From the species-area curves compiled for the ground vegetation (see Fig. 12) it can be seen that for all sample plots no new species were recorded in the final five quadrats: this suggested that the adopted sample size was satisfactory.

b. Species abundance. The actual measure of abundance adopted varied according to the life-form of the plants present in the area. Where possible, density measurements were taken which involved a count of the number of individuals within an area. Unfortunately, this method was only suitable for the easily recognised individuals. Some species, such as trailing cranberry (Arctostaphylos uva-ursi (L.) Spreng.), were rooted at several points along their length. In such cases, the number of times the species was rooted within the quadrat

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[1] Sapling was a general term used in this study to refer to an individual of a tree species less than one metre in height irrespective of its mode of origin. If these had arisen from seed (as in the case of the conifers), the term seedling was used. If the young individual was of vegetative origin, the term sucker was used for aspen and sprout was used for birch.

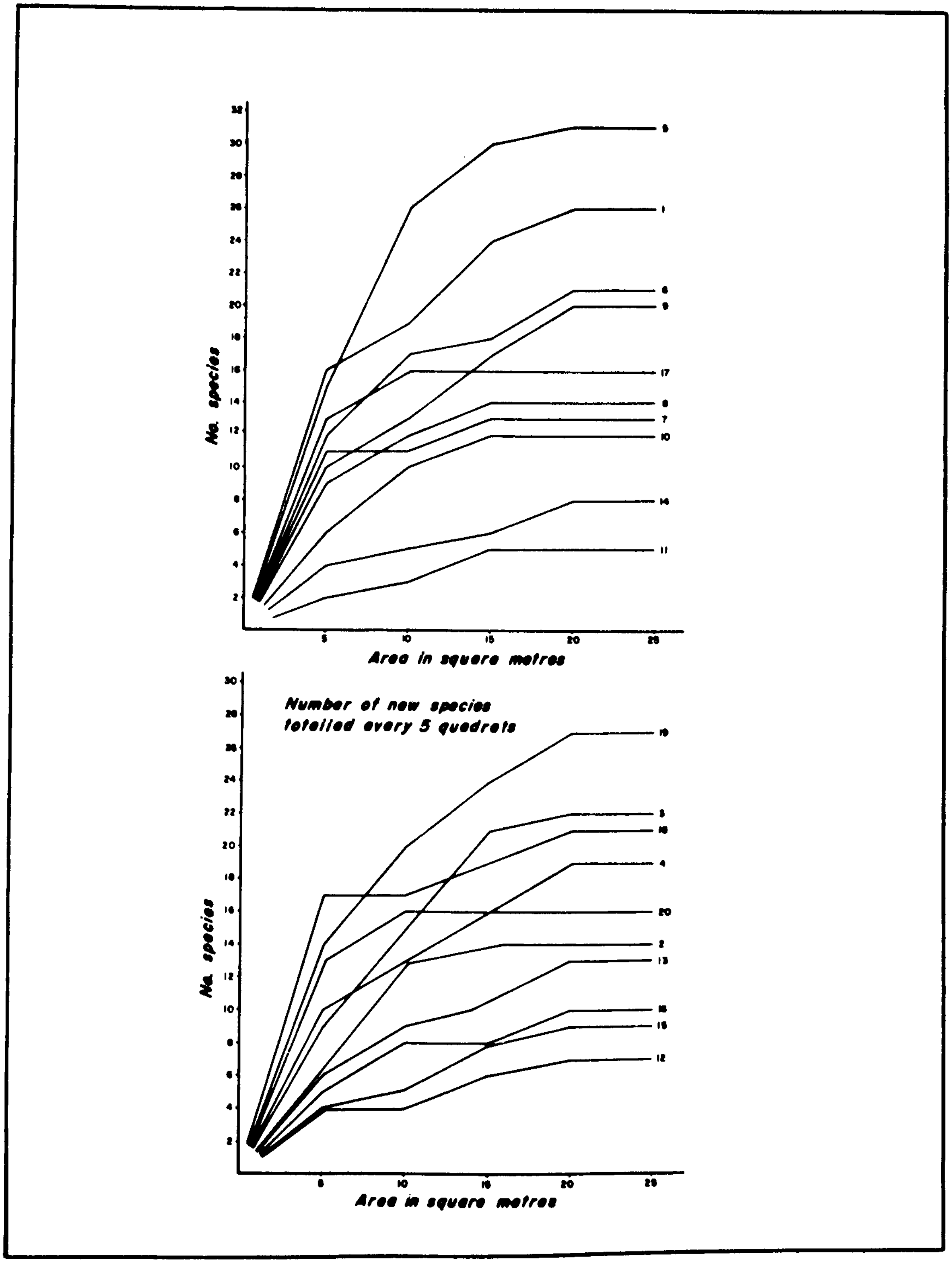


Fig. 12. Species-area curves for the 20 sample plots
(The control site is plot 1)

was used. For species that grew in a clumped habit, such as the grasses and mosses, abundance was assessed on a percent cover basis. The additional criterion of basal area was considered for the tree species, measurements being taken at a height of 1.5 m. All trees in each 10 x 10 m quadrat were measured. In cases where several trunks had developed from a single root stock, each was recorded.

c. Standing crop. The 1 x 1 m quadrat closest to the centre of each 10 x 10 m quadrat was sampled for the standing crop of the ground vegetation: five quadrats were therefore sampled at each plot. The material was cut and sorted into shrubs, broadleaf herbs, grasses, and bracken and subsequently weighed (fresh weight). Sub-samples were dried in an oven enabling all data to be recorded on a dry weight basis. In order to minimize felling, a range of trees of known basal area from several sample plots was cut and weighed (fresh weight). For each species, sub-samples of the felled trees were divided according to leaves, branches, and trunk. These were similarly dried in an oven and averaged to give a conversion factor (see Table 4) for the estimation of the species' dry weights.

TABLE 4

CONVERSION FACTORS FOR THE STANDING CROP DETERMINATIONS FOR THE TREE COVER

	Leaves	Branches	Trunk	Average
Birch	0.480	0.614	0.586	0.560
Trembling aspen	0.439	0.536	0.556	0.510
Coniferous species	0.589	0.550	0.734	0.624

Since volume increment is predominantly due to changes in diameter (Baker, 1950), linear correlations between fresh weight and basal area were carried out for the principal tree species; the results are given in Table 5, with the corresponding regression lines shown in Fig. 13. In all cases the regression lines failed to pass through the origin; hence freehand curves were considered (see Fig. 13). The reduction in the standard error of estimate for the freehand curves compared with the linear regression lines indicated the preference of this method (see Table 6). Standing crop data for the tree cover per sample plot were subsequently computed using density and average basal

TABLE 5

LINEAR CORRELATION BETWEEN FRESH WEIGHT AND BASAL AREA FOR THE TREE COVER

	r	N	Significance
Birch	0.9855	18	$P < 0.01$
Trembling aspen	0.9697	24	$P < 0.01$
Coniferous species	0.9571	15	$P < 0.01$

TABLE 6

STANDARD ERROR OF ESTIMATE FOR THE PREDICTION OF THE FRESH WEIGHT OF THE TREE COVER FROM BASAL AREA MEASUREMENTS USING LINEAR REGRESSION AND FREEHAND CURVES

	Linear Regression	Freehand Curve
Birch	5.643	4.079
Trembling aspen	11.538	8.538
Coniferous species	2.740	1.963

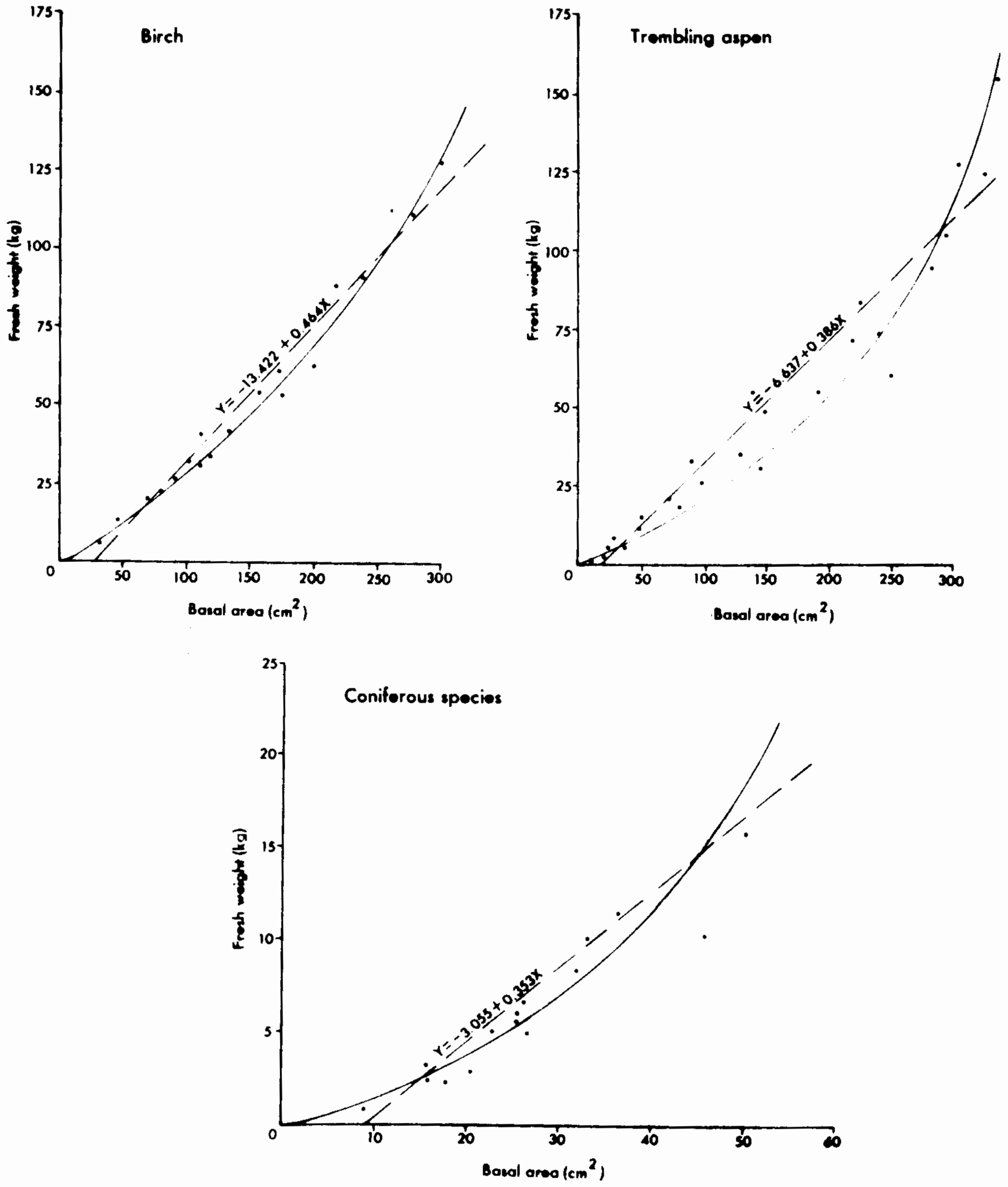


Fig. 13. Regression lines used for the prediction of the fresh weight of the tree cover from basal area

area measurements.

d. Age of the tree cover. A total of 175 increment borings were carried out on a range of individuals at each sample plot. Some of the smaller trees had to be felled and discs taken from the stumps. Since it was impossible to core all of the trees present, regression lines for basal area against age were computed for the principal tree species (see Fig. 14). This permitted a larger sample, 1,200 individuals, to be used in the subsequent estimation of the age class distributions, and hence, in the assessment of the reproductive status of the tree cover. Typical growth curves are sigmoid in form (Baker, 1950) with deviation from a straight line occurring in both the mature and sapling stages. Since few of the trees in the area could be considered mature, the former restraint was not applicable. The sapling stage typically persists for only a short period of time, although this might have been extended as a result of sulphur dioxide suppression. However, the majority of the trees started growth following pollution control so this too could theoretically be discounted. The validity of this assumption was demonstrated by the fairly even width of the annual rings in the sample cores. In addition, the linear correlations between age and basal area for birch, trembling aspen, and lodgepole pine were highly significant (see Table 7). Only in the oldest individuals, the conifers over 60 years old, was evidence of suppression of growth found (see Fig. 15).

The ranges in species basal areas were subdivided into corresponding age classes. Individuals less than five years old were considered as recently established growth: trees older than 30 years

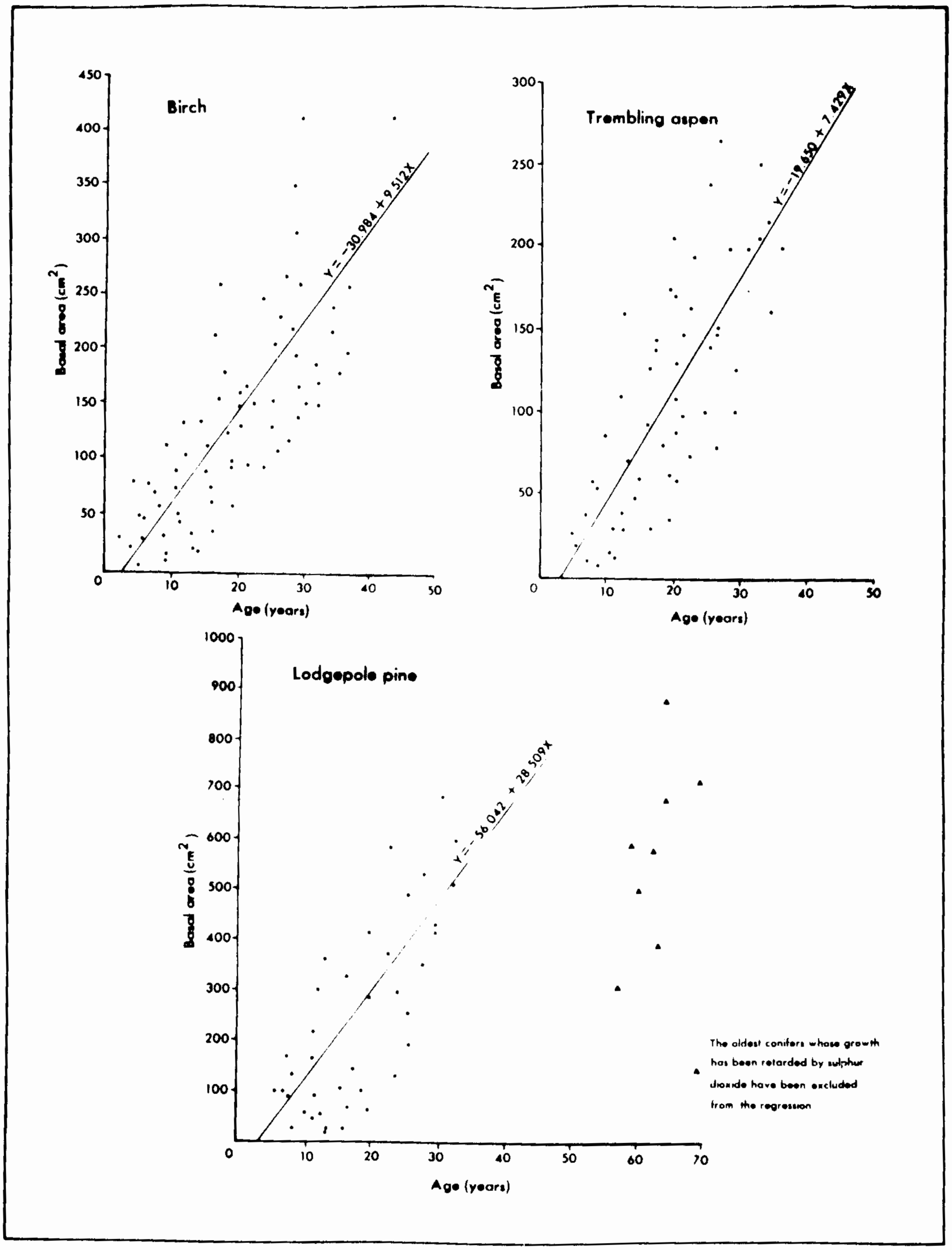


Fig. 14. Regression lines used for the prediction of the age of the tree cover from basal area

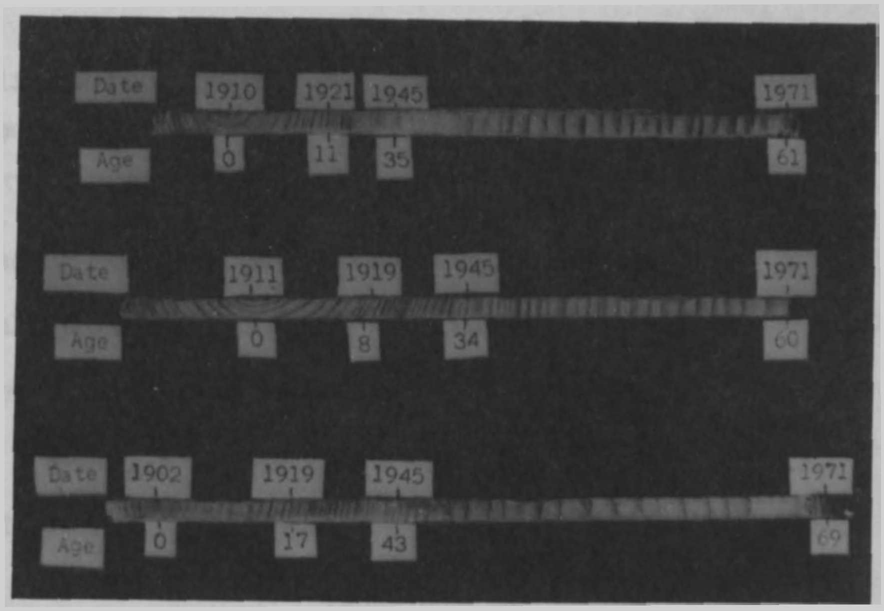


Fig. 15. Cores taken from lodgepole pine growing at plot 5 (14.5 km north of Trail). Growth in these specimens appears good until 1919-1920. Some suppression of growth is to be expected in the early stages of a tree's life as a result of competition from older individuals. However, from about 1920 until 1945 a severe reduction in growth can be seen. This is thought to reflect suppression by sulphur dioxide. The trees survived these fumigations and good growth occurred after 1945

TABLE 7

LINEAR CORRELATION BETWEEN AGE OF THE TREE COVER AND BASAL AREA

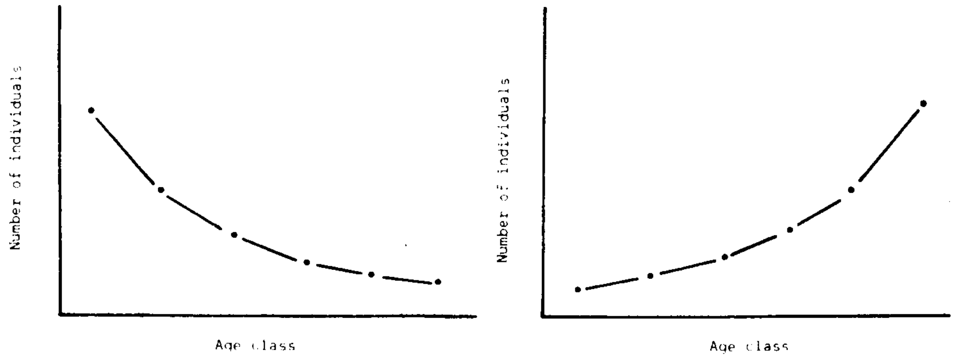
	r	N	Significance
Birch	0.7668	78	$P < 0.01$
Trembling aspen	0.7289	54	$P < 0.01$
Lodgepole pine	0.8504	39	$P < 0.01$

were regarded as remnants of the cover which had developed prior to the period of full pollution control. The intervening age classes selected, and the corresponding size classes as predicted from Fig. 14, are given in Table 8: the types of age class distributions anticipated are outlined in Fig. 16.

TABLE 8

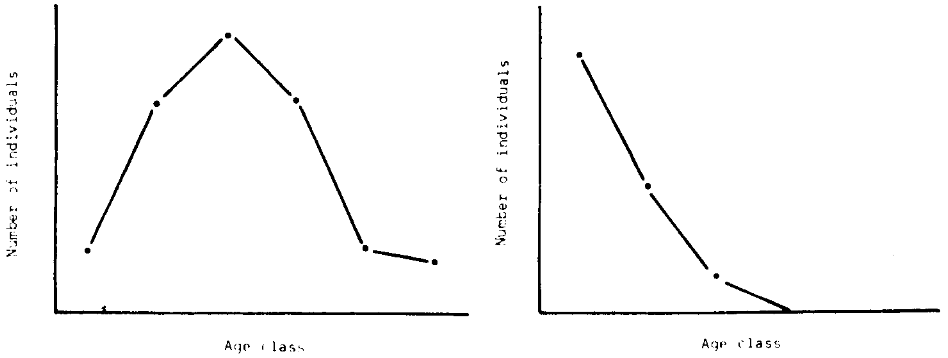
SIZE CLASS DIFFERENTIATION AND CORRESPONDING AGE CLASSES

Age class (years)	Age class midpoint	Size class (cm^2)		
		Birch	Trembling aspen	Lodgepole pine
< 5	< 5	< 12	< 10	< 14
5- 7	6	12- 30	10- 24	14- 63
8-12	10	31- 75	25- 56	64-164
13-19	16	76-135	57-115	165-229
20-30	25	136-225	116-184	230-475
> 30	>30	> 225	> 184	> 475



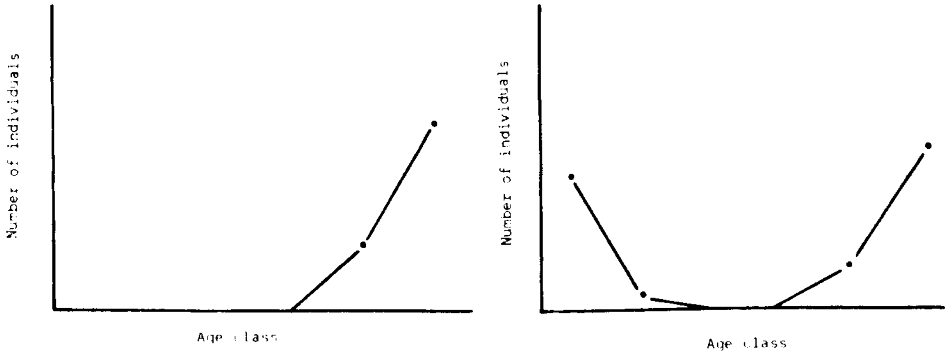
(i) Uneven aged species distribution showing the normal logarithmic curve for a constantly reproducing population.

(ii) Uneven aged distribution of an early colonising species which is no longer reproducing due to unfavourable habitat conditions.



(iii) Even aged species distribution in which a decline in the vigour of a species has occurred.

(iv) Species newly invading an area due to adequate autogenic modification or because an absence of viable propagules is now rectified.



(v) Remnant species from the former cover which persisted through the period of pollution but which is no longer reproducing due to a shortage of viable propagules or because of unfavourable habitat conditions.

(vi) Remnant of the former cover which is now reproducing in the area.

Fig. 16. Hypothetical age class distributions

e. Seed production. In order to estimate seed input into the study area, square flower pots, 10 x 10 cm in size, containing sterilised soil, were installed in the centres of three 1 x 1 m quadrats, selected at random, at each sample plot. The pots were set out by late May, 1971, and were collected in mid-October. This method ensured one year's input, although predation losses might have occurred. Germination in the laboratory was carried out at room temperature under fluorescent lamps set to a 16 hour photoperiod. This was started immediately following recovery, and continued until July, 1972. Because some germination had occurred prior to collection, no cold stratification was conducted.

3) Micro-environmental data

a. Micro-climate. The instrumentation used in the field included maximum and minimum thermometers, wet and dry bulb thermometers, and recording thermohygrographs mounted in single louvered instrument shelters for air temperature and humidity readings, together with integrating solarimeters for the assessment of shade (see Fig. 9). The instruments were located at ground level, and the data were considered to be representative of conditions in the zone below 50 cm. However, some vegetation disturbance was caused during the placement of the instrument shelter: often the smallest plants were covered and the shrubs had to be pushed aside. Where leaves touched the screen some reduction in air circulation might have resulted. Micro-climatic modification in plots with sparse, low growing vegetation was therefore undetected, whereas in plots with a well developed cover, an over representation of any autogenic modification might have occurred.

The principal methodological problem involved in the assessment of micro-climatic variability within the study area was a means of comparing the results from different stands. Because of the heterogeneity of the plant cover throughout the area, it was decided that the micro-climate of all plots should be sampled. However, because of limited equipment, it was necessary to sample the plots at different times. Thus, superimposed on any trends that might result from variation in the vegetation cover were daily and possibly seasonal fluctuations. The method adopted involved the use of two sets of matched instruments, with one set located on an area of bare soil adjacent to the sample plot, and the other located within the stand. The position of the instruments in the bare areas was chosen such that the readings would be unaffected by the surrounding vegetation. Positioning within each sample plot involved the random selection of one of the previously surveyed 10 x 10 m quadrats, with the instruments being moved in turn to the five 1 x 1 m quadrats enclosed therein. The period of time during which the micro-climatic readings were collected at each 1 x 1 m quadrat was determined by the amount of insolation received at the 'bare' site. It was decided prior to sampling that a cumulative reading of at least 240 cal/cm^2/day should be recorded at the respective 'bare' sites. Such a restriction minimised the reduced shading effect and temperature and humidity modifications brought about by the canopy under the diffuse light conditions of a cloudy day. In most cases this meant a 24 hour recording period at each 1 x 1 m quadrat, the instruments being rotated in the evenings. Differences in the micro-climatic conditions prevailing within the stand compared with those at the adjacent area of bare ground were expressed in terms of the degree of modification. This provided a standard basis for assessing the effects of recovery on the micro-climate of the study area.

b. Physical soil properties. Soil moisture was recorded at depths of 10 and 30 cm and soil temperatures at depths of 10, 30, and 60 cm for all plots. The sampling techniques are referred to on page 46.

c. Chemical soil properties. Chemical soil properties were assessed for all plots at depths of 5 and 15 cm. The variables selected were the same as those listed previously for the parent material. The sampling methods are given on page 49.

Chapter 3

VARIATION IN THE MACRO-ENVIRONMENT OF THE STUDY AREA

The sampling design adopted in the present research resulted in an extensive study area. Theoretically, any spatial variation in the cover of this area should have reflected different stages in the recovery of the vegetation. It was therefore essential to determine if any of the patterning exhibited by the vegetation could have resulted from inherent variation in the macro-environment.

Geology

An early geological survey of the region was carried out by Daly (1912). A more detailed account was later published by Little (1962, 1963). Fig. 17 shows the geology of the study region. The region is composed of two main formations; granodiorite of the Trail batholith of Mesozoic age, and material of the Rossland volcanic formation of Carboniferous to Cretaceous age. The latter consists mainly of flows and pyroclastic deposits of latites, andesites, and basalts. The town of Rossland is situated on a stock composed of monzonite thought to be of Mesozoic age. This intrusion is about 2.5 km wide at the surface and extends eastwards from Rossland for a distance of 5.5 km. To the east of Trail, in the vicinity of Fruitvale, are found flows and pyroclastic deposits of augite, andesite, and basalt of the Beaver Mountain volcanic complex, a Tertiary formation. Along the International Border the Pend d'Oreille schists outcrop. These are composed of carbonaceous phyllite,

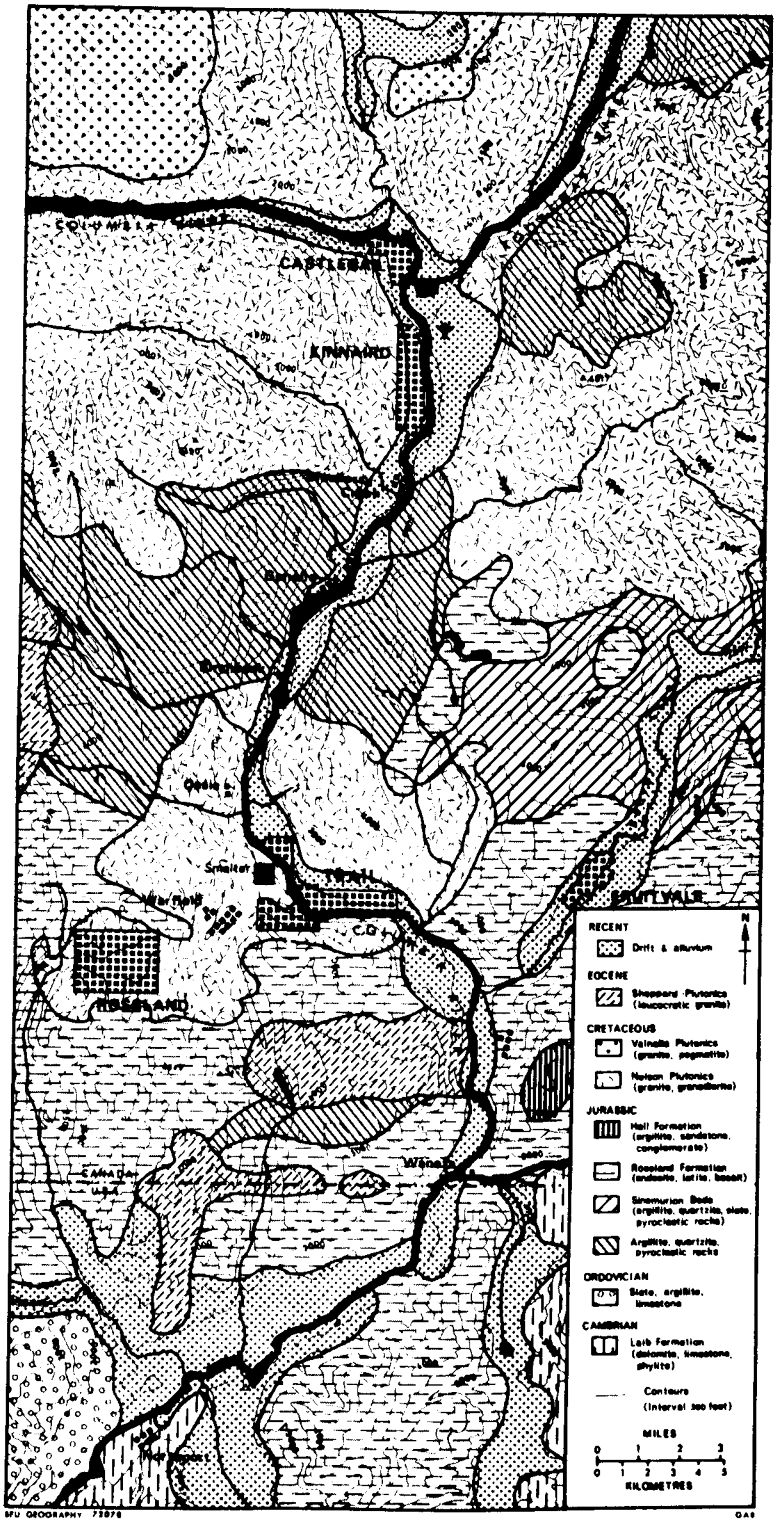


Fig. 17. The geology of the study area (after Little, 1962, 1963 and Wash. Dep. Conserv., 1960)

with quartzite and greenstone intercalations of Carboniferous to Ordovician age.

The entire area was glaciated during the Pleistocene. In general the ice moved southwards depositing a thin mantle of till throughout the region. In the valley of the Columbia River this has been resorted by fluvial action and subsequently deposited as terraces of sand, silt, and gravel which mask the underlying bedrock.

Such a varied geology gives rise to a wide range of parent materials. This is important to soil development and may be further reflected in the pattern of the existing vegetation; hence field work was restricted to the more uniform materials of the terraces.

Soils

The parent materials of the terraces consist of glacial outwash and river alluvium giving a generally well drained and comparatively smooth topography. Katz et al. (1939) list the soil types of this area as the Mission, and Springdale sands and loams. In their undisturbed state these would be classified as brunisols (Can. Dep. Agr., 1974). The former occurs to the north of Trail whereas to the south both are found interspersed. However, excessive erosion has occurred following the removal of the vegetation cover and much of the area to the south of the smelter is now occupied by immature regosols with Ah/C profiles. Standard field descriptions and textural analyses were conducted on selected samples in order to determine the nature of the soil on the terraces and to ascertain the degree of homogeneity within the sample area. Similarly, variations in the availability of water at depth and the chemical status of the parent material were assessed.

a. Field descriptions. Full profile descriptions are given in Appendix D5 with the typical appearance of the soils shown in Figs. 18-21. The consistence for dry soil was generally loose, and its structure typically a fine crumb. Thickness of the organic layer and the abundance of roots depended on the nature and density of the associated vegetation. Similarly, colour reflected the amount of organic material present. The upper section of the profiles were generally within the 10YR range with an abrupt boundary to more yellow 7.5Y or 5Y parent materials. Although some variation in the physical properties of the soil was demonstrated, it was not considered to be an important factor affecting the spatial distribution of the vegetation.

b. Textural analysis. The results of the analyses are listed in Table 9. In practically all samples there was a decrease in the silt and clay fractions with depth. Superimposed on this was a detectable increase in sand as one moved southwards through the study area. The soils to the north of Trail were classed as loams at 5, 15, and 30 cm, whereas to the south they were of a sandy loam texture. Similarly, at 60 cm the soils passed from a sandy loam to a loamy sand texture. Coarse rounded fragments up to 20 cm in length occurred in two zones within the study area, one in the vicinity of the control site (Plot 1) and one extending from 3 km north of Trail to 10 km south. The reason for this distribution was not investigated. The textural similarity of the soils can be seen from Fig. 22.

c. Soil moisture at depth. The results of the soil moisture determinations at 60 cm are shown, corrected for temperature, in Fig. 23.

Fig. 18. The soil profile at plot 1 (control site). Note the abundance of litter and the distribution of roots throughout the profile. Rounded pebbles up to 20 cm in length were common (The measuring stick is graded in cm)

Fig. 19. The soil profile at plot 5. Note the abundant litter and well developed organic horizon with roots common at all depths. Coarse material was absent

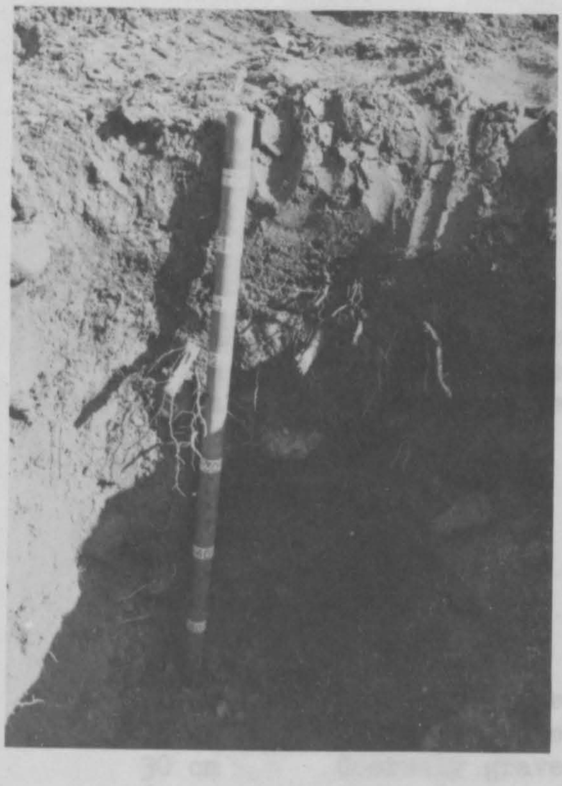


Fig. 20. The soil profile at plot 13. This was a poorly vegetated plot, a condition which was reflected by the absence of litter and an organic horizon. The roots (birch) were restricted to the upper horizons and were not found in the horizons containing the coarse fragments

Fig. 21. The soil profile at plot 15. Although some litter was present (aspen leaves) this had not been incorporated with the mineral matter to form a distinct organic horizon. Roots were sparse. No coarse material was present

TABLE 9

SOIL TEXTURAL CLASSIFICATION

Plot 1	
5 cm	Loam
15 cm	Coarsely gravelly loam
30 cm	Coarsely gravelly loam
60 cm	Coarsely gravelly sandy loam
Plot 5	
5 cm	Loam
15 cm	Loam
30 cm	Loam
60 cm	Sandy loam
Plot 10	
5 cm	Coarsely gravelly loam
15 cm	Coarsely gravelly loam
30 cm	Coarsely gravelly loam
60 cm	Coarsely gravelly sandy loam
Plot 15	
5 cm	Finely gravelly sandy loam
15 cm	Finely gravelly sandy loam
30 cm	Finely gravelly sandy loam
60 cm	Coarsely gravelly loamy sand
Plot 20	
5 cm	Sandy loam
15 cm	Sandy loam
30 cm	Sandy loam
60 cm	Loamy sand

An analysis-of-variance was conducted on the 18 weekly values derived for each of the 20 sample plots to determine if significant variation occurred between sample plots.[1] The result (F = 137.93, d.f. 19,340)

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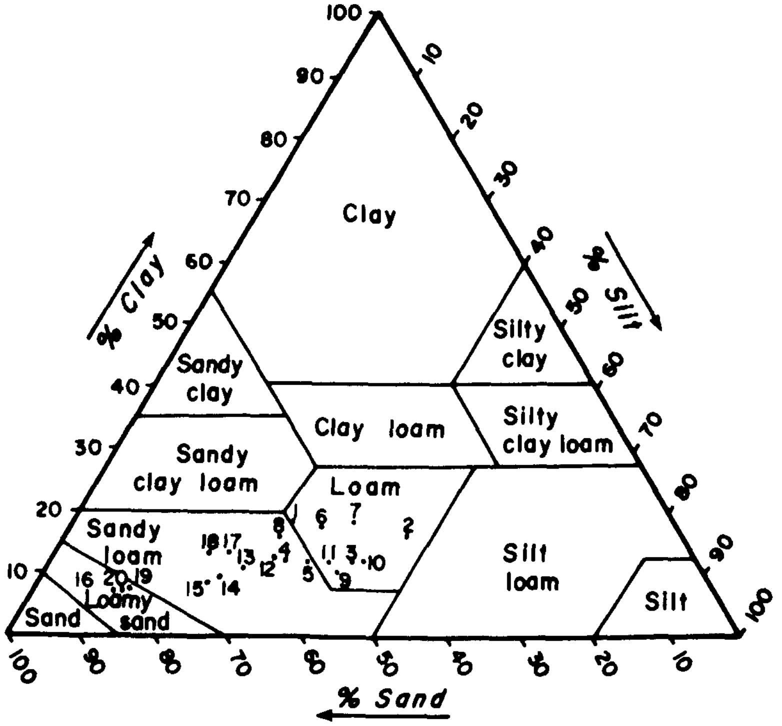
[1] These data are listed in Appendix D3.



Depth (cm)	LOCATION				
	40 km N.	14·5 km N.	3 km N.	9 km S.	23 km S.
5	1	5	9	13	17
15	2	6	10	14	18
30	3	7	11	15	19
60	4	8	12	16	20

Fig. 22. The texture of the soils of the study area (with key to the data points)

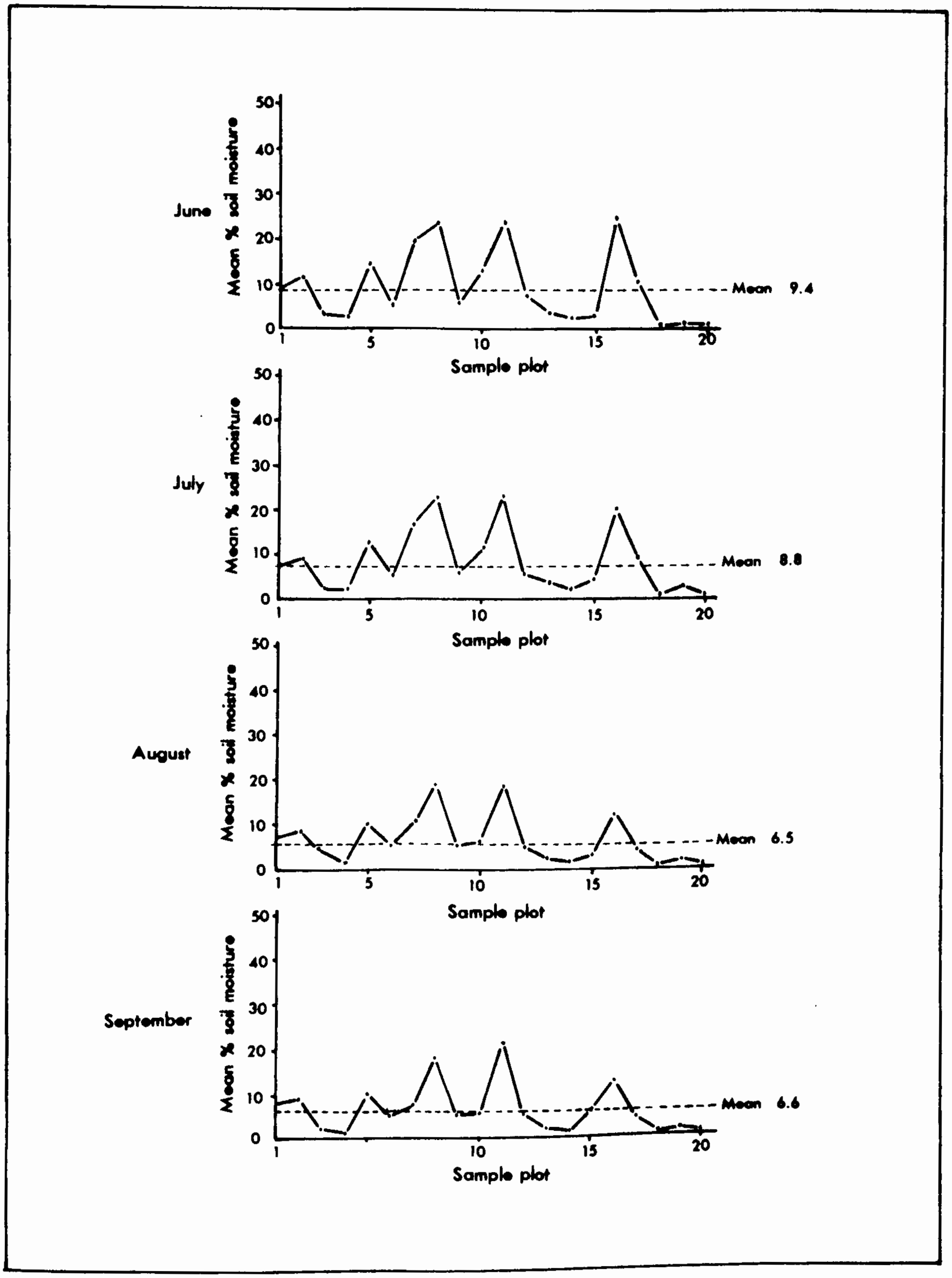


Fig. 23. Mean monthly soil moisture (%) at 60 cm depth (The control site is plot 1: Trail is located between plots 10 and 11)

was highly significant ($P < 0.01$), which suggested that soil moisture at depth might have been an important factor affecting the present vegetation pattern through more favourable moisture budgets at some plots. Plots 7, 8, 11, and 16 were noticeably moister than average for all months although plot 7 became appreciably drier late in the growing season. Two factors could account for such haphazard variation. First, differences in elevation above the Columbia River might result in differences in proximity to the water table. This was probably the major cause of high soil moisture at depth at plot 8 in which black cottonwood, a species favouring moister sites, was found. Secondly, physiographic relationships could be important. Plots 7, 11, and 16 were situated at the foot of the valley slopes which, because of their sparse vegetation and soil cover, might provide an important source of moisture to the adjacent valley floor through runoff..

d. Chemical status of the parent material. The results of the analyses are given in Fig. 24 and tabulated in Appendix D2. The concentration of sodium and soil acidity were relatively constant both at 30 and 60 cm. For the other variables, marked fluctuations occurred with much of this deviation being found at sample plots 1, 5, and 20. Each of these had a well developed cover (see pages 94-104) which might have effected some sub-surface alteration. However, plot 10, which supported only a poor vegetation cover, had an extremely high cation exchange capacity at 60 cm. This might represent the accumulation of colloidal material leached from the surface horizons following the earlier vegetation removal. Alternatively, this might reflect differences in the composition of the parent materials. A similarly high cation exchange

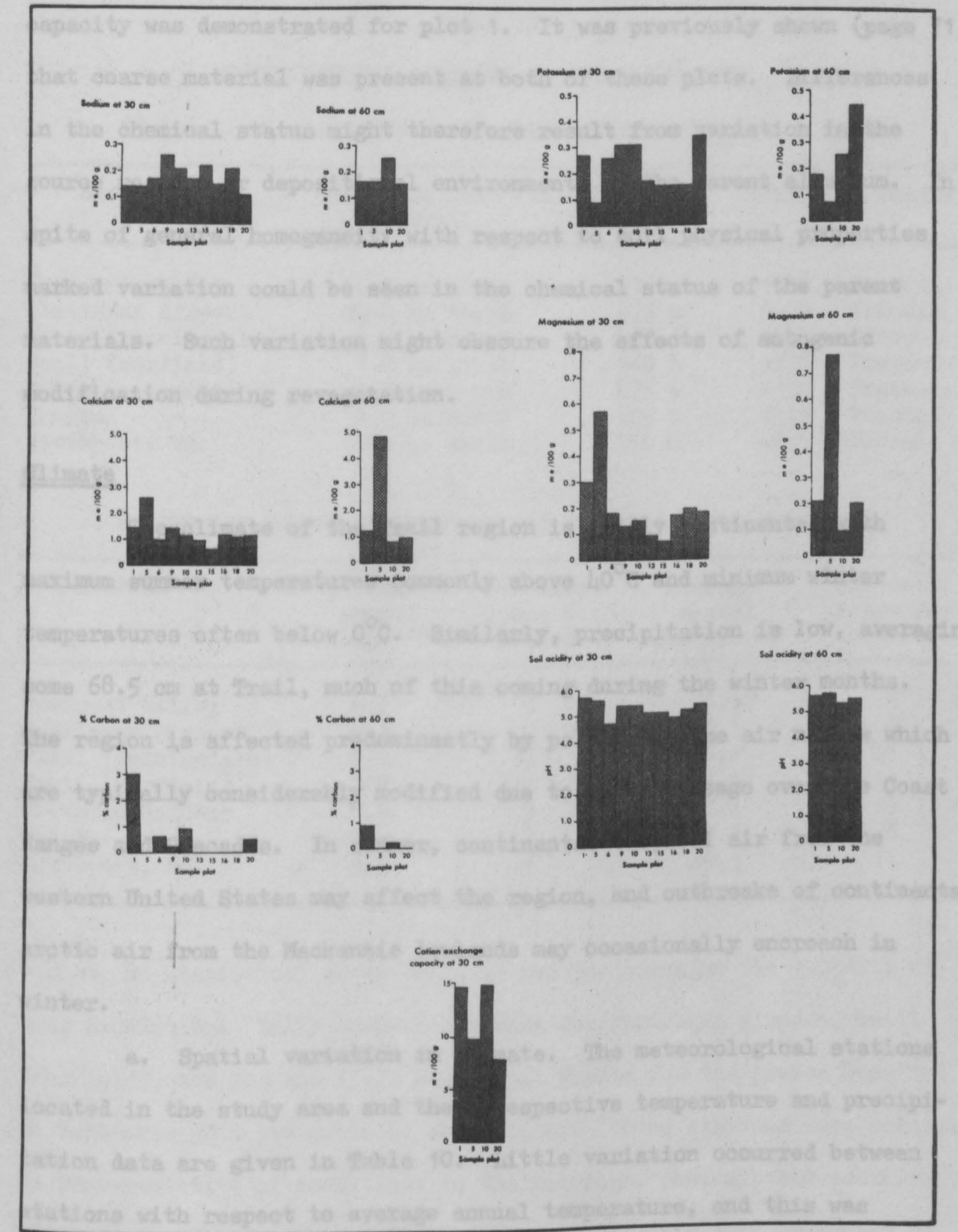


Fig. 24. The chemical status of the parent material
(The control site is plot 1)

capacity was demonstrated for plot 1. It was previously shown (page 71) that coarse material was present at both of these plots. Differences in the chemical status might therefore result from variation in the source regions or depositional environments of the parent alluvium. In spite of general homogeneity with respect to soil physical properties, marked variation could be seen in the chemical status of the parent materials. Such variation might obscure the effects of autogenic modification during revegetation.

Climate

The climate of the Trail region is mildly continental with maximum summer temperatures commonly above 40°C and minimum winter temperatures often below 0°C. Similarly, precipitation is low, averaging some 68.5 cm at Trail, much of this coming during the winter months. The region is affected predominantly by polar maritime air masses which are typically considerably modified due to their passage over the Coast Ranges and Cascades. In summer, continental tropical air from the western United States may affect the region, and outbreaks of continental arctic air from the Mackenzie lowlands may occasionally encroach in winter.

a. Spatial variation in climate. The meteorological stations located in the study area and their respective temperature and precipitation data are given in Table 10. Little variation occurred between stations with respect to average annual temperature, and this was discounted as a factor which might cause a differential response in species composition or vigour. However, because the years of record

TABLE 10

METEOROLOGICAL STATIONS IN THE STUDY AREA

A) Location, elevation, and period of record

Station	Location relative to Trail	Elevation	Period of record
Crescent Valley	55.0 km north	670 m	1940 - Present
Castlegar Airport	24.0 km north	475 m	1959 - Present
Trail (Sunningdale)	0.5 km north	475 m	1960 - Present
Trail (Warfield)	1.0 km south	660 m	1928 - Present
Columbia Gardens	9.0 km south	475 m	1939 - Present
Waneta	18.0 km south	625 m	1915 - Present
Northport, Wn.	30.0 km south	450 m	1931 - Present

B) Average annual temperature and precipitation, 1960-1970

Station	Average annual temp. °C	No. data years for period	Average annual precip. cm	No. data years for period
Crescent Valley	6.7	5	76.9	5
Castlegar Airport	8.3	7	68.1	8
Trail (Sunningdale)	9.0	10	69.1	11
Trail (Warfield)	8.9	11	71.1	11
Columbia Gardens	8.8	9	67.6	10
Waneta	7.4	6	59.9	6
Northport, Wn.	9.2	7	49.3	11

varied, no statistical tests could be run to determine the validity of this assumption. Daily temperature data for Castlegar Airport, Trail (Warfield), and for the field station at Waneta for the period June 1st to September 30th are given in Appendix B2. These stations were regarded as representative of conditions in the northern, central, and southern parts of the study area. Analysis-of-variance tests were conducted on the daily maxima and daily minima temperatures recorded for each month in order to determine if the differences between stations were significant. The results are given in Table 11. Variation between maximum temperatures was significant only for the month of September.

TABLE 11

ANALYSIS-OF-VARIANCE: DAILY TEMPERATURE DATA FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

A) Daily maximum temperature

Month	Mean Maximum Temp. °C Castlegar Airport	Trail (Warfield)	Waneta	df	F
June	21.5	21.7	21.0	2,87	0.19
July	28.5	29.4	27.3	2,90	0.74
August	32.7	32.7	31.3	2,90	0.70
September	19.3	20.1	16.9	2,87	4.74*

B) Daily minimum temperature

Month	Castlegar Airport	Trail (Warfield)	Waneta	df	F
June	8.8	11.0	9.2	2,87	7.77**
July	11.2	13.7	9.2	2,90	18.48**
August	12.3	15.3	11.7	2,90	16.50**
September	6.3	7.9	6.7	2,87	1.82

* $0.05 \geqslant P > 0.01$ ** $P < 0.01$

During this month the Waneta station recorded somewhat lower maximum temperatures than the others. The reason for this was unclear, although the more open nature of the valley at this point might affect the circulation pattern. In the case of minimum temperatures the reverse was true. Analyses for all months other than September resulted in highly significant F values with Trail (Warfield) recording higher temperatures than the other stations thus obscuring any down-valley trends. Such differences in minimum temperatures could possibly account for some of the variation in species composition throughout the area.

Annual precipitation data for Crescent Valley, Columbia Gardens, and Northport are given in Appendix B1. It was evident that there was a marked decrease in precipitation as one moved southwards from a maximum annual average of 79.2 cm at Crescent Valley to a minimum value of 50.3 cm at Northport. Because of the fairly complete records, it was possible to determine if the annual precipitation values for the stations varied significantly using an analysis-of-variance test for the period 1941-44, 1946-57, 1959-64. The result, as shown in Table 12, was significant at the 0.01 level. This, in conjunction with the fact that the difference between the mean annual precipitation for the north and south of the study region was 28.9 cm, would suggest that the decrease in precipitation to the south might be a major factor influencing the composition of the vegetation and complicating the recovery sequence.

TABLE 12

ANALYSIS-OF-VARIANCE: ANNUAL PRECIPITATION DATA FOR THE PERIOD 1941-44, 1946-57, 1959-64

Mean annual precipitation (cm)				
Crescent Valley	Columbia Gardens	Northport	df	F
79.2	64.5	50.3	2,22	49.34**

** $P < 0.01$

Similarly, an analysis-of-variance was conducted on the daily precipitation data from Castlegar Airport, Trail (Warfield), and Waneta which were collected during the period of field work, as given in Appendix B3. The results are presented in Table 13.

TABLE 13

ANALYSIS-OF-VARIANCE: DAILY AND MONTHLY PRECIPITATION DATA (CM) FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

	Castlegar Airport	Trail (Warfield)	Waneta	df	F
June	7.84	8.40	5.66	2,87	0.93
July	6.06	3.87	3.85	2,90	0.69
August	1.90	2.63	2.82	2,90	0.68
September	5.58	5.04	6.33	2,87	0.66
Total for the growing season	21.37	19.93	18.66	2,8	11.35**

** $P < 0.01$

Although no significant variation could be demonstrated for the daily data, significant variation was detected between stations for the complete growing season. The same trend was evident as with the annual data: Castlegar Airport in the north of the study area received more precipitation than the station at Waneta located in the south.

Daily maximum and minimum relative humidity data were compiled for Castlegar Airport, Trail (Warfield), and Waneta for the period June 1st to September 30th (see Appendix B4). An analysis-of-variance was conducted on these data to determine if the variation between stations was significant. The results are presented in Table 14.

TABLE 14

ANALYSIS-OF-VARIANCE: DAILY RELATIVE HUMIDITY DATA FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

A) Maximum relative humidity

Month	Mean maximum relative humidity %			df	F
	Castlegar Airport	Trail (Warfield)	Waneta		
June	90.3	87.3	98.0	2,87	38.36**
July	83.8	76.0	95.7	2,90	30.73**
August	77.7	70.1	95.1	2,90	79.49**
September	92.1	87.6	95.1	2,87	11.95**

B) Minimum relative humidity

Month	Mean minimum relative humidity %			df	F
	Castlegar Airport	Trail (Warfield)	Waneta		
June	44.2	40.4	41.7	2,87	0.44
July	31.2	26.6	27.0	2.90	1.18
August	22.3	22.3	19.4	2,90	1.11
September	40.2	36.2	35.7	2,87	0.82

** $P < 0.01$

From the analyses it could be seen that variation between minimum (daylight) humidities was not significant, and thus would be unlikely to have caused any differential susceptibility to sulphur dioxide during revegetation (see page 14). However, variation between maximum humidities was highly significant with the lowest monthly averages for maximum humidity always being recorded at Trail (Warfield), the highest at Waneta. This would suggest that proximity to the Columbia River was an important factor, influencing maximum humidities: the Waneta station was located within a few metres of the river whereas the Trail (Warfield) station was some 5 km from it. Such variation in maximum humidity should not have seriously affected revegetation patterns on the terraces with respect to sulphur dioxide damage although some reduction in transpiration rates might have compensated for possible shortages in soil moisture.

b. Climatic variation during revegetation. Fluctuations about the annual precipitation mean for each station were plotted for Crescent Valley, Columbia Gardens, and Northport for the period 1940-1970 (see Fig. 25). From 1940 to 1941 precipitation was above average throughout the area, particularly in the southern section. The following three years were noticeably drier than average. From 1948 to 1955 precipitation at Crescent Valley was predominantly higher than average, although since that date the reverse was true. A somewhat different trend was recorded at Columbia Gardens with yearly or biannual fluctuations both above and below the mean. However, in the last twelve years a general increase in precipitation was evident. A similar trend was recorded by the Northport station. The uniformity of such trends in annual precipitation within the study area was assessed by correlation analysis (see Table 15).

The highly significant results indicated that the precipitation regimes in the different localities had been very similar over the past 30 years and hence no variation in the present cover should be attributable to this factor.

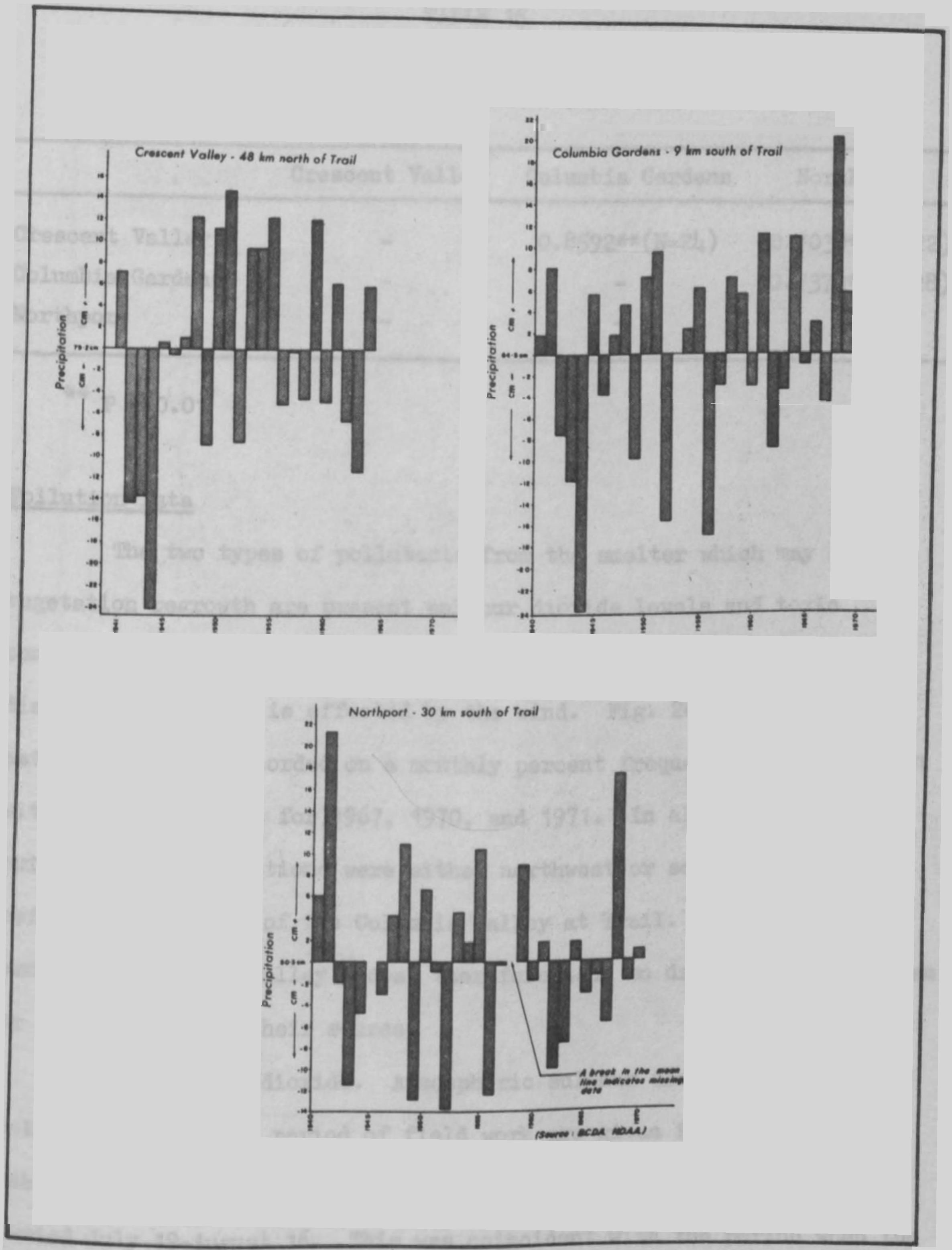


Fig. 25. Annual precipitation data for Crescent Valley, Columbia Gardens, and Northport for the period 1940-1970

TABLE 15

CORRELATION ANALYSIS OF ANNUAL PRECIPITATION REGIMES FOR THE PERIOD 1940-1970

	Crescent Valley	Columbia Gardens	Northport
Crescent Valley	-	0.8592**(N=24)	0.7030**(N=22)
Columbia Gardens	-	-	0.7373**(N=28)
Northport	-	-	-

** $P < 0.01$

Pollution Data

The two types of pollutants from the smelter which may affect vegetation regrowth are present sulphur dioxide levels and toxic concentrations of the heavy metals lead and zinc in the soil, the dispersion of which is effected by the wind. Fig. 26 shows the wind pattern at Trail recorded on a monthly percent frequency basis for 1971 with yearly averages for 1967, 1970, and 1971. In all cases the principal wind directions were either northwest or southeast which reflected the trend of the Columbia Valley at Trail. The fumes, constrained by the valley sides, therefore tend to drift either upstream or downstream from their source.

a. Sulphur dioxide. Atmospheric sulphur dioxide values collected during the period of field work are given in Fig. 27(i) and tabulated in Appendix E1. A noticeable decrease was noted during the period July 19-August 16. This was coincident with the period when the smelter was completely shut down, and during those four weeks the sulphur levels at plot 10, 1.5 km north, which normally exhibited the highest

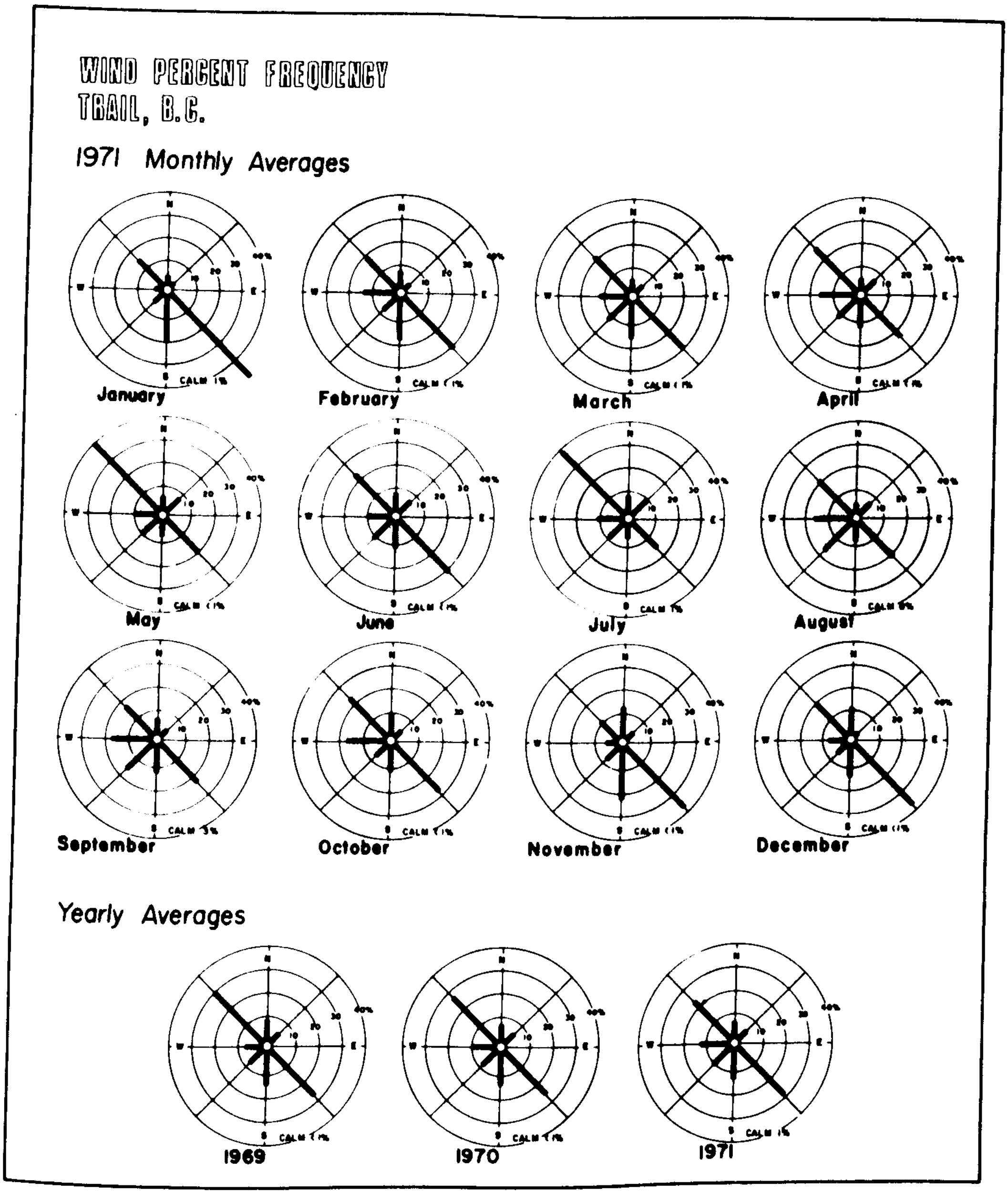


Fig. 26. Wind percent frequency for Trail

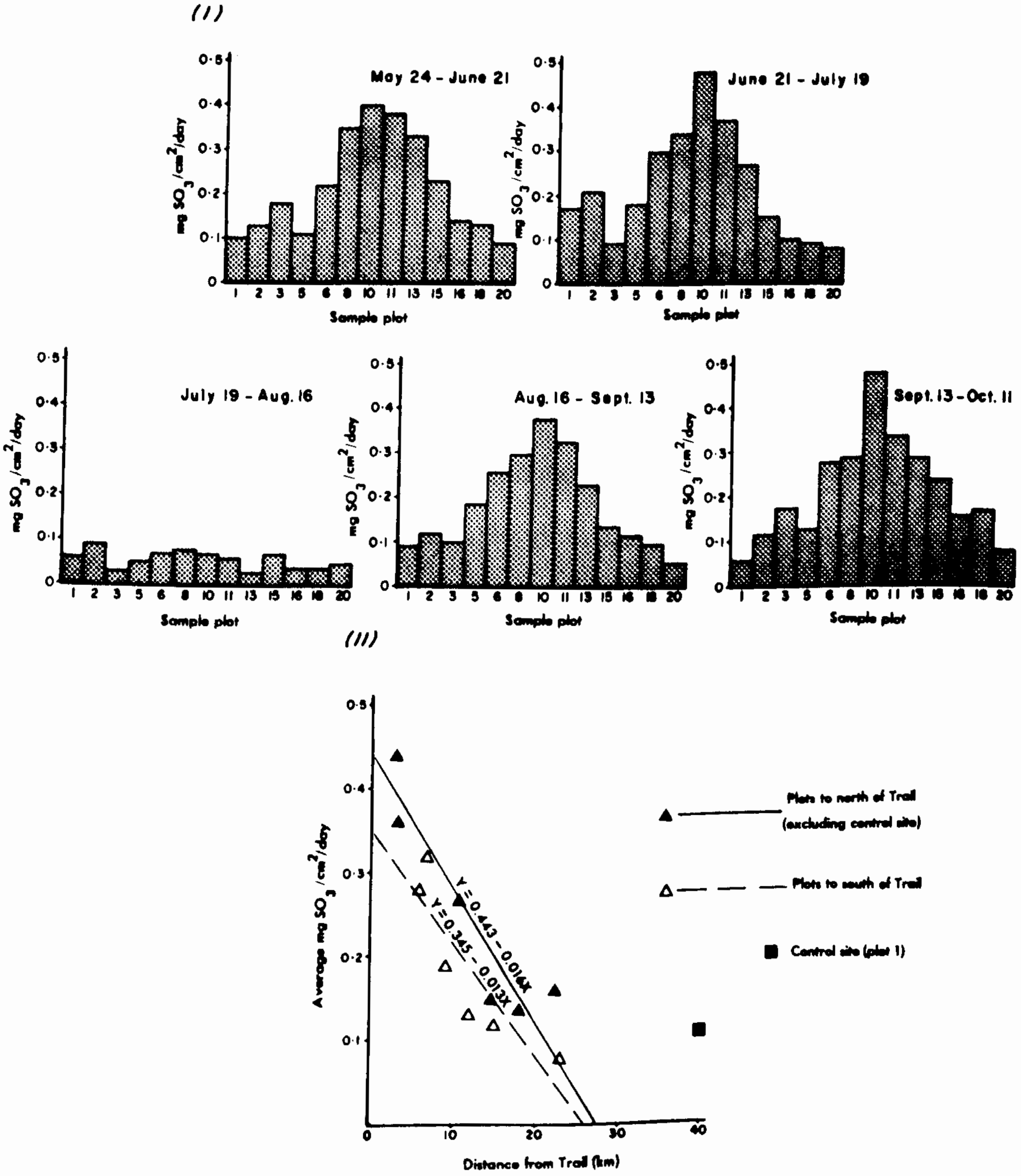


Fig. 27. (i) Sulphation rates for the period May 24th to October 11th (The control site is plot 1: Trail is located between plots 10 and 11)

(ii) Regression lines used for the prediction of missing sulphation data sulphation rate, and the control site (Plot 1) were 0.07 and 0.06 mg $SO_3/cm^2/day$ respectively. These values were therefore considered as the ambient background levels in the study area. During the other recording periods there was a marked increase in the sulphur levels in the plots close to Trail with plot 10 exhibiting an average sulphation rate of 0.44 mg $SO_3/cm^2/day$ compared with the average for the control site of 0.11 mg $SO_3/cm^2/day$. An analysis-of-variance test was conducted on the data collected during the period of smelter activity in order to determine if the differences in sulphur levels between plots was significant: the result was significant at the 0.01 level. Such variation was thought to be inversely related to distance from the smelter. The linear correlation between average sulphation rate and distance from the smelter gave $r = -0.7478$ ($P < 0.01$), which supported this view.

Because sulphur dioxide levels were only assessed at thirteen of the twenty sample plots it was necessary to interpolate the remaining values. This was achieved by means of a linear regression as shown in Fig. 27(ii). The highest correlations with distance from Trail and the lowest standard errors of estimate were given by the 6 plot groupings (see Table 16) and these were subsequently used in the prediction of the sulphation rates for plots 4, 7, 9, 12, 14, 17, and 19. The results are given in Table 17. The significant spatial variation in fume intensity suggested that sulphur dioxide might still be a factor which could affect the course of revegetation in the study area.

b. Heavy metals. Analysis of soil from depths of 30 and 60 cm demonstrated that the parent material was typically lead free, although

TABLE 16

THE ALTERNATIVE SAMPLE PLOT GROUPINGS USED FOR THE PREDICTION OF SULPHATION RATES

Sample Plots Used	Correlation with Distance from Trail r	N	Standard Error of Estimate
13 plots (including control site)	-0.7478**	13	0.0775
12 plots (excluding control site)	-0.8735**	12	0.0574
7 plots to north of Trail (including control site)	-0.8013*	7	0.0798
6 plots to north of Trail (excluding control site)	-0.9367**	6	0.0474
6 plots to south of Trail	-0.9145**	6	0.0511

* $0.05 \geq P > 0.01$ ** $P < 0.01$

TABLE 17

AVERAGE SULPHATION RATES FOR THE SAMPLE PLOTS

Plots to North of Trail		Plots to South of Trail	
Plot 1 (control)	0.11	Plot 11	0.36
Plot 2	0.15	Plot 12	0.29*
Plot 3	0.14	Plot 13	0.28
Plot 4	0.18*	Plot 14	0.25*
Plot 5	0.15	Plot 15	0.19
Plot 6	0.27	Plot 16	0.13
Plot 7	0.31*	Plot 17	0.12*
Plot 8	0.32	Plot 18	0.12
Plot 9	0.36*	Plot 19	0.09*
Plot 10	0.44	Plot 20	0.08

* Predicted

high concentrations of zinc were detected at some plots (Appendix D2). The results of the analysis of material from 5 and 15 cm are shown in Fig. 28 and tabulated in Appendix D2. It was evident that there was a decrease in the available zinc present at 5 cm at plots close to the smelter ($r = 0.5174$, $0.05 \geq P > 0.01$). At first sight this deficiency might be interpreted as a factor causing poor growth in the area. However, Black et al. (1965, p. 1090) state that "zinc is tenaciously adsorbed on organic matter and clays." In the present study, linear correlations between available zinc and percent carbon at depths of 5 and 15 cm were $r = 0.9054$ ($P < 0.01$) and $r = 0.5128$ ($0.05 \geq P > 0.01$) respectively, indicating that the higher zinc levels could have resulted from its retention in the better developed more humic soils rather than being a factor restricting vegetation development. As the vegetation developed in the area, zinc might have been brought up from the parent material and become concentrated in the upper soil horizons through leaf fall. However, it is possible that further vegetation development might be restricted if the accumulation of zinc reaches toxic concentrations.

A noticeable increase in the concentration of available lead was demonstrated as distance from the smelter decreased, as shown in Fig. 28. Linear correlations with distance gave $r = -0.5803$ ($P < 0.01$) at 5 cm, and $r = -0.3313$ ($0.05 \geq P > 0.01$) at 15 cm. This was in accord with other work which had been carried out in the area, typically veterinary research (Hammond and Aronson, 1964; Schmitt et al., 1971). Warren and Delavault (1960), following the analysis of some sixty Canadian soils derived from rocks of low natural lead content, conclude that the normal level of acid extractable lead present ranges from 0.5 to 5.0 ppm.

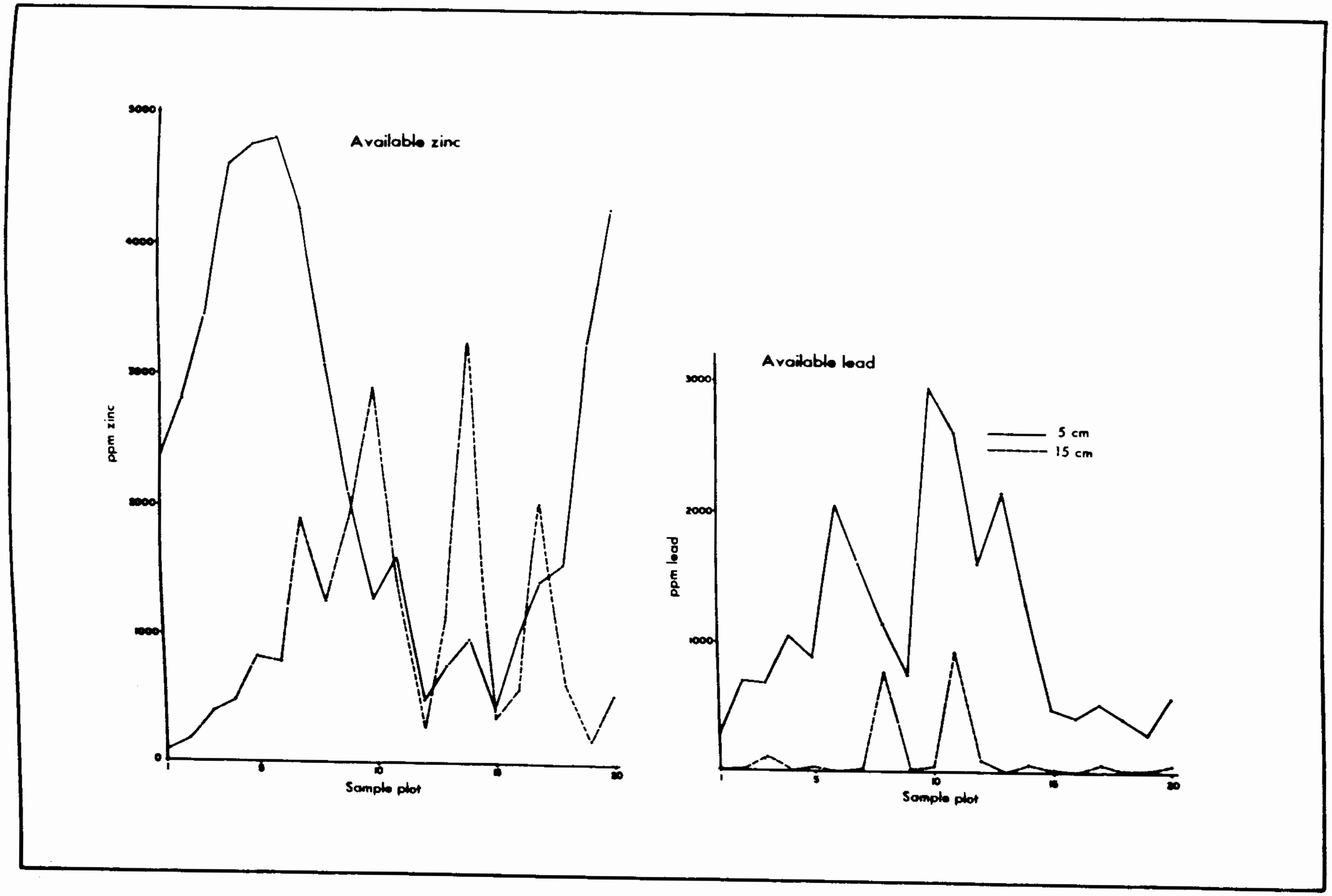


Fig. 28. Available lead and zinc in the soil at depths of 5 and 15 cm (The control site is plot 1: Trail is located between plots 10 and 11)

Soils from the present study contained from 265 ppm at the control site to 2,950 ppm at plot 10 at 5 cm depth. At 15 cm, lead was absent from many plots with a maximum value of 920 ppm recorded at plot 11. Variation in the heavy metal content of the soil, particularly lead in the surface horizons, might therefore affect species distributions in the study area.

Conclusion

At the outset of the field work it was thought that the restriction of sampling to the terraces would remove much of the macro-environmental heterogeneity within the area. However, it can be seen that this procedure was not totally successful. Although minimum variation was demonstrated for many of the physical soil properties, significant random differences occurred between plots with respect to soil moisture at depth, and most chemical properties. Consequently, variation in initial site conditions must be considered as a potentially important influence upon the present vegetation which could promote individualistic features rather than consistent spatial patterns in the cover.

For the climatic data, long term records showed that temperature differences throughout the area were unlikely to have produced spatial variation in the vegetation cover. However, a significant trend was demonstrated for precipitation. Some variation in the short term weather conditions was also demonstrated.

The outcome of the analysis of the pollution data was most conclusive in demonstrating the existence of present gradients, with spatial variation in present sulphur dioxide levels and available lead exhibiting significant decreases as one moved north or south from the smelter. Both of these factors must therefore be considered in later interpretations of the recovery sequence. However, for zinc, concentration appeared to be positively correlated with the amount of organic matter present in the soil, and was therefore no longer regarded as an adverse factor to regrowth although it was noted that continued accumulation in the soil might eventually give rise to toxic conditions.

Chapter 4

SPATIAL VARIATION IN THE PRESENT VEGETATION OF THE STUDY AREA

The General Appearance of the Vegetation

The control site (plot 1, 40.0 km north), which was taken as representative of the vegetation cover of most of the area north of Trail prior to its destruction by pollution, was composed of a fairly dense, regenerating cover of coniferous trees, mainly Douglas-fir and cedar. The undergrowth, although characteristically low growing, provided a fairly complete cover and was comprised of such species as bracken (Pteridium aquilinum (L.) Kuhn), mahonia (Mahonia aquifolium Nutt.), and trailing cranberry (Arctostaphylos uva-ursi (L.) Spreng.), with shrubs such as Saskatoon berry (Amelanchier alnifolia Nutt.), and hazel (Corylus cornuta Marsh.) also present (see Fig. 29).

Throughout much of the area to the north of Trail, birch and trembling aspen were found in mixed stands with well developed ground covers in which bracken was most pronounced (see Fig. 30). Some reproduction of the tree species was evident here. The stands became more open in the plots closer to the smelter (see Figs. 30, 31, and 32). Such generalisations did not however, apply to plots 5 (14.5 km north) and 9 (4.75 km north). In plot 5 a well developed canopy of regenerating lodgepole pine was present (see Fig. 33): this was not expected since this plot was located well within the zone thought to have been affected by sulphur dioxide fumes. In plot 9 a similar aberration was found.

Fig. 29. Control site (plot 1), 40.0 km north of Trail. A well developed cedar-Douglas-fir canopy was found here with much young growth present (foreground). A rich ground cover also occurred in this shady environment

Fig. 30. Plot 4, 16.25 km north of Trail. A well developed birch-aspen cover some 34 years of age was found at this plot with bracken abundant in the ground vegetation

Fig. 31. Plot 6, 10.25 km north of Trail. A well developed birch-aspen cover was found here, although some open areas were also present which were thought to reflect the former destruction of the cover by smelter fumes. Bracken and hazel were found in these openings and grass was also common: no areas of bare soil occurred

Fig. 32. Plot 8, 6.5 km north of Trail. An open stand of birch and aspen had developed at this plot with a ground cover composed predominantly of bracken and grass. Bare ground was present here which probably reflected the severity of the fume damage

Fig. 33. Plot 5, 14.5 km north of Trail. A mature canopy of lodgepole pine was found here together with all-age regeneration of this species, and a varied ground cover. This plot was thought to have escaped the full effect of the smelter fumes

Fig. 34. Plot 9, 4.75 km north of Trail. A mixed birch-aspen stand was present at this plot together with a well developed ground cover. This was the only mixed stand in which the yield of aspen was greater than that for birch. Although very close to the smelter, the vegetation at this plot was comparatively dense

Here a mixed stand of birch and aspen had given rise to a well developed canopy (see Fig. 34).

Within two or three kilometres north of Trail and for some distance south, the trees became much sparser and often the cover consisted of isolated clumps of buckbrush (*Ceanothus sanguineus* Pursh) and coppices of hazel interspersed with such species as dogbane (*Apocynum androsaemifolium* L.), field chickweed (*Silene menziesii* Hook.), false box (*Pachistima myrsinites* (Pursh) Raf.), grass and bracken. In most of these plots, for example plots 10 (3.0 km north) and 14 (7.5 km south), much bare ground was present (see Figs. 35 and 36). The most pronounced vegetation destruction appeared to have occurred in plots 11 (3.0 km south) and 12 (4.5 km south). Although some birch was present here, these plots were very open with little if any ground cover (see Figs. 37 and 38).

As one moved further south, trembling aspen and birch became more common and gave rise to progressively denser stands. However, unlike the stands to the north of Trail, those to the south were typically pure, and were composed of one or other of the deciduous tree species. For example, at plot 15 (10.0 km south), an open stand of aspen was present, interspersed with bracken and some buckbrush; bare soil was also found (see Fig. 39). At plot 17 (13.5 km south), a much denser stand had arisen, possibly as a result of vigorous suckering (see Fig. 40). Here, and at plot 18 (15.0 km south), the grasses and buckbrush became more common, and gave rise to an open grass-shrub cover at plot 18 in which aspens were noticeably sparse (see Fig. 41). Conversely, at plots 13 (6.0 km south), 16 (12.0 km south), and 19 (20.0 km south)

Fig. 35. Plot 10, 3.0 km north of Trail. An open stand composed predominantly of hazel with some buckbrush, bracken, and false box also present. In much of the plot bare soil was exposed

Fig. 36. Plot 14, 7.5 km south of Trail. A tree cover was absent from this plot. The sparse vegetation was composed of dogbane, false box, and hazel with occasional grasses

Fig. 37. Plot 11, 3.0 km south of Trail. The vegetation at this plot consisted of isolated birch trees associated with a sparse ground cover. Note the exposed rocks throughout the plot which suggested that prevalent soil erosion occurred following the removal of the former vegetation cover through fume damage

Fig. 38. Plot 12, 4.5 km south of Trail. Severe fume damage probably resulted in the sparse cover of birch and the poor ground cover at this plot. Areas of bare soil were extensive

Fig. 39. Plot 15, 9.0 km south of Trail. A pure stand of trembling aspen had developed at this plot. Bracken and buckbrush were common, although much of the soil was still exposed

Fig. 40. Plot 17, 13.5 km south of Trail. This pure stand exhibited the maximum density for trembling aspen, and probably resulted from vigorous suckering from the roots of the older individuals

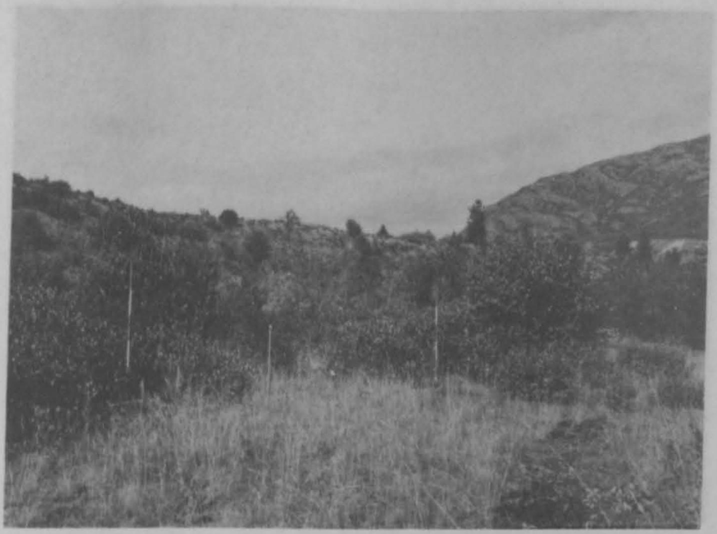


Fig. 41. Plot 18, 15.0 km south of Trail. The open vegetation here was composed of buckbrush (left foreground) and hazel (middle right). It was at this plot that the temporary weather station was set up

Fig. 42. Plot 13, 6.0 km south of Trail. An open stand of birch was present here, associated with a sparse ground cover

Fig. 43. Plot 16, 12.0 km south of Trail. The birch cover at this plot was some 32 years of age and gave the highest standing crop for this species. Bracken also flourished here

Fig. 44. Plot 19, 20.0 km south of Trail. A mature stand of birch occurred at this plot. The apparent denseness of the vegetation resulted from the presence of a well developed shrub and herb layer

a predominantly birch cover was developing (see Figs. 42, 43, and 44). Coniferous species became more widespread to the south of the International Border, with a well developed stand of ponderosa pine and lodgepole pine occurring at plot 20 (23.5 km south, see Fig. 45).

Although the appearance of the vegetation on the terraces was varied, two generalisations could be made. First, there was a comparative paucity of coniferous trees throughout the area affected by smelter fumes, and secondly, the stands became noticeably more open as one approached the smelter, a condition which was most pronounced in the area to the south of Trail. Such observations tended to support the idea that recovery had been controlled by the former pollution gradient, and hence could be related to distance from Trail: this is discussed below. However, the deviations from this trend suggested that some of the patterning apparent in the vegetation could have been caused by spatial variations in other extraneous factors: this aspect is treated in Chapter 6.

Spatial Variation in the Vegetation Cover

a. Floristic composition. The total species complement for the study area was comprised of 45 shrub and broadleaf herb species, 14 tree species, 12 grass species, and 2 moss species: their distribution is given in tables 18A-D. In accord with other studies (Gordon and Gorham, 1963; Gorham and Gordon, 1960), the total number of species recorded decreased as the smelter was approached (see Fig. 46), and resulted in a significant positive correlation with distance from Trail ($r = 0.5749$, $N = 19$, $P < 0.01$). This trend was most marked to the south of Trail.

Fig. 45. Plot 20, 23.5 km south of Trail. The mature ponderosa pine and lodgepole pine cover at this plot was some 48 years of age. The abundance of hazel resulted in a dense ground cover

TABLE 18A. THE DISTRIBUTION OF THE SHRUB AND BROADLEAF HERB SPECIES IN THE STUDY AREA

	SAMPLE PLOTS																				NO. OF OCCURRENCES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Apocynum androsaemifolium	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19
Silene menziesii		X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	17
Pteridium aquilinum	X	X	X	X	X	X	X	X	X	X		X			X	X	X		X	X	16
Mahonia aquifolium	X	X	X	X	X	X	X	X	X	X							X	X	X	X	14
Pachistima myrsinites	X	X	X	X		X		X	X	X		X	X	X	X		X	X			14
Amelanchier alnifolia	X	X	X	X	X	X			X	X			X		X		X	X	X	X	14
Corylus cornuta	X	X	X			X				X			X	X			X	X	X	X	11
Clintonia uniflora	X	X	X		X	X	X	X	X							X			X		10
Smilacina stellata	X		X		X				X									X	X	X	7
Aralia nudicaulis	X		X	X				X	X			X	X								7
Rosa gymnocarpa	X			X	X												X	X	X	X	7
Ceanothus sanguineus			X	X						X					X		X	X			6
Spiraea betulifolia			X			X							X				X		X	X	6
Chimaphila umbellata	X			X		X													X	X	5
Lilium columbianum	X				X				X	X								X			5
Arctostaphylos uva-ursi	X									X							X	X			4
Salix scouleriana				X	X	X			X												4
Rumex acetosella																	X	X	X	X	4
Disporum trachycarpum			X			X			X												3
Epilobium angustifolium				X					X									X			3
Symphoricarpos sp.					X					X			X								3
Linnaea borealis	X						X														2
Fragaria virginiana	X																		X		2
Lonicera utahensis	X				X																2
Lathyrus ochroleucus	X				X																2
Lysimachia ciliata	X				X																2
Hieracium canadense					X	X															2
Solidago canadensis					X														X		2
Panicum scribnerianum																		X	X		2
Lonicera ciliosa					X	X															2
Viola sp.																			X	X	2
Hieracium albiflorum	X																				1
Vaccinium membranaceum	X																				1
Rubus parviflorus			X																		1
Vaccinium caespitosum			X																		1
Vicia villosa					X																1
Galium boreale					X																1
Rhus radicans					X																1
Shepherdia canadensis								X													1
Asparagus officinalis									X												1
Achillea millefolium																			X		1
Philadelphus lewisii																			X		1
Trifolium procumbens																			X		1
Cirsium vulgare																			X		1
Unidentifiable					X																1
Total	20	8	15	12	20	14	6	8	14	11	1	5	8	4	6	3	12	14	20	12	

TABLE 18B. THE DISTRIBUTION OF THE TREE SPECIES IN THE STUDY AREA

	SAMPLE PLOTS																				NO. OF OCCUR-RENCES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Betula papyrifera	X	X	X	X	X	X	X	X	X	X	X	X	X			X			X		15
Populus tremuloides		X	X	X	X		X	X	X		X		X		X	X	X	X		X	14
Prunus virginiana			X	X						X	X		X	X		X	X	X		X	10
Pseudotsuga menziesii	X						X		X					X		X		X	X	X	8
Pinus contorta		X	X		X	X										X			X	X	7
Larix occidentalis	X						X												X	X	4
Alnus tenuifolia							X	X	X												3
Pinus monticola				X				X				X									3
Pinus ponderosa																			X	X	2
Populus trichocarpa						X		X													2
Acer glabrum			X																		1
Thuja plicata	X																				1
Crategus douglasii					X																1
Robinia pseudo-acacia								X													1
Total	4	3	5	4	4	3	5	6	4	2	3	2	3	2	1	5	2	3	5	6	

TABLE 18C. THE DISTRIBUTION OF THE GRASS SPECIES IN THE STUDY AREA

	SAMPLE PLOTS																				NO. OF OCCUR-RENCES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Agrostis scabra							X	X		X	X	X	X	X	X	X		X			10
Danthonia spicata		X	X	X		X	X	X	X					X		X					9
Oryzopsis asperifolia	X		X			X		X	X							X					6
Poa pratensis					X	X		X										X	X	X	6
Calamagrostis rubescens					X													X		X	4
Stipa occidentalis														X	X		X				3
Agrostis alba						X	X														2
Panicum scribnerianum																		X	X		2
Trisetum spicata																	X	X			2
Festuca occidentalis	X																				1
Phleum pratense					X																1
Agropyron caninum					X																1
Unidentifiable		X			X																2
Total	3	2	2	1	5	4	3	3	3	1	1	1	1	3	2	3	2	5	2	2	

TABLE 18D. THE DISTRIBUTION OF THE MOSS SPECIES IN THE STUDY AREA

	SAMPLE PLOTS																				NO. OF OCCUR-RENCES
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Pohlia nutans			X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	16
Polytrichum juniperinum	X	X	X	X	X														X		6
Total	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

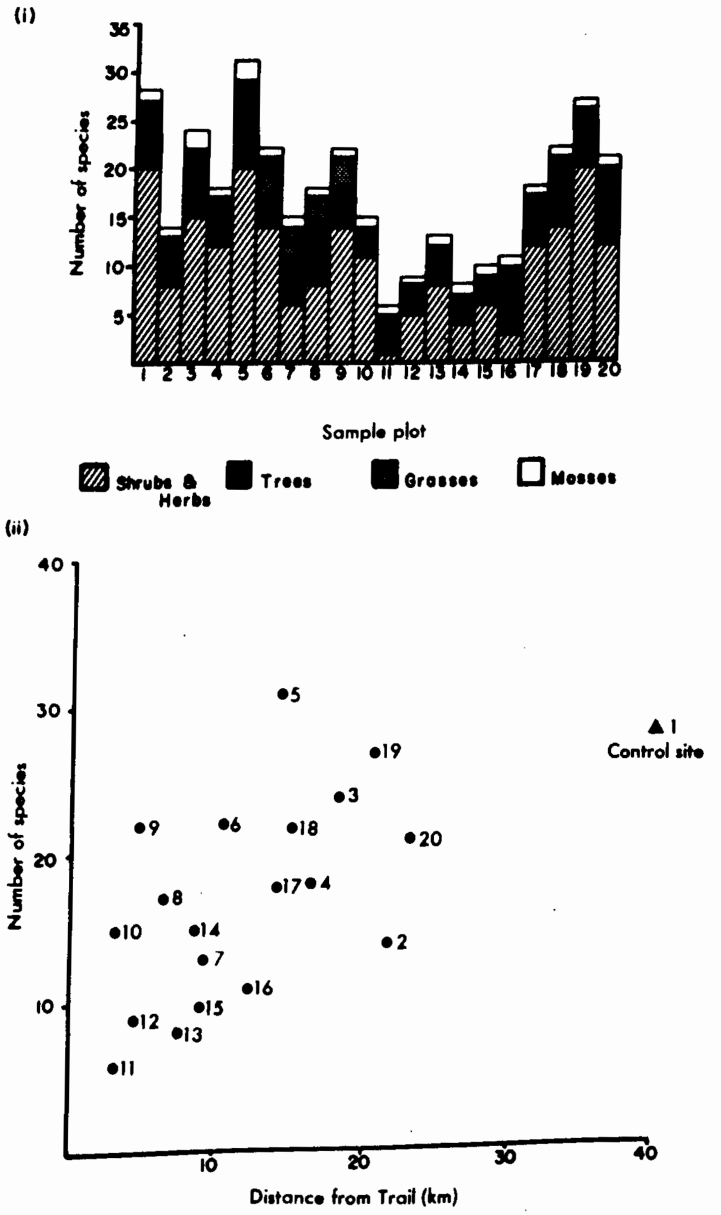


Fig. 46. The number of species present at the sample plots, and the relationship between floristic composition and distance from Trail (The control site is plot 1: Trail is located between plots 10 and 11)

Here the more distant plots (plots 17-20) ranged in composition from 18 to 27 species, decreasing to 6 at plot 11. To the north of Trail however, the trend was less marked with the major aberrations occurring at plots 5 and 9 where 31 and 32 species respectively were recorded. Twenty eight species were found at the control site (plot 1). The less common ground cover species, those occurring in two plots or less, appeared to be restricted to the sample plots with well developed overstories: none favoured the more open conditions found closer to the smelter.

b. Species abundance. The abundance of the ground and intermediate vegetation is given in appendices A3, A5, and A6. Because many of the species were found at only a few of the sample plots, no quantitative analyses were conducted on these data. However, this information does provide an indication of species performance at the different plots. For example, dogbane, the most frequently occurring species was least abundant at sample plots which either possessed a well developed cover or in which destruction of the former cover appeared to have been severe. Others, such as field chickweed and mahonia, were most abundant in the better developed stands, whereas false box favoured the more open plots. Bracken, although common throughout the area, was most abundant under a closed canopy.

The densities of the tree species found in the 10 x 10 m quadrats are given in Appendix A4. These have been converted to a per hectare basis for birch, trembling aspen, and the coniferous species, and are presented in Fig. 47 together with their respective cumulative basal

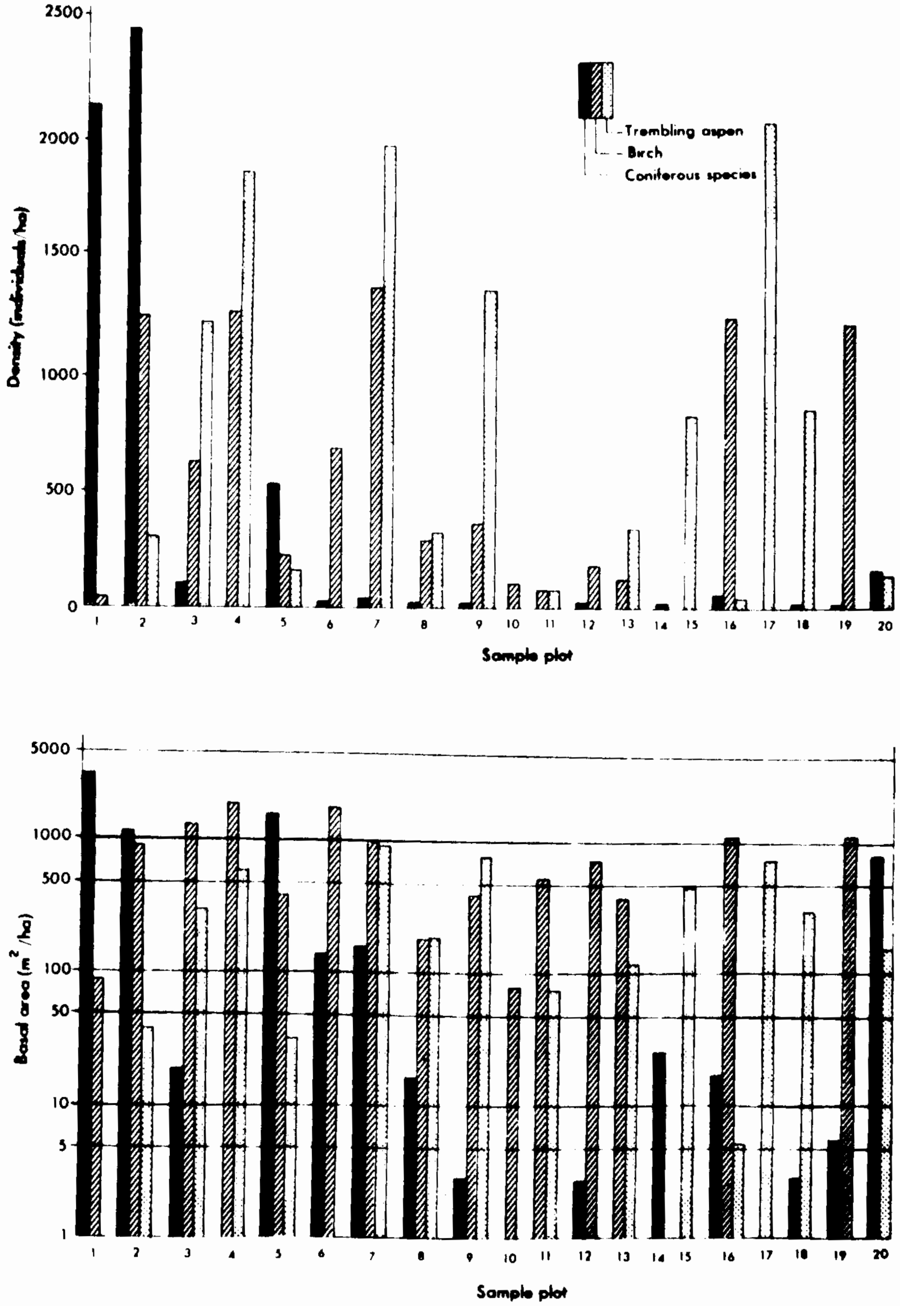


Fig. 47. Density and basal area contributions of birch, trembling aspen, and the coniferous species (The control site is plot 1: Trail is located between plots 10 and 11)

area contributions to each stand[1] (see also Appendix A8). Coniferous species were present in fourteen of the sample plots and ranged in abundance from 3101.4 m^2/ha at the control site (plot 1) to 2.6 m^2/ha at plot 12. Plots in which the coniferous species were least abundant or entirely absent were typically those close to the smelter. This pattern of variation was significantly related to distance from Trail (see Table 19). The range in basal area for birch was from 1904.6 m^2/ha at plot 4 (16.25 km north) to 86.0 m^2/ha at the control site (plot 1), with the species being entirely absent from five of the sample plots. No significant correlation was found between the abundance of birch and distance from Trail (see Table 19), which suggested that the regrowth birch cover had not been affected by pollution levels. However, the plots from which it was absent were located in the southern section

TABLE 19

LINEAR CORRELATIONS BETWEEN DISTANCE FROM TRAIL AND BASAL AREA FOR BIRCH, TREMBLING ASPEN, AND CONIFEROUS SPECIES (EXCLUDING THE CONTROL SITE)

	r	N	Significance
Birch	0.2463	19	not significant
Trembling aspen	-0.0408	19	not significant
Coniferous species	0.4950	19	$0.05 \geqslant P > 0.01$

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[1] Basal area measurements provided a means of differentiating between the sizes of individuals and obviated the problem of the coppiced growth form typical of the birch. It was therefore regarded as the more informative method of assessment.

of the study area which would indicate that environmental factors, possibly low precipitation, might exert some controls on the birch. Trembling aspen was found in fourteen of the sample plots and ranged in abundance from 939.4 m^2/ha at plot 7 (8.5 km north) to 5.0 m^2/ha at plot 16. The correlation between distance from Trail and abundance was not significant (see Table 19). This, in conjunction with the fact that the six plots from which the aspen was absent were dispersed throughout the study area, would suggest that haphazard variation in the environment, or chance factors of site colonisation might be more important than pollution as controlling factors in the regrowth of this species.

From the spatial distribution of the relative abundance of the principal tree species, it would appear that only the conifers had been significantly affected by pollution levels. In the case of the birch and trembling aspen, macro-environmental factors such as precipitation could possibly account for this variation. However, controls at a micro-level may come into operation as the cover develops further: this is discussed in Chapter 6.

c. Standing crop. The results of the standing crop measurements are given on a dry weight basis in Figs. 48, 49, and 50, and are tabulated in Appendix A9. Total standing crops, representing the sum of the ground cover and tree standing crops, ranged from 3226.4 kg (64,528 kg/ha) at the control site (plot 1) to 24.4 kg (488 kg/ha) at plot 14. A significant positive relationship was demonstrated between total standing crop and distance from Trail (see Table 20), which suggested that the present state of the stands reflects the former or existing pollution gradients, although much of this linear variation probably related to the

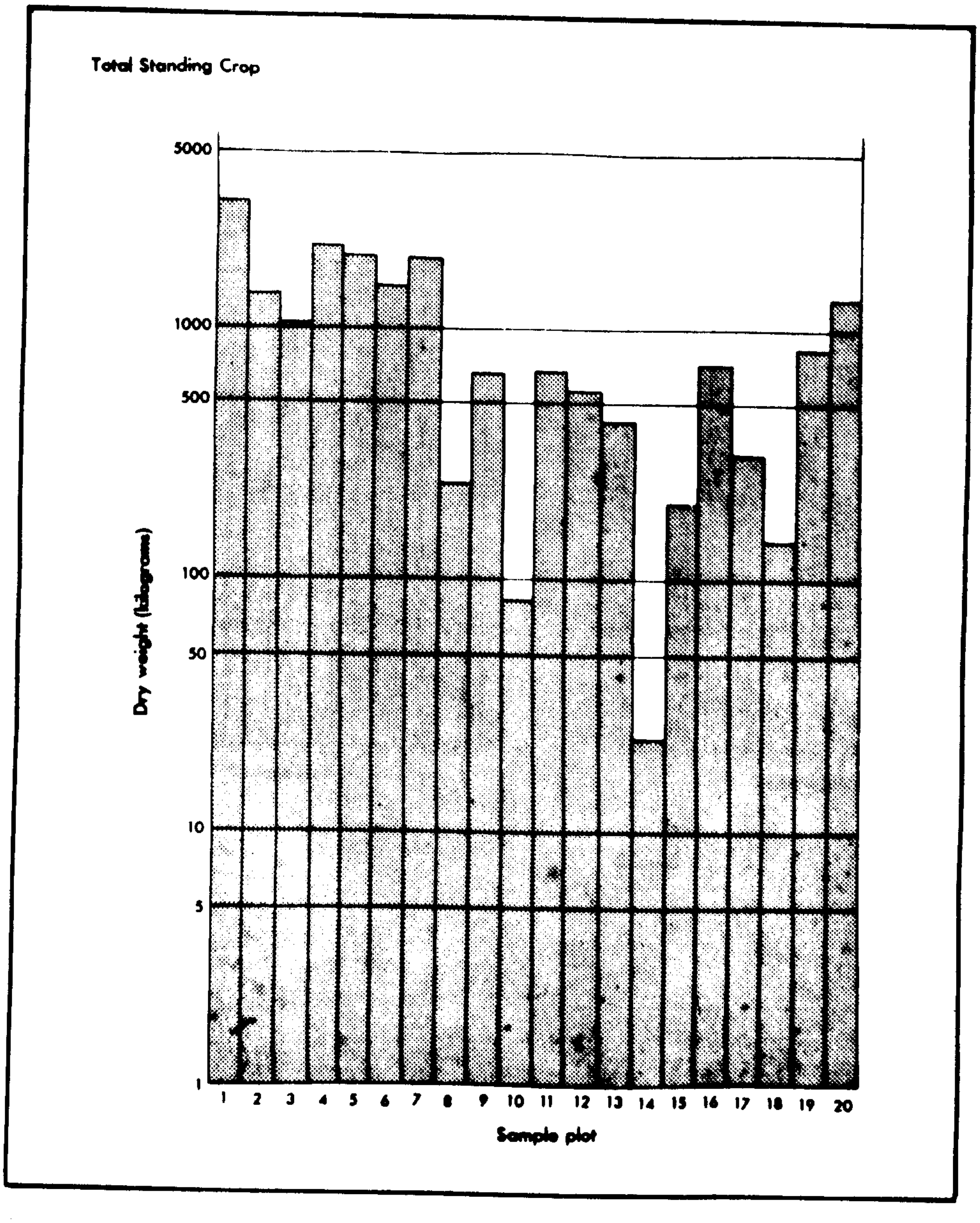

Fig. 48. Total standing crop data (The control site is plot 1: Trail is located between plots 10 and 11)

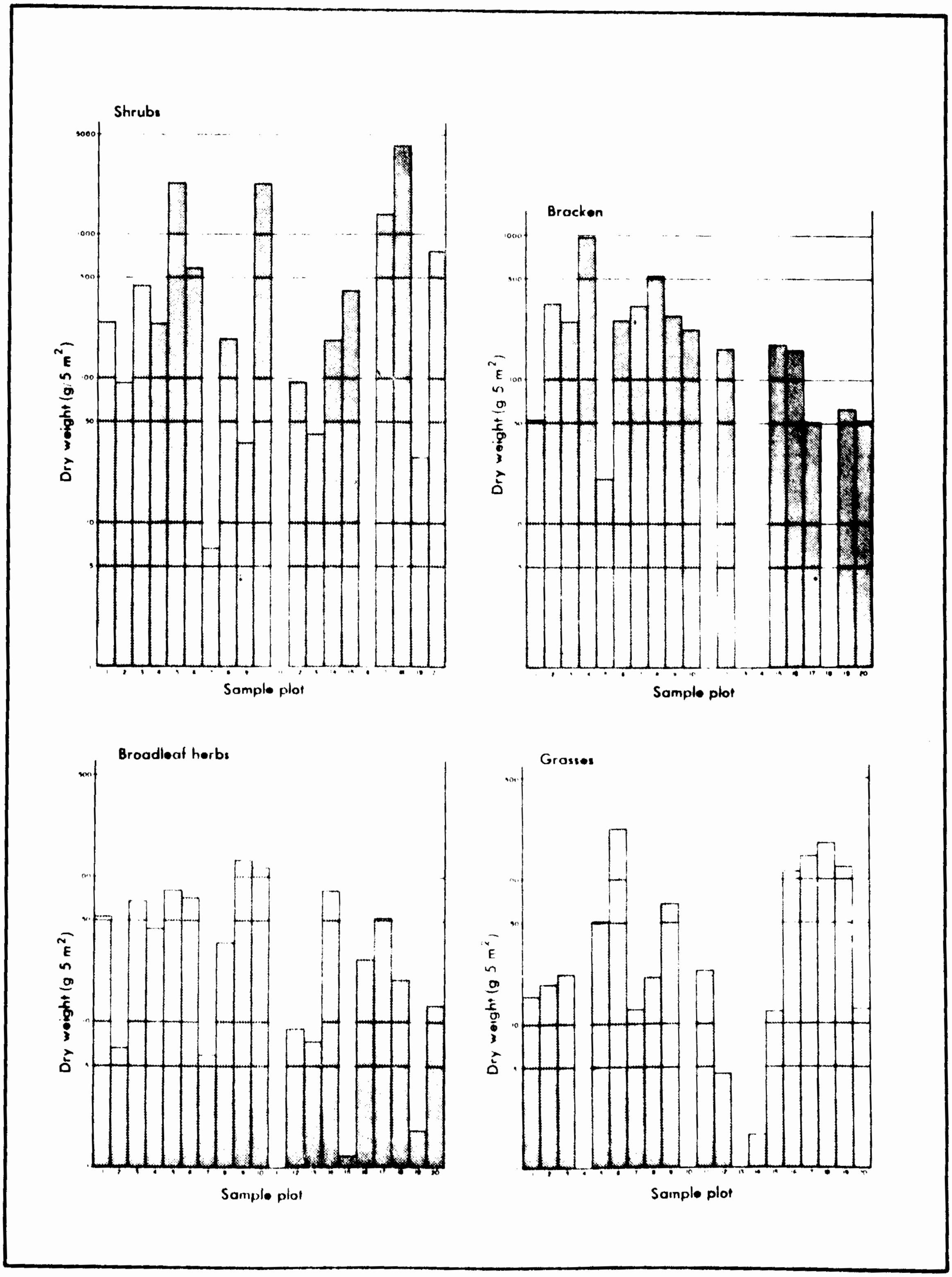

Fig. 49. Standing crop data for the ground vegetation (The control site is plot 1: Trail is located between plots 10 and 11)

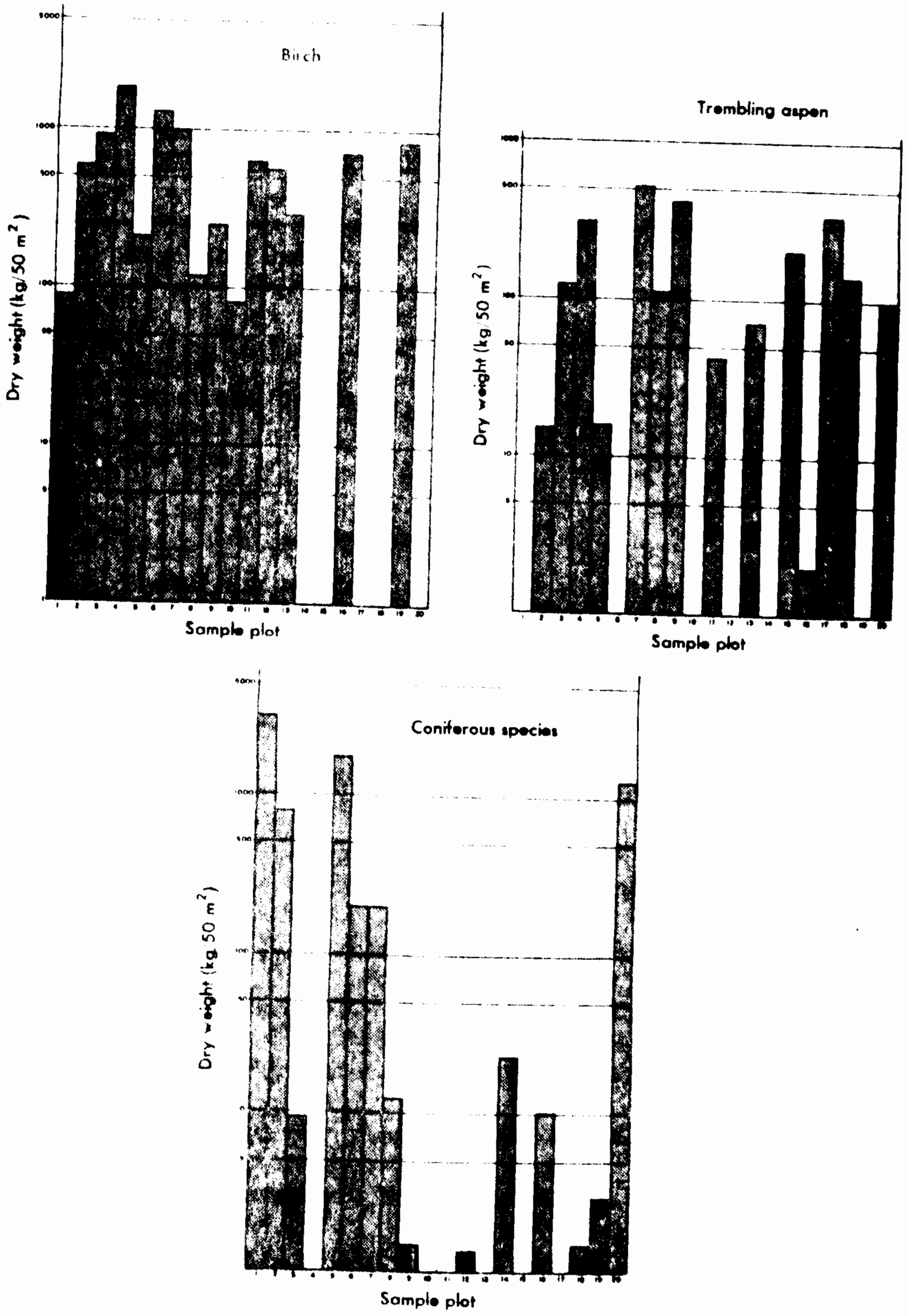

Fig. 50. Standing crop data for birch, trembling aspen, and the coniferous species (The control site is plot 1: Trail is located between plots 10 and 11)

distribution of the conifers (see below).

TABLE 20

LINEAR CORRELATIONS BETWEEN DISTANCE FROM TRAIL AND STANDING CROP DATA (EXCLUDING CONTROL SITE)

Standing Crop	r	N
Ground cover		
Shrubs	0.1266	19
Broadleaf herbs	-0.2707	19
Grasses	0.1650	19
Bracken	0.0728	19
Tree Cover		
Birch	0.1666	19
Trembling aspen	-0.0689	19
Coniferous species	0.4884*	19
Total	0.4682*	19

* $0.05 \geq P > 0.01$

The standing crops for the shrubs was generally less than 500 g per sample plot (<20 g/m^2), although exceptionally high yields were obtained at plots 5, 10, and 18. The distribution of shrub standing crops was not significantly related to distance from Trail (see Table 20). Typically, the yield per plot for the broadleaf herbs was less than 75 g (<3.0 g/m^2) throughout the study area, and ranged from 129.3 g (5.0 g/m^2) at plot 9 to 1.2 g (0.05 g/m^2) at plot 15. Again, the correlation with the pollution gradient was not significant (see Table 20). In the case of bracken, most of the plots to the north of Trail gave yields of over 200 g (8.0 g/m^2), with the maximum yield (39.0 g/m^2) being recorded at plot 4. Bracken was absent from four of the plots to the south of Trail, with yields at the remainder ranging from 2.0 to 7.0 g/m^2. Conversely, the grasses typically gave the highest yields, exceeding 5.0 g/m^2, in the more southerly plots (plots 16-19). Neither the bracken nor the grasses showed a significant correlation with distance from Trail (see Table 20). However, the spatial patterns evolved suggested that they might be responding to precipitation regimes, with bracken favouring the wetter area to the north of Trail and the grasses better adapted to the drier conditions to the south.

Yields for birch were varied, but were generally higher, in the northern section of the study area, ranging from 81.2 kg (1,624 kg/ha) at plot 10 to 1854.7 kg (37,094 kg/ha) at plot 4. Where present to the south of Trail, average yields were about 600 kg per plot (12,000 kg/ha). Similarly, average yields for trembling aspen were higher for the plots to the north of Trail (approx. 4,000 kg/ha) than they were for plots to the south (approx. 2,500 kg/ha). However, for neither species, was this pattern significantly related to distance from the smelter (see Table 20).

Only in the case of the coniferous species was a significant correlation demonstrated with respect to distance from Trail (see Table 20), which supported the idea that susceptibility to sulphur dioxide might be an important factor affecting the recovery of the conifers in the area. For all of the other components of the vegetation cover, any patterning which existed probably reflected random heterogeneity in the environment: this is examined in Chapter 6.

d. Age of the tree cover. For the purposes of this study, the age of the tree cover at each sample plot was taken to be the age of the oldest individual of any regenerating tree species. The presence of younger individuals of a species was therefore an integral criterion for distinguishing between regrowth and chance survivors from the pre-pollution cover. For example at plot 6 a solitary 48 year old lodgepole pine was found. Because of the absence of younger individuals of this species at this plot, it was considered as a chance remnant from the former cover, and therefore not used in the dating of the plot. Unfortunately, there was no means of assessing the age of the non-arboreal vegetation. The date at which pollution control became effective was taken as 1941 (after Wadey, 1970), thus the potential period for regrowth was regarded as thirty years. Inspection of the gas emission data (Fig. 2) and of the tree rings shown in Fig. 15 would suggest that 1944-45 might be a more appropriate date. However, precipitation for the years 1942-44 was well below average (see Fig. 25), and this might account for the extension of the period of growth suppression.

The results of the increment borings and basal area measurements are given in Fig. 51. Although the maximum age of the tree cover at nine of the sample plots was older than 30 years, only at plots 1, 5, 6, 7, and 20 had establishment occurred some considerable time before pollution abatement, with the oldest individuals being found at the control site (plot 1). The linear correlation between the maximum age of the tree cover and distance from Trail was not significant (r = 0.3107).[1] This would tend to contradict the idea that a gradual reduction in sulphur dioxide levels occurred during the implementation of control measures

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[1] This calculation excluded data from the control site.

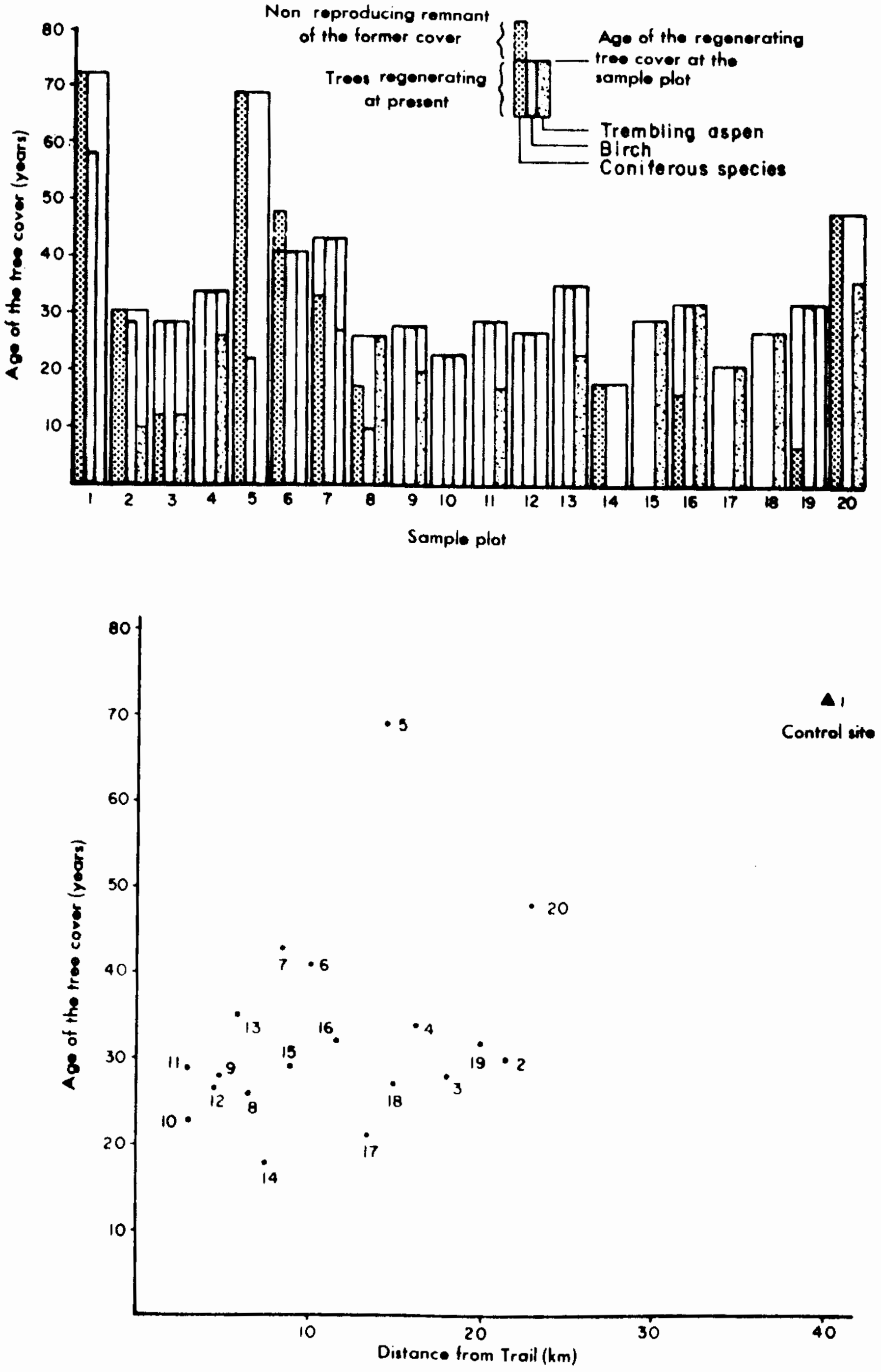

Fig. 51. The age of the oldest trees at the sample plots and its relationship to distance from Trail (The control site is plot 1: Trail is located between plots 10 and 11)

which favoured the earlier revegetation of the more distant plots. The revegetation of the remaining plots would appear to have started at approximately the same time, although at some, for example plots 14 and 17, regrowth was inexplicably retarded.

From Fig. 51 it can be seen that the cover at plots 5, 6, 7, and 20 was noticeably older than that for the remaining sample plots within the main Columbia Valley. These were thought to represent areas which either had escaped toxic gas fumigations, as in the case of plots 5 and 20, or had been subjected to non-injurious levels of sulphur dioxide earlier than the majority of the plots. Birches older than 30 years were found at plots 6 and 7 and the presence of younger individuals would indicate that they had been regenerating. This supported the idea of the early release of these plots from toxic fumigations.

Tree age class frequency distributions for each plot are presented in Fig. 52. Most of the plots exhibited a fairly even age class distribution with the maximum number of individuals typically represented in the 8-12 year old class. There appeared to be a paucity of individuals in both the older and younger age classes, although where present, individuals in the oldest age class (over 30 years old) were typically coniferous species, whereas the younger individuals (less than 8 years old) were primarily deciduous. However, at the control site (plot 1), not only was the cover predominantly coniferous, but individuals were found in all age classes which suggested that site conditions had been fairly stable for some period of time and that such conditions were favourable for the continued regeneration of the conifers.

Of the hypothetical growth curves described earlier (see

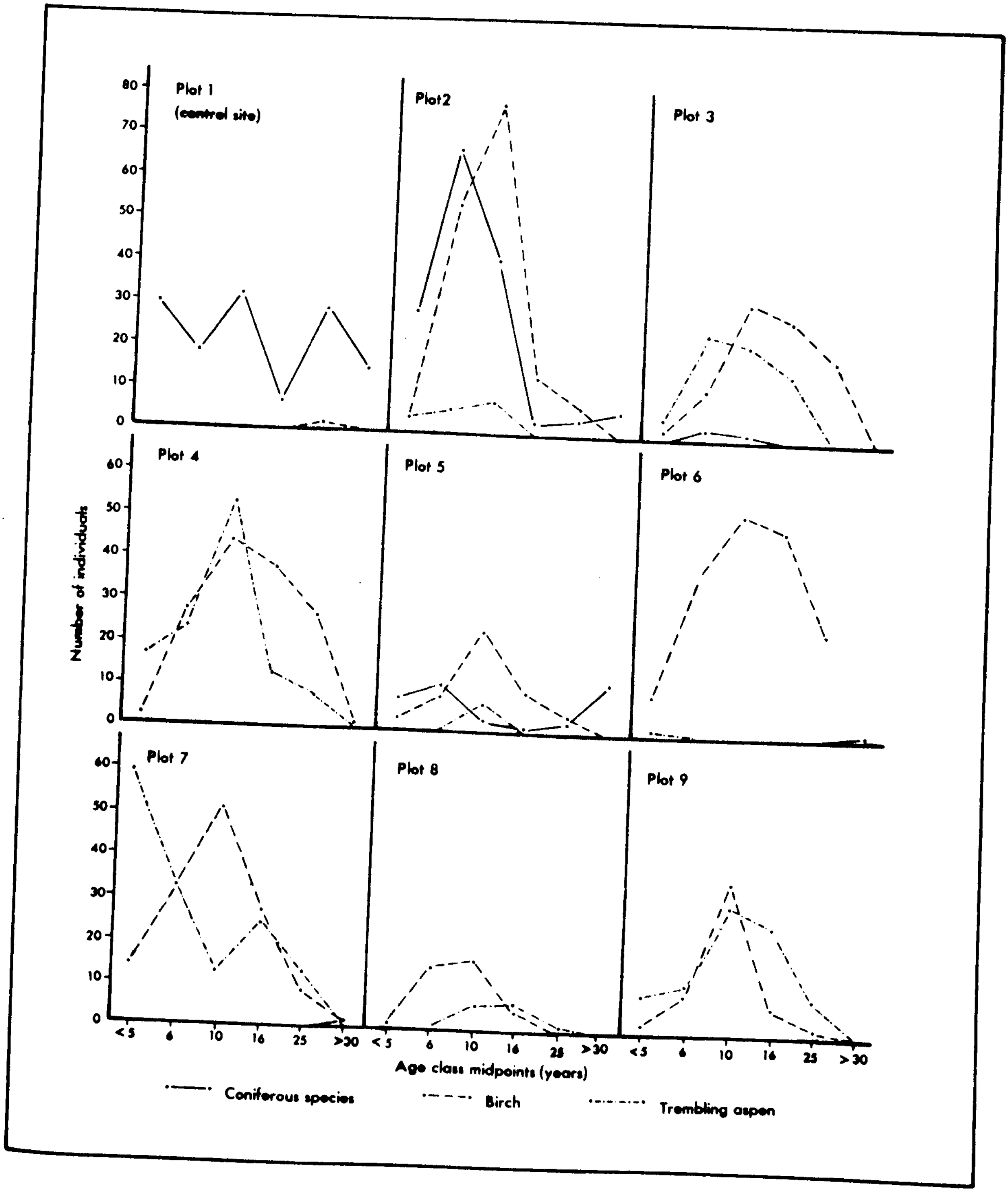

Fig. 52. Age class distributions for birch, trembling aspen, and the coniferous species (Continued overleaf)

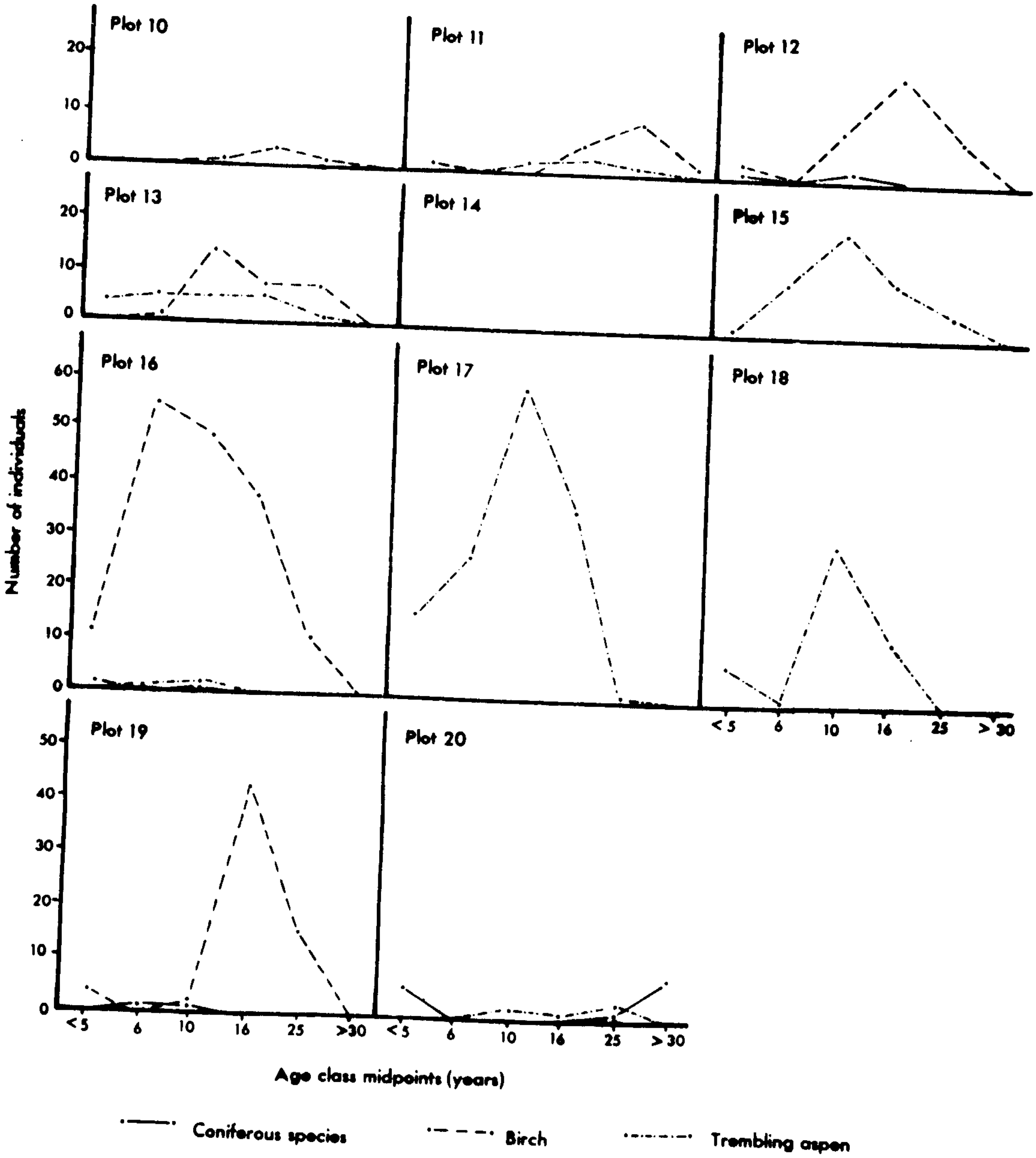

Fig. 52 (cont'd). Age class distributions for birch, trembling aspen, and the coniferous species (The control site is plot 1: Trail is located between plots 10 and 11)

Fig. 16), the even aged curve (Fig. 16 iii) was perhaps the most common, and was typical of many of the stands of birch (plots 3, 4, 6, 7, 12, and 16) and several stands of aspen (plots 3, 9, 15, 17, and 18). The normal logarithmic curve for a constantly reproducing population (Fig. 16 i) was evident only in the case of the trembling aspen at plot 7. The conifer at plot 6 could be taken as an example of a species in which the older individuals had not been regenerating (Fig. 16 v), whereas the conifers at plots 2, 5, and 20 were representative of species in which reproduction was curtailed for a period of time but which were now regenerating (Fig. 16 vi).

Birch and trembling aspen appeared to have re-entered the area at about the same time giving rise to mixed stands. However, at some plots (plots 1, 15, and 17), only one of these species had become established. This suggested that neither species had an advantage in the area, but rather, variations in the environment, availability of seed, or in numbers of viable rootstocks might have favoured the initial establishment of one or other of the species at the different plots. In several of the plots, birch was more numerous in the older age classes whereas trembling aspen was more abundant in the younger age classes (plots 3, 7, and 13). This suggested that either the initial site conditions might have been altered by the birch cover which consequently provided a more favourable environment for aspen reproduction, or that the aspens were now at the age for reproduction by suckering irrespective of any autogenic modification that might be brought about by the birch cover.

From Fig. 52 (see also Appendix A7) it is evident that with the exception of the control site (plot 1), there were few coniferous seedlings present in the area, particularly to the south of the smelter. The seedlings at the control site were all of Douglas-fir, indicating not only an abundance of seed but also the suitability of conditions at the plot for germination and hence for the maintenance of a coniferous cover. Similarly, at plots 2, 5, and 20, coniferous seedlings were found beneath the canopy of older individuals which again suggested that the critical factor controlling the re-establishment of the conifers might be a shortage of seed rather than adverse environmental conditions. Nowhere was young birch found in great quantities: young trembling aspen suckers were the most widespread.

The comparative absence of birch and aspen from the older age classes would indicate that these species were unable to tolerate the pollution levels which existed prior to the 1940's. Hence all of the deciduous cover found in the study area was regarded as regrowth. No evidence of seedling establishment was observed, and since there was no reason to suppose that seed from these species is any less abundant today than in the 1940's, it was concluded that the birch and aspen probably re-established from remnant rootstocks. It was envisaged that some rootstocks could have survived the pollution with minimal above ground development. Thus, as pollution levels were reduced, these remnant propagules could have permitted the rapid re-establishment of the birch and aspen, giving rise to predominantly even aged stands as a result of basal shoot development and suckering. Further development of the deciduous cover could be controlled by the rate at which the younger individuals reach sprouting or suckering age. As these stands mature, some seeding should occur.

At the majority of plots there was a complete absence of conifers in all but the youngest age class. Until a mature coniferous cover has developed at these plots, seed input from the adjacent areas would be the only natural means of reseeding. Eventually this should be supplemented by in situ production, and presumably, with time, the logarithmic age class distribution typical of a normally reproducing population will develop. Subsequent competition with the deciduous species should lead to the exclusion of the birch and aspen, and the resulting age class distributions should resemble those for the control site (plot 1). This process appeared to be proceeding most rapidly at plots 2, 5, and 20 in which conifers of seed bearing age were present.

Variation in the rate of development of the tree cover therefore seemed to be dependent on the amount of seed produced by the conifers and the suitability of the environment for its germination, on the asexual reproductive capacity of the deciduous species, and on the competitive abilities of the component species. If no seed input occurs for birch and aspen the resultant age class distributions may become somewhat stepped, each step representing the time required for individuals of the preceding generation to mature to their respective sprouting or suckering ages. This was thought to account for the current absence of young individuals at most plots. Such breaks in the age class distributions should be obscured if seed input and successful germination occurs.

e. Seed production. The results of the seed trapping are set out in Table 21 and suggested that one of the major causes for the sparse cover in the Trail region was a shortage of available seed. Only

TABLE 21

RESULTS OF THE SEED TRAPPING EXPERIMENT

Species germinated	Sample plot																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Amelanchier alnifolium						1														
Epilobium angustifolium	9*	2*			2*		2*													
Salix scouleriana					2	1						1*								
Silene menziesii														1						
Viola sp.																	1			
Agropyron caninum																			2	
Agrostis scabra										2	21				1					
Calamagrostis rubescens					1													2	1	
Oryzopsis asperifolia						1														
Phleum pratense					1															
Poa pratensis												2								
Pinus contorta																				1
Total number of species/plot	1	1			4	3	1			1	1	2		1	1		1	1	2	1

* not found growing at the sample plot

20 of the 60 pots contained viable material.[1] Grasses were most frequent, occurring in pots throughout the study area, and reflected the species growing at the respective plots. Fireweed was the most common species, germinating at plots 1, 2, 5, and 7, although this species was absent from the ground vegetation at these plots. Willow at plots 5, 6, and 12, and Saskatoon berry at plot 6 were the only shrub species which germinated, and of the tree species only one specimen germinated, a lodgepole pine seedling at plot 20. Although the sample size was necessarily small, the results suggested that a genuine shortage of seed existed in the area. This was thought to reflect both a poor in situ production and a lack of transported propagules. The former might be accounted for by the general immaturity of the cover, the latter by the distance to the surrounding stands of mature timber. This too suggested that the majority of the regrowth in the area had developed from buried viable rootstocks.

Conclusion

The initial analysis of the field data was designed to demonstrate the nature of the spatial variation in the vegetation cover. A significant decrease in the number of species present was detected as the smelter was approached. Only the coniferous species were significantly related to distance from Trail with respect to density and standing crop. This suggested that their present distribution might reflect the pollution gradient. Spatial variation in the ground vegetation groupings and in

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[1] Practically all of the pots contained moss and ladyfern (Athyrium filix-femina (L.) Roth), however, the latter was not found anywhere in the study area and was thought to have germinated following contamination by spores within the laboratory.

the other tree species appeared to be more haphazard and was thought to have been related to variations in the environment. At the majority of the sample plots the maximum age of the tree cover ranged from 25 to 30 years: no trends were detected which could be related to distance from the smelter. Plots at which the older trees appreciably exceeded 30 years in age were regarded as containing elements of the cover which existed prior to pollution control. Few tree seedlings were found in the area which suggested that much of the regrowth may have come from remnant rootstocks. This idea was supported by the results of the seed trapping experiment which indicated that only minimal seed input was occurring.

Since the pattern in the vegetation was not closely related to distance from Trail, the role of environmental controls over this pattern remain to be considered. Spatial variation in the macro-environment was discussed in Chapter 3. Apart from the linear trend exhibited by the precipitation régime throughout the study area, and the existence of a pollution gradient, variation in the macro-environment was haphazard, and this could underly the patterning in the vegetation. In addition, autogenic modification of the stand micro-environments could affect the distribution of the species: the spatial pattern in the micro-environment is discussed in the succeeding chapter. The possibility that variation in both macro- and micro-environmental factors could be related to the vegetation cover is treated in Chapter 6.

Chapter 5

MICRO-ENVIRONMENTAL VARIATION IN THE STUDY AREA

Progressive change in the vegetation cover of an area typically results in the alteration of the micro-environment. As the mass of vegetation at a site increases, the micro-climate of that site becomes increasingly the product of the stand. A similar modification may be expected within the soil. Such autogenic modification is regarded as one of the prime factors affecting the course of revegetation in an area. An examination of the micro-environmental conditions of the vegetation stands might therefore provide a useful insight into the process of vegetation recovery at Trail and thus offer some explanation for the vegetation patterns described previously.

a. Micro-climatic modification. Full data relating to micro-climatic modification are given in Appendix C. The extent to which the recovering vegetation has modified the selected micro-climatic variables is shown in Fig. 53. In order to determine if differences between plots were significant, the data collected at each 1 x 1 m quadrat were used in analysis-of-variance tests: the results are given in Table 22. Variation in all micro-climatic variables was significant at the 0.01 level.

The percentage reduction in solar radiation produced by the vegetation in the area was the most marked micro-climatic modification. The greatest effect was exhibited at the control site at which over 90% of the incident sunlight was lost. Apart from plot 10, all plots to the

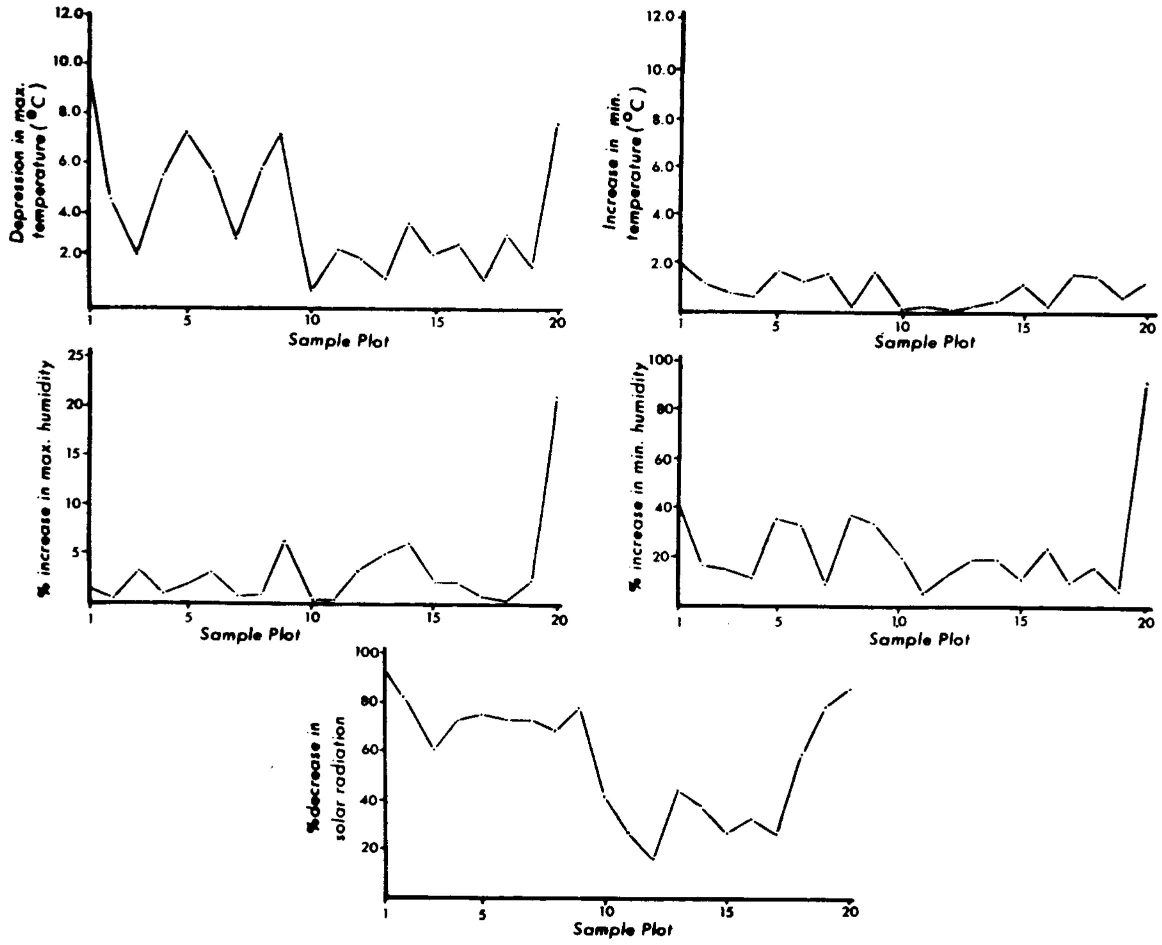

Fig. 53. Autogenic modification of the micro-climatic conditions (The control site is plot 1: Trail is located between plots 10 and 11)

TABLE 22

MICRO-CLIMATIC DATA

A) Mean values at each sample plot

	Mean dep. of max. temp. °C	Mean inc. of min. temp. °C	Mean % inc. in max.R.H.	Mean % inc. in min.R.H.	Mean % dec. in sol. rad.
Plot 1	9.6	2.0	1.3	41.2	93.8
Plot 2	4.2	1.0	0.4	17.3	81.3
Plot 3	2.0	0.8	3.2	14.8	60.5
Plot 4	5.4	0.6	0.8	11.9	73.1
Plot 5	6.8	1.6	1.9	35.7	75.9
Plot 6	5.4	1.0	3.0	32.7	74.0
Plot 7	3.4	1.4	0.6	9.4	73.3
Plot 8	5.4	0.2	0.7	37.6	69.4
Plot 9	6.6	1.4	6.3	33.8	78.0
Plot 10	0.8	0.0	0.4	20.4	41.7
Plot 11	2.0	0.2	0.2	5.2	27.9
Plot 12	1.8	0.0	3.5	13.0	16.2
Plot 13	1.6	0.2	5.0	19.3	45.3
Plot 14	4.4	0.4	6.2	19.0	38.5
Plot 15	2.6	1.0	2.4	10.2	27.0
Plot 16	3.2	0.2	2.1	23.5	32.7
Plot 17	1.4	1.4	0.8	9.2	26.1
Plot 18	3.2	1.4	0.2	15.6	58.3
Plot 19	1.6	0.6	2.2	5.7	79.2
Plot 20	7.4	1.0	21.3	90.2	86.5

B) Analysis-of-variance: micro-climatic data

Mean depression of max. temperature °C	19,80	3.88**
Mean increase in min. temperature °C	19,80	2.27**
Mean % increase in max. relative humidity	19,80	40.34**
Mean % increase in min. relative humidity	19,80	14.59**
Mean % decrease in solar radiation	19,80	10.04**

$^{**}P < 0.01$

north of Trail showed light reductions exceeding 60%. However, to the south of Trail only plots 18, 19, and 20 exhibited exceptionally shaded conditions. The most open site in this respect was plot 12 at which the reduction in solar radiation was only 16.2%. A significant positive correlation was demonstrated between percentage reduction in solar radiation and distance from Trail (see Table 23).

TABLE 23

LINEAR CORRELATIONS BETWEEN MICRO-CLIMATIC VARIABLES AND DISTANCE FROM TRAIL (EXCLUDING THE CONTROL SITE

Variable	r	N
Mean % decrease in solar radiation	0.5620*	19
Mean depression of max. temperature	0.4810*	19
Mean increase in min. temperature	0.4607*	19
Mean % increase in max. relative humidity	0.3209	19
Mean % increase in min. relative humidity	0.2914	19

*$0.05 \geqslant P > 0.01$

The linear correlation between mean depression of maximum temperature and distance from Trail was also significant (see Table 23). The effect was most apparent in the plots to the north of Trail, with modification typically exceeding a value of 5.0°C. Apart from plot 20 in which a depression value of 7.4°C was recorded, variation to the south of Trail was less marked, averaging about 2.5°C. The highest average depression in maximum temperature readings occurred at plots 1, 5, and 20 suggesting the importance of a coniferous cover.

The modifying effect of the vegetation cover on minimum temperatures was less marked with the greatest increase (2.0°C) being recorded at the control site (plot 1). No modification was recorded at plots 10 and 12. Variation was again significantly related to distance from Trail (see Table 23).

The vegetation at plot 20 appeared to exert a considerable modification on humidity with a 21.3% increase in maximum humidity and a 90.2% increase in minimum humidity. This suggested that the effect of a well-developed vegetation cover was accentuated in a generally drier climatic zone. Apart from plot 20, modification of maximum humidities was typically less than 2.5% and correlation with distance from Trail was not significant. This might be accounted for by the proximity of the Columbia River which possibly provides moisture to the atmosphere, and during the night this moist air could pervade the entire area. Variations superimposed on this 2.5% level might reflect additions to the air from soil moisture and transpiration, both of which are increased by a vegetation cover. During the less turbulent night time period, dispersion of this accumulated moisture would be reduced.

However, such an explanation is more applicable to differences in minimum humidity values. The shading effect of a canopy reduces the rapid loss of soil moisture which, because of more gradual evaporation, maintains higher daytime humidity levels for a more extended period than is the case for a non-vegetated area of similar substrate. Further, dispersion of this moister air by wind currents might be reduced by the vegetation, resulting in a high degree of variability in minimum humidity values. However, it should be remembered that this graph plots the percentage modification, not absolute values. Thus, the excessive modification recorded at plot 20 represented an increase from an average of 32% humidity for open conditions to 61% humidity under the canopy. Other plots at which a marked increase in minimum humidity occurred were plots 1, 5, 6, 8, and 9. At plots 1 and 5 this probably resulted from the shading effect of the mature coniferous canopy. Similarly, at plots 6 and 9 transpiration from the well-developed birch and aspen cover together with reduced air movement within the stand could possibly account for the high daytime humidities. In plot 8 however, the high humidity was probably connected with evaporation from soil moisture reserves (see Fig. 54): such an explanation seemed tenable in view of the fact that the correlation between percent increase in minimum relative humidity and distance from Trail was not significant.

Of the five micro-climatic variables studied, percent decrease in solar radiation, mean depression in maximum temperature, and mean increase in minimum temperature were shown to be positively related to distance from Trail. However, both percent increase in maximum relative humidity, and percent increase in minimum relative humidity appeared to be uncorrelated with distance from the smelter: proximity to the Columbia River was thought to be an important factor determining the humidity régimes at the sample plots.

b. Selected physical properties of the soil. Weekly soil moisture and soil temperature data are given in Appendices D3 and D4: mean monthly values are plotted in Figs. 54 and 55. At most plots there was a decrease in percent soil moisture with depth. Superimposed upon this trend was a general reduction in soil moisture during the months of June, July, and August followed by an increase through September. From

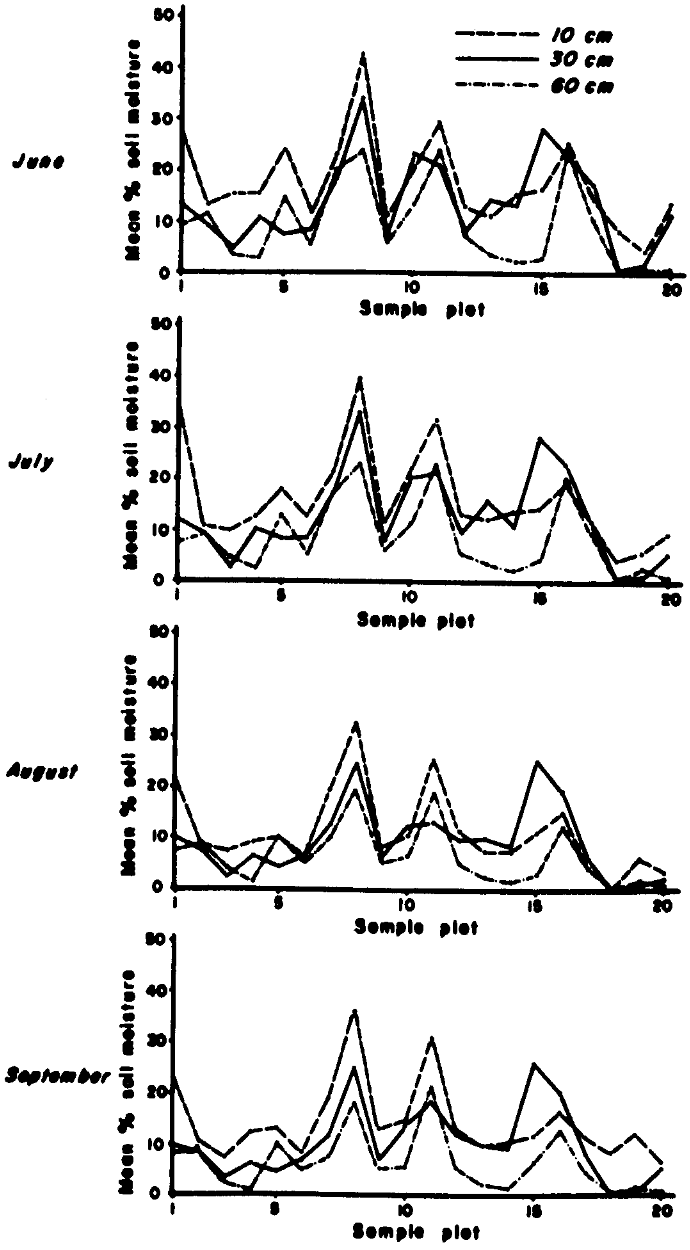

Fig. 54. Soil moisture conditions at the sample plots (The control site is plot 1: Trail is located between plots 10 and 11)

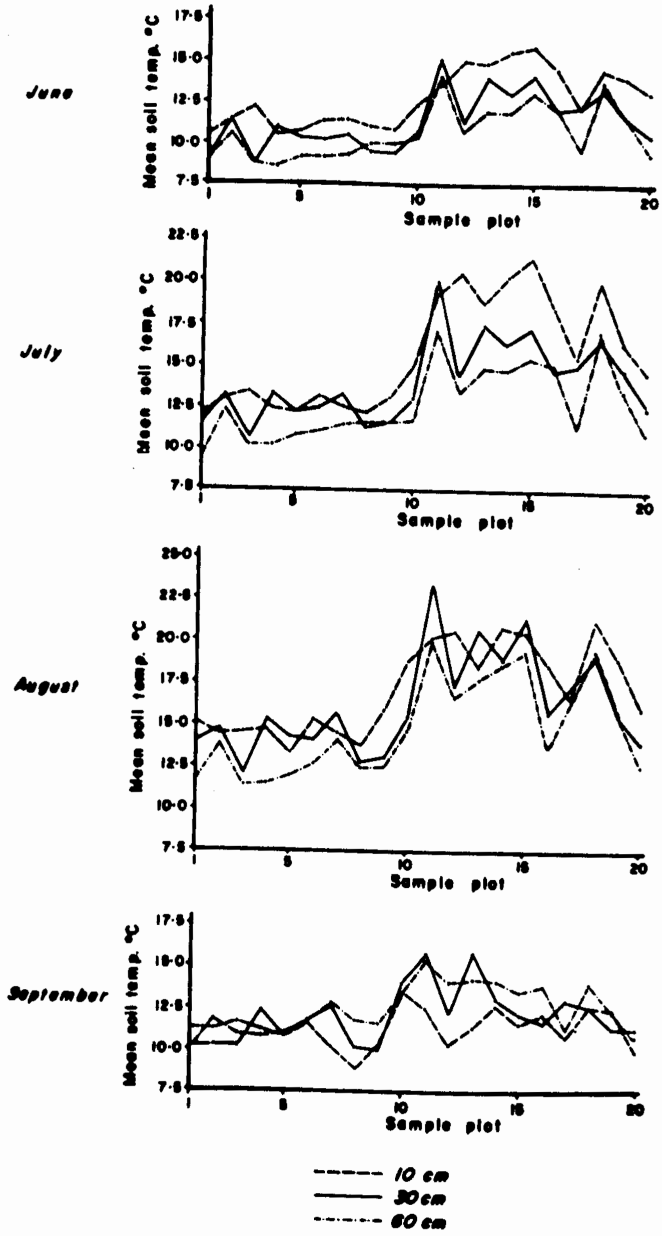

Fig. 55. Soil temperature conditions at the sample plots (The control site is plot 1: Trail is located between plots 10 and 11)

Fig. 54 it would appear that the average soil moisture for the study area was in the order of 10% with noticeably moister soils being found at plots 1, 8, 11, and 15. The moisture values at 10 cm and 30 cm closely followed those obtained at 60 cm, as shown by the correlation values listed in Table 24. This suggested that the surface soil moisture régimes were strongly influenced by the deeper reserves, which as discussed earlier (see page 75) were thought to be largely controlled by physiographic phenomena such as slope conditions. Consequently, few significant relationships could be detected between distance from Trail and mean monthly soil moisture at 10 and 30 cm, as shown in Table 25. Hoover (1949) shows that the absence of a tree cover reduces soil moisture loss by transpiration, and similarly, loss through interception is reduced. Some variation in soil moisture content might also be explained in this manner, although it would appear that increased losses through evaporation outweighed the reduced transpiration losses from poorly vegetated areas, for example plots 14 and 18. The relationships

TABLE 24

LINEAR CORRELATIONS BETWEEN MEAN MONTHLY SOIL MOISTURE AT 60 CM AND MEAN MONTHLY SOIL MOISTURE AT 10 AND 30 CM FOR THE PERIOD JUNE TO SEPTEMBER 1971

Month	60 cm v 10 cm	60 cm v 30 cm	N
June	0.8147**	0.6133**	20
July	0.7677**	0.6826**	20
August	0.8568**	0.5641**	20
September	0.7327**	0.6819**	20

**$P < 0.01$

TABLE 25

LINEAR CORRELATIONS BETWEEN DISTANCE FROM TRAIL AND MEAN MONTHLY SOIL MOISTURE AT 10 AND 30 CM (EXCLUDING THE CONTROL SITE)

Month	Distance v 10 cm	Distance v 30 cm	N
June	-0.3828	-0.4411	19
July	-0.3566	-0.4870*	19
August	-0.4009	-0.5487*	19
September	-0.3254	-0.4399	19

*$0.05 \geq P > 0.01$

between the vegetation and soil moisture are further treated in Chapter 6.

The régime illustrated by soil temperature (see Fig. 55) was the converse of that demonstrated by soil moisture. During June, July, and August a general increase in soil temperature occurred throughout the study area followed by a decline in September. However, a marked difference was evident between the plots to the north of Trail and those to the south, with soil temperatures in the northern zone averaging some 12°C compared to 17°C in the southern zone. Similarly, monthly variations in soil temperatures were more marked in the southern zone. It is interesting to note the cycle of soil temperatures. During June the upper layers of the soil were generally the warmest, although the difference between the 10 cm and 60 cm levels was small. By July the upper layers had become markedly warmer, particularly in the southern plots. During August this warming effect had penetrated to 60 cm such that all depths were again at similar temperatures. September marked the beginning of the cooling period, with rapid heat loss occurring from the surface layers, although some heat was retained at depth. During September the 60 cm layer typically exhibited the warmest temperatures.

No significant relationship with distance from Trail was evident in the mean monthly soil temperatures at 10 cm, as shown in Table 26, although a significant inverse relationship was demonstrated for the 30 and 60 cm data for September. However, if the pattern displayed by the soil temperature data reflected autogenic modification then a strong relationship between these variables and total standing crop should be detected: this is discussed in Chapter 6.

TABLE 26

LINEAR CORRELATIONS BETWEEN DISTANCE FROM TRAIL AND MEAN MONTHLY SOIL TEMPERATURES FOR THE PERIOD JUNE TO SEPTEMBER 1971 (EXCLUDING THE CONTROL SITE)

Month	Distance v 10 cm	Distance v 30 cm	Distance v 60 cm	N
June	-0.1376	-0.2562	-0.2876	19
July	-0.3113	-0.3428	-0.2986	19
August	-0.3443	-0.3932	-0.3907	19
September	-0.0632	-0.5648*	-0.5956**	19

*$0.05 \geqslant P > 0.01$ **$P < 0.01$

c. Selected chemical properties of the soil. Soil chemical data for 5 and 15 cm are given in Appendix D2 and are presented in Fig. 56. Two features were noted with regards to the soil acidity data. First, the soils tended to become less acid with depth with the mean pH value

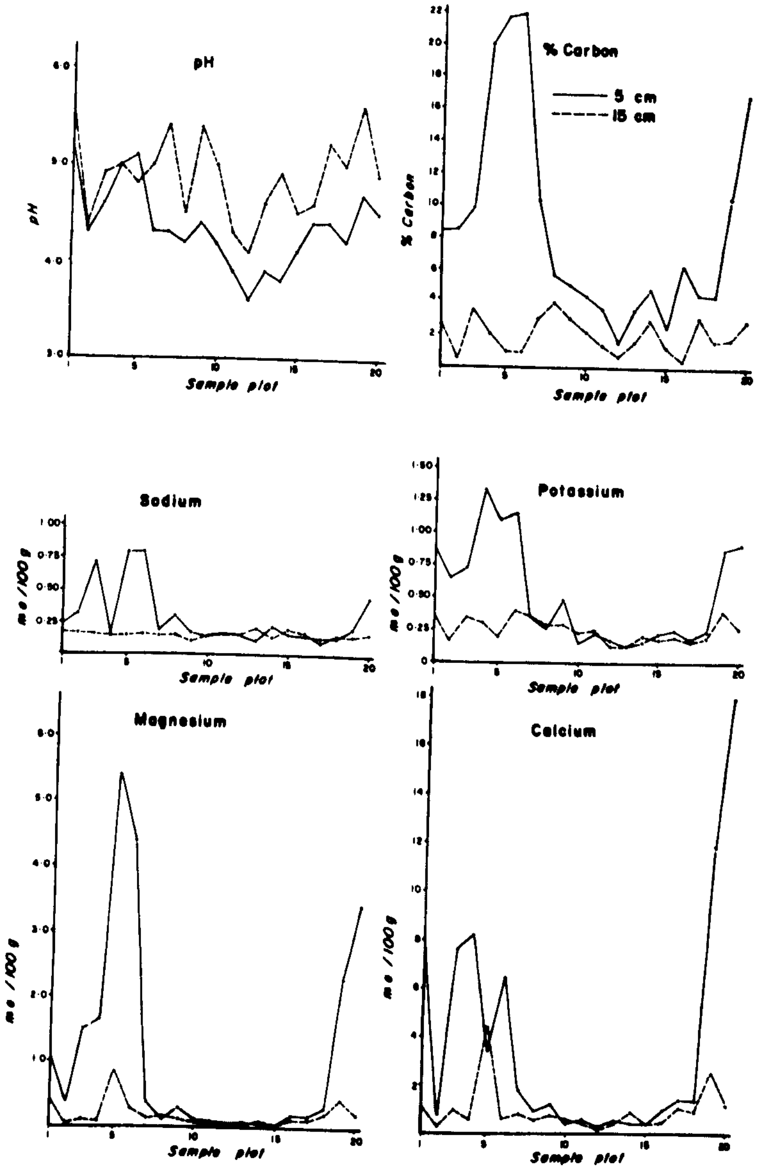

Fig. 56. The chemical status of the soil at 5 and 15 cm depth (The control site is plot 1: Trail is located between plots 10 and 11)

for the area being 4.4 at 5 cm and 4.9 at 15 cm.[1] Secondly, soil acidity showed some decrease in relation to distance from Trail. Earlier research around industrial centres has been inconclusive. Although some workers (Kelly, 1924; McCool and Mehlich, 1938) conclude that soils adjacent to centres of considerable sulphur dioxide emission are not noticeably altered, Katz et al. (1939, pp. 131-164), working in the Trail area, suggest that sulphur dioxide adversely affected the soil, resulting in increased acidity in the surface layers. The present research would tend to substantiate this, with a significant linear correlation being recorded for soil acidity against distance from Trail, as shown in Table 27. The importance of the vegetation in affecting soil acidity is treated in Chapter 6.

TABLE 27

LINEAR CORRELATIONS BETWEEN DISTANCE FROM TRAIL AND SELECTED CHEMICAL PROPERTIES OF THE SOIL AT 5 AND 15 CM DEPTH (EXCLUDING THE CONTROL SITE)

	Distance v 5 cm	Distance v 15 cm	N
Soil acidity	0.6223**	0.0599	19
Percent organic matter	0.4092	-0.0665	19
Concentration of sodium	0.3673	-0.0767	19
Concentration of potassium	0.3953	0.1450	19
Concentration of magnesium	0.4776*	0.3329	19
Concentration of calcium	0.7056**	0.3515	19

*$0.05 \geqslant P > 0.01$ **$P < 0.01$

---

[1] Soil acidity data from deeper horizons substantiated this: see Appendix D2.

The graph illustrating percent carbon at 5 cm showed a decline with proximity to the smelter with the highest values recorded at plots 4, 5, 6, and 20. At 15 cm variation was less marked. However, no significant relationship could be demonstrated between percent carbon and distance from Trail (see Table 27): it was expected that vegetation factors would be more important. This is discussed in Chapter 6.

The macro-nutrients, sodium, potassium, magnesium, and calcium showed a marked similarity in their distribution throughout the area, with concentration being generally higher and more variable at 5 cm than at 15 cm. The mean concentration for sodium at 15 cm was 0.15 me/100 g with markedly higher values occurring at 5 cm, particularly at plots 3, 5, 6, and 20, the maximum concentration of 0.79 me/100 g being found at plot 5. Similarly, potassium, magnesium, and calcium would appear to be concentrated in the upper layer of the soil, possibly following the decay of plant material, and these elements, like sodium, might be only slowly carried downwards. The mean concentration of potassium at 5 and 15 cm was 0.83 and 0.26 me/100 g respectively; for magnesium 1.11 and 0.18 me/100 g, and for calcium 3.80 and 0.98 me/100 g. Two zones of comparatively high concentration were evident from the graphs, one representing the majority of the plots to the north of Trail, the other comprising plots 19 and 20. Between these a zone of lower concentration could be discerned, representing the plots closer to the smelter and extending southwards to plot 18. This distribution was thought to illustrate the effects of leaching following the removal of the vegetation during the period of high pollution levels which, in some plots, had been subsequently counteracted as revegetation proceeded. However, only the concentrations of magnesium and calcium at 5 cm showed significant correlations with distance from Trail (see Table 27). The importance of the vegetation in replenishing soil nutrients in the surface horizons is considered more fully in Chapter 6.

Conclusion

Spatial variation in three micro-climatic factors exhibited linear trends with respect to distance from Trail. However, departures from this were demonstrated for both maximum and minimum relative humidities. It was hoped that the relationship between the micro-climatic variables and vegetation factors might explain the causes underlying such variation. Some of the variation in soil temperatures at 30 and 60 cm could be related to distance from Trail. Similarly, a correlation was demonstrated between soil moisture for July and August at 30 cm and distance from Trail. However, the highly significant correlation exhibited between soil moisture values at 10 and 30 cm with values at 60 cm suggested the importance of physiographic controls. Variation in moisture supply might therefore be an important factor controlling the present appearance of the regrowth in the area. The relationship between the vegetation of the area and the physical soil properties is discussed in the succeeding chapter. Soil acidity at 5 cm and the concentration of magnesium and calcium at 5 cm were significantly related to distance from Trail. Further insight into the distribution pattern of the various soil chemical variables was expected when their relationships with the vegetation factors were treated.

Chapter 6

THE INTEGRATION OF THE PRESENT VEGETATION WITH ITS ENVIRONMENT

Introduction

The type and extent of spatial variation in the vegetation and environment of the study area is readily apparent from the preceding chapters. However, the foregoing descriptive approach provides no insight into the relationship between the factors exhibiting this diversity, that is between the vegetation and its environment. The following section is concerned with the integration of the field data in order that some insight into the causative factors underlying the distribution of the vegetation might be gained, and subsequently, to incorporate this information into an account of the process of revegetation of the Trail area.

This collective assessment has been attempted through the use of a stepwise multiple regression analysis. The analysis of data was undertaken in two parts. The first group of analyses involved the use of selected vegetation characteristics as dependent variables and provided a means of determining the various factors which were important to the distribution of the vegetation in the area. In the second group of analyses micro-environmental factors were selected as the dependent variables. Theoretically this latter set of data should indicate the manner in which the vegetation had affected the environment. The integration of these results provided the basis for the interpretation of the nature of the recolonization in the Trail area. The dependent and independent variables used in the successive computer runs are given in Table 28. The rationale underlying their choice is included in the relevant discussions of results.

In the stepwise technique the computer first calculates the simple regression between the dependent variable and the independent variable that explains the greatest part of the variation in the dependent variable. In the next step, a second independent variable is included in the regression equation; the independent variable chosen is the one that makes the greatest additional contribution to the explained variance. This additive procedure is repeated until all the required independent variables have been incorporated into the regression equation: the stepwise procedure is such that each independent variable is therefore used in order of its importance.

In practise it was found that a high proportion of the variance in the dependent variable (R^2) was obtained before all independent variables were incorporated into the routine. Some method of terminating the regression sequence was therefore required. At each step in the procedure the statistic F was calculated from the standard errors of the net regression coefficients. The F value was used to test the significance of each independent variable, the null hypothesis being that they had zero effect; hence the procedure adopted was to include in the regression equations only those independent variables significant at the 0.05 level or lower (Nie et al., 1970, p. 180). In the majority of cases these provided an R^2 value in excess of 0.9000. The variance ratio test (F test) was also used to test the significance of R.

TABLE 28

THE DEPENDENT AND INDEPENDENT VARIABLES USED IN THE MULTIPLE REGRESSION ANALYSES

	A1	A2	A3	A4	A5	A6
Density of conifers over 30 years old	***	-	-	-	-	*
Density of conifers 20-30 years old	***	-	-	-	-	*
Density of conifers 13-19 years old	***	-	-	-	-	*
Density of conifers 8-12 years old	***	-	-	-	-	*
Density of conifers 5-7 years old	***	-	-	-	-	*
Density of conifers under 5 years excl. saplings	***	-	-	-	-	*
Density of birch over 30 years old	***	-	-	-	-	*
Density of birch 20-30 years old	***	-	-	-	-	*
Density of birch 13-19 years old	***	-	-	-	-	*
Density of birch 8-12 years old	***	-	-	-	-	*
Density of birch 5-7 years old	***	-	-	-	-	*
Density of birch under 5 years excl. saplings	***	-	-	-	-	*
Density of aspen over 30 years old	***	-	-	-	-	*
Density of aspen 20-30 years old	***	-	-	-	-	*
Density of aspen 13-19 years old	***	-	-	-	-	*
Density of aspen 8-12 years old	***	-	-	-	-	*
Density of aspen 5-7 years old	***	-	-	-	-	*
Density of aspen under 5 years excl. saplings	***	-	-	-	-	*
Density of conifer saplings	-	-	-	-	-	**
Density of birch saplings	-	-	-	-	-	**
Density of aspen saplings	-	-	-	-	-	**
Standing crop of conifers over 30 years old	-	*	*	*	*	-
Standing crop of conifers 20-30 years old	-	*	*	*	*	-
Standing crop of conifers 13-19 years old	-	*	*	*	*	-
Standing crop of conifers 8-12 years old	-	*	*	*	*	-
Standing crop of conifers 5-7 years old	-	*	*	*	*	-
Standing crop of conifers under 5 years excl. saplings	-	*	*	*	*	-
Standing crop of birch over 30 years old	-	*	*	*	*	-
Standing crop of birch 20-30 years old	-	*	*	*	*	-
Standing crop of birch 13-19 years old	-	*	*	*	*	-
Standing crop of birch 8-12 years old	-	*	*	*	*	-
Standing crop of birch 5-7 years old	-	*	*	*	*	-
Standing crop of birch under 5 years excl. saplings	-	*	*	*	*	-
Standing crop of aspen over 30 years old	-	*	*	*	*	-
Standing crop of aspen 20-30 years old	-	*	*	*	*	-
Standing crop of aspen 13-19 years old	-	*	*	*	*	-
Standing crop of aspen 8-12 years old	-	*	*	*	*	-
Standing crop of aspen 5-7 years old	-	*	*	*	*	-
Standing crop of aspen under 5 years excl. saplings	-	*	*	*	*	-
Standing crop of shrubs	-	*	*	*	***	*
Standing crop of broadleaf herbs	-	*	*	*	***	*
Standing crop of grass	-	*	*	*	***	*
Standing crop of bracken	-	*	*	*	***	*
Percent decrease in solar radiation	-	**	-	-	*	*
Mean depression of max. daily temperatures	-	**	-	-	*	*
Mean increase in min. daily temperature	-	**	-	-	*	*
Percent increase in max. daily humidities	-	**	-	-	*	*
Percent increase in min. daily humidities	-	**	-	-	*	*
Mean soil temperature at 10 cm depth	-	-	**	-	*	*
Mean soil temperature at 30 cm depth	-	-	**	-	*	-
Mean soil temperature at 60 cm depth	-	-	**	-	*	-
Mean soil moisture at 10 cm depth	*	-	-	-	*	*
Mean soil moisture at 30 cm depth	*	-	-	-	*	-
Mean soil moisture at 60 cm depth	*	-	-	-	*	-
Concentration of sodium in soil at 5 cm depth	-	-	-	**	*	*
Concentration of potassium in soil at 5 cm depth	-	-	-	**	*	*
Concentration of calcium in soil at 5 cm depth	-	-	-	**	*	*
Concentration of magnesium in soil at 5 cm depth	-	-	-	**	*	*
Percent carbon in soil at 5 cm depth	-	-	-	**	*	*
Soil acidity at 5 cm depth	-	-	-	**	*	*
Concentration of sodium in soil at 15 cm depth	*	-	-	-	*	-
Concentration of potassium in soil at 15 cm depth	*	-	-	-	*	-
Concentration of calcium in soil at 15 cm depth	*	-	-	-	*	-
Concentration of magnesium in soil at 15 cm depth	*	-	-	-	*	-
Percent carbon in soil at 15 cm depth	*	-	-	-	*	-
Soil acidity at 15 cm depth	*	-	-	-	*	-
Concentration of available lead in soil at 5 cm depth	-	-	-	-	*	*
Concentration of available zinc in soil at 5 cm depth	-	-	-	-	*	*
Concentration of available lead in soil at 15 cm depth	*	-	-	-	*	-
Concentration of available zinc in soil at 15 cm depth	*	-	-	-	*	-
Mean sulphur dioxide levels in atmosphere	*	-	-	-	*	*

*	Used only as an independent variable
**	Used only as a dependent variable
***	Used either as a dependent or independent variable (see text for details)
-	Variable excluded from the regression run

A1	Factors affecting the density of the tree species
A2	Autogenic modification of micro-climatic conditions
A3	Autogenic modification of soil temperatures
A4	Autogenic modification of soil chemical status
A5	Factors affecting the abundance of the ground vegetation
A6	Factors affecting the establishment of the tree saplings

For small samples of less than N=100 it is desirable to carry out a shrinkage technique (Guilford, 1965, p. 400) to eliminate any chance variation in the sample which would favour an abnormally high R value. The shrinkage is calculated by the formula:

$$_cR^2 = 1 - (1 - R^2)\left(\frac{N - 1}{N - m}\right)$$

where:

$_cR^2$ = correction in R for bias resulting from small sample size,

N = sample size,

m = number of variables correlated, and

N - m = numbers of degrees of freedom, one degree being lost for each mean, there being one mean per variable.

The correction makes the greatest difference when N is small and m is relatively large.

The regression coefficients (b's) measure the net effect of each independent variable on the dependent variable, but because each of the independent variables are recorded in different units these b coefficients cannot be used to determine their relative importance. However, the use of beta (β) coefficients, the net regression coefficients expressed in terms of their own standard deviations, eliminates the problems of differing units of measurement and establishes a basis for comparison, since the betas are pure numbers.

The Regression Analyses

The following analyses were conducted on data from all of the

20 sample plots. Simple correlation data are also given where appropriate. The results are summarised in tables throughout the text.

1) Factors affecting the density of birch, trembling aspen, and the coniferous species, excluding saplings

In order to determine the response of the tree species to environmental conditions the trees were grouped by species into the age classes previously determined (see pages 58-61). This gave six categories excluding the saplings. Such a breakdown therefore enabled one to distinguish between the older plants which were responding primarily to macro-environmental conditions, and the younger plants which were probably more influenced by conditions existing beneath the older canopy. The independent variables used were as follows. For a given age group the density of conifers, birch and trembling aspen in that age group together with the densities of individuals of older age groups were incorporated as biotic variables. The importance of the older individuals as a base for suckering or as a source of seed might become apparent if significant positive relationships with younger age classes result: conversely, negative relationships would suggest the adverse effects of competition. Of the soil physical properties, soil moisture, unlike soil temperature was unaffected by the total biomass at the sample plots (see Table 29); hence soil moistures at all depths were included in the regression model.

Soil chemical status was thought to be affected by the organic material in the soil rather than by total standing crop per se. The chemical properties measured at 5 cm (see Chapter 5) were significantly associated with percent carbon at the corresponding depth (see Table 30).

TABLE 29

LINEAR CORRELATIONS BETWEEN TOTAL STANDING CROP AND SOIL MOISTURE AND SOIL TEMPERATURE

Depth	Soil Moisture	N	Soil Temperature	N
10 cm	0.1300	20	-0.6047**	20
30 cm	-0.2717	20	-0.4847*	20
60 cm	0.0296	20	0.4480*	20

$^{*}0.05 \geq P > 0.01$ $^{**}P < 0.01$

TABLE 30

LINEAR CORRELATIONS BETWEEN PERCENT CARBON AND SELECTED SOIL CHEMICAL VARIABLES AT 5 AND 15 CM

	5 cm	N	15 cm	N
Soil acidity	0.6226**	20	0.4248	20
Sodium	0.7249**	20	-0.3305	20
Potassium	0.4868**	20	0.3059	20
Calcium	0.6099**	20	-0.0314	20
Magnesium	0.8979**	20	-0.0145	20

$^{**}P < 0.01$

However no relationship existed between these variables and percent carbon at 15 cm (see Table 30) which suggested that the effects of vegetation recovery were restricted to the surface layers. Soil chemical properties at 15 cm were therefore used in the multiple regression analysis because they appeared to be unaffected by the plant cover. The levels of available lead and zinc in the soil at 15 cm were also included as external variables. Although one cannot predict past sulphur dioxide levels at the sample plots from the present measurements, it was considered appropriate to include these values since they exhibited a trend with respect to distance from Trail which was probably similar to past pollution gradients. The general hypothesis tested was that the density of the older birch, aspen, and coniferous species had been affected by macro-environmental conditions, competition from other mature vegetation, and also influenced by the availability of viable propagules.

a. Factors affecting the density of the older coniferous species. With the exception of lodgepole pine, the other coniferous species occurred in too limited numbers or in too few plots to enable regression analyses to be conducted on individual species. Thus in order to determine the factors which have affected the re-establishment of the former mixed coniferous cover, data relating to all coniferous species were combined as the dependent variable in the successive runs. The results are given in Table 31.

The density of coniferous species over 30 years in age was apparently affected solely by the inorganic status of the soil. Plots rich in magnesium appeared to have been most favourable for early regrowth ($\beta = 1.748$) with some detrimental effect being exerted by high concentrations of calcium ($\beta = -1.119$) and potassium ($\beta = -0.404$) in the subsoil. The negative effect of calcium was similarly important for conifers of the age class 20-30 years ($\beta = -0.451$) although soil acidity at 15 cm was positively related ($\beta = 0.253$). However, the positive relationship of this age class with older conifers ($\beta = 0.984$) indicated the importance of an in situ source of seed. This was further exemplified in the case of conifers of the age class 13-19 years for which the only significant independent variable was the density of conifers over 30 years old (β = 0.954).

Four variables were important in accounting for the density of 8-12 year old conifers. Establishment appeared to have been reduced in plots in which 13-19 year old individuals have become established (β = -1.835): this was possibly indicative of intraspecific competition. However, a positive relationship was shown with respect to the older individuals 20-30 years in age (β = 1.014). The negative effect of potassium at 15 cm (β = -0.215) and mean soil moisture at 30 cm (β = -0.196) suggested that heterogeneity in edaphic conditions might account for some of the spatial variation in the younger coniferous regrowth.

The three variables significant in accounting for the density of the 5-7 year old conifers all related to the density of individuals in the older age classes, with the highest beta value being recorded for the 8-12 year old conifers (β = 1.245) and in decreasing importance the 20-30 year old conifers (β = -0.654), and finally the over 30 year old conifers (β = 0.170). Such a result would indicate that some competition might occur between the younger conifers and the 20-30 year old individuals. However, continued regeneration again appeared to depend on seed produced by the oldest individuals.

A positive relationship was shown between the younger age class of conifers (excluding saplings) and the 5-7 year old birch (β = 0.515). However, it would appear from the negative beta extracted for the 20-30 year old aspen (β = -0.221) that the early establishment of trembling aspen produced unfavourable conditions for the youngest coniferous regrowth. Similarly, high concentrations of potassium in the subsurface

TABLE 31

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH DENSITY OF CONIFEROUS SPECIES OF VARIOUS AGE CLASSES AS THE DEPENDENT VARIABLES

Y = Density of coniferous species over 30 years old

$R = 0.7968$ St. Err. = 2.769 $R^2 = 0.6349$ $F = 6.52^{**}$ $_cR^2 = 0.5920$

	b	β	F	r
X_1 = Conc. of magnesium in the soil at 15 cm depth	36.854	1.748	12.33**	0.6649**
X_2 = Conc. of calcium in the soil at 15 cm depth	-4.824	-1.119	5.58**	0.5090*
X_3 = Conc. of potassium in the soil at 15 cm depth	-17.745	-0.404	4.07*	0.1099
Constant	17.643			

$$Y = 17.643 + 36.854X_1 - 4.824X_2 - 17.745X_3$$

Y = Density of the 20-30 year old coniferous species

$R = 0.8868$ St. Err. = 3.370 $R^2 = 0.7864$ $F = 19.64^{**}$ $_cR^2 = 0.7613$

	b	β	F	r
X_1 = Density of conifers over 30 years old	1.617	0.984	53.73**	0.8296**
X_2 = Conc. of calcium in the soil at 15 cm depth	-3.194	-0.451	10.67**	0.9358**
X_3 = Soil acidity at 15 cm depth	3.631	0.253	4.47*	-0.7144**
Constant	-15.899			

$$Y = -15.899 + 1.617X_1 - 3.194X_2 + 3.631X_3$$

Y = Density of the 13-19 year old coniferous species

$r = 0.9544$ St. Err. = 0.571 $r^2 = 0.9109$ $F = 183.95^{**}$ $_cR^2$ = ---

	b	β	F	r
X = Density of 20-30 year old conifers	0.265	0.954	183.95**	0.9544**
Constant	0.233			

$$Y = 0.233 + 0.265X$$

Y = Density of the 8-12 year old coniferous species

$R = 0.9113$ St. Err. = 5.338 $R^2 = 0.8305$ $F = 18.37^{**}$ $_cR^2 = 0.7987$

	b	β	F	r
X_1 = Density of 13-19 year old conifers	-11.363	-1.835	25.71**	0.8154**
X_2 = Density of 20-30 year old conifer	1.745	1.014	7.68**	0.6870**
X_3 = Conc. of potassium in the soil at 15 cm depth	-26.677	-0.215	3.69*	-0.0345
X_4 = Mean soil moisture at 30 cm depth	-0.290	-0.196	3.27*	-0.1178
Constant	9.344			

$$Y = 9.344 - 11.363X_1 + 1.745X_2 - 26.677X_3 - 0.290X_4$$

Y = Density of the 5-7 year old coniferous species

$R = 0.9979$ St. Err. = 1.067 $R^2 = 0.9956$ $F = 1254.31^{**}$ $_cR^2 = 0.9951$

	b	β	F	r
X_1 = Density of 8-12 year old conifers	1.626	1.245	2847.33**	0.9093**
X_2 = Density of 20-30 year old conifers	-1.470	-0.654	540.51**	0.3350
X_3 = Density of conifers over 30 years old	0.629	0.170	38.46**	0.4863*
Constant	-0.239			

$$Y = 0.239 + 1.626X_1 - 1.470X_2 + 0.629X_3$$

Y = Density of the under 5 year old coniferous species (excluding saplings)

$R = 0.9208$ St. Err. = 0.180 $R^2 = 0.8478$ $F = 20.89^{**}$ $_cR^2 = 0.8193$

	b	β	F	r
X_1 = Density of conifers over 30 years old	0.072	0.714	47.46**	0.7308**
X_2 = Density of 5-7 year old birch	0.011	0.515	24.38**	0.4527*
X_3 = Conc. of potassium in the soil at 15 cm depth	-0.968	-0.218	4.52*	-0.1385
X_4 = Density of 20-30 year old aspen	-0.024	-0.221	4.40*	0.3044
Constant	0.220			

$$Y = 0.220 + 0.072X_1 + 0.011X_2 - 0.968X_3 - 0.024X_4$$

*$0.05 \geq P > 0.01$ **$P < 0.01$

soil appeared detrimental to this age class of conifers (β = -0.218). The presence of the oldest conifers at a plot was selected as the most significant factor affecting the density of this youngest age class (β = 0.714): this again indicated the importance of a mature seed bearing cover at a plot.

The results of the regression analyses for coniferous species indicated that two main factors affected the density of the conifers during the course of revegetation. The importance of an available seed source was paramount to satisfactory coniferous establishment. Only in plots in which numerous older trees were found had regrowth been widespread. Secondly, variation in the concentration of soil nutrients at 15 cm particularly potassium might be reflected by some variation in coniferous regrowth between plots. The problem of sapling establishment is discussed below (see page 177).

b. Factors affecting the density of the older birches. The variables affecting the regrowth of birch are given in Table 32. No significant variables could be extracted from the data matrix to account for the re-establishment of birch prior to effective pollution control. Such a result supported the idea that the chance survival of root stocks might be the sole factor which led to the re-establishment of the birch in the area.

For the 20-30 year old birch, soil conditions and competition from the oldest conifers seemed to be important, with the concentration of soil potassium at 15 cm positively related (β = 0.629) and percent carbon at 15 cm negatively related (β = -0.548). This suggested that re-establishment might have proceeded best in the badly devastated sites

TABLE 32

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH DENSITY OF BIRCH OF VARIOUS AGE CLASSES AS THE DEPENDENT VARIABLES

Y = Density of birch over 30 years old

No significant independent variables were selected in this run

Y = Density of the 20-30 year old birch

$R = 0.7172$ St. Err. = 6.416 $R^2 = 0.5144$ $F = 5.65$** ${}_{o}R^2 = 0.4573$

	b	β	F	r
X_1 = Conc. of potassium in the soil at 15 cm depth	57.357	0.629	11.54**	0.4235
X_2 = Percent carbon in the soil at 15 cm depth	-3.865	-0.548	8.78**	-0.3200
X_3 = Density of conifers over 30 years old	-0.707	-0.341	3.69*	-0.2137
Constant	2.171			

$$Y = 2.171 + 57.357X_1 - 3.865X_2 - 0.707X_3$$

Y = Density of the 13-19 year old birch

$R = 0.9731$ St. Err. = 4.635 $R^2 = 0.9469$ $F = 38.66$** ${}_{o}R^2 = 0.9280$

	b	β	F	r
X_1 = Density of 20-30 year old birch	1.989	1.010	165.19**	0.9068**
X_2 = Density of birch over 30 years old	8.703	0.344	19.81**	0.1988
X_3 = Density of aspen over 30 years old	15.573	0.209	9.50**	0.1422
X_4 = Percent carbon in the soil at 15 cm depth	-3.811	-0.275	11.40**	-0.3768
X_5 = Conc. of sodium in the soil at 15 cm depth	-156.726	-0.247	8.67**	-0.0284
X_6 = Mean soil moisture at 60 cm depth	0.339	0.158	4.12*	-0.2566
Constant	30.515			

$$Y = 30.515 + 1.989X_1 + 8.703X_2 + 15.573X_3 - 3.811X_4 - 156.726X_5 + 0.339X_6$$

Y = Density of the 8-12 year old birch

$R = 0.9135$ St. Err. = 11.160 $R^2 = 0.8345$ $F = 14.12$** ${}_{o}R^2 = 0.7904$

	b	β	F	r
X_1 = Density of 13-19 year old birch	0.672	0.475	16.71**	0.6014**
X_2 = Density of 20-30 year old aspen	2.616	0.412	13.02**	0.2973
X_3 = Density of 20-30 year old conifers	-5.368	-1.526	11.01**	-0.1394
X_4 = Density of 13-19 year old conifers	-16.948	-1.339	5.52**	0.0568
X_5 = Density of 8-12 year old conifers	-0.859	-0.420	3.53*	0.3281
Constant	-1.200			

$$Y = -1.200 + 0.672X_1 + 2.616X_2 - 5.368X_3 - 16.948X_4 - 0.859X_5$$

Y = Density of the 5-7 year old birch

$R = 0.9407$ St. Err. = 6.623 $R^2 = 0.8850$ $F = 65.40$** ${}_{o}R^2 = 0.8786$

	b	β	F	r
X_1 = Density of 8-12 year old birch	0.734	0.936	129.06**	0.9271**
X_2 = Mean soil moisture at 30 cm depth	0.380	0.160	3.78*	0.1083
Constant	-6.759			

$$Y = -6.759 + 0.734X_1 + 0.380X_2$$

Y = Density of the under 5 year old birch (excluding saplings)

$R = 0.9745$ St. Err. = 0.651 $R^2 = 0.9496$ $F = 52.80$** ${}_{o}R^2 = 0.9362$

	b	β	F	r
X_1 = Density of 5-7 year old birch	0.090	0.666	80.98**	0.6908**
X_2 = Density of aspen over 30 years old	6.038	0.542	68.26**	0.7328**
X_3 = Density of 5-7 year old conifers	-0.063	-0.378	29.45**	-0.0601
X_4 = Density of birch over 30 years old	-0.840	-0.222	11.87**	0.0483
X_5 = Mean soil moisture at 60 cm depth	0.072	0.186	7.97**	0.4308
Constant	-0.193			

$$Y = 0.193 + 0.090X_1 + 6.038X_2 - 0.063X_3 - 0.840X_4 + 0.072X_5$$

*$0.05 > P > 0.01$ **$P < 0.01$

in which organic material had been removed. Such an idea was supported by the negative relationship with the density of the conifers over 30 years old ($\beta = -0.341$) since such individuals were only found in the plots least damaged by fumes.

Six significant variables were selected in the equation for the 13-19 year old birch. The two most significant factors were the densities of the 20-30 year old birch ($\beta = 1.010$) and of the birch over 30 years old ($\beta = 0.344$) which suggested that sprouting from the parent root stocks was an important factor in the re-establishment of birch in the area. The incorporation of the density of the aspen over 30 years old ($\beta = 0.209$) into the equation would possibly indicate that both species could tolerate similar habitat conditions. Again plots low in organic material at 15 cm ($\beta = -0.275$) appeared most favourable particularly when associated with low concentrations of sodium (β -0.247). Soil moisture at 30 cm ($\beta = 0.158$) might also have been important in controlling the establishment of the 13-19 year old birch.

The growth of the 8-12 year old birch appeared to have been curtailed at plots in which conifers were present, with negative relationships exhibited by conifers of the 20-30 year age class ($\beta = -1.526$), the 13-19 year age class ($\beta = -1.339$) and the 8-12 year age class ($\beta = -0.420$). As in the case of the 13-19 year old birch the presence of older aspen ($\beta = 0.412$) at a plot did not seem to inhibit the establishment of the younger birch. However, the positive relationship between the 8-12 year old birch and 13-19 year old growth ($\beta = 0.475$) again suggested the importance of early establishment followed by vigorous reproduction by sprouting.

For the 5-7 year old birch the most significant variable was the density of the next older stocks ($\beta = 0.936$). Soil moisture at 30 cm was also positively related ($\beta = 0.160$).

The density of the birch under 5 years old (excluding saplings) was positively related to the density of the 5-7 year old birch ($\beta = 0.666$) although a negative relationship was shown with the birch over 30 years old ($\beta = -0.222$). This suggested that although sprouting was important for the maintenance of the species, only at plots with a well-developed younger birch cover was regeneration continuing. This is discussed further on page 177. The presence at a plot of aspen over 30 years old did not appear to be detrimental to the youngest birch ($\beta = 0.542$), although young conifers of the 5-7 year age class were negatively associated ($\beta = -0.378$). Soil moisture at depth also appeared to be a factor which might explain the differential establishment in the youngest birch ($\beta = 0.186$).

The lack of any significant variables which might provide some explanation for the initial re-establishment of the birch was thought to support the idea that these older trees had developed from buried root-stocks. Subsequent development of the birch cover appeared to depend upon the in situ reproduction of the older growth, with the species being maintained by sprouting from the bases of the parent trees. With the establishment of other species, particularly the conifers, competition has become an important factor restricting the recent development of the birch.

c. Factors affecting the density of the older trembling aspen. The variables affecting the regrowth of the aspen are given in Table 33.

TABLE 33

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH DENSITY OF TREMBLING ASPEN OF VARIOUS AGE CLASSES AS THE DEPENDENT VARIABLES

Y = Density of aspen over 30 years old

No significant independent variables were selected in this run

Y = Density of the 20-30 year old aspen

$r = 0.6856$ St. Err. $= 2.773$ $r^2 = 0.4701$ $F = 15.97^{**}$ ${}_{o}R^2 =$ ---

	b	β	F	r
X = Density of aspen over 30 years old	11.368	0.686	15.97^{**}	0.6856^{**}
Constant	1.632			

$$Y = 1.632 + 11.368X$$

Y = Density of the 13-19 year old aspen

$R = 0.7302$ St. Err. $= 7.840$ $R^2 = 0.5332$ $F = 9.71^{**}$ ${}_{o}R^2 = 0.5074$

	b	β	F	r
X_1 = Percent carbon in the soil at 15 cm depth	4.317	0.477	7.82^{**}	0.5832^{**}
X_2 = Density of 20-30 year old aspen	1.324	0.452	7.03^{**}	0.5644^{**}
Constant	-4.235			

$$Y = -4.235 + 4.317X_1 + 1.324X_2$$

Y = Density of the 8-12 year old aspen

$R = 0.9600$ St. Err. $= 5.777$ $R^2 = 0.9217$ $F = 32.95^{**}$ ${}_{o}R^2 = 0.9008$

	b	β	F	r
X_1 = Density of 13-19 year old aspen	1.589	0.973	143.11^{**}	0.8216^{**}
X_2 = Density of aspen over 30 years old	33.853	0.427	24.14^{**}	0.0020
X_3 = Density of birch over 30 years old	10.450	0.387	19.87^{**}	0.1894
X_4 = Conc. of available lead in the soil at 15 cm depth	-0.016	-0.225	6.53^{**}	-0.1682
X_5 = Mean atmospheric sulphur dioxide levels	-34.208	-0.179	4.44^{*}	-0.0650
Constant	7.434			

$$Y = 7.434 + 1.589X_1 + 33.853X_2 + 10.450X_3 - 0.016X_4 - 34.208X_5$$

Y = Density of the 5-7 year old aspen

$R = 0.9159$ St. Err. $= 4.657$ $R^2 = 0.8390$ $F = 27.80^{**}$ ${}_{o}R^2 = 0.8201$

	b	β	F	r
X_1 = Density of 13-19 year old aspen	0.733	0.747	46.84^{**}	0.8156^{**}
X_2 = Density of birch over 30 years old	0.386	0.306	9.13^{**}	0.2200
X_3 = Density of aspen over 30 years old	13.612	0.286	6.96^{**}	0.5690^{**}
Constant	-2.020			

$$Y = -2.020 + 0.733X_1 + 0.386X_2 + 13.612X_3$$

Y = Density of the under 5 year old aspen (excluding saplings)

$R = 0.9992$ St. Err. $= 0.531$ $R^2 = 0.9984$ $F = 1842.03^{**}$ ${}_{o}R^2 = 0.9980$

	b	β	F	r
X_1 = Density of aspen over 30 years old	46.487	0.888	4400.73^{**}	0.9903^{**}
X_2 = Density of 5-7 year old aspen	0.202	0.184	156.73^{**}	0.6683^{**}
X_3 = Conc. of sodium in the soil at 15 cm depth	23.466	0.053	13.67^{**}	-0.1503
X_4 = Conc. of calcium in the soil at 15 cm depth	0.414	0.034	7.80^{**}	-0.0558
X_5 = Conc. of available zinc in the soil at 15 cm depth	0.001	0.028	4.95^{**}	0.2133
Constant	-4.453			

$$Y = 4.453 + 46.487X_1 + 0.202X_2 + 23.466X_3 + 0.414X_4 + 0.001X_5$$

$^{*}0.05 > P > 0.01$ $^{**}P < 0.01$

No significant variables were extracted which were related to the density of the oldest trembling aspen. As in the case of the birch, this would substantiate the idea that the deciduous cover probably developed from buried rootstocks. Only one variable, the density of the aspen over 30 years old, was significantly related to the density of the 20–30 year old individuals ($\beta = 0.686$) which suggested that once established the aspen could propagate through suckering.

The density of aspen in the 13–19 year age class was directly affected by the number of 20–30 year old individuals present at a plot ($\beta = 0.452$). The density of this age class was further affected by the amount of organic material present in the soil at 15 cm ($\beta = 0.477$), although this preference for plots with some organic matter present could simply reflect the presence of the older trees.

The importance of suckering was again demonstrated in the 8–12 year age class with direct associations between the dependent variable and the 13–19 year old aspen ($\beta = 0.973$) and the aspen over 30 years old ($\beta = 0.427$). The presence of a long established birch cover did not appear to inhibit the development of aspen at this stage ($\beta = 0.387$).. However, two pollution variables were incorporated into this equation; both were negatively related to the 8–12 year old aspen. Plots in which high available lead concentrations were present appeared unfavourable to the aspen (β -0.225), and similarly, high sulphur dioxide levels in the atmosphere might have inhibited regrowth ($\beta = -0.179$). Such susceptibility to pollution levels both in the soil and atmosphere could account for the exclusion of the species from the badly devastated plots close to Trail.

Two of the three variables extracted for the 5-7 year old aspen relate to older individuals of the species. The direct correlation with the 13-19 year old aspen ($\beta = 0.747$) and with the aspen over 30 years old ($\beta = 0.286$) again indicated the importance of suckering in maintaining the aspen. As in the case of the 8-12 year old aspen, the presence of a birch cover exceeding 30 years in age was not inhibitive to the development of the younger aspen ($\beta = 0.306$).

Vigorous suckering by parent trees was similarly important to the establishment of the youngest aspen with positive relationships demonstrated between the aspen over 30 years old ($\beta = 0.888$) and the 5-7 year old individuals ($\beta = 0.184$). The other three significant variables reflected soil conditions, resulting in direct associations with the concentration of sodium at 15 cm ($\beta = 0.053$), the concentration of calcium at 15 cm ($\beta = 0.034$), and the concentration of available zinc at 15 cm ($\beta = 0.028$).

It would appear from the regression analyses that the re-establishment of the aspen was primarily controlled by its ability to sucker. Competition with other species had not inhibited aspen development. The adverse effects of pollution were demonstrated by the 8-12 year old individuals, and this might have restricted the aspen to the less devastated areas. Variation in the chemical status of the soil could further account for the spatial variation exhibited by the youngest regrowth.

2) <u>The autogenic modification of micro-climatic conditions</u>

The general hypothesis that was tested in this analysis was that the micro-climate, as assessed at ground level, was affected by the amount of vegetation at a plot. Simple correlations between the micro-climatic variables and total standing crop are given in Table 34.

TABLE 34

LINEAR CORRELATIONS BETWEEN THE MICRO-CLIMATIC VARIABLES AND TOTAL STANDING CROP

Variable	N	r
Percent decrease in solar radiation	20	0.6777**
Mean depression of max. temperature	20	0.6739**
Mean increase in min. temperature	20	0.5717**
Percent increase in max. relative humidity	20	0.0011
Percent increase in min. relative humidity	20	0.2397

**$P < 0.01$

The results indicated that percent decrease in solar radiation, mean depression of maximum temperature and mean increase in minimum temperature were significantly correlated with total standing crop. However, because significant inter-plot differences were shown to exist (pages 129-134) for all of the micro-climatic variables, they were each used as dependent variables in the multiple regression analysis. The independent variables comprised the standing crop data for each of the tree species subdivided according to age classes, together with the standing crop data for the shrubs, broadleaf herbs, grasses, and bracken. The results are given in Table 35.

a. Factors affecting the decrease in solar radiation. Five variables were extracted which significantly affected the decrease in solar radiation recorded at ground level. Of these, the standing crop

TABLE 35

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH MICRO-CLIMATIC FACTORS AS THE DEPENDENT VARIABLES

<u>Y = Percent reduction in solar radiation</u>

$R = 0.8648$ St. Err. $= 15.026$ $R^2 = 0.7478$ $F = 5.09^{**}$ ${}_oR^2 = 0.6314$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.035	1.406	14.01^{**}	0.5601^{*}
X_2 = Standing crop of 13-19 year old birch	0.101	0.788	13.82^{**}	0.2591
X_3 = Standing crop of 13-19 year old aspen	0.307	0.944	9.15^{**}	-0.0230
X_4 = Standing crop of conifers under 5 years (excl. saplings)	114.976	0.893	6.37^{**}	0.3872
X_5 = Standing crop of 5-7 year old aspen	-2.690	-0.732	6.07^{**}	-0.0537
Constant	30.240			

$$Y = 30.240 + 0.035X_1 + 0.101X_2 + 0.307X_3 + 114.976X_4 - 2.690X_5$$

<u>Y = Mean depression in maximum temperature</u>

$R = 0.9027$ St. Err. $= 1.294$ $R^2 = 0.8148$ $F = 7.55^{**}$ ${}_oR^2 = 0.7293$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.002	0.673	11.13^{**}	0.7271^{**}
X_2 = Standing crop of 20-30 year old aspen	0.017	0.610	8.05^{**}	0.1479
X_3 = Standing crop of aspen under 5 years (excl. saplings)	-0.594	-0.692	7.66^{**}	-0.0937
Constant	2.043			

$$Y = 2.043 + 0.002X_1 + 0.017X_2 - 0.594X_3$$

<u>Y = Mean increase in minimum temperature</u>

$R = 0.9117$ St. Err. $= 0.273$ $R^2 = 0.8313$ $F = 18.48^{**}$ ${}_oR^2 = 0.7997$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.001	0.832	51.62^{**}	0.6198^{**}
X_2 = Standing crop of 13-19 year old aspen	0.006	0.717	38.42^{**}	0.4079
X_3 = Standing crop of 20-30 year old birch	0.002	0.254	4.16^{*}	-0.1932
Constant	0.237			

$$Y = 0.237 + 0.001X_1 + 0.006X_2 + 0.002X_3$$

<u>Y = Percent increase in maximum relative humidity</u>

$R = 0.9361$ St. Err. $= 2.269$ $R^2 = 0.8762$ $F = 7.86^{**}$ ${}_oR^2 = 0.8432$

	b	β	F	r
X_1 = Standing crop of conifers under 5 years (excl. saplings)	51.777	2.044	34.25^{**}	0.1115
X_2 = Standing crop of conifers over 30 years old	0.011	2.252	32.38^{**}	0.1608
X_3 = Standing crop of 5-7 year old conifers	0.204	0.629	13.13^{**}	0.1725
X_4 = Standing crop of aspen over 30 years old	-0.067	-0.485	5.20^{*}	-0.1270
Constant	2.713			

$$Y = 2.713 + 51.777X_1 + 0.011X_2 + 0.204X_3 - 0.067X_4$$

<u>Y = Percent increase in minimum relative humidity</u>

$R = 0.9232$ St. Err. $= 8.493$ $R^2 = 0.8523$ $F = 16.16^{**}$ ${}_oR^2 = 0.7996$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.050	2.505	72.58^{**}	0.4369
X_2 = Standing crop of conifers under 5 years (excl. saplings)	202.298	1.969	51.61^{**}	0.1679
X_3 = Standing crop of 5-7 year old conifers	0.855	0.650	26.59^{**}	-0.0115
X_4 = Standing crop of aspen under 5 years (excl. saplings)	-3.126	-0.458	10.70^{**}	-0.2052
X_5 = Standing crop of birch under 5 years (excl. saplings)	4.450	0.245	3.02^{*}	-0.0534
Constant	16.555			

$$Y = 16.555 + 0.050X_1 + 202.298X_2 + 0.855X_3 - 3.126X_4 + 4.450X_5$$

${}^{*}0.05 \geq P > 0.01$ ${}^{**}P < 0.01$

of coniferous species over 30 years in age was the most important ($\beta = 1.406$). It is interesting to note the inclusion of the youngest coniferous species (excluding saplings) as a positive variable in the regression equation ($\beta = 0.893$). This would suggest that only in plots in which the conifers were regenerating was the shade factor most pronounced. Percent decrease in solar radiation was further controlled by the fairly recently established cover of birch ($\beta = 0.788$) and aspen ($\beta = 0.944$) with the standing crops of the 13-19 year old individuals of both species positively related to the dependent variable. The standing crop of the 5-7 year old aspen was however negatively associated with the percent decrease in solar radiation ($\beta = -0.732$) suggesting that aspen regeneration might be stimulated by high light conditions: this agrees with the autecology of the species.

b. Factors affecting the mean depression of maximum temperature. The standing crop of the oldest conifers was a significant factor affecting the lowering of maximum daily temperature ($\beta = 0.673$) with the resulting closed canopy reducing insolation and air movement at ground level. A similar effect was produced by the 20-30 year old aspen ($\beta = 0.610$). However, the youngest aspens (excluding saplings) were negatively related to the dependent variable (β -0.692). This again reflected the open nature of the stands with which the young aspen regrowth was associated.

c. Factors affecting the mean increase in minimum temperature. The positive relationship between standing crop of conifers over 30 years old and mean increase in minimum temperatures ($\beta = 0.832$) demonstrated the insulating effects of a well-developed canopy against heat loss through radiation. This effect was also brought about by a cover of aspen of 13-19 years ($\beta = 0.717$) and to some extent by the 20-30 year old birches ($\beta = 0.254$).

d. Factors affecting the increase in maximum relative humidity. The standing crops of three age classes of conifers were positively related to the dependent variable with the most significant relationships demonstrated for the oldest ($\beta = 2.252$) and youngest individuals ($\beta = 2.044$). Similar results were shown for the 5-7 year old conifers ($\beta = 0.629$). Conversely, the standing crop of the oldest age class of aspen was negatively related to the dependent variable ($\beta = -0.485$).

e. Factors affecting the increase in minimum relative humidity. The same age classes of conifers were extracted as significant in this analysis as for the previous one, with standing crop of the over 30 year old individuals being most important ($\beta = 2.505$). This, together with the standing crop of the conifers under 5 years old ($\beta = 1.969$) and the 5-7 year old conifers ($\beta = 0.650$), accounted for much of the variation exhibited by the dependent variable. Plots in which young birch occurred ($\beta = 0.245$) also recorded greater increases in minimum humidity whereas the opposite was the case for plots in which young aspen were found ($\beta = -0.458$).

From the preceding analyses it was evident that the most marked autogenic modification of micro-climate was brought about by a well-developed coniferous cover. Plots in which young aspen were abundant did not exhibit such modification. This was thought to reflect conditions most suitable for suckering, that is high light intensities and warm temperatures. With time however, the developing aspen cover should exert some modifying effect on the micro-climate. The effect of the birch was less marked, and primarily resulted in a decrease in solar radiation at the sample plots.

3) Autogenic modification of soil temperatures

The general hypothesis tested in this set of analyses was that the mass of vegetation at a plot would be negatively related to soil temperature. As the vegetation cover develops less solar radiation will reach the soil, and hence lower soil temperatures will be recorded. The simple correlations between soil temperature at 10, 30, and 60 cm and total standing crop are given in Table 29: in all cases the results were significant. It was anticipated that the multiple regression analyses would show those particular plant covers which were important in effecting such autogenic modification. The independent variables used in these analyses were the same as those outlined for the micro-climatic analyses: the results are given in Table 36.

a. Mean soil temperature at 10 cm. The principal factor which affected soil temperature at this depth was the standing crop of the conifers over the age of 30 years. This negative relationship ($\beta = -1.035$) presumably resulted from the great amount of shade produced by the heavy coniferous canopy. A similar effect was produced by the 13-19 year old aspens ($\beta = -0.448$) and by the amount of bracken ($\beta = -0.445$).

b. Mean soil temperature at 30 cm. Of the four factors which were significantly related to soil temperatures at 30 cm, the greatest modification resulted from the standing crop of the oldest conifers

TABLE 36

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH SOIL TEMPERATURES AS THE DEPENDENT VARIABLES

Y = Mean soil temperature at 10 cm

$R = 0.9029$ St. Err. = 2.246 $R^2 = 0.8152$ $F = 7.56^{**}$ ${}_cR^2 = 0.7299$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	-0.005	-1.035	8.91**	-0.4602*
X_2 = Standing crop of 13-19 year old aspen	-0.026	-0.448	5.52**	-0.0553
X_3 = Standing crop of bracken	-0.008	-0.445	7.07**	-0.4977*
Constant	63.799			

$$Y = 63.799 - 0.005X_1 - 0.026X_2 - 0.008X_3$$

Y = Mean soil temperature at 30 cm

$R = 0.9127$ St. Err. = 2.205 $R^2 = 0.8334$ $F = 5.54^{**}$ ${}_cR^2 = 0.7122$

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	-0.004	-0.988	7.17**	-0.3836
X_2 = Standing crop of bracken	-0.012	-0.732	12.49**	-0.3851
X_3 = Standing crop of birch over 30 years old	-0.028	-0.573	10.39**	0.2748
X_4 = Standing crop of 13-19 year old birch	-0.008	-0.376	3.52*	-0.3108
Constant	60.746			

$$Y = 60.746 - 0.004X_1 - 0.012X_2 - 0.028X_3 - 0.008X_4$$

Y = Mean soil temperature at 60 cm

$R = 0.9036$ St. Err. = 533.471 $R^2 = 0.8165$ $F = 16.69^{**}$ ${}_cR^2 = 0.7821$

	b	β	F	r
X_1 = Standing crop of bracken	-2.731	-0.574	16.92**	-0.7858**
X_2 = Standing crop of 20-30 year old birch	-5.213	-0.379	8.35**	-0.7118**
X_3 = Standing crop of birch under 5 years (excl. saplings)	-232.214	-0.219	3.63*	-0.1201
Constant	-416.166			

$$Y = -416.166 - 2.731X_1 - 5.213X_2 - 232.214X_3$$

$^{*}0.05 \geq P > 0.01$ $^{**}P < 0.01$

(β = -0.988). Further variation was explained by the bracken (β = -0.732), the 13-19 year old birch (β = -0.376), and the oldest birch (β = -0.573).

c. Mean soil temperature at 60 cm. The amount of bracken growing at the plots had the greatest effect on soil temperatures at this depth (β = -0.574). A similar negative relationship was demonstrated for both the 20-30 year (β = -0.379) and the youngest (β = -0.219) age categories of birch.

Modification of soil temperature conditions was primarily brought about by the increasing growth of bracken. Bracken was widespread in the study area, being found in all but 4 of the sample plots. Typically, the fronds formed a luxuriant growth which shaded the soil from the direct rays of the run; this shading effect was further enhanced at plots at which the coniferous cover had long been established. However, such modification was most pronounced in the soils at 10 and 30 cm depth. Soil temperature régimes at 60 cm depth, although predominantly affected by bracken, were also controlled to some extent by the birch cover. This change from coniferous to deciduous elements as independent variables was difficult to explain: soil temperatures at 60 cm tended to exhibit a lag effect and it was possible that the deciduous cover accentuated this, although the mechanism of operation was uncertain.

4) Autogenic modification of soil chemical status

The inorganic nutrients in an area, after being taken up from the soil by the roots, are stored in the tissues of the plants. Such organically held nutrients are subsequently released to the soil through the decay of the plant litter which results in their concentration in the surface horizons. The nutrient status of the soil at 5 cm was related to the amount of organic matter in the soil and hence to the vegetation at the plots (see Table 30). The general aim of this set of regression analyses was to determine which elements of the vegetation produced the greatest modification in soil chemical conditions. The independent variables were again the standing crop data, which for the tree species, were subdivided according to species/age classes, and which for the ground cover were subdivided into shrubs, broadleaf herbs, grasses and bracken. The results are given in Table 37.

a. Percent carbon at 5 cm. The principal factor affecting the buildup of organic material in the soil was the oldest conifers ($\beta = 1.065$). However care must be taken in interpreting this factor. The conifers over 30 years in age were considered as remnants from the former cover and were therefore much older than the regrowth found at the majority of plots. Consequently, more time had been available during which litter might have been incorporated into the surface soil. Similarly, the ground vegetation associated with such plots was generally well-developed; this too would contribute to the litter. The effect of the conifers was further demonstrated by the inclusion of 13-19 year old individuals in the regression equation ($\beta = 0.656$). A significant increase in organic carbon was also attributed to the abundance of the 20-30 year old birch ($\beta = 0.524$).

b. Concentration of sodium at 5 cm. All of the five

TABLE 37

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH THE CHEMICAL STATUS OF THE SURFACE SOIL AS THE DEPENDENT VARIABLES

Y = Percent carbon at 5 cm

$R = 0.9193$ $R^2 = 0.8452$ ${}_cR^2 = 0.8162$

St. Err. = 2.881 F = 20.48**

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.007	1.065	55.01**	0.4472*
X_2 = Standing crop of 20-30 year old birch	0.012	0.524	19.38**	0.5178*
X_3 = Standing crop of 13-19 year old conifers	0.211	0.656	21.93**	-0.0061
Constant	2.403			

$$Y = 2.403 + 0.007X_1 + 0.012X_2 + 0.211X_3$$

Y = Concentration of sodium at 5 cm

$R = 0.9099$ $R^2 = 0.8278$ ${}_cR^2 = 0.7663$

St. Err. = 0.110 F = 10.42**

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.001	1.044	32.68**	0.4239
X_2 = Standing crop of 20-30 year old conifers	0.001	0.805	19.00**	0.0322
X_3 = Standing crop of birch over 30 years old	-0.002	-0.755	17.68**	-0.2478
X_4 = Standing crop of 20-30 year old birch	-0.001	-1.610	16.18**	0.3335
X_5 = Standing crop of 13-19 year old birch	-0.001	-0.980	6.27**	0.2751
Constant	0.148			

$$Y = 0.148 + 0.001X_1 + 0.001X_2 - 0.002X_3 - 0.001X_4 - 0.001X_5$$

Y = Concentration of potassium at 5 cm

$R = 0.8767$ $R^2 = 0.7687$ ${}_cR^2 = 0.6005$

St. Err. = 0.955 F = 3.69*

	b	β	F	r
X_1 = Standing crop of 20-30 year old birch	-0.010	-1.911	17.24**	0.4946*
X_2 = Standing crop of birch over 30 years old	-0.014	-0.785	13.72**	-0.0525
Constant	0.009			

$$Y = 0.009 - 0.010X_1 - 0.014X_2$$

Y = Concentration of calcium at 5 cm

$R = 0.9118$ $R^2 = 0.8315$ ${}_cR^2 = 0.7713$

St. Err. = 2.453 F = 10.69**

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	-0.012	-2.228	46.32**	0.3432
X_2 = Standing crop of conifers under 5 years (excl. saplings)	-47.217	-1.764	33.72**	0.1285
X_3 = Standing crop of 20-30 year old birch	0.014	0.764	22.01**	0.2833
X_4 = Standing crop of 5-7 year old conifers	-0.147	-0.429	6.47**	-0.0816
X_5 = Standing crop of 8-12 year old birch	0.034	0.435	6.20**	-0.0907
Constant	0.988			

$$Y = 0.988 - 0.012X_1 - 47.217X_2 + 0.014X_3 - 0.147X_4 + 0.034X_5$$

Y = Concentration of magnesium at 5 cm

$R = 0.9076$ $R^2 = 0.8238$ ${}_cR^2 = 0.8031$

St. Err. = 0.727 F = 24.94**

	b	β	F	r
X_1 = Standing crop of conifers over 30 years old	0.002	1.172	65.09**	0.5442*
X_2 = Standing crop of 13-19 year old conifers	0.069	0.773	29.27**	-0.0356
X_3 = Standing crop of 20-30 year old birch	0.003	0.485	20.33**	0.3273
Constant	0.003			

$$Y = 0.003 + 0.002X_1 + 0.069X_2 + 0.003X_3$$

Y = Soil acidity at 5 cm

$R = 0.9400$ $R^2 = 0.8837$ ${}_cR^2 = 0.8527$

St. Err. = 0.171 F = 21.27**

	b	β	F	r
X_1 = Distance from Trail[1]	0.040	0.832	32.38**	-
X_2 = Standing crop of conifers under 5 years (excl. saplings)	-1.258	-0.541	16.59**	-0.6686**
X_3 = Standing crop of 13-19 year old conifers	-0.010	-0.456	8.94**	-0.4988*
Constant	3.627			

$$Y = 3.627 + 0.040X_1 - 1.258X_2 - 0.010X_3$$

*0.05 ≥ P > 0.01 **P < 0.01

[1] Distance from Trail was used as an independent variable only for the soil acidity analysis (see text).

independent variables selected related to elements of the tree cover. The standing crop of the 20-30 year old birches produced the most significant effect ($\beta = -1.610$), with a similar negative relationship exhibited by the 13-19 year old birch ($\beta = -0.980$) and the oldest birch ($\beta = -0.755$). The two oldest classes of conifers both exhibited a positive association with sodium. This was most pronounced for the conifers over 30 years old ($\beta = 1.044$), with a beta value of 0.805 recorded for the 20-30 year old class. Such results suggested that sodium might be removed by the birch and restored by the conifers. However, it seemed more likely that these relationships reflected the degree of destruction of the former cover and subsequent leaching of the sodium. Hence, birch was found in the more disturbed plots which were low in sodium, and the conifers were found in the less disturbed plots which had suffered little leaching.

c. Concentration of potassium at 5 cm. The only significant variables in this run were the standing crops of the 20-30 year old birch and of the birch over 30 years old. Of these, the former was the more important ($\beta = -1.911$) with the latter giving a beta value of -0.785. This negative effect on soil potassium could indicate storage of the element in the plant tissue, particularly since potassium at 15 cm was included as a requirement for the development of the 20-30 year old birch (see page 153).

d. Concentration of calcium at 5 cm. Two factors were important in this analysis, the standing crop of the conifers and the standing crop of the birch: the former gave a net negative effect and the latter was positively related to the dependent variable. For the conifers, the individuals over 30 years old were the most important (β -2.228); the effect of the under 5 year old individuals, excluding saplings, was also very significant ($\beta = -1.764$), with the 5-7 year individuals giving a beta value of -0.429. This reduction could represent storage of the element in the plant tissue, although it was shown earlier (see page 150) that calcium might be detrimental to the development of the conifers. It was therefore concluded that the general change to acid soils at plots in which conifers were well established and regenerating might largely be controlled by the rate at which calcium was leached from the soil. The positive relationship with the 20-30 year old birch ($\beta = 0.764$) and the 8-12 year old birch ($\beta = 0.435$) could possibly be accounted for by the extraction of calcium by the roots of this species with its rapid return to the soil through leaf fall.

e. Concentration of magnesium at 5 cm. The positive relationship with the conifers was most marked with respect to the individuals over 30 years old ($\beta = 1.172$), with the 13-19 year individuals giving a beta of 0.773. The significant positive relationship shown earlier (see page 150) between magnesium at 15 cm, and the oldest conifers could indicate a rapid turnover rate for this element with the net result being a replenishment of magnesium in the surface soil horizons. Birch of the age class 20-30 years was similarly positively related to the concentration of magnesium at 5 cm ($\beta = 0.485$).

f. Soil acidity at 5 cm. It was previously shown that significant correlations existed between soil acidity at 5 cm and both percent carbon (see Table 30) and distance from the smelter (see

Table 27). Because of this latter relationship, distance from the smelter was added as a further independent variable in this run. Three variables were subsequently extracted. Of these, distance from the smelter accounted for most of the variance ($\beta = 0.832$). This again substantiated the findings of earlier workers in the Trail region (see page 141). A negative relationship with soil acidity was demonstrated for conifers of two age classes, those under 5 years old (excluding saplings) ($\beta = -0.541$) and the 13-19 year individuals ($\beta = -0.456$). The development of the conifers, as suggested earlier, was therefore associated with increasingly acid soil conditions, presumably brought about by their acid litter.

In all of the preceding analyses it was elements of the macrovegetation which were important in effecting the autogenic modification of the chemical status of the soil, although trembling aspen appeared to have no effect on surface soil conditions. The conifers, particularly the oldest individuals, affected all variables excluding potassium, and in most cases their effect was to increase the nutrient status of the soil. However, this was thought to reflect the age of the cover rather than being a specific result of its coniferous character. Negative relationships were demonstrated between the conifers and the concentration of calcium and soil acidity. However, some covariation was thought to be operating here since a decrease in calcium would necessarily result in more acid soils. The dependent variables typically exhibited negative relationships with a well-developed birch cover. This was thought to represent storage of nutrients in the plant tissues: such storage might result in tight nutrient budgets which could affect further regrowth at some plots. For soil acidity, distance from the smelter showed a significant positive relationship, indicating that less acid soil conditions were found in the more distant plots. The coniferous regrowth was negatively related to soil acidity.

5) Factors affecting the standing crops of the ground vegetation

Three groups of factors were considered to affect the development of the ground vegetation: these were competition, micro-climate, and soil conditions. Competition could be from both the tree cover and elements of the ground vegetation; hence the standing crop data for trees subdivided according to species/age classes, and the standing crop data for the sub-elements of the ground vegetation were included as one set of independent variables. Because the ground vegetation was within the zone most affected by the overlying canopy, micro-climatic data was also incorporated as an additional set of independent variables. The abundance of the ground vegetation might be further affected by conditions in the rooting zone; therefore soil moisture and temperature data for 10, 30, and 60 cm, and soil chemical data for 5 and 15 cm were also included in the regression analysis. Further independent variables included atmospheric sulphur dioxide levels and the concentration of available lead and zinc in the soil at 5 and 15 cm. The results are given in Table 38.

a. Factors affecting the standing crop of the shrubs. The dependent variable in this run represented the standing crops of all species of the ground vegetation which possessed woody stems. Three of the nine significant variables extracted from the data matrix were

TABLE 38

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH THE STANDING CROP OF THE GROUND VEGETATION AS THE DEPENDENT VARIABLES

Y = Standing crop of shrubs

R = 0.9382 R^2 = 0.8801 $_cR^2$ = 0.7722

St. Err. = 542.583 F = 6.61**

	b	β	F	r
X_1 = Standing crop of 13-19 year old birch	-11.215	-1.931	42.89**	-0.3325
X_2 = Standing crop of grass	23.606	0.432	37.77**	0.3735
X_3 = Mean soil temperature at 60 cm depth	0.886	0.910	24.80**	-0.0944
X_4 = Standing crop of aspen over 30 years old	-30.432	-0.949	14.99**	-0.1454
X_5 = Mean depression of maximum daily temperature	-339.256	-0.752	13.56**	-0.0653
X_6 = Standing crop of 13-19 year old aspen	-14.789	-1.000	13.72**	0.0354
X_7 = Mean soil temperature at 30 cm depth	143.543	0.521	6.94**	0.0618
X_8 = Conc. of potassium in the soil at 15 cm	326.427	0.436	6.84**	-0.0603
X_9 = Conc. of calcium in the soil at 15 cm	335.012	0.293	5.32**	0.3486
Constant	9989.098			

$$Y = 9989.098 - 11.215X_1 + 23.606X_2 + 0.886X_3 - 30.432X_4 - 339.256X_5 - 14.789X_6 + 143.543X_7 + 325.427X_8 + 335.012X_9$$

Y = Standing crop of broadleaf herbs

R = 0.9255 R^2 = 0.8566 $_cR^2$ = 0.8184

St. Err. = 17.053 F = 16.73**

	b	β	F	r
X_1 = Conc. of available zinc in the soil at 15 cm depth	0.042	1.005	51.75**	0.5382*
X_2 = Mean soil temperature at 30 cm depth	-6.371	-0.645	28.03**	-0.4200
X_3 = Standing crop of 20-30 year old aspen	-0.557	-0.485	20.06**	-0.2129
X_4 = Mean increase in minimum daily temperature	20.829	0.318	7.61**	0.1800
X_5 = Percent carbon in the soil at 15 cm	-10.079	-0.313	5.09**	0.3710
Constant	363.124			

$$Y = 363.124 + 0.042X_1 - 6.371X_2 - 0.557X_3 + 20.829X_4 - 10.079X_5$$

Y = Standing crop of grass

R = 0.9251 R^2 = 0.8558 $_cR^2$ = 0.7893

St. Err. = 31.260 F = 10.17**

	b	β	F	r
X_1 = Standing crop of 13-19 year old birch	-0.398	-1.131	53.84**	0.3088
X_2 = Standing crop of 20-30 year old aspen	-1.550	-0.797	37.38**	-0.1481
X_3 = Standing crop of shrubs	0.030	0.495	16.99**	0.3735
X_4 = Standing crop of 13-19 year old aspen	0.471	0.525	14.95**	0.0935
X_5 = Conc. of potassium in the soil at 5 cm depth	-18.090	-0.398	10.80**	0.0718
X_6 = Mean soil temperature at 60 cm depth	0.023	0.396	4.40*	-0.1937
Constant	-9.132			

$$Y = -9.132 - 0.398X_1 - 1.550X_2 + 0.030X_3 + 0.471X_4 - 18.090X_5 + 0.023X_6$$

Y = Standing crop of bracken

R = 0.9534 R^2 = 0.9089 $_cR^2$ = 0.8856

St. Err. = 78.916 F = 37.42**

	b	β	F	r
X_1 = Mean soil temperature at 60 cm depth	-0.152	-0.726	78.57**	-0.7858**
X_2 = Standing crop of 8-12 year old birch	0.976	0.270	9.18**	0.5835**
X_3 = Mean soil moisture at 30 cm depth	10.100	0.338	17.42**	0.1714
X_4 = Mean soil temperature at 30 cm depth	-19.038	-0.321	13.26**	-0.3851
Constant	-24.650			

$$Y = -24.650 - 0.152X_1 + 0.976X_2 + 10.100X_3 - 19.038X_4$$

*$0.05 \geq P > 0.01$ **$P < 0.01$

related to the state of the tree cover, with the standing crop of the 13-19 year old birch giving a beta of -1.931, and the standing crops of the 13-19 year old aspen and of the aspen over 30 years old giving betas of -1.000 and -0.949 respectively. This significant negative relationship would suggest that competition between the shrub cover and the established tree cover might lead to a decline in the abundance of the shrubs. The inclusion of mean depression of maximum temperature ($\beta = -0.752$) and mean soil temperatures at 30 and 60 cm ($\beta = 0.521$ and 0.910 respectively) in the regression equation would further suggest that the mechanism of competition between the tree cover and the shrubs operates through the unfavourable modification of air and soil temperatures. The concentration of potassium in the soil at 15 cm and the concentration of calcium in the soil at 15 cm were both positively associated with the shrub standing crop with betas of 0.436 and 0.293 respectively. Some variation in soil chemical condition could therefore account for variability in the abundance of the shrub cover. The positive relation with the grass crop ($\beta = 0.432$) is difficult to explain. However, the reciprocal inclusion of the standing crop of shrubs as a significant independent variable in the regression equation derived for the standing crop of grass would suggest that similarity in site conditions rather than a dependence of one on the other might provide a possible explanation.

b. Factors affecting the standing crop of the broadleaf herbs. The dependent variable in this analysis included the standing crop of all herbaceous species in the ground vegetation excluding the grasses and bracken. The concentration of available zinc at 15 cm gave the highest beta in this analysis ($\beta = 1.005$) which suggested that the plots closer to Trail would be best suited for the growth of these herbs. However, this might be a somewhat spurious relationship since it was previously shown (see page 90) that zinc could have become concentrated in the soil following the development of a vegetation cover. However, the inclusion of the additional soil variable, percent carbon at 15 cm, as a negative factor ($\beta = -0.313$) would substantiate the idea that the badly devastated plots closer to the smelter with comparatively high concentrations of available zinc might be more favourable for the development of a herb cover. However, this preference for open plot conditions appeared to be offset by the inclusion of soil temperature at 30 cm as a negative factor ($\beta = -0.645$), and by the positive relationship with mean increase in minimum air temperature ($\beta = 0.318$), both of which were affected by a fairly well-developed canopy. The standing crop of the 20-30 year old aspen was the only element of the overstory which was extracted and gave a beta of -0.485. This relationship was thought not to represent a competitive factor, but rather, was considered to indicate covariance with soil and air temperatures: the plots in which aspen stands were abundant were typically more open and therefore less effective in altering these temperature conditions. Thus, no clear explanation regarding the abundance of the broadleaf herbs was apparent.

c. Factors affecting the standing crop of the grasses. Two elements of the tree cover gave negative relationships with the standing crop of grass: the standing crops of the 13-19 year old birch, and of the 20-30 year old aspen resulted in betas of -1.131 and -0.797

respectively. However, the standing crop of the 13-19 year old aspen was positively related (β = 0.525) which suggested that the warmer conditions conducive to suckering were also favourable for the development of a grass cover. This was substantiated by the positive relationship exhibited between the grass crop and mean soil temperatures at 60 cm (β = 0.396). In addition, variation in the abundance of the grasses appeared to be brought about by the concentration of potassium in the soil at 5 cm (β = -0.398), with the grasses favouring soils with a lower potassium status. The inclusion of the standing crop of the shrubs as a predictor variable (β = 0.495) was regarded as indicative of the similarity of environmental requirements for the grass and shrubs.

d. Factors affecting the standing crop of bracken. The standing crop of bracken appeared to be most affected by soil temperatures with negative relationships given for soil temperatures at 60 cm (β = -0.726) and 30 cm (β = -0.321). This suggested that the bracken would develop best under a tree canopy. This was substantiated by the inclusion in the equation of the 8-12 year old birch (β = 0.270). Additional variation in the abundance of bracken could be accounted for by differences in soil moisture conditions at 30 cm (β = 0.338), growth being favoured by damper soils.

A negative relationship between the ground vegetation and various elements of the overstory was the most noticeable result in this set of regression analyses. Additional variables commonly included in the equations were air and soil temperatures. It was therefore thought that the overstory effected a modification of the microenvironment which was unfavourable to the ground vegetation. Further variation between plots was related to differences in soil moisture and soil chemical status.

6) Factors affecting the establishment of saplings of birch, trembling aspen, and the coniferous species

Reversion to a well-developed tree cover will be dependent upon the successful establishment of saplings whether they be from seed or from rootstocks. In these analyses the dependent variables were species abundance data for the trees under 1 m high, and the independent variables were factors considered important in affecting their development such as competition, and micro-environmental conditions. The saplings, being some of the youngest elements in the cover, would necessarily be subjected to competition from all plants at a plot, although some beneficial effects, such as an in situ source of seed, might arise from the presence of mature individuals of the species under study. Standing crop data for the ground vegetation, and density assessments for the trees subdivided according to species/age classes were included as independent variables in this regression. Being by definition relatively small, the saplings would be subjected to the micro-climatic condition existing beneath the canopy; hence micro-climatic factors were considered as important independent variables in this run. Soil conditions at the surface might be critical to the initial establishment of the saplings; hence soil chemical data at 5 cm and soil temperature and moisture conditions at 10 cm were used as predictor variables. The concentration of available lead and zinc in the soil at 5 cm, and present atmospheric sulphur dioxide levels were included as pollution variables. The results are given in Table 39.

TABLE 39

RESULTS OF THE MULTIPLE REGRESSION ANALYSES WITH DENSITY OF THE TREE SAPLINGS AS THE DEPENDENT VARIABLES

Y = Density of birch saplings

$R = 0.9832$ St. Err. = 0.859 $R^2 = 0.9666$ $F = 154.37^{**}$ ${}_cR^2 = 0.9627$

	b	β	F	r
X_1 = Density of birch over 30 years old	14.973	0.776	262.69**	0.8781**
X_2 = Density of 13-19 year old birch	0.079	0.305	28.30**	0.5350*
X_3 = Density of 8-12 year old birch	0.037	0.200	11.36**	0.6121**
Constant	0.222			

$Y = 0.222 + 14.973X_1 + 0.079X_2 + 0.037X_3$

Y = Density of trembling aspen saplings

$R = 0.9325$ St. Err. = 2.124 $R^2 = 0.8695$ $F = 24.99^{**}$ ${}_cR^2 = 0.8450$

	b	β	F	r
X_1 = Density of 5-7 year old aspen	0.301	0.614	18.06**	0.7848**
X_2 = Conc. of potassium in the soil at 5 cm	-1.547	-0.427	15.85**	-0.0299
X_3 = Conc. of available zinc in the soil at 5 cm	0.001	0.311	9.41**	0.3091
X_4 = Density of 8-12 year old aspen	0.108	0.368	7.43**	0.7572**
Constant	-1.552			

$Y = -1.552 + 0.301X_1 - 1.547X_2 + 0.001X_3 + 0.108X_4$

Y = Density of coniferous saplings

$R = 0.9698$ St. Err. = 1.881 $R^2 = 0.9404$ $F = 134.18^{**}$ ${}_cR^2 = 0.9371$

	b	β	F	r
X_1 = Density of 13-19 year old conifers	2.010	0.513	25.15**	0.9247**
X_2 = Density of 8-12 year old conifers	0.320	0.505	24.38**	0.9232**
Constant	0.400			

$Y = 0.400 + 2.010X_1 + 0.320X_2$

$^{*}0.05 \geq P > 0.01$ $^{**}P < 0.01$

a. Factors affecting the establishment of birch saplings. The three variables significant to the establishment of birch saplings were the density of the 20-30 year old birch ($\beta = 0.776$), the density of the 13-19 year old birch ($\beta = 0.305$), and the density of the 8-12 year old birch ($\beta = 0.200$). Although it was unlikely that the youngest age class would be capable of sprouting, its inclusion in the regression equation implied that present sapling establishment would be most likely to occur at plots in which a recent cover had developed. The absence of any environmental variables from the regression results indicated that the presence of parent trees rather than suitable habitat conditions was the principal factor restricting sapling development.

b. Factors affecting the establishment of trembling aspen saplings. Of the four variables extracted, two were related to the older aspen regrowth and two to the chemical status of the surface soil. The inclusion of the density of aspen in the age classes 5-7 years ($\beta = 0.614$) and 8-12 years ($\beta = 0.368$) again indicated the importance of older individuals at a plot: in this case reproduction was by suckering. High concentrations of potassium in the surface soil appeared to inhibit the establishment of aspen ($\beta = -0.427$), although regeneration was stimulated by the presence of zinc ($\beta = 0.311$).

c. Factors affecting the establishment of coniferous saplings. The significant variables for this analysis were the densities of coniferous trees in the age classes 13-19 years ($\beta = 0.513$) and 8-12 years ($\beta = 0.505$). This strongly supported the idea that the main factor preventing the re-establishment of the conifers was lack of seed rather than environmental conditions. Lodgepole pine is capable of producing seed at a very young age (Fowells, 1965), and the inclusion of the younger age classes in the regression equation could represent actual seed production from such individuals. However, as in the case of the deciduous species, the regression results might best be interpreted as representing continued establishment at plots in which recent regrowth had occurred.

These youngest individuals of the tree species, like their elders, were dependent upon older established individuals either for a source of seed, or for a base from which to sprout. From this it was inferred that much of the present regrowth had probably arisen from a residual flora. This was most easily accepted in the case of the coniferous species, for plots with abundant young conifers also supported individuals which became established during the period of pollution. Only at such plots, which presumably escaped the full impact of sulphur dioxide, had rapid reversion to the original cover been possible. For the birch and aspen, regrowth was initiated either from the chance input of seed, or more probably, from the development of buried viable rootstocks.

Successional Implications of the Regression Analysis

Three conclusions could be drawn from a synthesis of the results of the foregoing regression analyses. First, the development of the tree cover depended upon the early establishment and subsequent in situ production of viable propagules. Secondly, for most elements of the vegetation cover, present sulphur dioxide levels were sufficiently low, during the growing season at least, that gas fumigations could be disregarded as a restraint to regrowth. Thirdly, no single successional pathway could be postulated which would account for the pattern of revegetation of the entire study region: this reflected the spatial variation in environmental conditions.

The importance of a residual flora was well exemplified by the conifers, with the most widespread reproduction occurring at plots with a well-established cover. Although some variation in abundance of conifers might be due to the chemical status of the soil, the results of the regression analyses strongly supported the idea that seed shortage was the principal factor preventing their widespread re-establishment. This shortage resulted from the destruction of the conifers by past fume emissions and was augmented by the short seed dispersal range of these species.

Although the seed of birch and aspen is far more mobile than that of the conifers (see Table 40), development of the deciduous cover was similarly significantly related to the previously established individuals, with much of the younger growth having developed by sprouting or suckering from the older rootstocks. However, no clear mechanism of initial establishment was evident. To suppose that the deciduous cover remained during the period of pollution was contrary to the field data, since no old individuals were found, apart from a single 58 year old birch at the control plot. According to McBride (1937), the majority of the cover beyond the zone of fumigation was coniferous in character; hence the possibility of widespread input of seed from the adjacent undisturbed region was slight. The shortage of both seed and seedlings today would similarly tend to contradict any assumption

TABLE 40

SEED PRODUCTION, DISPERSAL, AND GERMINATION DATA FOR THE PRINCIPAL TREE SPECIES FOUND IN THE STUDY AREA*

Species	Minimum seed bearing age (years)	Optimum seed producing age (years)	Frequency of good seed crops (years)	Number of seeds/kg	Dispersal distance (metres)	Viability	Seedling survival
Birch	15	40-70	Almost every year	0.7M	Usually close to parent tree	Rapidly lose viability	Dependent on environmental conditions
Cedar	16	16+	2-3	188200	120	73%	44-97% loss
Douglas-fir	10	100-200	3-7	19100	100-200	Good	75% mortality
Larch	25	40-400	5-14	65000	120	5-42%	Up to 85% loss
Lodgepole pine	5	10-80	1-3	46400	60	Good	Good
Ponderosa pine	16	60-350	2	26000	50	Good	Good
Trembling aspen	20	50-70	4-5	1.1-1.4M	Several km	Rapidly lose viability	High mortality offset by suckering
White pine	10	40-70	3-4	12300	120	40%	65% mortality
White spruce	30	60+	2-6	109100	600	25%	High mortality

*after Fowells (1965), and U.S. Dep. Agr. Forest Serv. (1948)

that the broadleaf trees had originated predominantly from seed. The only remaining source of propagules would be buried viable rootstocks. Early logging operations and fire damage could have permitted the birch and aspen to become more widespread in the area prior to severe fume damage. Such a cover could be representative of stage 2 of Bell's (1965) secondary succession sequence (see page 17). Chance survival of some rootstocks from this 'pre-fume' deciduous cover could account for the present nature of the regrowth. Where present, these remnant rootstocks could have given rise to the even aged stands of birch and aspen. Further development of this cover will depend on continued propagation from these older bases, and from the younger individuals once they have reached sprouting or suckering ages. However, subsequent regrowth may be more widespread since environmental conditions, particularly with respect to atmospheric sulphur dioxide levels, should be more favourable today.

In the badly devastated plots, the initial colonisers had to contend primarily with the physical environment. As the vegetation cover developed, competition between individuals would have become more pronounced. Reproduction by vegetative methods in the birch and aspen might be advantageous in such situations; however, the stands at most of the sample plots were still fairly open. The main advantage of vegetative reproduction in these species might therefore be the greater chance of survival in the rather poor soil conditions. As competition increases a natural thinning of a stand may occur, associated with the decline in vigour and vitality of a species. Where several species are involved, this may subsequently lead to a change in stand composition, and hence to a change in the dominant species of an area. Such relationships were evident from the regression analyses for birch, aspen, and the coniferous species. Birch was incorporated as a positive factor in the equations derived for the younger conifers. Such a relationship indicated that autogenic modification by a birch canopy might be beneficial to the re-development of the conifers. However, the conifers were typically negatively associated with birch suggesting that plots in which widespread coniferous regrowth was found were unfavourable for the continued development of the birch. Similarly, birch was negatively associated with aspen, but this was reciprocated in the aspen analyses and would indicate that neither of the deciduous species had a competitive advantage; rather, environmental conditions were such that plots which favoured the growth of one were possibly unfavourable to the other.

Using a similar interpretation of the regression analyses the ground vegetation can be fitted into this scheme as follows. The negative relationship exhibited between the shrubs and both aspen and birch would suggest that plots with a well-developed deciduous tree cover tended to be unfavourable to the shrubs. Two interpretations can be given to this. Either the shrubs entered the area early in the recolonisation period and were subsequently ousted directly by the trees, or alternatively, shrub development was most pronounced under a coniferous canopy in which competition between the trees led to the decline of the deciduous species and thus indirectly favoured the shrubs. This latter explanation was extremely unlikely, since an abundant ground vegetation was not common under a coniferous canopy. The idea that the shrubs were typically the early colonisers of the area was supported by the inclusion of high soil temperatures as a factor favourable to shrub development.

The broadleaf herbs were negatively related to the aspen cover which suggested their preference for plots in which aspen was not well-developed. However, the negative relationship with soil temperature and the positive relationship with increase in minimum air temperature would indicate that some form of canopy was beneficial to the broadleaf herbs. A developing birch or coniferous cover might therefore provide the best conditions for the broadleaf herbs. Such a conclusion is necessarily a generalisation since the broadleaf herb category was comprised of several species, each of which could have had a different environmental preference.

Conditions unfavourable for grass appeared to be associated with plots in which medium aged birch was well-developed. The relationship with aspen was more complicated. Plots in which 20-30 year old aspen had become established were also unfavourable for the grass; yet for younger aspen a positive relationship was shown. The positive relationship with soil temperatures suggested that development of the grass, like suckering in aspen, was favoured by warmer conditions. It was therefore concluded that grass, now prominent in the plots supporting open stands of aspen, will gradually decline in abundance as the cover at these plots develops. For bracken however, the converse applied; development here being stimulated by conditions beneath a birch cover.

The Successional Status of the Vegetation in the Study Area

With the exception of the control site (plot 1), the remaining plots could be subdivided into four groups according to appearance and age class structures:

1) The northern zone of moderate disturbance,

2) The central zone of intense disturbance,

3) The southern zone of moderate disturbance, and

4) Plots in which a regenerating, remnant coniferous element was present.

1) <u>The northern zone of moderate disturbance</u>

This group included plots 3, 4, 6, 7, 8, and 9 and represented a zone which was subjected to fairly extensive fume damage such that no regenerating remnants of the former coniferous cover remained.[1] Perusal of the age class distributions and species lists suggested that none of these plots had followed identical pathways in their recovery. At plot 3, birch and aspen were well-developed, although both seemed to be declining in importance, with present sapling counts totalling 3(600/ha) and 2(400/ha) respectively. However, a few conifers had become established, and as these reach seed producing age a pronounced increase in abundance is envisaged. Plot 3 was considered to be in a fairly advanced stage of recovery. The ground vegetation was both varied and abundant with bracken and shrubs giving large standing crops. The species composition of the shrubs was not noticeably different from that in the plots closer to Trail; however, buckbrush was much less prominent, and species such as mahonia, which were common at the control plot, were

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[1] An old lodgepole pine was found at plot 6. However, the absence of any younger individuals indicated that this species had not been regenerating.

more abundant. Conversely, the broadleaf herbs were more varied than in the badly devastated plots close to Trail, although some species such as sarsaparilla (Aralia nudicaulis L.) and dogbane were found throughout the area. Compared with the more open plots, the standing crop of grass was fairly low.

A similar mixed deciduous cover was found at plots 4 and 9 (see Figs. 30 and 34) together with high standing crops for all elements of the ground vegetation with the exception of grasses at plot 4. Present reproduction at these plots totalled 5 birch saplings (1000/ha) and 15 aspen saplings (3000/ha) at plot 4, with 4 birch saplings (800/ha) and 8 aspen saplings (1600/ha) at plot 9. Although conifers were not present in the older age classes, 2 saplings (400/ha) were found at plot 4: they were entirely absent at plot 9. This would indicate that these plots were less advanced than plot 3.

At plot 6 (see Fig. 31) the canopy was composed entirely of birch with grasses common in the ground vegetation. Although absent from the older age classes, a solitary aspen sapling (200/ha) was found. Some birch reproduction was noted at this plot with 7 saplings (1400/ha) recorded. The distinctive cover of this plot indicated either a shortage of aspen propagules, or failure to establish prior to the development of the dense canopy of birch. Recovery appeared to be halted by a shortage of coniferous seed.

The noticeable increase in aspen over birch in the last 8 years at plot 7 appeared to have been offset by recent reproductive activity with 19 birch saplings (3800/ha) and 16 aspen saplings (3200/ha) recorded at the plot. The presence of a few young conifers suggested that this oscillating trend will become subordinate in the future as increasing in situ production of seed gives rise to a coniferous canopy.

Two general pathways of vegetation development were evident in this northern zone of moderate disturbance. The principal one commenced with the early establishment of birch and aspen. Associated with this increasing canopy there was a corresponding change in the ground vegetation, with many of the early species being excluded through autogenic modification of the environment, these being replaced by shade tolerant species. Such a process could be traced from the moderately developed cover at plot 8 (see Fig. 32) through plots 9, 7, and 4 with plot 3 representing a fairly advanced stage in which coniferous regrowth was under way. The alternative route was exemplified by plot 6 in which aspen had failed to establish. Subsequent development in the ground vegetation was however similar in both pathways.

2) The central zone of intense disturbance

This included plots 10, 11, 12, 13, 14, and 15 in which widespread vegetation and environmental disturbance had occurred, and in which recovery had been limited. At plots 10 and 12 (see Figs. 35 and 38) birch alone started early regrowth following pollution control. No saplings were found at plot 10 although 3 birch saplings (600/ha) were recorded at plot 12. Associated with this rudimentary cover was one Douglas-fir and a seedling of the same species (200/ha) at plot 12. Although the ground vegetation was fairly varied at plot 10, the dominant species was buckbrush. However, at plot 12, all elements of the ground vegetation, except bracken, were sparse.

Both aspen and birch developed early at plots 11 and 13 (see Figs. 37 and 42). However, present reproduction is minimal with 1 birch sapling (200/ha) recorded at plot 11 and 1 sapling (200/ha) each of birch and aspen at plot 13. Beneath this meagre cover a sparse ground vegetation had become established. Despite the early establishment of aspen at plot 15 (see Fig. 39), recent development had been minimal, and no saplings were recorded. At plot 14 (see Fig. 36) no trees of any age were found.

Four distinct recovery patterns were found in this zone, all of which were developing slowly. The plots in which both aspen and birch were present were regarded as an early stage of the main recovery sequence postulated for zone 1 above. Plots in which birch or aspen alone were found were considered as modifications of this pattern, induced by a shortage of viable propagules. Plot 14, in which no trees were found, provided a useful record of the early ground vegetation species, and was considered as the main starting point for revegetation in the severely disturbed areas. The shrub-herb community will develop in association with the birch-aspen cover with subsequent modification of the species composition of the ground vegetation occurring as the canopy develops. The rate of recovery has therefore been dependent upon the state of the environment and the nature of the residual flora.

3) The southern zone of moderate disturbance

Apart from plot 16 (see Fig. 43) in which relatively high soil moisture conditions were recorded, plots 17, 18, and 19 (see Figs. 40, 41, and 44) provided a comparatively dry environment for the developing cover. At plots 16 and 19 the dominant tree species was birch with minimal aspen development. At neither plot was young regrowth prolific, with only 3 birch saplings (600/ha) recorded at plot 16 and 4 (800/ha) at plot 19. The probability that disturbance was less intense at plot 19 was indicated by the more abundant regrowth in the older age classes: the presence of several young conifers and 3 coniferous saplings (600/ha) would substantiate this. At plots 17 and 18, aspen was the only tree species found, with 11 saplings (2200/ha) recorded at plot 17 and 8 (1600/ha) at plot 18. The most noticeable difference in the composition of the ground vegetation between plots in this zone was the poor representation of shrubs beneath the birch canopy: buckbrush was very abundant at plots 17 and 18 but was entirely absent at plots 16 and 19, presumably reflecting its intolerance of micro-environmental conditions beneath the birch canopy. Two features which were difficult to explain were the absence of bracken from plot 18 and the very low standing crop of broadleaf herbs at plot 19. The former was possibly associated with the very dense growth of buckbrush; no explanation can be given for the latter, although evidence of grazing was noted.

The two distinctly different recovery pathways which were evident in this zone were the fairly direct birch-conifer sequence, and the slower, more open buckbrush-aspen sequence. The latter requires the thinning out of the buckbrush by competition with the aspen, and under these more open conditions the germination of transported coniferous seed may occur.

4) Plots in which a regenerating, remnant coniferous element was present

Three plots, 2, 5, and 20, were included in this group. At all of these, older conifers were found which had survived the fumigations and which acted as an in situ source of seed. At plots 2 and 5 (see Fig. 33) birch had become established early beneath the remnant conifers and had become fairly abundant some 10-15 years thereafter. Aspen however, entered these plots only later and never became very prominent. Both of these broadleaf species were declining in importance with respective sapling establishment for conifers, birch, and aspen being 19 (3800/ha), 4(800/ha), and 3(600/ha) at plot 2, and 5(100/ha), 3(600/ha), and 1(200/ha) at plot 5. At plot 20 (see Fig. 45) birch had been excluded although a few aspen had entered early in the post fume period. This species was never abundant, and recent reproduction was absent. However, 6 conifer saplings (1200/ha) were found at this plot.

The shrub cover at all of the plots in this zone was abundant and consisted mainly of Saskatoon berry and mahonia. Conversely, the grass crop was comparatively low. The standing crop of bracken at plot 2 was considerably greater than at the other plots and competition from this species probably accounted for the relatively low abundance of herbs and generally poor floristic composition. Although some variation occurred with respect to the ground vegetation, the remnant conifers provided the necessary seed for the rapid recovery of these plots.

In addition to the interrelationships exhibited by the principal tree species of the area, three points must be considered in deriving the pathways of vegetation recovery. First, it was essential that the degree of previous vegetation destruction be taken into account. Secondly, it was important to distinguish elements of the ground cover which favoured open conditions, for example buckbrush, from those which grew best under a closed canopy, for example mahonia. Thirdly, variations in the macro-environment must be incorporated. The final model of vegetation recovery is shown in Fig. 57.

The rate of recovery will be most rapid in plots which suffered little vegetation destruction. A longer period of time will be required at the more extensively damaged plots which reflects not only the growth rate of the plant populations but also the need for autogenic modification of the environment. The rate of recovery will ultimately depend on the amount of coniferous seed that becomes available to the area. Seed input from outside regions will be small, and the initial rate of re-establishment necessarily slow. However, an accelerated rate of recovery should be noted once a coniferous population becomes established in the fume damaged area. As the valley sides become recolonised, occasional seed input from the higher zones could eventually lead to the development of a more mixed coniferous stand in the valley floor. Regrowth in the deciduous cover appeared to have been controlled by the distribution of viable rootstocks present in the area at the end of the pollution period. Vegetative reproduction from these gave rise to predominantly even aged stands. From the age class distributions, it would appear that a decline in their vegetative reproductive vigour had occurred, and further development of the birch and aspen may be retarded until some of the younger trees presently found in the area have themselves reached sprouting or suckering age.

Most of the plots to the south of Trail should eventually revert to an open ponderosa pine "parkland" interspersed with some areas of trembling aspen, lodgepole pine, and the occasional Douglas-fir. Such

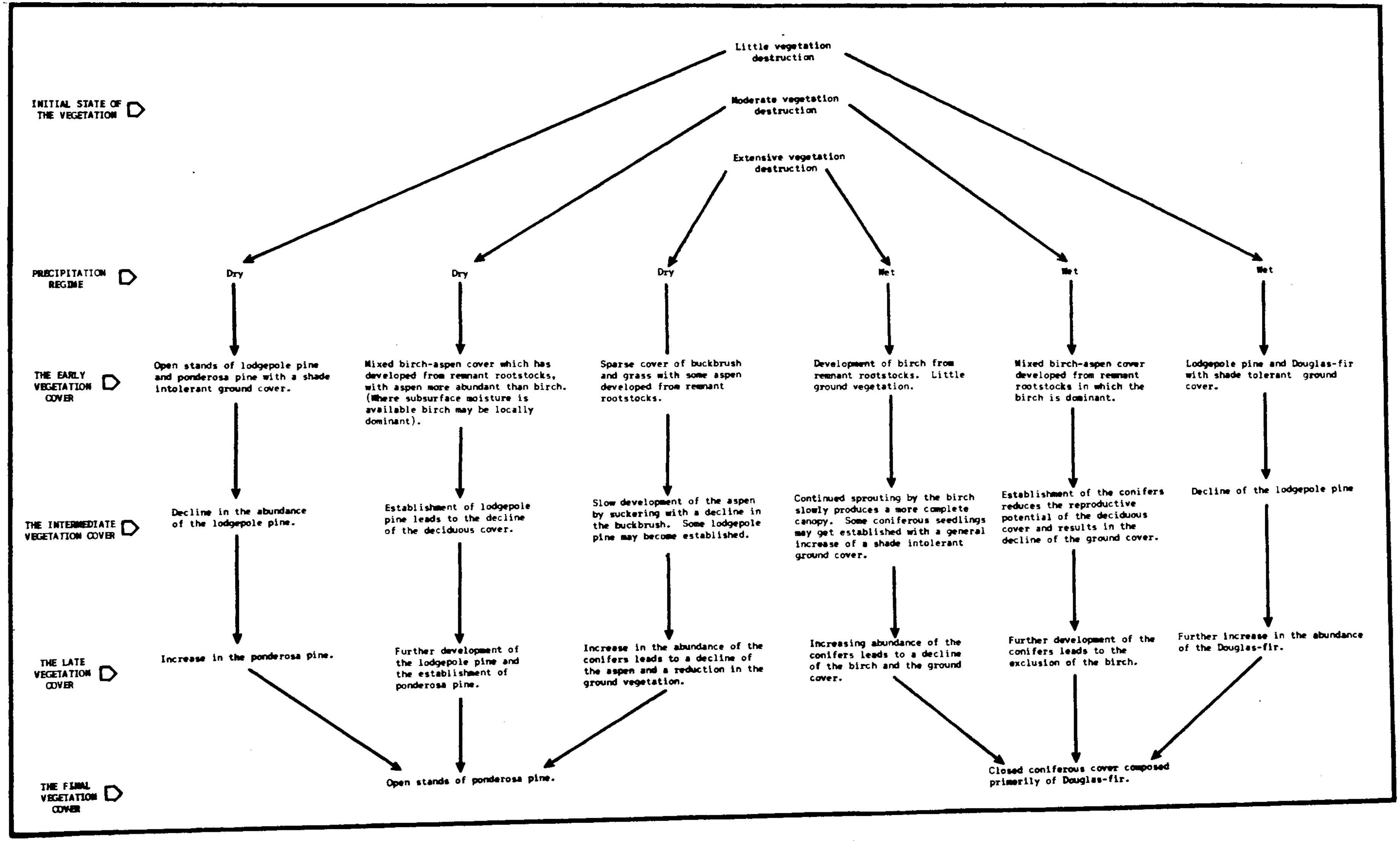

Fig. 57. The recovery pathways of the study area

a cover may be susceptible to, and hence maintained by fires. To the north of Trail a canopy of Douglas-fir should develop, resulting in a cover similar to that found at the control site.

The secondary succession sequence outlined by Bell (1965) (see page 17) corresponds most closely with the recovery pathways proposed for the extensively damaged areas (see Fig. 57). However, although it was possible to detect certain groupings which roughly parallel the stages put forward by Bell (1965), successional relationships appeared less clear cut than he envisaged. This possibly reflects the rather unusual manner in which the previous cover was removed, with degree of former destruction and environmental variation in the area being important factors underlying the recovery of the vegetation in the Trail area.

Chapter 7

CONCLUDING REMARKS

Past investigations in the Trail region have shown that toxic levels of sulphur dioxide in the atmosphere were unquestionably the cause of the destruction of the surrounding vegetation. As a result of these earlier findings successful pollution control measures were implemented. The purpose of this study has been to ascertain the extent and manner in which vegetation recovery has proceeded during the 30 year period of improved air quality.

Data collected in the field were used to test four basic hypotheses formulated to explain the present appearance of the secondary cover in the area. The first of these stated that the present vegetation of the area represents a developmental sequence related to the former pollution gradient. This implied that vegetation recovery was related to the period of time elapsed since toxic fumigations last affected the area, and was based on the assumption that a progressive reduction in sulphur dioxide levels occurred favouring the earlier recolonisation of the more distant plots. However, no significant correlation could be demonstrated between distance from Trail and the age of the tree cover at the sample plots. This suggested that re-establishment of the tree cover was contemporaneous at all plots.

[illegible]

The second hypothesis stated that variation in the present cover at Trail reflects differing degrees of destruction of the former vegetation cover. If this were the case then one would expect to find some variation in species age class distributions between plots. This was most noticeable for the conifers, with individuals which became established prior to the period of pollution control being important elements of the present cover, particularly as an in situ source of seed. The younger individuals were typically found at plots in association with a mature remnant coniferous cover. The importance of early establishment was further demonstrated by the deciduous species, with the abundance of the older individuals commonly being selected as significant independent variables in the regression equations for the density of birch and aspen of various age classes. This strong relationship between the abundance of the early established individuals and the abundance of the younger members of these species in the present cover was thought to reflect the importance of the intensity of former destruction on the differential survival of buried rootstocks.

The third hypothesis was concerned with the effects of outbreaks of sulphur dioxide since 1941. Inspection of the age class distributions showed that there were periods during which regeneration was reduced. This suggested that some suppression of regrowth subsequent to the initial establishment of the tree species might have occurred. However, present day establishment and the development of the ground vegetation appeared to be unaffected by sulphur dioxide levels. Since data relating to past gas levels at the sample plots were unavailable, there was no direct way of testing this hypothesis. However, it is very unlikely that pollution intensities and durations sufficient to curtail the reproductive vigour of the plants would have been allowed to persist. It was therefore concluded that the reduction in the number of individuals in certain age classes of the deciduous species reflected a decline in the sprouting and suckering potential of the original remnant rootstocks. As younger individuals mature, further development of the deciduous cover may occur following renewed vegetative reproduction possibly supplemented by an in situ source of seed. Variation in the numbers of conifers in the different age classes occurred even at the control site which was located outside the zone affected by sulphur dioxide from the smelter. This was thought to reflect the inherent variation in the abundance of seed produced in different years, augmented by high seedling mortality rates.

The final hypothesis put forward considered the effects of macro-environmental variation on the recolonisation of the area. Although there was marked consistency within soil texture and the physical properties of the soil, noticeable variation was demonstrated for soil moisture, the level of toxic elements in the soil, and the chemical properties of the parent materials. Similarly, differences in climate, particularly with regards to precipitation, were significant. The importance of spatial variation in the macro-environment of the study area as a factor affecting the course of vegetation recovery was evident from the results of the multiple regression analyses for the tree species and the ground vegetation.

The major drawbacks to a uniform process of re-establishment were the inherent heterogeneity of the environmental conditions and the variability in biotic composition which reflected the history of devegetation within the area. The general sequence put forward to explain the recovery of the vegetation incorporated the degree of former destruction and variation in the macro-environment, specifically precipitation. Consequently, there was little evidence of any successional relationships between sample plots, and no seral stages could be readily identified. It was concluded therefore that variation in initial physical and biotic conditions, and subsequent chance migration of propagules, had led to the individualistic recovery of each sample plot.

The re-establishment of the vegetation in the Trail area appeared to be restricted by a shortage of viable propagules; hence successful migration into the fume devastated area was the major restraint to recovery. Salisbury (1942) shows that many of the plants typical of the early stages of a succession possess abundant, light, wind borne seeds. This adaptation is possessed by both the birch and aspen (see Table 40). However, the tree species characteristic of later stages in a succession tend to produce less numerous seeds of a larger size. These do not disperse well, but rather, provide a young seedling with a food reserve which may enable it to survive in a competitive situation: the conifers in the area would fit into this category (see Table 40).

Seddon (1971) suggests that three conditions must be met in order that successful plant migration might occur:

> First the existing mature plants must produce viable propagules. . . . Secondly, dispersal must be effected into territory outside that occupied by the parent population. Thirdly, the propagule must successfully establish itself. . . . (Seddon, 1971, pp. 135-136)

The rate of migration is determined by the distance over which seed can be dispersed and by the length of time required for a seedling to reach the seed producing age (Good, 1953). This information is shown in Table 40 for the principal tree species of the Trail area. Since the seedling will almost invariably be establishing in an area in which other species are found, the rate of migration will be further affected by the competitive ability of the establishing plant. Similarly, the suitability of the micro-habitat has been shown by Harper et al. (1961) to be a critical factor affecting the germination of seeds. Modification of the micro-environment appeared to be most important for the re-establishment of the ground vegetation in the Trail area. It is therefore thought that widespread artificial seeding would probably result in the rapid acceleration of the recovery process. The most suitable species are considered to be lodgepole pine and Douglas-fir in the zone to the north of Trail: to the south, lodgepole pine and ponderosa pine seem best adapted.

Artificial regeneration has been carried out by Cominco since 1948 (Hodson, 1971). From 1948 to 1963 deciduous species, including black locust (Robinia pseudo-acacia L.) and silver maple (Acer saccharinum L.), were successfully established in the vicinity of the smelter. Since 1964, coniferous species, including Douglas-fir and ponderosa pine, have been extensively planted around the townsite. The success of the coniferous planting projects has been variable. This is thought to reflect summer temperature conditions (Hodson, 1971) with high soil temperatures possibly being injurious to the roots. In addition, the rapid evapotranspiration needs may not be met because of the low moisture retention properties of the soil. Research by Clark (1969) and Illingworth and Clark (1966) elsewhere in the Interior of British Columbia has shown that seedling survival depends upon adequate site preparation of the mineral seedbed by furrowing etc. principally to improve soil moisture conditions, and on treatment to eliminate competition for moisture from other vegetation. This substantiates the findings of the current research in that site modification by early successional species did not appear to be a prerequisite for the re-establishment of the conifers. Clark (1969) stresses that if restocking is to be carried out by seeding, the seed must be protected against loss to rodents and that good quality seed should be used. Illingworth and Clark (1966) suggest that survival will probably be highest if 2+1 nursery stock is used.

Further research in the area should be in the following major fields. First, a general survey of the vegetation surrounding the area of devastation should be conducted. This should provide information on the potential seed source available for the natural restocking of the valley floor. Secondly, further studies should be carried out on the actual amount, and species composition of seed input into the area. Thirdly, experimental work on seedling establishment and survival should be conducted throughout the study area in plots protected from rodent predation within the area of fume damage. In addition, the effects of differential grazing pressures throughout the study area should be investigated. Some loss of regrowth is thought to have occurred in the area to the south of Trail as a result of deer browsing. As well as an intensive survey of seedlings, further work is required on the problem of the initial establishment of the deciduous species. Extensive excavations around the rootstocks might provide additional information on the age and extent of the relic birch and aspen cover.

Although it can unquestionably be shown that industry was the cause of the widespread demise of the vegetation in the Trail area, the company's awareness of the problem, no matter how it was invoked, and its subsequent modification of the smelting techniques, has been instrumental in the slow recovery of the plant life. The various individualistic pathways shown to underlie this revegetation process indicate that one deleterious factor in the environment, in this case sulphur dioxide, can have widespread ramifications, each of which must be amended during the lengthy recolonisation period. Although much of the area immediately surrounding the smelter is still in a precarious state, vegetation is beginning to make its reappearance. It is to be hoped that no lack of vigilance on the part of Cominco will result in the loss of these tenuous precursors.

Shortsightedness on the part of industry can produce unnecessary disfigurement of the landscape. Although recovery is far from complete, the beneficial effects of industrial reaction to an environmental threat can be viewed in the Trail area. It is urged that this lesson be applied elsewhere before devastation has reached the point at which a court injunction is again required to induce some rectification of the problem. The eradication of such destruction can only be brought about by the re-establishment of the vegetation, but since natural recovery is a slow process, unsightly scars which last for interminable periods of time may be the unfortunate legacy of industrialisation.

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APPENDIX A: PLANT DATA

A1: Species present in the study area

A2: The relative susceptibility of the native coniferous and deciduous tree species to sulphur dioxide (after Katz et al., 1939; and Scheffer and Hedgecock, 1955)

A3: The abundance of shrub and herb species in the 1 x 1 m quadrats

A4: Density of tree species in the 10 x 10 m quadrats

A5: Density of grass species in the 1 x 1 m quadrats

A6: Density of moss species in the 1 x 1 m quadrats

A7: Density of tree saplings in the 1 x 1 m quadrats

A8: Density and basal area assessments for birch, trembling aspen, and the coniferous species

- i) Density (individuals/ha)
- ii) Basal area (m^2/ha)

A9: Standing crop data for the ground cover, birch, aspen, and the conifers

A1: SPECIES PRESENT IN THE STUDY AREA*

Shrubs and herbs

Achillea millefolium L.
Amelanchier alnifolia Nutt.
Apocynum androsaemifolium L.
Aralia nudicaulis L.
Arctostaphylos uva-ursi (L.) Spreng.
Asparagus officinalis L.

Ceanothus sanguineus Pursh
Chimaphila umbellata (L.) Bart.
Cirsium vulgare (Savi) Airy-Shaw
Clintonia uniflora (Schult.) Kunth
Corylus cornuta Marsh.

Disporum trachycarpum (Wats.) Benth. & Hook.

Epilobium angustifolium L.

Fragaria virginiana Duchesne

Galium boreale L.

Hieracium albiflorum Hook.
Hieracium canadense Michx.

Lathyrus ochroleucus Hook.
Lilium columbianum Hanson
Linnaea borealis L.
Lonicera ciliosa (Pursh) DC.
Lysimachia ciliata L.

Mahonia aquifolium Nutt.

Pachistima myrsinites (Pursh) Raf.
Philadelphus lewisii Pursh
Pteridium aquilinum (L.) Kuhn

Rhus radicans L.
Rosa gymnocarpa Nutt.
Rubus parviflorus Nutt.
Rumex acetosella L.

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*Classification of vascular plants according to Hitchcock et al. (1969); classification of mosses according to Lawton (1971)

Salix scouleriana Barratt
Shepherdia canadensis (L.) Nutt.
Silene menziesii Hook.
Smilacina stellata (L.) Desf.
Solidago canadensis L.
Spirea betulifolia Pall.
Symphoricarpus sp. Duhamel.

Trifolium procumbens L.

Vaccinium caespitosum Michx.
Vaccinium membranaceum Dougl. ex Hook.
Vicia villosa Roth
Viola sp. L.

Unidentifiable - one species

Trees

Acer glabrum Torr.
Alnus tenuifolia Nutt.

Betula papyrifera Marsh.

Crategus douglasii Lindl.

Larix occidentalis Nutt.

Pinus contorta Dougl. ex Lourd.
Pinus monticola Dougl. ex D. Don
Pinus ponderosa Dougl. ex Laws.
Populus tremuloides Michx.
Populus trichocarpa Torr. & Gray ex Hook.
Prunus virginiana L.
Pseudotsuga menziesii (Mirb.) Franco

Robinia pseudo-acacia L.

Thuja plicata Donn

Grasses

Agropyron caninum (L.) Beauv.
Agrostis alba L.
Agrostis scabra Willd.

Calamagrostis rubescens Buckl.

Danthonia spicata (L.) Beauv.

Festuca occidentalis Hook.

Oryzopsis asperifolia Michx.

Panicum scribnerianum Nash
Phleum pratense L.
Poa pratensis L.

Stipa occidentalis Thurb. ex Wats.

Trisetum spicatum (L.) Richter

Unidentifiable - two specimens

Mosses

Pohlia nutans (Hedw.) Lindb.
Polytrichum juniperinum Hedw.

A2: THE RELATIVE SUSCEPTIBILITY OF THE NATIVE CONIFEROUS AND DECIDUOUS TREE SPECIES TO SULPHUR DIOXIDE (AFTER KATZ ET AL., 1939, AND SCHEFFER AND HEDGECOCK, 1955)*

<u>Coniferous species</u>:

	Katz et al.	Scheffer and Hedgecock
most susceptible	Larch	Cedar
	Douglas-fir	Douglas-fir
	Ponderosa pine	White pine
	White pine	Ponderosa pine
	Lodgepole pine	Lodgepole pine
least susceptible	Cedar	Larch

<u>Deciduous species</u>:

	Katz et al.	Scheffer and Hedgecock
most susceptible	Birch	Alder
	Aspen	Birch
	Maple	Maple
	Willow	Cherry
	Black cottonwood	Willow
	Black locust	Black cottonwood
	Alder	Hawthorn
least susceptible	Cherry	Aspen

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*Scheffer and Hedgecock (1955, p. 24) suggest that the discrepancies result from the use of different criteria of susceptibility and to the fact that injury differed considerably with respect to location, year, and injury zone.

A3: THE ABUNDANCE OF SHRUB AND HERB SPECIES IN THE 1 x 1 M QUADRATS*

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 1						
Amelanchier alnifolia	16	-	2	19	21	51
Apocynum androsaemifolium	1	-	1	-	1	3
Aralia nudicaulis	4	-	4	4	-	12
Arctostaphylos uva-ursi	-	-	15%	-	35%	50%
Chimaphila umbellata	41	43	18	10	33	145
Clintonia uniflora	27	-	-	1	1	29
Corylus cornuta	-	-	1	-	1	2
Fragaria virginiana	10	-	11	-	-	21
Hieracium albiflorum	55	23	-	2	8	88
Lathyrus ochroleucus	7	14	13	3	11	48
Lilium columbianum	-	2	-	-	-	2
Linnaea borealis	-	35%	15%	5%	10%	65%
Lonicera utahensis	-	-	2	-	-	2
Lysimachia ciliata	-	-	3	7	2	12
Mahonia aquifolium	18	37	23	28	21	127
Pachistima myrsinites	-	-	-	26	-	26
Pteridium aquilinum	-	2	21	3	-	26
Rosa gymnocarpa	13	16	10	5	9	53
Smilacina stellata	1	-	1	3	-	5
Vaccinium membranaceum	16	8	7	-	-	31
Plot 2						
Amelanchier alnifolia	-	8	-	1	-	9
Apocynum androsaemifolium	9	4	12	6	4	35
Clintonia uniflora	-	1	-	-	78	79
Corylus cornuta	2	-	-	-	-	2
Mahonia aquifolium	-	-	1	4	-	5
Pachistima myrsinites	12	7	3	-	-	22
Pteridium aquilinum	19	28	45	32	31	155
Silene menziesii	-	9	53	97	3	164

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*Column entries represent numbers of individuals present. Where percentages are shown, species were assessed on a cover basis with each entry out of a possible 5 x 100% and the total out of a possible 2,500%.

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 3						
Amelanchier alnifolia	-	8	-	-	2	10
Apocynum androsaemifolium	26	4	16	32	21	99
Aralia nudicaulis	23	38	-	5	2	68
Ceanothus sanguineus	-	-	-	4	1	5
Clintonia uniflora	4	17	23	5	27	76
Corylus cornuta	1	3	-	1	-	5
Disporum trachycarpum	-	3	-	-	-	3
Mahonia aquifolium	14	7	11	3	-	35
Pachistima myrsinites	33	20	5	14	4	76
Pteridium aquilinum	18	19	15	13	41	106
Rubus parviflorus	-	10	1	2	4	17
Silene menziesii		118	13	-	30	161
Smilacina stellata	-	-	1	-	2	3
Spirea betulifolia	-	-	87	65	-	152
Vaccinium caespitosum	-	11	-	-	8	19
Plot 4						
Amelanchier alnifolia	2	-	-	4	-	6
Apocynum androsaemifolium	38	36	40	23	51	188
Aralia nudicaulis	-	-	12	7	-	19
Ceanothus sanguineus	2	-	-	-	-	2
Chimaphila umbellata	-	-	62	-	-	62
Epilobium angustifolium	1	-	-	-	-	1
Mahonia aquifolium	-	1	2	3	3	9
Pachistima myrsinites	25	31	7	17	20	100
Pteridium aquilinum	19	17	27	16	16	95
Rosa gymnocarpa	-	-	1	1	-	2
Salix scouleriana	1	-	-	-	-	1
Silene menziesii	10	344	103	-	235	692
Plot 5						
Amelanchier alnifolia	3	7	3	7	8	28
Clintonia uniflora	38	5	5	12	26	86
Galium boreale	2	-	29	-	30	61
Hieracium canadense	-	16	12	-	31	59
Lathyrus ochroleucus	-	20	2	7	23	52
Lilium columbianum	35	16	34	27	31	143
Lonicera ciliosa	-	1	0	0	0	1
Lonicera utahensis	27	-	31	10	16	84
Lysimachia ciliata	-	28	8	-	3	39
Mahonia aquifolium	13	8	-	6	3	30
Pteridium aquilinum	5	2	-	11	-	18
Rhus radicans	119	163	146	118	64	610
Rosa gymnocarpa	2	-	1	1	4	8
Salix scouleriana	-	1	-	-	-	1
Silene menziesii	-	-	1	53	1	55
Smilacina ciliata	72	54	17	24	51	218
Solidago canadensis	-	10	13	-	18	41
Symphoricarpus sp.	-	14	-	-	-	14
Vicia villosa	41	9	8	-	7	65
Unidentifiable	-	1	-	-	-	1

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 6						
Amelanchier alnifolia	-	-	33	-	-	33
Apocynum androsaemifolium	18	18	11	8	21	74
Chimaphila umbellata	5	14	-	-	-	19
Clintonia uniflora	218	149	132	73	143	715
Corylus cornuta	-	1	-	-	-	1
Disporum trachycarpum	-	5	-	-	-	5
Hieracium canadense	-	2	-	-	-	2
Lonicera ciliosa	-	-	-	2	-	2
Mahonia aquifolium	5	-	1	-	-	6
Pachistima myrsinites	4	1	-	11	-	16
Pteridium aquilinum	8	9	27	20	26	90
Salix scouleriana	-	4	-	-	-	4
Silene menziesii	218	381	47	240	279	1165
Spirea betulifolia	7	2	-	-	-	9
Plot 7						
Apocynum androsaemifolium	7	-	19	4	2	32
Clintonia uniflora	8	-	162	-	-	170
Linnaea borealis	40	-	-	-	-	40
Mahonia aquifolium	3	-	1	-	-	4
Pteridium aquilinum	17	-	4	32	33	86
Silene menziesii	2	-	7	174	-	183
Plot 8						
Aralia nudicaulis	1	-	-	-	-	1
Apocynum androsaemifolium	9	25	6	13	15	68
Clintonia uniflora	45	79	-	-	-	124
Mahonia aquifolium	-	2	-	-	5	7
Pachistima myrsinites	-	5	69	50	8	132
Pteridium aquilinum	66	73	58	17	4	218
Shepherdia canadensis	4	-	-	-	-	4
Silene menziesii	55	-	-	81	18	154
Plot 9						
Amelanchier alnifolia	-	-	1	6	-	7
Apocynum androsaemifolium	37	28	27	29	36	157
Aralia nudicaulis	6	3	8	1	-	18
Asparagus officinalis	-	-	-	1	-	1
Clintonia uniflora	23	4	-	22	-	49
Disporum trachycarpum	-	-	1	-	-	1
Epilobium angustifolium	-	-	-	1	2	3
Lilium columbianum	1	-	-	1	-	2
Mahonia aquifolium	-	-	5	6	-	11
Pachistima myrsinites	49	-	3	41	11	104
Pteridium aquilinum	15	12	7	6	6	46
Salix scouleriana	-	-	-	4	4	8
Silene menziesii	30	-	75	116	6	227
Smilacina stellata	-	-	1	-	-	1

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 10						
Amelanchier alnifolia	-	4	-	-	-	4
Apocynum androsaemifolium	1	18	16	11	31	77
Arctostaphylos uva-ursi	20%	90%	-	-	70%	180%
Ceanothus sanguineus	4	2	3	-	1	10
Corylus cornuta	-	2	1	2	-	5
Lilium columbianum	-	1	-	-	-	1
Mahonia aquifolium	-	10	-	4	-	14
Pachistima myrsinites	-	6	-	7	16	29
Pteridium aquilinum	32	-	24	17	6	79
Silene menziesii	4	72	-	53	-	129
Symphoricarpus sp.	-	-	11	17	4	32
Plot 11						
Apocynum androsaemifolium	-	1	-	-	-	1
Plot 12						
Apocynum androsaemifolium	-	4	-	-	-	4
Aralia nudicaulis	7	11	1	19	8	46
Pachistima myrsinites	1	-	-	-	4	5
Pteridium aquilinum	-	-	58	-	-	58
Silene menziesii	-	37	-	-	-	37
Plot 13						
Amelanchier alnifolia	-	6	-	-	-	6
Apocynum androsaemifolium	25	2	9	-	-	36
Aralia nudicaulis	-	-	-	20	5	25
Corylus cornuta	1	-	1	-	-	2
Pachistima myrsinites	5	83	28	-	-	116
Silene menziesii	-	5	-	-	19	24
Spirea betulifolia	-	-	-	18	-	18
Symphoricarpus sp.	1	-	1	-	4	6
Plot 14						
Apocynum androsaemifolium	4	23	6	15	5	53
Corylus cornuta	-	-	-	1	1	2
Pachistima myrsinites	-	1	12	15	4	32
Silene menziesii	13	-	8	-	96	117

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 15						
Amelanchier alnifolia	-	-	-	2	-	2
Apocynum androsaemifolium	2	16	4	16	7	45
Ceanothus sanguineus	-	-	6	-	-	6
Pachistima myrsinites	-	-	1	-	87	88
Pteridium aquilinum	7	54	40	15	19	135
Silene menziesii	-	-	2	9	-	11
Plot 16						
Apocynum androsaemifolium	14	12	25	14	13	78
Clintonia uniflora	-	-	-	1	2	3
Pteridium aquilinum	19	33	25	28	27	132
Plot 17						
Amelanchier alnifolia	-	50	3	2	7	62
Apocynum androsaemifolium	32	16	14	2	14	78
Arctostaphylos uva-ursi	5%	-	5%	-	-	10%
Ceanothus sanguineus	-	10	6	-	6	22
Corylus cornuta	1	-	3	-	-	4
Mahonia aquifolium	-	3	68	24	55	150
Pachistima myrsinites	10	-	12	37	17	76
Pteridium aquilinum	1	-	31	2	-	34
Rosa gymnocarpa	1	-	1	-	-	2
Rumex acetosella	81	46	-	97	-	224
Silene menziesii	4	15	18	22	118	177
Spirea betulifolia	1	2	-	-	-	3
Plot 18						
Amelanchier alnifolia	3	15	-	5	11	34
Apocynum androsaemifolium	54	12	11	22	8	107
Arctostaphylos uva-ursi	-	-	5%	-	-	5%
Ceanothus sanguineus	2	23	-	14	14	53
Corylus cornuta	1	2	1	1	-	5
Epilobium angustifolium	1	-	-	-	-	1
Lilium columbianum	5	-	1	-	-	6
Mahonia aquifolium	8	4	-	23	7	42
Pachistima myrsinties	1	-	-	7	-	8
Rosa gymnocarpa	-	-	-	1	-	1
Rumex acetosella	16	15	42	26	58	157
Silene menziesii	61	71	-	58	13	203
Smilacina stellata	1	1	1	-	-	3

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 19						
Achillea millefolium	2	-	-	-	-	2
Amelanchier alnifolia	-	-	6	1	-	7
Apocynum androsaemifolium	-	1	-	3	4	8
Chimaphila umbellata	-	-	6	2	6	14
Cirsium vulgare	1	-	1	-	2	4
Clintonia uniflora	-	3	-	-	-	3
Corylus cornuta	2	2	2	1	-	7
Fragaria virginiana	-	-	2	-	3	5
Mahonia aquifolium	31	11	6	8	18	74
Philadelphus lewisii	4	-	6	9	2	21
Pteridium aquilinum	7	12	-	21	-	40
Rosa gymnocarpa	-	-	-	2	-	2
Rumex acetosella	4	8	13	11	2	38
Silene menziesii	42	35	31	50	23	181
Smilacina stellata	-	1	-	-	-	1
Solidago canadensis	-	2	-	-	-	2
Spirea betulifolia	-	3	1	-	-	4
Trifolium procumbens	18	4	-	-	4	14
Viola sp.	6	4	-	-	4	14
Plot 20						
Amelanchier alnifolia	15	18	29	8	22	92
Apocynum androsaemifolium	1	-	2	-	2	5
Chimaphila umbellata	16	18	15	4	-	53
Corylus cornuta	1	1	1	2	-	5
Mahonia aquifolium	84	17	22	50	109	282
Pteridium aquilinum	6	2	11	13	-	32
Rosa gymnocarpa	-	3	2	3	5	13
Rumex acetosella	1	-	-	-	1	2
Silene menziesii	22	80	32	6	48	188
Smilacina stellata	-	3	-	-	3	6
Spirea betulifolia	1	-	-	1	-	2
Viola sp.	2	-	-	3	-	5

A4: DENSITY OF TREE SPECIES IN THE 10 x 10 M QUADRATS

	10 x 10 m quadrats					
	1	2	3	4	5	Total
Plot 1						
Betula papyrifera	-	1	1	-	-	2
Larix occidentalis	1	-	-	-	-	1
Pseudotsuga menziesii	8	10	5	7	13	43
Thuja plicata	8	12	16	18	9	63
Plot 2						
Betula papyrifera	7	14	13	9	19	62
Pinus contorta	49	25	6	4	37	121
Populus tremuloides	-	-	-	15	-	15
Plot 3						
Acer glabrum	-	-	1	-	-	1
Betula papyrifera	2	9	3	-	17	31
Pinus contorta	1	1	3	-	-	5
Populus tremuloides	6	-	19	30	6	61
Prunus virginiana	-	-	1	-	-	1
Plot 4						
Betula papyrifera	9	10	19	10	16	63
Pinus monticola	-	1	-	-	-	1
Populus tremuloides	12	36	18	20	7	93
Prunus virginiana	1	2	-	-	5	8
Plot 5						
Betula papyrifera	2	2	2	5	-	11
Crategus douglasii	-	-	-	1	5	6
Pinus contorta	4	11	5	4	2	26
Populus tremuloides	-	4	2	2	-	8
Plot 6						
Betula papyrifera	7	5	4	6	15	37
Pinus contorta	-	1	-	-	-	1
Populus trichocarpa	-	-	1	-	-	1
Plot 7						
Alnus tenuifolia	-	2	3	-	-	5
Betula papyrifera	19	14	5	23	7	68
Larix occidentalis	-	1	-	-	-	1
Populus tremuloides	25	16	17	18	25	101
Pseudotsuga menziesii	1	-	-	-	-	1

	10 x 10 m quadrats					
	1	2	3	4	5	Total
Plot 8						
Alnus tenuifolia	4	1	-	-	-	5
Betula papyrifera	5	5	1	-	3	14
Pinus monticola	-	-	1	-	-	1
Populus tremuloides	-	4	2	5	5	16
Populus trichocarpa	2	-	-	-	-	2
Robinia pseudo-acacia	-	-	-	1	3	4
Plot 9						
Alnus tenuifolia	-	2	-	-	-	2
Betula papyrifera	-	7	9	1	1	18
Populus tremuloides	16	29	8	11	4	68
Pseudotsuga menziesii	-	-	-	1	-	1
Plot 10						
Betula papyrifera	-	-	-	5	-	5
Prunus virginiana	-	-	-	5	-	5
Plot 11						
Betula papyrifera	1	1	1	1	-	4
Populus tremuloides	-	4	-	-	-	4
Prunus virginiana	-	-	-	1	-	1
Plot 12						
Betula papyrifera	1	1	1	1	5	9
Pinus monticola	-	1	-	-	-	1
Plot 13						
Betula papyrifera	-	-	1	4	1	6
Populus tremuloides	4	13	-	-	-	17
Prunus virginiana	-	4	-	-	-	4
Plot 14						
Prunus virginiana	-	6	-	-	-	6
Pseudotsuga menziesii	-	-	-	1	-	1
Plot 15						
Populus tremuloides	13	6	6	5	11	41
Plot 16						
Betula papyrifera	10	11	11	14	16	62
Pinus contorta	-	1	-	-	-	1
Populus tremuloides	-	-	-	2	-	2
Prunus virginiana	-	1	-	-	-	1
Pseudotsuga menziesii	-	2	-	-	-	2

	10 x 10 m quadrats					
	1	2	3	4	5	Total
Plot 17						
Populus tremuloides	39	18	14	22	11	104
Prunus vifginiana	-	1	-	4	5	10
Plot 18						
Populus tremuloides	38	-	5	-	-	43
Prunus virginiana	2	1	2	4	3	12
Pseudotsuga menziesii	1	-	-	-	-	1
Plot 19						
Betula papyrifera	15	12	-	20	14	61
Larix occidentalis	-	-	-	1	-	1
Pinus contorta	-	1	-	-	-	1
Pinus ponderosa	-	-	1	-	-	1
Pseudotsuga menziesii	-	-	1	-	-	1
Plot 20						
Larix occidentalis	-	1	-	-	-	1
Pinus contorta	1	1	-	2	1	5
Pinus ponderosa	-	-	1	-	-	1
Populus tremuloides	1	4	-	-	2	7
Prunus virginiana	-	-	-	3	-	3
Pseudotsuga menziesii	-	-	1	-	-	1

A5: DENSITY OF GRASS SPECIES IN THE 1 x 1 M QUADRATS*

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 1						
Calamagrostis rubescens	-	-	10%	15%	20%	45%
Festuca occidentalis	-	-	20%	10%	-	30%
Oryzopsis asperifolia	5%	25%	-	15%	-	45%
Plot 2						
Danthonia spicata	270%	30%	15%	80%	-	395%
Unidentifiable	-	5%	5%	-	-	10%
Plot 3						
Danthonia spicata	5%	-	260%	-	-	265%
Oryzopsis asperifolia	-	5%	5%	-	-	10%
Plot 4						
Danthonia spicata	-	-	10%	-	-	10%
Plot 5						
Agropyron caninum	5%	-	15%	5%	-	25%
Calamagrostis rubescens	15%	10%	45%	-	-	70%
Phleum pratense	-	-	10%	5%	-	15%
Poa pratensis	-	-	5%	-	-	5%
Unidentifiable	5%	-	-	-	5%	10%
Plot 6						
Agrostis alba	40%	55%	40%	35%	-	170%
Danthonia spicata	65%	30%	-	60%	-	155%
Oryzopsis asperifolia	-	45%	35%	15%	25%	120%
Poa pratensis	15%	-	-	15%	-	30%
Plot 7						
Agrostis alba	5%	5%	10%	5%	25%	50%
Agrostis scabra	-	-	5%	-	15%	20%
Danthonia spicata	15%	-	-	-	40%	55%
Plot 8						
Agrostis scabra	-	-	5%	55%	5%	65%
Danthonia spicata	5%	5%	-	-	-	10%
Oryzopsis asperifolia	-	5%	-	-	5%	10%

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*The grass species were assessed on a cover basis, therefore each column entry is out of a possible 5 x 100% and the total is out of a possible 2,500%.

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 9						
Danthonia spicata	20%	45%	120%	30%	170%	385%
Oryzopsis asperifolia	5%	15%	45%	15%	85%	165%
Poa pratensis	-	10%	-	-	25%	35%
Plot 10						
Agrostis scabra	-	-	30%	10%	5%	45%
Plot 11						
Agrostis scabra	-	45%	5%	-	10%	60%
Plot 12						
Agrostis scabra	-	-	30%	5%	-	35%
Plot 13						
Agrostis scabra	-	5%	-	5%	-	10%
Plot 14						
Agrostis scabra	5%	-	35%	-	25%	65%
Danthonia spicata	-	-	15%	-	5%	20%
Plot 15						
Agrostis scabra	-	-	5%	10%	15%	30%
Stipa occidentalis	10%	15%	5%	-	-	30%
Plot 16						
Agrostis scabra	-	-	-	30%	5%	35%
Danthonia spicata	25%	5%	55%	15%	135%	235%
Oryzopsis asperifolia	-	5%	20%	5%	-	30%
Plot 17						
Stipa occidentalis	95%	45%	-	-	15%	155%
Trisetum spicatum	215%	80%	5%	75%	35%	410%
Plot 18						
Agrostis scabra	-	-	65%	-	-	65%
Calamagrostis rubescens	25%	30%	35%	5%	20%	115%
Panicum scribnerianum	-	-	-	5%	5%	10%
Poa pratensis	95%	-	125%	-	-	220%
Trisetum spicatum	60%	85%	85%	35%	55%	320%
Plot 19						
Panicum scribnerianum	-	-	5%	-	5%	10%
Poa pratensis	160%	285%	180%	140%	140%	905%
Plot 20						
Calamagrostis rubescens	5%	35%	15%	-	5%	60%
Poa pratensis	60%	125%	50%	15%	10%	260%

A6: DENSITY OF MOSS SPECIES IN THE 1 x 1 M QUADRATS*

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 1						
Polytrichum juniperinum	40%	10%	15%	10%	-	75%
Plot 2						
Polytrichum juniperinum	5%	-	-	5%	-	10%
Plot 3						
Pohlia nutans	-	-	5%	-	-	5%
Polytrichum juniperinum	-	-	5%	5%	5%	15%
Plot 4						
Polytrichum juniperinum	5%	5%	-	-	5%	15%
Plot 5						
Pohlia nutans	-	-	-	5%	-	5%
Polytrichum juniperinum	-	10%	-	-	-	10%
Plot 6						
Pohlia nutans	-	-	-	5%	-	5%
Plot 7						
Pohlia nutans	5%	10%	5%	-	-	20%
Plot 8						
Pohlia nutans	5%	55%	145%	100%	230%	535%
Plot 9						
Pohlia nutans	-	10%	5%	10%	-	25%
Plot 10						
Pohlia nutans	25%	15%	15%	5%	35%	95%
Plot 11						
Pohlia nutans	30%	60%	15%	70%	15%	190%
Plot 12						
Pohlia nutans	60%	55%	95%	25%	115%	350%
Plot 13						
Pohlia nutans	30%	10%	90%	135%	295%	560%

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*The moss species were assessed on a cover basis, therefore each column entry is out of a possible 5 x 100% and the total is out of a possible 2,500%.

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
Plot 14						
Pohlia nutans	200%	315%	55%	165%	10%	745%
Plot 15						
Pohlia nutans	160%	40%	50%	65%	165%	480%
Plot 16						
Pohlia nutans	55%	75%	35%	100%	40%	305%
Plot 17						
Pohlia nutans	5%	5%	-	5%	-	15%
Plot 18						
Pohlia nutans	5%	5%	10%	5%	10%	35%
Plot 19						
Polytrichum juniperinum	5%	-	25%	-	15%	45%
Plot 20						
Pohlia nutans	5%	5%	5%	5%	5%	25%

A7: DENSITY OF TREE SAPLINGS IN THE 1 x 1 M QUADRATS*

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
<u>Plot 1</u>						
Pseudotsuga menziesii	4	3	3	7	11	28
<u>Plot 2</u>						
Betula papyrifera	-	1	-	-	3	4
Pinus contorta	-	8	4	2	5	19
Populus tremuloides	-	1	-	2	-	3
<u>Plot 3</u>						
Acer glabrum	-	-	1	-	-	1
Betula papyrifera	1	-	-	-	2	3
Populus tremuloides	-	-	2	-	-	2
<u>Plot 4</u>						
Betula papyrifera	-	1	3	-	1	5
Pinus monticola	-	1	-	1	-	2
Populus tremuloides	1	9	1	-	4	15
Prunus virginiana	-	-	-	2	-	2
<u>Plot 5</u>						
Betula papyrifera	-	1	1	-	1	3
Pinus contorta	-	3	-	2	-	5
Populus tremuloides	-	-	-	1	-	1
<u>Plot 6</u>						
Betula papyrifera	2	1	1	2	1	7
Populus tremuloides	-	-	-	1	-	1
<u>Plot 7</u>						
Alnus tenuifolia	-	-	1	-	-	1
Betula papyrifera	1	2	-	3	-	6
Populus tremuloides	7	1	5	-	3	16
<u>Plot 8</u>						
Betula papyrifera	1	-	-	-	-	1
Populus tremuloides	-	-	2	-	-	2
<u>Plot 9</u>						
Betula papyrifera	1	-	2	-	1	4
Populus tremuloides	-	5	3	-	-	8

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*A sapling is defined as a tree species less than 1 m high growing in a 1 x 1 m quadrat.

	1 x 1 m quadrats					
	1-5	6-10	11-15	16-20	21-25	Total
<u>Plot 10</u>						
No seedlings present	-	-	-	-	-	-
<u>Plot 11</u>						
Betula papyrifera	-	-	1	-	-	1
Prunus virginiana	1	-	-	-	-	1
<u>Plot 12</u>						
Betula papyrifera	1	-	1	-	1	3
Pinus monticola	-	-	-	1	-	1
<u>Plot 13</u>						
Betula papyrifera	-	-	1	-	-	1
Populus tremuloides	1	-	-	-	-	1
Prunus virginiana	-	-	-	1	-	1
<u>Plot 14</u>						
Prunus virginiana	-	-	-	2	-	2
<u>Plot 15</u>						
No seedlings present	-	-	-	-	-	-
<u>Plot 16</u>						
Betula papyrifera	1	2	1	-	-	3
Prunus virginiana	-	1	-	-	-	1
Pseudotsuga menziesii	-	1	-	-	-	1
<u>Plot 17</u>						
Populus tremuloides	5	1	-	3	2	11
<u>Plot 18</u>						
Populus tremuloides	6	-	2	-	-	8
Prunus virginiana	2	-	1	1	-	4
<u>Plot 19</u>						
Betula papyrifera	4	-	-	-	-	4
Larix occidentalis	-	-	-	1	-	1
Pinus contorta	-	1	-	-	-	1
Pinus ponderosa	1	-	-	-	-	1
Prunus virginiana	-	-	-	1	-	1
<u>Plot 20</u>						
Pinus contorta	-	3	2	-	1	6

A8: DENSITY AND BASAL AREA ASSESSMENTS FOR BIRCH, TREMBLING ASPEN, AND THE CONIFEROUS SPECIES

i) Density (individuals/ha)

Sample plot	Birch	Trembling aspen	Coniferous species
1	40	0	2140
2	1240	300	2420
3	620	1220	100
4	1260	1860	0
5	220	160	520
6	740	0	20
7	1360	2020	40
8	280	320	20
9	360	1360	20
10	100	0	0
11	80	80	0
12	180	0	20
13	120	340	0
14	0	0	20
15	0	820	0
16	1240	40	60
17	0	2080	0
18	0	860	20
19	1220	0	20
20	0	140	160

ii) Basal area (m^2/ha)

1	86.0	0.0	3101.4
2	899.6	37.2	1100.2
3	1251.4	293.2	18.2
4	1904.6	587.6	0.0
5	374.2	27.6	1526.8
6	1807.0	0.0	137.6
7	975.6	939.4	157.2
8	168.0	174.4	15.2
9	381.8	775.6	2.8
10	98.6	0.0	0.0
11	520.4	74.8	0.0
12	723.6	0.0	2.6
13	369.8	117.4	0.0
14	0.0	0.0	24.6
15	0.0	447.2	0.0
16	1090.8	5.0	16.2
17	0.0	744.0	0.0
18	0.0	303.4	2.8
19	1139.0	0.0	5.4
20	0.0	156.6	824.8

A9: STANDING CROP DATA FOR THE GROUND COVER, BIRCH, ASPEN, AND THE CONIFERS

	Ground cover (g/five 1 x 1 m quadrats)				Trees (kg/five 10 x 10 m quadrats)			
Sample plot	Shrubs	Herbs	Bracken	Grass	Birch	Aspen	Conifers	Total (kg)
1	244.9	53.2	53.3	16.4	87.9	0.0	3138.1	3226.4
2	93.1	6.7	333.8	19.0	586.7	15.3	792.8	1395.3
3	445.0	56.7	250.1	22.0	913.9	123.2	9.4	1047.3
4	238.6	44.0	971.1	0.0	1854.7	309.1	0.0	2165.1
5	2282.2	80.4	20.2	50.7	210.6	16.1	1740.9	1970.0
6	576.6	71.4	252.6	221.9	1293.6	0.0	202.8	1497.5
7	6.6	6.0	325.7	12.7	1201.2	524.0	199.7	1925.3
8	187.2	35.1	523.7	20.8	120.1	112.7	12.5	246.1
9	36.1	129.3	281.6	66.7	250.9	417.7	1.5	670.6
10	2224.4	115.4	222.5	0.0	81.2	0.0	0.0	83.8
11	0.0	0.0	0.0	23.2	638.4	42.8	0.0	681.2
12	94.0	9.0	160.9	4.6	574.0	0.0	1.4	575.7
13	42.7	7.4	0.0	0.0	292.3	71.4	0.0	363.8
14	184.7	80.0	0.0	1.7	0.0	0.0	23.1	24.4
15	417.8	1.2	172.0	12.1	0.0	204.0	0.0	204.6
16	0.0	27.0	159.8	112.0	716.8	2.0	10.3	732.1
17	1396.2	52.4	50.9	142.7	0.0	339.2	0.0	340.8
18	4189.5	29.5	0.0	176.0	0.0	140.8	1.5	146.7
19	28.7	1.8	62.2	120.3	846.7	0.0	3.0	849.9
20	765.5	13.1	52.9	12.8	0.0	96.4	1268.0	1365.2

APPENDIX B: MACRO-CLIMATIC DATA

B1: Precipitation data for Crescent Valley, Columbia Gardens, and Northport (1940-1970)

B2: Daily maximum and minimum temperatures for Castlegar Airport, Trail (Warfield), and Waneta for the period June 1st to September 30th

B3: Daily precipitation data for Castlegar Airport, Trail (Warfield), and Waneta for the period June 1st to September 30th

B4: Daily maximum and minimum relative humidities for Castlegar Airport, Trail (Warfield), and Waneta for the period June 1st to September 30th

B1: PRECIPITATION DATA FOR CRESCENT VALLEY, COLUMBIA GARDENS, AND NORTHPORT (1940-1970)

Year	Crescent Valley cm	Columbia Gardens cm	Northport cm
1940	-	67.0	56.8
1941	86.7	73.4	72.3
1942	65.6	57.4	47.8
1943	66.1	53.1	40.3
1944	55.7	40.9	45.9
1945	80.6	70.7	-
1946	79.6	61.3	47.6
1947	81.0	67.0	55.2
1948	92.3	69.7	61.7
1949	71.0	55.2	37.7
1950	91.4	72.3	57.5
1951	94.8	74.9	50.0
1952	71.3	49.3	36.9
1953	89.5	65.1	55.7
1954	89.5	67.4	52.7
1955	82.3	71.0	61.2
1956	75.0	47.9	38.3
1957	79.8	62.0	50.5
1958	75.1	72.3	-
1959	92.3	70.8	60.0
1960	75.2	36.2	49.0
1961	86.0	76.5	52.4
1962	73.1	56.0	40.4
1963	68.2	61.7	43.0
1964	85.9	76.2	52.5
1965	-	64.2	47.8
1966	-	68.1	49.4
1967	-	60.4	44.9
1968	-	85.6	68.3
1969	-	70.9	48.7
1970	-	-	52.0
Mean	79.2	64.5	50.3

B2: DAILY MAXIMUM AND MINIMUM TEMPERATURES FOR CASTLEGAR AIRPORT, TRAIL (WARFIELD), AND WANETA, FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

June 1st to 30th

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max.T°C	Min.T°C	Max.T°C	Min.T°C	Max.T°C	Min.T°C
1	25.0	9.4	26.7	12.2	26.1	12.2
2	16.1	10.6	14.4	10.0	12.2	12.2
3	20.6	8.3	22.2	10.0	19.4	11.1
4	18.9	9.4	19.4	11.7	18.9	12.2
5	16.7	11.4	18.9	12.2	18.3	12.2
6	21.1	10.3	23.3	13.3	22.2	11.1
7	16.1	11.1	16.7	11.7	16.7	12.2
8	15.0	8.6	17.8	7.2	18.3	9.4
9	17.8	5.5	20.0	9.4	22.8	8.3
10	17.2	8.0	16.7	11.1	19.4	10.6
11	21.7	10.0	21.1	10.0	22.8	11.1
12	25.0	7.2	26.1	11.7	26.1	8.9
13	16.1	8.0	16.1	8.3	17.8	8.9
14	18.9	6.6	21.1	8.3	17.2	7.7
15	20.0	5.0	21.1	8.8	21.1	5.5
16	20.6	6.9	20.6	8.9	20.0	6.6
17	22.2	5.0	23.3	12.2	25.6	5.0
18	19.4	10.0	20.6	12.8	18.3	10.0
19	21.7	11.7	21.7	12.2	21.1	11.7
20	25.6	9.2	25.6	13.9	25.0	7.7
21	28.3	11.1	30.5	15.6	29.4	9.4
22	31.6	13.3	33.8	16.7	30.5	11.1
23	25.0	14.2	24.4	11.1	22.8	13.9
24	23.3	9.7	22.8	12.2	21.1	6.6
25	17.8	10.3	16.7	8.9	18.3	10.6
26	20.6	5.5	22.2	8.9	20.0	4.4
27	18.3	6.9	17.8	8.9	16.1	6.6
28	20.0	7.2	19.4	8.9	16.1	6.1
29	23.9	6.4	23.9	10.6	22.2	5.5
30	32.2	8.3	26.1	13.3	24.4	5.5
Mean	21.5	8.8	21.7	11.0	21.0	9.2

July 1st to 31st

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max.T°C	Min.T°C	Max.T°C	Min.T°C	Max.T°C	Min.T°C
1	31.1	12.8	25.6	10.0	25.0	12.2
2	22.8	14.2	24.4	8.3	22.2	5.0
3	22.2	5.5	24.4	10.6	22.2	3.4
4	25.6	8.9	23.9	12.2	23.3	6.1
5	16.1	9.2	15.0	10.0	11.7	10.6
6	13.3	9.2	15.6	7.7	12.8	7.7
7	21.7	9.2	23.9	8.9	22.2	5.5
8	20.6	4.4	22.8	12.2	21.1	9.4
9	21.7	10.6	22.2	13.3	19.4	9.4
10	17.2	11.1	17.8	11.1	16.7	11.1
11	17.8	10.0	19.4	7.7	17.8	8.9
12	23.9	6.1	27.2	7.7	25.0	5.0
13	28.8	7.5	28.8	11.7	26.7	6.1
14	30.5	8.6	31.1	13.3	28.8	7.2
15	33.3	10.0	34.4	14.4	31.1	8.3
16	35.5	11.1	33.8	14.4	32.7	10.0
17	31.6	12.0	32.7	16.1	31.6	7.7
18	30.0	12.2	36.6	16.1	33.3	8.9
19	31.6	13.3	37.7	17.2	34.4	11.7
20	31.6	13.9	33.8	17.8	33.3	11.7
21	36.1	13.9	35.0	17.8	33.8	12.2
22	35.5	13.9	35.5	17.2	33.3	13.3
23	34.4	13.9	34.4	17.8	32.2	11.7
24	31.1	15.6	33.3	15.6	30.0	10.6
25	31.6	12.2	32.2	14.4	30.0	8.3
26	34.4	11.1	34.4	15.6	32.7	8.9
27	35.0	12.2	35.0	16.7	34.4	10.6
28	31.6	13.3	31.1	15.6	32.7	11.7
29	34.4	12.2	35.0	17.2	31.1	10.6
30	35.5	15.0	35.5	17.8	32.7	9.4
31	37.2	13.9	37.7	18.9	31.6	10.0
Mean	28.5	11.2	29.4	13.7	27.3	9.2

August 1st to 31st

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max.T°C	Min.T°C	Max.T°C	Min.T°C	Max.T°C	Min.T°C
1	38.8	15.9	40.0	18.9	32.7	12.2
2	36.6	16.7	35.5	16.7	34.4	13.3
3	33.3	13.3	32.7	15.0	36.6	14.4
4	34.4	11.7	34.4	16.7	36.6	11.1
5	38.3	14.4	37.7	17.8	41.1	13.3
6	33.8	16.1	33.3	17.8	34.4	13.9
7	36.6	15.0	36.6	20.0	38.8	13.9
8	38.3	16.7	39.4	16.7	40.5	16.1
9	36.1	12.8	36.1	16.7	35.5	12.2
10	38.3	12.5	28.3	16.7	36.6	12.2
11	38.3	13.1	37.7	16.7	37.2	12.2
12	37.7	13.6	37.7	14.4	34.4	12.8
13	36.1	10.0	36.6	10.0	35.0	8.9
14	31.1	12.2	30.0	13.3	28.8	11.7
15	31.1	9.4	31.1	13.3	28.3	13.3
16	30.0	7.2	30.0	12.8	28.3	10.0
17	28.8	7.2	28.8	13.9	26.7	7.7
18	30.0	10.9	30.0	14.4	27.7	6.1
19	33.8	9.2	34.4	16.1	31.6	5.5
20	32.2	11.1	30.5	15.6	28.3	13.3
21	30.0	14.2	28.8	16.7	27.7	11.1
22	22.2	12.0	21.1	11.1	17.8	13.3
23	23.9	9.4	23.9	10.6	21.7	10.6
24	29.4	7.5	28.8	11.7	26.7	7.7
25	32.2	9.7	32.2	13.3	30.0	8.9
26	33.8	9.7	34.4	14.4	32.2	9.4
27	33.8	10.0	35.0	16.1	32.7	8.9
28	32.2	15.6	33.3	16.7	30.5	16.7
29	32.8	12.8	35.0	18.3	32.7	11.7
30	27.2	16.1	28.8	16.7	27.7	16.7
31	20.6	15.6	19.4	11.1	16.1	12.2
Mean	32.7	12.3	32.7	15.3	31.3	11.7

September 1st to 30th

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max.T°C	Min.T°C	Max.T°C	Min.T°C	Max.T°C	Min.T°C
1	14.4	9.4	15.0	10.6	11.1	9.4
2	16.7	9.2	16.7	10.6	15.6	8.9
3	20.6	12.0	21.1	13.3	18.3	11.1
4	23.3	12.0	23.3	11.1	21.1	10.6
5	28.8	7.7	28.3	12.2	25.0	5.5
6	17.8	9.2	18.3	9.4	13.9	7.2
7	20.6	6.6	21.1	9.4	17.8	5.5
8	22.2	6.6	22.2	9.4	18.9	5.0
9	22.8	12.5	25.0	12.2	21.7	10.6
10	28.3	8.9	27.7	12.8	24.4	12.2
11	23.3	12.5	23.9	13.3	26.1	11.7
12	21.7	10.6	21.7	7.7	18.9	10.6
13	19.4	6.6	20.0	5.5	17.2	11.1
14	18.9	3.9	19.4	4.4	17.8	3.3
15	20.0	0.6	20.6	4.4	17.8	1.7
16	20.0	2.5	21.1	4.4	18.3	2.2
17	20.0	0.0	23.2	3.3	16.7	0.6
18	21.1	1.2	21.1	5.0	16.7	1.7
19	19.4	4.4	21.1	7.2	17.2	5.5
20	18.3	5.3	19.4	5.5	15.0	7.2
21	19.4	1.5	21.1	4.4	16.7	1.7
22	21.7	2.2	22.8	3.9	18.9	2.2
23	24.4	3.6	23.3	6.1	21.1	3.3
24	17.8	7.2	18.3	8.3	16.1	7.7
25	17.2	7.2	17.8	8.3	13.9	5.5
26	15.0	7.7	16.7	8.9	13.3	7.2
27	11.1	7.5	12.2	8.9	10.6	8.3
28	12.2	6.1	13.9	7.7	11.1	8.3
29	8.9	4.2	10.0	5.0	7.7	6.7
30	13.9	1.7	16.1	3.9	13.3	5.5
Mean	19.3	6.3	20.1	7.9	16.9	6.7

B3: DAILY PRECIPITATION DATA FOR CASTLEGAR AIRPORT, TRAIL (WARFIELD), AND WANETA FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

June 1st to 30th

Date	Castlegar Airport cm	Trail (Warfield) cm	Waneta cm
1	0.00	0.13	0.03
2	0.41	1.12	0.13
3	0.00	0.01	0.13
4	0.48	0.51	0.10
5	0.03	1.07	0.08
6	0.01	0.01	0.23
7	1.09	0.43	0.20
8	0.81	0.71	0.28
9	0.00	0.00	0.00
10	0.01	1.04	0.20
11	0.00	0.00	0.00
12	0.00	0.36	0.00
13	2.03	1.88	2.18
14	0.01	0.15	0.00
15	0.01	0.00	0.00
16	0.01	0.01	0.00
17	0.00	0.00	0.00
18	0.23	0.43	0.18
19	0.03	0.05	0.18
20	0.03	0.00	0.00
21	0.00	0.00	0.00
22	0.58	0.41	0.00
23	0.46	0.00	0.38
24	0.33	1.63	0.15
25	1.25	0.58	0.91
26	0.00	0.08	0.00
27	0.03	0.03	0.30
28	0.01	0.00	0.00
29	0.01	0.00	0.00
30	0.00	0.00	0.00
Total	7.84	8.40	5.66

July 1st to 31st

Date	Castlegar Airport cm	Trail (Warfield) cm	Waneta cm
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.01	0.25	0.05
5	0.89	0.10	1.47
6	0.66	0.25	0.15
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.05	1.09	0.51
10	2.54	1.32	1.67
11	1.87	0.56	0.00
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	0.00	0.00	0.00
15	0.00	0.00	0.00
16	0.00	0.00	0.00
17	0.00	0.00	0.00
18	0.00	0.00	0.00
19	0.00	0.00	0.00
20	0.01	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.00	0.00	0.00
28	0.03	0.00	0.00
29	0.00	0.00	0.00
30	0.00	0.00	0.00
31	0.00	0.00	0.00
Total	6.06	3.87	3.85

August 1st to 31st

Date	Castlegar Airport cm	Trail (Warfield) cm	Waneta cm
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.01	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	0.00	0.00	0.00
15	0.00	0.00	0.00
16	0.00	0.00	0.00
17	0.00	0.00	0.00
18	0.00	0.00	0.00
19	0.00	0.00	0.03
20	0.01	0.00	0.00
21	0.00	0.20	0.00
22	0.74	0.53	0.38
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.00	0.00	0.00
28	0.00	0.00	0.00
29	0.00	0.00	0.00
30	0.15	0.38	0.30
31	0.99	1.52	2.11
Total	1.90	2.63	2.82

September 1st to 30th

Date	Castlegar Airport cm	Trail (Warfield) cm	Waneta cm
1	0.89	0.66	0.69
2	0.18	0.28	0.74
3	0.01	0.03	0.00
4	0.00	0.00	0.00
5	0.05	0.10	0.28
6	1.68	1.60	1.70
7	0.00	0.00	0.00
8	0.00	0.01	0.00
9	0.03	0.00	0.08
10	0.00	0.00	0.00
11	0.01	0.00	0.03
12	0.00	0.00	0.00
13	0.00	0.00	0.23
14	0.00	0.00	0.13
15	0.00	0.00	0.00
16	0.00	0.00	0.00
17	0.00	0.00	0.00
18	0.00	0.00	0.00
19	0.15	0.20	0.00
20	0.13	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.01	0.00	0.00
25	0.03	0.15	0.03
26	0.38	0.03	0.44
27	0.25	0.03	0.33
28	1.12	1.52	0.58
29	0.66	0.43	1.07
30	0.00	0.00	0.00
Total	5.58	5.04	6.33

B4: DAILY MAXIMUM AND MINIMUM RELATIVE HUMIDITIES FOR CASTLEGAR AIRPORT, TRAIL (WARFIELD), AND WANETA, FOR THE PERIOD JUNE 1ST TO SEPTEMBER 30TH

June 1st to 30th

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max. RH%	Min. RH%	Max. RH%	Min. RH%	Max. RH%	Min. RH%
1	89	31	79	26	99	34
2	86	59	95	75	100	83
3	84	43	90	33	100	50
4	89	56	94	55	100	58
5	93	75	97	60	100	66
6	96	55	82	43	99	46
7	93	74	94	78	99	82
8	93	59	91	39	100	45
9	91	47	81	39	98	39
10	92	57	94	60	100	57
11	96	39	87	39	100	43
12	88	29	94	25	100	35
13	92	67	97	65	100	60
14	96	39	90	37	100	36
15	100	31	83	27	98	26
16	82	34	80	30	97	32
17	89	30	67	25	97	18
18	93	50	91	53	96	48
19	93	58	94	51	96	46
20	92	36	80	32	96	34
21	93	37	78	28	96	30
22	75	30	94	21	94	29
23	90	26	87	21	95	24
24	86	27	91	23	95	28
25	93	58	94	56	95	32
26	96	28	87	28	98	23
27	86	46	87	48	98	46
28	88	43	90	48	98	52
29	89	35	81	26	98	26
30	86	27	69	21	97	24
Mean	90	44	87	40	98	42

<u>July 1st to 31st</u>

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max. RH%	Min. RH%	Max. RH%	Min. RH%	Max. RH%	Min. RH%
1	73	23	68	19	96	22
2	47	19	76	17	97	16
3	82	32	69	24	97	25
4	82	21	85	22	96	27
5	89	51	97	60	96	67
6	88	63	91	59	98	49
7	91	32	80	21	98	29
8	83	47	74	38	96	38
9	89	52	97	46	97	50
10	93	57	86	61	95	46
11	93	64	100	45	96	43
12	100	30	93	21	97	26
13	96	24	79	20	96	16
14	92	25	74	20	96	20
15	92	23	75	14	95	16
16	89	22	76	17	96	14
17	69	23	64	19	96	16
18	79	31	69	20	95	23
19	82	21	70	19	95	26
20	88	37	75	29	96	30
21	92	25	78	24	96	23
22	86	21	67	17	95	24
23	80	21	62	18	93	20
24	57	23	58	17	93	20
25	71	22	68	20	96	19
26	89	23	62	22	96	20
27	86	22	69	22	94	17
28	85	33	76	30	95	27
29	85	24	79	22	96	21
30	86	29	70	23	95	24
31	85	26	68	19	95	22
Mean	84	31	76	27	96	27

August 1st to 31st

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max. RH%	Min. RH%	Max. RH%	Min. RH%	Max. RH%	Min. RH%
1	80	25	71	21	94	22
2	78	21	64	26	95	18
3	85	18	72	18	95	19
4	72	23	70	21	94	20
5	75	21	70	20	95	19
6	77	25	75	24	94	27
7	83	20	65	24	96	17
8	78	14	64	15	92	14
9	76	15	64	18	95	12
10	80	22	69	18	96	13
11	82	15	64	14	95	10
12	75	22	64	14	96	8
13	69	11	55	14	94	8
14	62	13	61	14	89	15
15	67	16	61	16	99	16
16	66	15	71	20	96	18
17	76	20	66	19	98	16
18	63	17	65	22	92	22
19	77	23	64	17	97	14
20	63	17	61	20	90	20
21	61	19	81	23	96	22
22	88	23	94	57	96	44
23	89	47	88	33	97	35
24	92	35	85	23	99	22
25	85	25	72	18	97	14
26	85	24	72	18	97	14
27	93	17	60	15	95	10
28	70	24	69	24	94	23
29	86	25	62	22	95	18
30	80	38	82	34	94	31
31	96	47	94	49	96	42
Mean	78	22	70	22	95	19

September 1st to 30th

Date	Castlegar Airport		Trail (Warfield)		Waneta	
	Max. RH%	Min. RH%	Max. RH%	Min. RH%	Max. RH%	Min. RH%
1	96	56	94	60	93	53
2	96	64	97	64	94	60
3	95	41	82	39	86	34
4	86	35	84	35	96	34
5	96	28	89	28	96	27
6	96	59	87	50	98	54
7	96	42	90	34	98	44
8	100	39	94	37	97	40
9	91	38	94	28	96	38
10	92	29	79	26	97	29
11	72	22	93	19	83	20
12	82	35	89	36	92	39
13	88	23	83	20	99	20
14	82	26	85	22	98	23
15	95	23	81	19	97	17
16	79	20	80	20	97	16
17	95	23	87	19	98	19
18	100	31	89	30	98	26
19	85	38	89	36	96	32
20	91	28	81	24	85	26
21	95	30	88	31	98	23
22	100	35	100	29	97	28
23	100	33	93	30	95	26
24	88	36	86	34	93	30
25	92	48	86	41	96	38
26	96	61	90	53	95	42
27	96	71	93	65	96	68
28	96	68	93	56	96	58
29	93	72	93	64	98	62
30	95	51	88	37	96	44
Mean	92	40	88	36	95	36

APPENDIX C: MICRO-CLIMATIC DATA

C: MICRO-CLIMATIC DATA*

	Sample quadrats and control readings									
	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 1										
Max. Temp.	21.1	25.6	22.2	28.8	23.3	31.1	26.7	32.2	24.4	26.7
Dep. Max. Temp.	4.5		6.6		7.8		5.5		2.3	
Min. Temp.	5.0	2.8	8.9	7.2	10.6	10.0	11.1	10.0	14.4	14.4
Inc. Min. Temp.	2.2		1.7		0.6		1.1		0.0	
Max. R.H.	98	96	100	100	99	99	99	97	98	96
% Inc. Max. R.H.	2.1%		0.0%		0.0%		2.1%		2.1%	
Min. R.H.	43	33	50	38	56	34	55	36	45	34
% Inc. Min. R.H.	30.3%		31.6%		64.7%		52.8%		26.5%	
Sol. Rad.	32.4	518.4	40.5	826.2	16.2	599.4	48.6	542.7	40.5	494.1
% Dec. Sol. Rad.	93.7%		95.1%		97.3%		91.0%		91.8%	
Plot 2										
Max. Temp.	22.7	25.0	25.0	27.2	23.3	26.1	21.7	22.2	19.4	21.7
Dep. Max. Temp.	2.3		2.2		2.8		0.5		2.3	
Min. Temp.	10.0	10.0	6.1	5.5	5.5	4.4	4.4	3.9	5.5	5.0
Inc. Min. Temp.	0.0		0.6		1.1		0.5		0.5	
Max. R.H.	100	100	100	98	100	100	100	100	98	98
% Inc. Max. R.H.	0.0%		2.0%		0.0%		0.0%		0.0%	
Min. R.H.	45	39	33	29	60	48	46	44	44	34
% Inc. Min. R.H.	15.4%		12.1%		25.0%		4.5%		29.4%	
Sol. Rad.	89.1	445.5	72.9	494.1	72.9	583.2	145.8	421.2	64.8	437.4
% Dec. Sol. Rad.	80.0%		85.2%		87.5%		65.4%		85.2%	

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*Max. and Min. Temps. are recorded in °C.

Dep. Max. Temp. and Inc. Min. Temp. represent difference in temperature values between sample quadrats and control areas.

Max. R.H. and Min. R.H. are recorded on a percent basis.

% Inc. Max. R.H. and % Inc. Min. R.H. represent difference between sample quadrats and control areas expressed on a percent basis.

Sol. Rad. is recorded in cal/cm^2/day.

% Dec. Sol. Rad. represents the reduction in solar radiation received by the sample quadrats compared to the control areas expressed on a percent basis.

Sample quadrats and control readings

	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 3										
Max. Temp.	23.3	23.3	16.7	16.7	23.9	26.1	25.6	27.7	28.8	30.0
Dep. Max. Temp.	0.0		0.0		2.2		2.1		1.2	
Min. Temp.	1.2	1.2	3.3	2.2	1.2	1.2	0.0	0.0	3.3	2.2
Inc. Min. Temp.	0.0		1.1		0.0		0.0		1.1	
Max. R.H.	99	97	98	96	98	94	98	94	97	94
% Inc. Max. R.H.	2.1%		2.1%		4.3%		4.3%		3.2%	
Min. R.H.	29	26	75	72	60	42	29	26	26	25
% Inc. Min. R.H.	11.5%		4.2%		42.9%		11.5%		4.0%	
Sol. Rad.	89.1	550.8	202.5	542.7	332.1	469.8	234.9	526.5	145.8	494.1
% Dec. Sol. Rad.	83.8%		62.7%		29.3%		55.4%		70.5%	
Plot 4										
Max. Temp.	24.4	31.1	23.3	25.6	19.4	19.4	22.8	26.7	20.0	22.2
Dep. Max. Temp.	6.7		2.3		0.0		3.9		2.2	
Min. Temp.	9.4	9.4	7.7	7.2	8.9	8.9	10.0	9.4	9.4	8.9
Inc. Min. Temp.	0.0		0.5		0.0		0.6		0.5	
Max. R.H.	98	98	100	99	98	98	100	99	100	99
% Inc. Max. R.H.	1.0%		1.0%		0.0%		1.0%		1.0%	
Min. R.H.	48	20	46	42	46	41	62	59	63	56
% Inc. Min. R.H.	20.0%		9.5%		12.2%		5.1%		12.5%	
Sol. Rad.	234.9	793.8	178.2	1263.6	97.2	356.4	218.7	437.4	129.6	340.2
% Dec. Sol. Rad.	70.4%		85.9%		72.7%		50.0%		61.9%	
Plot 5										
Max. Temp.	27.6	30.0	18.9	22.2	24.4	27.2	22.8	28.3	23.9	28.8
Dep. Max. Temp.	3.3		3.3		2.8		5.5		4.9	
Min. Temp.	10.0	7.7	8.9	8.3	10.0	8.9	2.2	2.2	3.9	3.3
Inc. Min. Temp.	2.3		0.6		1.1		0.0		0.6	
Max. R.H.	97	94	99	98	98	97	100	96	98	98
% Inc. Max. R.H.	3.2%		1.0%		1.0%		4.2%		0.0%	
Min. R.H.	42	38	67	59	47	32	39	32	41	34
% Inc. Min. R.H.	10.5%		13.6%		46.9%		21.9%		20.6%	
Sol. Rad.	153.9	688.5	145.8	729.0	178.2	591.3	218.7	785.7	97.2	502.2
% Dec. Sol. Rad.	77.7%		80.0%		69.9%		72.2%		80.6%	

Sample quadrats and control readings

	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 6										
Max. Temp.	23.3	23.9	18.3	23.9	18.9	21.1	23.3	26.1	23.9	27.7
Dep. Max. Temp.	0.6		5.6		2.2		2.5		3.8	
Min. Temp.	7.7	6.6	6.6	6.6	6.6	6.1	5.5	5.0	6.6	6.1
Inc. Min. Temp.	1.1		0.0		0.5		0.5		0.5	
Max. R.H.	99	95	100	99	100	92	99	99	100	99
% Inc. Max. R.H.	4.2%		1.0%		8.7%		0.0%		1.0%	
Min. R.H.	40	30	48	44	62	45	47	37	44	28
% Inc. Min. R.H.	33.3%		8.3%		37.8%		27.0%		57.1%	
Sol. Rad.	234.9	348.3	162.0	753.3	40.5	332.1	105.3	623.7	97.2	405.0
% Dec. Sol. Rad.	32.6%		78.5%		87.8%		83.1%		76.0%	
Plot 7										
Max. Temp.	25.6	27.7	25.6	27.2	25.6	25.6	25.0	26.7	22.8	24.4
Dep. Max. Temp.	2.1		1.6		0.0		1.7		1.6	
Min. Temp.	7.7	7.7	6.1	5.0	4.4	4.4	7.2	6.1	4.4	2.8
Inc. Min. Temp.	0.0		0.9		0.0		1.1		1.6	
Max. R.H.	98	97	97	97	99	99	100	98	98	98
% Inc. Max. R.H.	1.0%		0.0%		0.0%		2.0%		0.0%	
Min. R.H.	34	29	30	26	36	34	32	32	39	36
% Inc. Min. R.H.	17.2%		15.4%		5.9%		0.0%		8.3%	
Sol. Rad.	89.1	445.5	170.1	591.3	218.7	558.9	202.5	437.4	178.2	1182.6
% Dec. Sol. Rad.	80.0%		71.2%		60.9%		53.7%		84.9%	
Plot 8										
Max. Temp.	36.6	40.0	33.8	41.1	40.0	41.1	37.7	39.4	36.6	38.3
Dep. Max. Temp.	3.4		7.3		1.1		1.7		1.7	
Min. Temp.	8.3	8.3	8.9	8.9	8.9	8.3	5.5	5.5	6.6	6.6
Inc. Min. Temp.	0.0		0.0		0.6		0.0		0.0	
Max. R.H.	95	95	95	94	95	94	94	94	93	92
% Inc. Max. R.H.	0.0%		1.1%		1.1%		0.0%		1.1%	
Min. R.H.	30	22	40	29	26	18	26	18	25	20
% Inc. Min. R.H.	36.4%		37.9%		44.4%		44.4%		25.0%	
Sol. Rad.	56.7	558.9	105.3	453.6	162.0	534.6	153.9	599.4	251.1	453.6
% Dec. Sol. Rad.	89.9%		76.8%		69.7%		74.3%		44.6%	

	Sample quadrats and control readings									
	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 9										
Max. Temp.	33.3	39.4	27.7	31.1	28.3	31.6	28.8	34.4	35.5	35.5
Dep. Max. Temp.	6.1		3.4		3.3		5.6		0.0	
Min. Temp.	7.7	7.2	6.1	5.0	5.0	4.4	6.1	5.5	7.2	6.1
Inc. Min. Temp.	0.5		0.9		0.6		0.6		1.1	
Max. R.H.	99	92	98	95	98	94	98	90	99	92
% Inc. Max. R.H.	7.6%		3.2%		4.3%		8.9%		7.6%	
Min. R.H.	30	21	44	35	34	25	29	23	29	21
% Inc. Min. R.H.	42.9%		25.7%		36.0%		26.1%		38.1%	
Sol. Rad.	283.5	947.7	81.0	437.4	89.1	558.9	81.0	486.0	97.2	445.5
% Dec. Sol. Rad.	70.1%		81.5%		84.5%		83.3%		78.2%	
Plot 10										
Max. Temp.	34.4	34.4	34.4	34.4	33.3	33.3	33.3	33.3	35.0	37.2
Dep. Max. Temp.	0.0		0.0		0.0		0.0		2.2	
Min. Temp.	5.0	5.0	5.5	5.5	5.5	5.5	8.9	8.9	8.9	8.9
Inc. Min. Temp.	0.0		0.0		0.0		0.0		0.0	
Max. R.H.	95	95	95	95	94	94	93	92	95	94
% Inc. Max. R.H.	0.0%		0.0%		0.0%		1.0%		1.1%	
Min. R.H.	17	14	18	16	20	18	26	21	20	15
% Inc. Min. R.H.	21.4%		12.5%		11.1%		23.8%		30.3%	
Sol. Rad.	656.1	947.7	445.5	510.3	486.0	542.7	105.3	429.3	48.6	558.9
% Dec. Sol. Rad.	30.8%		12.7%		10.4%		75.5%		91.3%	
Plot 11										
Max. Temp.	35.0	35.5	36.1	36.6	36.1	40.5	30.0	30.0	29.4	29.4
Dep. Max. Temp.	0.5		0.5		6.4		0.0		0.0	
Min. Temp.	11.1	10.6	16.7	16.7	13.3	13.3	15.6	15.6	10.6	10.6
Inc. Min. Temp.	0.5		0.0		0.0		0.0		0.0	
Max. R.H.	90	90	78	78	91	91	88	88	93	92
% Inc. Max. R.H.	0.0%		0.0%		0.0%		0.0%		1.1%	
Min. R.H.	16	14	28	26	26	25	38	38	54	54
% Inc. Min. R.H.	14.2%		7.7%		4.0%		0.0%		0.0%	
Sol. Rad.	275.4	388.8	275.4	372.6	275.4	405.0	202.5	267.3	194.4	259.2
% Dec. Sol. Rad.	29.2%		26.1%		32.0%		24.2%		25.9%	

	Sample quadrats and control readings									
	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 12										
Max. Temp.	21.1	22.8	21.1	21.7	21.1	21.7	20.6	21.1	19.4	21.1
Dep. Max. Temp.	1.7		0.6		0.6		0.5		0.7	
Min. Temp.	2.2	2.2	1.2	1.2	2.2	2.2	0.6	0.6	1.7	1.7
Inc. Min. Temp.	0.0		0.0		0.0		0.0		0.0	
Max. R.H.	100	93	99	97	100	99	100	96	100	97
% Inc. Max. R.H.	7.5%		2.0%		1.0%		4.0%		3.1%	
Min. R.H.	30	24	23	22	26	25	33	27	35	32
% Inc. Min. R.H.	25.0%		4.5%		4.0%		22.2%		9.4%	
Sol. Rad	194.4	291.6	283.5	324.0	275.4	356.4	234.9	243.0	218.7	243.0
% Dec. Sol. Rad.	33.4%		12.5%		22.7%		3.4%		10.0%	
Plot 13										
Max. Temp.	38.8	41.1	33.8	33.8	37.2	39.4	41.1	41.1	38.8	38.8
Dep. Max. Temp.	2..3		0.0		2.2		0.0		0.0	
Min. Temp.	12.8	12.8	15.0	15.0	13.3	13.3	16.7	16.7	12.2	11.7
Inc. Min. Temp.	0.0		0.0		0.0		0.0		0.5	
Max. R.H.	93	88	92	87	94	88	87	83	93	91
% Inc. Max. R.H.	5.7%		5.7%		6.8%		4.8%		2.2%	
Min. R.H.	23	20	32	27	26	21	19	15	18	16
% Inc. Min. R.H.	15.0%		18.5%		23.8%		26.7%		12.5%	
Sol. Rad.	356.4	550.8	186.3	307.8	324.0	575.1	153.9	486.0	275.4	437.4
% Dec. Sol. Rad.	35.3%		39.5%		43.7%		68.3%		77.0%	
Plot 14										
Max. Temp.	36.1	40.0	38.3	40.0	35.5	37.7	34.4	37.7	35.0	36.1
Dep. Max. Temp.	3.9		1.7		2.2		3.3		1.1	
Min. Temp.	12.8	12.2	13.3	13.3	15.0	14.4	13.3	13.3	10.0	10.0
Inc. Min. Temp.	0.6		0.0		0.6		0.0		0.0	
Max. R.H.	93	90	92	88	91	86	93	85	93	86
% Inc. Max. R.H.	3.3%		4.5%		5.8%		9.4%		8.1%	
Min. R.H.	28	20	26	23	26	21	25	22	23	22
% Inc. Min. R.H.	40.0%		13.0%		23.8%		13.6%		4.5%	
Sol. Rad.	299.7	567.0	486.0	567.0	259.2	558.9	324.0	591.3	388.8	575.1
% Dec. Sol. Rad.	47.1%		14.3%		53.6%		45.2%		32.4%	

	Sample quadrats and control readings									
	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 15										
Max. Temp.	34.4	37.2	34.4	36.1	37.2	38.8	33.3	34.4	37.2	37.2
Dep. Max. Temp.	2.8		1.7		1.6		1.1		0.0	
Min. Temp.	9.4	8.9	10.6	10.0	10.0	9.4	11.7	10.6	10.0	10.0
Inc. Min. Temp.	0.5		0.6		0.6		1.1		0.0	
Max. R.H.	96	93	91	89	93	91	92	90	92	90
% Inc. Max. R.H.	3.2%		2.2%		2.2%		2.2%		2.2%	
Min. R.H.	22	20	21	20	19	16	27	24	22	21
% Inc. Min. R.H.	10.0%		5.0%		18.8%		12.5%		4.8%	
Sol. Rad.	526.5	631.8	364.5	615.6	372.6	623.7	343.3	461.7	972.0	1206.9
% Dec. Sol. Rad	16.7%		40.8%		40.3%		24.6%		19.5%	
Plot 16										
Max. Temp.	36.1	37.2	36.6	37.7	37.2	38.3	35.5	37.2	33.3	37.2
Dep. Max. Temp.	1.1		1.1		1.1		1.7		3.9	
Min. Temp.	11.1	11.1	12.2	12.2	12.2	12.2	11.1	11.1	10.6	10.0
Inc. Min. Temp.	0.0		0.0		0.0		0.0		0.6	
Max. R.H.	97	95	99	98	98	96	98	96	99	96
% Inc. Max. R.H.	2.1%		1.0%		2.1%		2.1%		3.1%	
Min. R.H.	34	27	30	24	30	23	24	23	29	22
% Inc. Min. R.H.	25.9%		25.0%		30.4%		4.2%		31.8%	
Sol. Rad.	356.4	599.4	437.4	558.9	364.5	591.3	413.1	575.1	380.7	575.1
% Dec. Sol. Rad.	40.5%		21.7%		38.4%		28.2%		33.8%	
Plot 17										
Max. Temp.	33.8	35.0	35.5	35.5	35.0	35.0	36.1	36.1	34.4	37.2
Dep. Max. Temp.	1.2		0.0		0.0		0.0		2.8	
Min. Temp.	5.5	4.4	6.6	6.6	5.0	4.4	7.7	7.2	11.1	9.4
Inc. Min. Temp.	1.1		0.0		0.6		0.5		1.7	
Max. R.H.	100	100	100	98	100	100	100	100	100	98
% Inc. Max. R.H.	0.0%		2.0%		0.0%		0.0%		2.0%	
Min. R.H.	30	28	28	28	31	28	34	32	39	32
% Inc. Min. R.H.	7.1%		0.0%		10.7%		6.3%		21.9%	
Sol. Rad.	518.4	631.8	526.5	631.8	664.2	688.5	461.7	648.0	170.1	567.0
% Dec. Sol. Rad.	17.9%		16.7%		3.5%		28.7%		70.0%	

	Sample quadrats and control readings									
	Q1	C	Q2	C	Q3	C	Q4	C	Q5	C
Plot 18										
Max. Temp.	23.9	24.4	23.9	24.4	26.1	27.7	28.3	31.1	30.0	33.3
Dep. Max. Temp.	0.5		0.5		1.6		2.8		3.3	
Min. Temp.	8.9	7.7	8.9	8.3	4.4	4.4	6.6	5.0	6.6	6.1
Inc. Min. Temp.	1.2		0.6		0.0		1.6		0.5	
Max. R.H.	100	100	100	100	100	100	100	100	100	99
% Inc. Max. R.H.	0.0%		0.0%		0.0%		0.0%		1.0%	
Min. R.H.	56	45	60	49	43	40	32	32	42	34
% Inc. Min. R.H.	24.4%		22.4%		7.5%		0.0%		23.5%	
Sol. Rad.	145.8	996.3	356.4	437.4	453.6	664.2	145.8	648.0	251.1	688.5
% Dec. Sol. Rad.	85.4%		18.5%		39.7%		77.5%		63.5%	
Plot 19										
Max. Temp.	21.1	22.8	23.9	25.6	28.8	28.8	24.4	25.6	21.1	21.1
Dep. Max. Temp.	1.7		1.7		0.0		1.2		0.0	
Min. Temp.	11.1	11.1	8.3	7.7	13.3	13.3	9.4	8.9	5.0	4.4
Inc. Min. Temp.	0.0		0.6		0.0		0.5		0.6	
Max. R.H.	100	97	100	98	100	95	98	98	98	98
% Inc. Max. R.H.	3.1%		2.4%		5.3%		0.0%		0.0%	
Min. R.H.	47	40	44	42	35	33	50	50	35	35
% Inc. Min. R.H.	17.5%		4.8%		6.1%		0.0%		0.0%	
Sol. Rad.	56.7	267.3	56.7	372.6	81.0	380.7	48.6	372.6	121.5	356.4
% Dec. Sol. Rad.	78.8%		84.8%		78.7%		87.0%		65.9%	
Plot 20										
Max. Temp.	17.2	21.1	20.6	25.6	23.9	27.2	26.7	31.6	20.6	23.9
Dep. Max. Temp.	3.9		5.0		4.7		4.9		3.3	
Min. Temp.	10.0	10.0	11.1	10.6	7.7	6.1	12.2	12.2	5.5	5.0
Inc. Min. Temp.	0.0		0.5		1.6		0.0		0.5	
Max. R.H.	100	83	97	82	96	79	100	82	98	79
% Inc. Max. R.H.	20.5%		18.3%		21.5%		22.0%		24.1%	
Min. R.H.	90	55	55	28	48	24	43	20	68	33
% Inc. Min. R.H.	63.6%		96.4%		100.0%		85.0%		106.1%	
Sol. Rad.	72.9	299.7	40.5	291.6	32.4	307.8	24.3	340.2	64.8	502.2
% Dec. Sol. Rad.	75.7%		86.1%		89.5%		92.9%		87.1%	

APPENDIX D: SOIL DATA

D1: Mechanical analysis of soils by the hydrometer method
- a) Method
- b) Calculation
- c) Results
  - i) Percent by weight of coarse fraction (Over 2 mm diam.)
  - ii) Textural analysis

D2: Soil chemical data
- a) Analytical methods
  - i) Exchangeable cations
  - ii) Cation exchange capacity
  - iii) Soil acidity
  - iv) Soil carbon by Leco induction furnace
  - v) Available lead and zinc
- b) Results
  - i) Macro-nutrients (sodium, potassium, calcium, and magnesium)
  - ii) Available lead and zinc, organic matter, soil acidity, and exchange capacity

D3: Soil moisture data (in percent) for the period May 31st to September 27th
- i) Weekly readings
- ii) Mean monthly soil moisture

D4: Soil temperature data (°C) for the period May 31st to September 27th
- i) Weekly readings
- ii) Mean monthly soil temperature

D5: Soil profile descriptions

D1: MECHANICAL ANALYSIS OF SOILS BY THE HYDROMETER METHOD

a) Method

1. Soil material is sieved through a standard 2 mm sieve.
2. Weight of coarse fraction (material greater than 2 mm diam.) is recorded as a percentage of the total weight of the soil sample.
3. 100 g of oven dry soil (less than 2 mm diam.) is added to the dispersing cup together with distilled water and 100 ml of "Calgon" dispersing agent.
4. Where necessary, organic matter is oxidised with hydrogen peroxide.
5. Mixture stirred for 5 min. then transferred to 1,000 ml cylinder and sufficient water added to bring level to the 1,000 ml graduation and then vigorously shaken.
6. The hydrometer is read after 40 sec. for calculation of the sand fraction, and after 60 min. for calculation of the clay fraction, and the readings are corrected for temperature.

b) Calculation

$$\text{Coarse fraction} = \frac{\text{weight (g) of material over 2 mm diam.}}{\text{total weight (g) of soil}} \times 100$$

$$\text{\% sand} = 100 - \left(\frac{\text{corrected hydrometer reading at 40 sec.}}{\text{weight of oven dry soil (g)}} \times 100\right)$$

$$\text{\% clay} = \frac{\text{corrected hydrometer reading at 60 min.}}{\text{weight of oven dry soil (g)}} \times 100$$

$$\text{\% silt} = (\text{\% sand} + \text{\% clay})$$

c) Results

i) Percent by weight of coarse fraction (over 2 mm diam.)

Plot 1	
5 cm	0.0%
15 cm	21.7%
30 cm	50.4%
60 cm	79.9%

Plot 5	
5 cm	0.0%
15 cm	0.0%
30 cm	0.0%
60 cm	0.0%

Plot 10	
5 cm	4.0%
15 cm	16.9%
30 cm	24.9%
60 cm	51.3%

Plot 15	
5 cm	1.0%
15 cm	2.4%
30 cm	9.6%
60 cm	14.1%

Plot 20	
5 cm	0.0%
15 cm	0.0%
30 cm	0.0%
60 cm	0.0%

ii) Textural analysis

	% sand	% silt	% clay
Plot 1			
5 cm	52.0	30.2	17.8
15 cm	38.4	46.0	15.6
30 cm	47.4	41.0	11.6
60 cm	56.4	32.0	11.6
Plot 5			
5 cm	52.6	35.0	12.4
15 cm	49.4	34.0	16.6
30 cm	44.4	38.0	17.6
60 cm	55.4	29.0	15.6
Plot 10			
5 cm	50.4	39.0	10.6
15 cm	46.4	42.0	11.6
30 cm	50.4	38.0	11.6
60 cm	57.4	31.0	11.6
Plot 15			
5 cm	62.4	27.0	10.6
15 cm	66.4	24.0	9.6
30 cm	68.4	23.0	8.6
60 cm	82.4	11.0	6.6
Plot 20			
5 cm	73.2	14.0	12.8
15 cm	76.4	14.0	9.6
30 cm	79.4	13.0	7.6
60 cm	80.4	13.0	6.6

D2: SOIL CHEMICAL DATA*

a) Analytical methods

i) Exchangeable cations

1. Soil saturated with 1.0 N ammonium acetate of pH 7.
2. Extraction of ammonium acetate solution containing exchangeable cations.
3. Determination of sodium, potassium, calcium, and magnesium by atomic absorption spectrophotometer.

ii) Cation exchange capacity

1. Soil saturated with potassium chloride, 1.0 N.
2. Free potassium chloride washed out with a 1:1 solution of ethyl alcohol and water.
3. Exchange of potassium by sodium using a 1.0 N sodium chloride solution.
4. Determination of potassium in sodium chloride solution by atomic absorption spectrophotometer.

iii) Soil acidity

1. Suspension made of 1 part soil to 2 parts water.
2. Soil acidity measured with glass electrode pH meter.

iv) Soil carbon by Leco induction furnace

1. High temperature combustion and collection of combustion gases in volumetric burette.
2. Gases passed over potassium hydroxide and carbon dioxide is absorbed.
3. Difference between original volume and final volume equals amount of carbon dioxide generated during combustion.
4. Direct reading of burette calibrated in % carbon provides measure of soil carbon.

v) Available lead and zinc

1. Soil shaken for 1 hour with 0.1 N hydrochloric acid.
2. Extract obtained by filtration.
3. Available lead and zinc determined by atomic absorption spectrophotometer.

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*Analyses were conducted at the University of British Columbia Soils Laboratory.

b) Results

i) Macro-nutrients

	Sodium (me/100g)	Potassium (me/100g)	Calcium (me/100g)	Magnesium (me/100g)
Plot 1				
5 cm	0.24	0.88	7.92	1.14
15 cm	0.17	0.39	1.19	0.42
30 cm	0.14	0.27	1.43	0.30
60 cm	0.16	0.18	1.20	0.21
Plot 2				
5 cm	0.32	0.66	0.80	0.39
15 cm	0.16	0.14	0.31	0.05
Plot 3				
5 cm	0.71	0.72	7.56	1.47
15 cm	0.16	0.34	0.97	0.12
Plot 4				
5 cm	0.17	1.33	8.25	1.65
15 cm	0.13	0.31	0.59	0.08
Plot 5				
5 cm	0.79	1.10	3.40	5.40
15 cm	0.14	0.20	4.40	0.84
30 cm	0.14	0.09	2.55	0.57
60 cm	0.16	0.07	4.84	0.77
Plot 6				
5 cm	0.78	1.15	6.50	4.40
15 cm	0.17	0.41	0.62	0.28
30 cm	0.17	0.26	0.94	0.18
Plot 7				
5 cm	0.19	0.36	1.80	0.39
15 cm	0.14	0.30	0.78	0.13
Plot 8				
5 cm	0.30	0.26	1.05	0.13
15 cm	0.16	0.37	0.61	0.16
Plot 9				
5 cm	0.17	0.49	1.27	0.29
15 cm	0.11	0.30	0.78	0.13
30 cm	0.26	0.32	1.39	0.13

	Sodium (me/100g)	Potassium (me/100g)	Calcium (me/100g)	Magnesium (me/100g)
Plot 10				
5 cm	0.15	0.15	0.51	0.08
15 cm	0.14	0.23	0.63	0.11
30 cm	0.21	0.32	1.09	0.15
60 cm	0.25	0.25	0.79	0.09
Plot 11				
5 cm	0.17	0.23	0.51	0.08
15 cm	0.17	0.26	0.43	0.06
Plot 12				
5 cm	0.16	0.18	0.32	0.06
15 cm	0.16	0.13	0.23	0.02
Plot 13				
5 cm	0.11	0.13	0.48	0.06
15 cm	0.21	0.13	0.44	0.03
30 cm	0.17	0.17	0.97	0.09
Plot 14				
5 cm	0.23	0.17	0.45	0.06
15 cm	0.14	0.21	0.89	0.08
Plot 15				
5 cm	0.16	0.23	0.41	0.05
15 cm	0.20	0.18	0.41	0.04
30 cm	0.22	0.15	0.62	0.07
Plot 16				
5 cm	0.14	0.26	1.01	0.21
15 cm	0.17	0.20	0.50	0.14
30 cm	0.15	0.15	1.15	0.17
Plot 17				
5 cm	0.13	0.18	1.61	0.19
15 cm	0.10	0.17	1.13	0.14
Plot 18				
5 cm	0.14	0.25	1.43	0.22
15 cm	0.15	0.20	0.99	0.21
30 cm	0.21	0.15	1.06	0.19
Plot 19				
5 cm	0.21	0.88	11.88	2.31
15 cm	0.14	0.41	2.52	0.44
Plot 20				
5 cm	0.46	0.92	17.90	3.44
15 cm	0.17	0.27	1.19	0.22
30 cm	0.16	0.34	1.09	0.18
60 cm	0.15	0.44	0.97	0.20

ii) Available lead and zinc, organic matter, soil acidity, and exchange capacity

	Available lead (ppm)	Available zinc (ppm)	% carbon	Soil acidity	C.E.C. (me/100g)
Plot 1					
5 cm	265	2350	8.4	5.3	36.5
15 cm	0	90	2.7	5.5	23.0
30 cm	10	10	3.0	5.7	15.0
60 cm	0	10	0.9	5.6	-
Plot 2					
5 cm	700	2820	8.5	4.3	34.5
15 cm	10	180	0.6	4.4	-
Plot 3					
5 cm	680	3450	9.8	4.6	-
15 cm	105	400	3.5	4.9	-
Plot 4					
5 cm	1050	4600	20.0	5.0	56.5
15 cm	0	480	2.0	5.0	-
Plot 5					
5 cm	880	4750	21.7	5.1	74.0
15 cm	30	820	1.0	4.8	10.5
30 cm	0	50	0.0	5.6	10.0
60 cm	0	60	0.0	5.7	-
Plot 6					
5 cm	2050	4800	21.9	4.3	-
15 cm	0	780	0.9	5.0	-
30 cm	0	340	0.6	4.7	-
Plot 7					
5 cm	1600	4260	10.3	4.3	-
15 cm	10	1900	3.0	5.4	-
Plot 8					
5 cm	1140	3070	5.7	4.2	-
15 cm	770	1260	5.0	4.5	-
Plot 9					
5 cm	750	2090	5.0	4.4	-
15 cm	10	1900	3.0	5.4	-
30 cm	0	1150	0.2	5.4	-

	Available lead (ppm)	Available zinc (ppm)	% carbon	Soil acidity	C.E.C. (me/100g)
Plot 10					
5 cm	2950	1280	4.4	4.2	7.0
15 cm	40	2900	2.1	5.0	12.5
30 cm	40	330	0.9	5.4	15.5
60 cm	10	1140	0.7	5.3	-
Plot 11					
5 cm	2600	1600	3.6	3.9	-
15 cm	920	1420	1.3	4.3	-
Plot 12					
5 cm	1600	490	1.5	3.6	-
15 cm	90	280	0.7	4.1	-
Plot 13					
5 cm	2150	780	3.5	3.9	14.0
15 cm	0	1150	1.6	4.6	-
30 cm	0	2250	0.0	5.1	-
Plot 14					
5 cm	1400	980	4.8	3.8	-
15 cm	55	3250	2.9	4.9	-
Plot 15					
5 cm	485	440	2.5	4.1	11.0
15 cm	10	350	1.2	4.5	-
30 cm	0	1140	0.0	5.1	-
Plot 16					
5 cm	420	980	6.2	4.4	15.0
15 cm	0	580	0.4	4.6	-
30 cm	0	400	0.0	4.9	-
Plot 17					
Plot 17					
5 cm	530	1420	4.5	4.4	-
15 cm	55	2020	3.1	4.9	-
Plot 18					
5 cm	420	1560	4.4	4.2	14.0
15 cm	10	630	1.6	5.0	-
30 cm	0	140	0.0	5.2	-
Plot 19					
5 cm	290	3260	10.5	4.7	-
15 cm	10	180	1.7	5.6	-
Plot 20					
5	580	4280	16.8	4.5	49.0
15 cm	45	540	2.8	4.9	8.5
30 cm	0	300	0.5	5.4	8.0
60 cm	0	10	0.0	5.5	-

D3: SOIL MOISTURE DATA (IN PERCENT) FOR THE PERIOD MAY 31ST TO SEPTEMBER 27TH

i) <u>Weekly readings</u>

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 1				**Plot 2**			
May 31	22.5	13.5	10.5		9.0	9.5	17.0
June 7	23.5	13.5	10.5		9.0	9.5	10.5
June 14	27.0	13.0	9.0		13.5	10.0	10.5
June 21	26.0	14.0	9.0		18.0	9.5	9.5
June 28	38.0	13.5	9.5		17.0	9.5	9.0
July 5	36.5	12.0	8.0		14.0	9.5	9.0
July 12	38.0	12.5	8.0		10.0	9.5	9.5
July 19	34.0	12.0	7.5		10.0	9.0	9.0
July 26	26.0	11.5	7.0		9.0	8.5	9.0
Aug. 2	23.0	10.5	7.0		8.0	8.0	9.0
Aug. 9	20.0	10.0	7.5		10.0	7.5	9.0
Aug. 16	20.0	9.5	7.5		7.5	7.0	8.5
Aug. 23	25.0	9.5	7.0		9.0	7.0	8.5
Aug. 30	20.0	9.5	8.0		7.0	6.5	8.5
Sept. 6	25.5	10.0	8.0		10.5	6.5	8.5
Sept. 13	23.5	10.0	8.5		12.0	5.5	8.5
Sept. 20	20.5	9.5	8.5		11.0	9.0	8.5
Sept. 27	23.5	10.0	8.5		10.0	9.0	9.0
Plot 3				**Plot 4**			
May 31	7.5	5.0	2.5		12.0	8.5	3.0
June 7	7.5	5.0	3.5		12.0	9.5	3.0
June 14	24.5	5.0	4.5		22.0	11.5	3.0
June 21	15.0	5.0	4.5		15.0	11.0	3.0
June 28	21.0	3.0	4.5		17.0	14.0	3.0
July 5	13.0	3.0	4.0		14.0	11.5	3.0
July 12	11.5	3.0	4.5		12.5	11.0	3.0
July 19	9.0	3.0	4.5		13.0	10.5	2.5
July 26	6.0	2.5	4.5		11.0	8.0	2.5
Aug. 2	4.5	2.5	4.0		10.0	7.0	2.0
Aug. 9	4.5	2.5	3.5		10.0	6.5	1.0
Aug. 16	4.5	2.5	3.5		9.5	6.5	1.0
Aug. 23	11.0	2.5	3.0		10.0	6.0	1.0
Aug. 30	11.0	2.5	3.0		10.0	6.0	1.0
Sept. 6	30.0	5.0	2.5		12.5	6.0	1.0
Sept. 13	25.0	3.0	2.5		11.5	6.5	1.0
Sept. 20	28.0	2.5	2.5		14.5	6.0	1.0
Sept. 27	27.0	2.5	3.5		11.0	6.0	1.0

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 5				**Plot 6**			
May 31	25.5	7.0	17.5		9.5	8.5	5.5
June 7	28.5	7.5	15.0		10.5	8.5	6.0
June 14	22.5	8.0	14.5		12.0	9.0	6.0
June 21	22.0	8.0	14.0		11.5	8.5	6.0
June 28	22.0	9.0	13.5		15.0	9.0	6.0
July 5	17.5	8.5	13.0		13.0	9.0	5.5
July 12	24.5	8.5	13.0		15.0	9.0	5.5
July 19	17.0	8.5	13.0		12.0	8.0	5.5
July 26	13.5	8.0	12.5		11.0	8.5	5.5
Aug. 2	11.0	6.5	11.5		8.5	8.0	5.5
Aug. 9	8.0	5.0	10.5		7.0	7.0	5.5
Aug. 16	7.5	3.5	10.0		6.0	6.5	5.0
Aug. 23	12.5	3.5	10.0		5.5	6.0	5.0
Aug. 30	11.0	3.5	10.0		5.5	5.0	5.0
Sept. 6	17.0	5.5	11.0		8.5	6.0	5.0
Sept. 13	13.0	5.0	10.0		9.0	7.5	5.5
Sept. 20	11.5	4.5	10.0		8.5	7.5	5.0
Sept. 27	11.5	4.0	10.0		7.0	7.0	5.0
Plot 7				**Plot 8**			
May 31	24.0	20.0	20.0		41.0	27.0	24.0
June 7	24.0	17.5	20.5		46.0	37.0	24.0
June 14	23.5	17.5	20.5		43.0	36.5	24.0
June 21	22.5	18.0	20.0		42.0	35.0	24.0
June 28	22.0	18.0	19.5		43.0	35.0	23.5
June 5	21.5	17.5	18.5		41.0	35.0	23.5
July 12	21.5	17.5	18.5		43.0	35.0	23.0
July 19	21.5	17.5	18.0		39.0	33.0	23.0
July 26	21.0	17.0	16.5		36.0	29.0	23.0
Aug. 2	20.0	16.5	14.0		31.5	27.0	31.5
Aug. 9	19.5	14.0	11.0		30.5	25.5	21.0
Aug. 16	19.0	11.0	9.5		30.0	24.5	18.0
Aug. 23	19.0	10.5	8.0		41.0	23.5	18.0
Aug. 30	19.0	10.5	8.0		30.0	22.5	18.0
Sept. 6	19.0	11.5	7.5		44.0	23.0	18.0
Sept. 13	19.0	11.5	7.5		33.0	23.5	18.0
Sept. 20	19.0	11.5	7.0		37.0	26.5	18.0
Sept. 27	19.0	11.5	7.0		31.5	27.5	18.0

		Depth				Depth	
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 9				**Plot 10**			
May 31	9.5	7.0	6.0		19.0	20.0	14.0
June 7	9.5	7.5	6.5		18.5	21.5	13.0
June 14	11.0	8.0	6.5		20.5	24.5	14.0
June 21	13.0	8.0	6.0		24.0	26.5	13.0
June 28	13.5	8.0	6.0		23.0	24.0	13.0
July 5	13.5	8.0	6.5		23.0	22.0	13.0
July 12	15.0	8.0	6.5		23.0	22.0	12.5
July 19	9.5	8.0	6.0		23.0	21.0	10.5
July 26	9.0	7.5	6.0		19.5	18.0	9.0
Aug. 2	8.5	7.0	5.5		16.0	15.0	8.0
Aug. 9	8.0	6.5	5.5		10.0	13.0	7.0
Aug. 16	8.0	6.5	5.5		9.0	12.0	5.0
Aug. 23	8.0	6.5	5.0		9.0	12.0	6.0
Aug. 30	8.5	6.5	5.0		9.0	11.0	5.0
Sept. 6	11.5	7.0	5.0		22.0	12.0	5.5
Sept. 13	11.0	7.0	5.0		18.5	12.0	5.5
Sept. 20	11.0	8.0	5.0		12.5	12.5	5.5
Sept. 27	21.0	15.0	6.5		22.0	20.0	7.5
Plot 11				**Plot 12**			
May 31	25.0	19.0	23.5		11.5	4.5	7.5
June 7	28.0	21.0	24.0		14.5	7.0	7.5
June 14	31.5	21.5	24.0		14.0	9.0	7.5
June 21	31.5	22.0	24.0		13.5	9.5	7.0
June 28	32.5	22.0	24.0		13.0	10.0	7.0
July 5	33.5	22.0	23.0		14.0	10.0	6.0
July 12	33.5	22.0	23.5		13.5	10.0	6.0
July 19	30.0	21.5	23.0		13.0	10.0	5.0
July 26	30.0	21.0	22.0		12.5	10.0	5.0
Aug. 2	27.0	16.5	21.5		12.0	10.0	5.0
Aug. 9	25.5	14.0	20.5		12.0	10.0	5.0
Aug. 16	24.0	13.0	20.0		12.0	10.0	5.0
Aug. 23	25.0	12.0	18.0		11.5	10.0	5.0
Aug. 30	24.5	10.5	17.0		11.5	10.0	5.0
Sept. 6	23.0	15.5	20.5		13.0	10.5	5.0
Sept. 13	34.0	19.0	21.5		13.0	10.5	5.5
Sept. 20	34.0	20.5	22.0		13.0	12.0	5.5
Sept. 27	34.0	30.5	22.0		14.0	15.5	6.0

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 13				Plot 14			
May 31	9.5	10.0	3.5		12.0	13.0	2.0
June 7	11.0	11.5	4.0		16.5	13.0	2.0
June 14	12.0	16.0	4.0		16.5	15.0	3.0
June 21	11.5	17.5	4.0		16.5	14.0	3.5
June 28	13.0	17.0	4.0		15.0	12.0	3.0
July 5	13.0	16.5	3.5		14.5	11.5	2.0
July 12	14.0	19.0	4.0		14.0	12.0	2.0
July 19	12.0	17.0	3.5		14.5	11.0	2.0
July 26	10.5	12.0	3.5		12.5	11.5	2.0
Aug. 2	9.5	10.5	3.0		10.5	11.0	2.0
Aug. 9	8.5	10.0	2.5		9.0	10.0	1.5
Aug. 16	7.5	10.0	2.5		6.0	9.0	1.5
Aug. 23	7.0	10.0	2.5		8.0	8.0	1.0
Aug. 30	7.0	10.0	2.5		5.5	5.0	1.0
Sept. 6	9.5	10.0	2.5		12.0	9.0	1.5
Sept. 13	9.5	10.0	2.5		10.5	10.0	1.5
Sept. 20	10.5	10.0	2.5		9.5	10.0	1.5
Sept. 27	10.5	10.0	2.5		10.0	10.0	1.5
Plot 15				Plot 16			
May 31	14.0	27.5	2.0		27.5	21.0	22.5
June 7	21.5	28.5	2.5		25.5	22.0	23.5
June 14	15.5	29.0	3.5		27.5	23.5	25.0
June 21	15.0	29.0	4.0		25.0	23.5	22.5
June 28	15.5	29.0	3.0		21.0	23.0	23.0
July 5	15.5	29.0	4.0		19.0	22.0	21.5
July 12	15.5	29.0	4.5		20.0	23.0	23.5
July 19	14.5	28.0	4.5		20.0	25.5	19.5
July 26	13.0	27.0	4.0		18.0	22.5	16.0
Aug. 2	11.5	26.5	3.0		17.0	22.0	14.0
Aug. 9	11.0	25.5	2.5		16.0	21.5	13.0
Aug. 16	11.0	25.5	3.0		14.5	19.0	12.0
Aug. 23	11.0	25.0	3.0		14.0	18.0	11.5
Aug. 30	11.0	23.0	3.5		14.0	16.0	11.0
Sept. 6	12.0	27.0	4.5		14.5	18.0	11.5
Sept. 13	12.0	27.5	5.0		15.0	20.0	12.5
Sept. 20	12.0	26.5	6.5		17.5	21.5	13.0
Sept. 27	12.0	25.0	10.0		18.0	21.5	14.5

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 17				Plot 18			
May 31	10.0	15.0	10.0		4.0	0.5	0.5
June 7	16.0	20.0	10.0		12.5	0.5	0.5
June 14	19.0	22.0	10.5		8.5	0.5	0.5
June 21	14.0	15.5	11.0		7.5	1.0	1.0
June 28	14.0	14.0	10.5		10.0	1.0	1.0
July 5	13.0	11.0	10.0		8.0	1.0	1.0
July 12	15.0	14.0	10.0		7.0	0.5	0.5
July 19	11.0	11.0	10.0		2.5	0.5	0.5
July 26	9.0	7.5	9.0		1.0	0.5	0.5
Aug. 2	5.0	5.5	5.5		0.5	0.5	0.5
Aug. 9	4.5	5.4	5.0		0.5	0.5	0.5
Aug. 16	4.5	5.5	4.5		0.5	0.5	0.5
Aug. 23	4.5	4.5	4.5		0.5	0.5	0.5
Aug. 30	4.5	4.5	4.5		0.5	0.5	0.5
Sept. 6	14.5	9.5	4.5		9.5	0.5	0.5
Sept. 13	11.5	8.0	4.5		7.0	0.5	0.5
Sept. 20	10.0	7.5	4.5		8.0	0.5	0.5
Sept. 27	10.5	8.5	5.5		9.0	0.5	0.5
Plot 19				Plot 20			
May 31	4.5	3.0	4.0		16.0	12.0	1.0
June 7	4.5	2.0	4.0		16.0	12.0	1.0
June 14	4.5	1.5	3.5		11.0	12.5	1.0
June 21	5.5	0.5	3.5		12.0	12.0	1.0
June 28	5.5	0.5	3.5		15.0	8.0	1.0
July 5	6.0	1.0	3.0		14.0	7.0	1.0
July 12	6.5	1.0	3.0		14.5	6.0	1.0
July 19	5.5	1.0	2.5		6.5	5.0	1.0
July 26	5.5	1.0	2.5		4.0	3.0	1.0
Aug. 2	4.5	1.0	2.0		4.0	3.0	1.0
Aug. 9	4.5	1.0	2.0		3.0	2.5	1.0
Aug. 16	4.0	1.0	1.5		3.0	2.0	1.0
Aug. 23	9.0	1.0	1.5		6.5	2.0	1.0
Aug. 30	8.5	1.0	1.5		3.0	3.0	1.0
Sept. 6	13.5	1.0	1.5		10.0	7.0	1.0
Sept. 12	10.5	1.0	1.5		6.5	8.0	1.0
Sept. 20	10.5	1.0	1.5		5.5	3.0	1.0
Sept. 27	15.5	1.0	1.5		5.5	3.0	1.0

ii) Mean monthly soil moisture (in percent)

	June	July	Aug.	Sept.	Average
Plot 1					
10 cm	27.4	33.6	21.6	23.3	26.3
30 cm	13.5	12.0	9.8	9.9	11.3
60 cm	9.7	7.6	7.4	8.4	8.3
Plot 2					
10 cm	13.3	10.8	8.3	10.9	10.8
30 cm	9.6	9.1	7.2	8.5	8.6
60 cm	11.3	9.1	8.7	8.6	9.5
Plot 3					
10 cm	15.1	9.9	7.1	27.5	14.9
30 cm	4.6	2.9	2.5	3.3	3.3
60 cm	3.9	4.4	3.4	2.8	3.6
Plot 4					
10 cm	15.6	12.6	9.1	12.4	12.4
30 cm	10.9	10.3	6.4	6.1	8.4
60 cm	3.0	2.8	1.2	1.0	2.0
Plot 5					
10 cm	24.1	8.1	10.0	13.3	14.8
30 cm	7.9	8.4	4.4	4.8	6.3
60 cm	14.9	12.9	10.4	10.3	12.2
Plot 6					
10 cm	11.7	12.8	6.5	8.3	9.7
30 cm	8.7	8.6	6.5	7.0	7.7
60 cm	5.9	5.5	5.2	5.0	5.4
Plot 7					
10 cm	23.2	21.4	19.3	19.0	20.7
30 cm	18.4	17.4	12.5	11.5	15.0
60 cm	20.1	17.9	10.1	7.3	14.0
Plot 8					
10 cm	43.0	39.8	32.6	36.4	37.9
30 cm	34.1	33.0	24.6	25.1	29.2
60 cm	23.9	23.1	19.3	18.0	21.1
Plot 9					
10 cm	11.3	11.7	8.2	13.6	11.1
30 cm	7.7	7.9	6.6	7.4	7.8
60 cm	6.2	6.3	5.3	5.4	5.8
Plot 10					
10 cm	21.0	22.1	10.6	15.0	17.9
30 cm	23.3	20.8	12.6	14.1	17.7
60 cm	13.4	11.3	6.2	6.0	9.3

	June	July	Aug.	Sept.	Average
Plot 11					
10 cm	29.7	31.8	25.2	31.3	29.3
30 cm	21.1	21.6	13.2	18.9	18.5
60 cm	23.9	22.9	19.4	21.5	21.9
Plot 12					
10 cm	13.3	13.3	11.8	13.3	12.9
30 cm	8.0	10.0	10.0	12.1	9.9
60 cm	7.3	5.5	5.0	5.5	5.9
Plot 13					
10 cm	11.4	12.4	7.9	10.0	10.3
30 cm	14.4	16.1	10.1	10.0	12.6
60 cm	3.9	3.6	3.6	3.5	3.2
Plot 14					
10 cm	15.3	13.9	7.8	10.5	11.8
30 cm	13.4	11.5	8.6	9.8	10.8
60 cm	2.7	2.0	1.4	1.5	1.9
Plot 15					
10 cm	16.3	14.6	11.1	12.0	13.5
30 cm	28.6	28.3	25.1	26.5	27.1
60 cm	3.0	4.3	3.0	6.5	4.1
Plot 16					
10 cm	25.3	19.3	15.1	16.3	19.1
30 cm	22.6	23.3	19.3	20.3	21.3
60 cm	23.3	20.1	12.3	12.9	17.2
Plot 17					
10 cm	14.6	12.0	4.6	11.6	10.6
30 cm	17.3	10.9	6.1	8.4	10.5
60 cm	10.4	9.8	4.1	4.8	7.4
Plot 18					
10 cm	8.5	4.6	0.5	8.4	5.4
30 cm	0.7	0.6	0.5	0.5	0.6
60 cm	0.7	0.6	0.5	0.5	0.6
Plot 19					
10 cm	4.9	5.9	6.1	12.5	7.1
30 cm	2.2	1.0	1.0	1.0	1.3
60 cm	0.1	2.8	1.7	1.5	2.4
Plot 20					
10 cm	14.0	9.8	3.9	6.9	8.7
30 cm	11.3	5.3	2.3	5.3	6.1
60 cm	1.0	1.0	1.0	1.0	1.0

D4: SOIL TEMPERATURE DATA (°C) FOR THE PERIOD MAY 31ST TO SEPTEMBER 27TH

i) Weekly readings

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 1				Plot 2			
May 31	10.9	8.3	6.7		11.7	10.0	8.9
June 7	10.6	8.9	6.7		12.5	11.4	10.3
June 14	10.6	9.2	7.5		10.0	11.4	11.1
June 21	10.6	9.7	7.5		12.5	12.0	11.1
June 28	9.4	9.7	8.0		10.6	12.2	11.7
July 5	10.6	10.0	8.0		12.2	12.2	11.7
July 12	9.4	10.0	8.0		10.6	11.7	11.7
July 19	13.6	12.5	9.2		14.4	13.6	12.2
July 26	14.4	13.6	11.1		14.4	15.3	13.9
Aug. 2	16.4	14.7	11.4		16.7	16.1	13.9
Aug. 9	15.6	14.7	11.7		15.6	16.1	14.4
Aug. 16	14.7	13.6	11.7		13.3	14.4	13.9
Aug. 23	12.8	13.3	11.7		12.2	13.9	13.3
Aug. 30	15.6	13.6	11.4		14.4	13.9	13.3
Sept. 6	13.6	12.5	11.1		13.3	13.3	13.3
Sept. 13	11.7	10.6	11.1		11.7	13.3	12.8
Sept. 20	9.7	8.9	8.3		8.9	10.0	11.1
Sept. 27	9.7	9.2	8.9		10.9	11.7	11.7
Plot 3				Plot 4			
May 31	12.8	7.5	7.5		10.0	9.2	7.2
June 7	12.2	9.4	9.2		10.6	10.6	7.5
June 14	11.1	8.9	8.3		9.7	10.9	9.4
June 21	12.8	9.2	9.4		11.7	12.2	9.4
June 28	11.7	9.2	9.4		10.6	13.3	9.4
July 5	12.2	10.0	9.4		11.4	13.3	9.4
July 12	11.7	9.2	9.4		10.6	12.2	9.4
July 19	15.0	11.7	10.6		13.6	14.4	10.6
July 26	14.7	11.7	11.1		13.9	14.4	11.1
Aug. 2	16.4	12.8	11.7		16.1	15.6	11.4
Aug. 9	15.0	12.8	11.7		15.3	16.1	11.7
Aug. 16	13.3	11.7	11.1		13.6	15.0	11.7
Aug. 23	13.3	11.4	11.1		13.3	13.9	11.1
Aug. 30	14.7	11.7	11.4		15.3	15.6	11.7
Sept. 6	14.2	11.4	11.4		13.3	13.9	11.4
Sept. 13	12.2	11.1	11.4		12.0	13.9	11.7
Sept. 20	9.7	9.4	10.6		9.7	10.6	10.0
Sept. 27	10.6	9.2	10.6		9.7	10.9	10.0

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 5				**Plot 6**			
May 31	11.7	9.2	7.8		11.1	8.6	8.6
June 7	11.1	10.9	10.0		11.1	9.7	8.3
June 14	8.9	10.0	8.3		11.1	10.6	9.4
June 21	12.0	10.9	9.4		12.2	11.7	9.4
June 28	10.0	10.9	10.0		11.1	10.6	10.0
July 5	11.1	10.9	10.0		12.0	11.1	10.0
July 12	10.0	10.9	10.0		12.0	11.1	10.0
July 19	13.9	13.3	11.1		14.4	13.3	11.7
July 26	13.3	13.9	12.0		15.0	13.9	12.2
Aug. 2	15.0	15.0	12.0		16.1	15.0	12.8
Aug. 9	13.9	15.0	12.2		15.6	15.0	12.8
Aug. 16	12.0	13.9	12.0		15.0	13.3	12.2
Aug. 23	11.7	13.3	12.0		15.0	13.3	12.8
Aug. 30	14.2	14.2	12.0		15.0	13.9	13.1
Sept. 6	13.6	13.6	12.2		12.8	13.3	12.2
Sept. 13	10.3	13.3	12.0		12.8	13.1	13.1
Sept. 20	10.0	10.3	10.3		10.0	9.7	10.6
Sept. 27	9.4	11.4	10.0		10.6	10.6	11.4
Plot 7				**Plot 8**			
May 31	10.6	8.3	7.0		11.4	8.0	8.3
June 7	12.0	9.4	9.4		12.2	9.2	9.4
June 14	10.6	12.0	9.4		9.7	10.0	10.6
June 21	12.2	11.1	10.0		11.7	10.0	10.6
June 28	11.7	11.7	10.6		10.0	10.6	10.1
July 5	11.1	11.7	10.6		11.7	10.6	11.1
July 12	10.6	11.7	11.1		9.4	10.6	11.4
July 19	14.2	13.9	11.4		13.9	11.7	11.7
July 26	14.2	15.6	12.8		13.3	12.2	11.7
Aug. 2	16.7	16.1	13.6		16.7	13.3	12.8
Aug. 9	15.0	16.1	13.9		13.9	13.3	12.2
Aug. 16	13.3	15.6	16.1		11.7	12.2	12.8
Aug. 23	12.2	15.0	13.6		11.7	12.2	12.8
Aug. 30	15.3	15.6	13.6		15.0	12.8	12.2
Sept. 6	11.4	13.6	13.1		10.6	12.2	12.8
Sept. 13	11.4	13.6	12.8		9.2	11.7	12.2
Sept. 20	8.9	11.7	12.0		8.1	8.3	11.1
Sept. 27	8.9	11.7	13.6		8.1	10.6	11.1

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 9				Plot 10			
May 31	11.4	8.6	10.9		12.5	9.4	8.3
June 7	9.4	9.2	8.9		12.2	10.3	10.9
June 14	11.1	10.1	10.6		11.4	10.9	10.0
June 21	12.2	10.0	10.0		14.2	11.4	11.4
June 28	10.0	9.4	10.0		11.7	11.4	10.6
July 5	12.2	10.0	11.7		13.3	11.7	9.4
July 12	10.0	10.0	10.6		13.3	11.7	11.7
July 19	15.6	12.5	11.1		16.4	13.3	12.5
July 26	14.4	13.6	12.8		17.0	15.3	13.3
Aug. 2	17.8	13.6	12.8		21.7	15.3	14.4
Aug. 9	16.7	13.9	12.8		19.4	15.6	15.0
Aug. 16	15.6	12.5	12.2		19.4	15.3	15.0
Aug. 23	13.6	12.2	12.2		15.6	15.0	14.4
Aug. 30	15.6	13.3	12.8		17.8	16.4	15.0
Sept. 6	11.1	11.7	12.5		13.6	14.2	14.4
Sept. 13	11.1	11.4	12.0		15.3	15.0	14.4
Sept. 20	8.3	9.2	11.1		11.7	13.1	12.5
Sept. 27	10.3	10.6	10.9		13.3	13.9	12.8
Plot 11				Plot 12			
May 31	12.8	13.6	12.8		12.8	9.7	10.0
June 7	13.3	14.7	13.3		12.8	11.4	9.7
June 14	12.8	14.7	14.7		15.3	11.7	11.4
June 21	16.7	17.2	15.0		21.7	12.2	11.4
June 28	12.2	15.6	14.2		12.2	11.7	11.4
July 5	15.0	18.1	15.3		14.7	12.8	12.2
July 12	16.1	17.0	14.2		18.1	12.2	12.2
July 19	21.7	22.2	17.8		23.9	15.6	13.3
July 26	24.4	22.8	21.1		25.6	17.2	15.9
Aug. 2	23.3	25.0	20.0		26.4	18.1	16.4
Aug. 9	21.1	25.0	21.1		22.8	18.3	17.0
Aug. 16	20.0	23.3	21.1		18.1	17.0	16.7
Aug. 23	16.7	21.1	18.9		17.5	16.1	16.7
Aug. 30	19.4	22.2	18.9		18.3	17.2	16.1
Sept. 6	13.9	17.8	17.0		12.0	13.9	15.6
Sept. 13	12.8	17.0	15.3		11.4	13.6	15.0
Sept. 20	11.1	13.6	14.2		9.2	11.1	12.8
Sept. 27	11.1	14.7	13.3		8.9	10.3	12.8

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 13				Plot 14			
May 31	11.7	12.2	10.6		13.9	12.8	10.3
June 7	13.9	13.9	10.6		14.4	12.5	11.1
June 14	13.9	13.9	12.8		15.0	12.0	12.8
June 21	16.1	15.0	12.8		21.7	14.7	12.8
June 28	13.8	14.7	13.3		12.8	12.8	12.8
July 5	15.0	16.1	13.3		16.1	16.1	13.3
July 12	17.2	15.6	13.3		18.6	13.9	13.6
July 19	21.7	18.3	15.6		22.8	17.5	15.0
July 26	21.1	20.0	17.2		23.9	17.8	16.7
Aug. 2	21.7	21.7	18.3		22.2	20.0	18.1
Aug. 9	18.9	22.2	18.9		22.2	20.0	18.3
Aug. 16	17.2	21.7	18.3		18.9	18.9	18.3
Aug. 23	16.1	18.9	18.3		21.7	17.5	17.2
Aug. 30	18.9	18.9	18.3		19.4	18.3	17.2
Sept. 6	13.6	17.8	16.1		13.3	14.7	16.7
Sept. 13	12.0	16.4	15.6		13.9	13.9	14.4
Sept. 20	9.4	15.6	13.3		9.4	12.0	12.8
Sept. 27	10.3	13.9	12.2		10.0	11.7	12.5
Plot 15				Plot 16			
May 31	13.9	12.2	11.7		11.7	10.9	11.1
June 7	14.4	13.6	12.2		13.9	11.7	12.2
June 14	15.0	14.4	13.6		14.2	11.7	12.8
June 21	21.1	15.6	13.6		18.3	13.3	13.3
June 28	14.4	14.4	14.2		13.9	12.5	13.9
July 5	16.7	14.7	12.8		12.0	12.0	14.7
July 12	20.0	15.6	13.9		17.8	12.5	13.1
July 19	24.7	19.4	17.0		21.7	16.1	15.0
July 26	24.4	19.4	18.3		22.2	18.3	16.7
Aug. 2	24.4	23.9	19.2		22.8	16.7	16.7
Aug. 9	22.8	22.2	20.6		18.9	16.7	17.8
Aug. 16	18.9	22.0	17.0		16.7	15.0	16.7
Aug. 23	16.7	18.9	18.3		16.7	14.7	16.7
Aug. 30	20.0	20.0	18.3		17.8	15.3	15.6
Sept. 6	13.9	15.0	16.7		15.0	13.6	15.6
Sept. 13	11.1	12.5	15.9		12.8	12.5	14.2
Sept. 20	11.1	10.3	13.6		9.4	10.0	12.8
Sept. 27	10.3	10.6	13.3		11.1	10.6	12.8

	Depth				Depth		
	10 cm	30 cm	60 cm		10 cm	30 cm	60 cm
Plot 17				Plot 18			
May 31	10.9	11.1	8.3		12.8	11.7	12.8
June 7	11.7	12.2	9.4		13.3	10.6	11.4
June 14	11.7	12.0	10.0		16.1	16.1	14.4
June 21	15.3	13.9	10.0		19.2	15.0	15.6
June 28	14.4	12.2	10.3		11.4	12.8	15.0
July 5	11.7	13.6	10.6		14.4	14.4	16.1
July 12	13.9	13.6	10.6		19.4	14.4	15.0
July 19	18.3	16.4	11.7		22.5	17.2	17.8
July 26	18.3	16.4	12.8		23.9	20.3	19.7
Aug. 2	18.9	18.3	13.9		25.0	20.0	21.1
Aug. 9	17.2	18.3	13.9		22.8	20.6	21.1
Aug. 16	15.6	16.7	13.9		20.3	18.9	18.9
Aug. 23	14.7	16.1	13.9		18.3	17.3	17.8
Aug. 30	17.2	17.0	13.3		20.3	18.6	18.3
Sept. 6	12.5	15.0	12.5		15.0	15.3	15.9
Sept. 13	12.0	14.4	12.5		13.9	13.9	15.6
Sept. 20	9.4	11.4	10.0		10.6	11.1	12.2
Sept. 27	9.7	11.4	10.0		11.1	11.1	12.2
Plot 19				Plot 20			
May 31	12.2	11.1	10.6		11.1	9.7	8.9
June 7	12.8	11.1	10.6		12.2	9.7	8.9
June 14	14.2	11.4	11.7		13.6	10.9	9.4
June 21	17.8	12.8	12.2		16.7	11.1	10.0
June 28	13.3	11.1	12.5		12.2	10.6	10.0
July 5	13.9	12.5	12.5		12.5	11.1	10.0
July 12	14.4	12.0	12.5		12.5	11.1	10.6
July 19	18.3	15.0	13.9		16.7	13.3	11.1
July 26	18.9	15.0	15.0		16.7	14.4	12.5
Aug. 2	21.1	16.7	16.1		18.9	14.7	12.5
Aug. 9	21.1	16.7	16.1		18.3	14.7	12.8
Aug. 16	17.8	15.0	16.1		14.4	13.6	12.8
Aug. 23	16.7	14.4	15.0		13.3	13.3	12.5
Aug. 30	18.3	15.0	15.0		15.6	13.6	12.5
Sept. 6	13.6	12.8	13.9		10.0	12.2	11.7
Sept. 13	13.9	12.5	13.3		11.1	12.2	11.7
Sept. 20	9.4	9.4	10.6		8.9	10.6	9.4
Sept. 27	12.5	10.6	11.4		9.4	9.4	10.0

ii) Mean monthly soil temperatures (°C)

	June	July	Aug.	Sept.	Average
Plot 1					
10 cm	10.4	12.1	15.0	7.2	12.2
30 cm	9.1	11.6	14.0	10.3	11.3
60 cm	9.0	9.1	11.6	9.9	10.1
Plot 2					
10 cm	11.5	13.0	14.4	11.2	12.8
30 cm	11.4	13.3	14.9	10.3	12.5
60 cm	10.7	12.4	13.9	12.2	12.2
Plot 3					
10 cm	12.2	13.4	14.5	11.7	13.0
30 cm	8.8	10.7	12.1	10.3	10.5
60 cm	8.8	10.2	11.4	11.1	10.3
Plot 4					
10 cm	10.5	12.4	14.7	11.2	12.2
30 cm	11.0	14.9	15.2	12.3	13.0
60 cm	8.6	10.2	11.5	10.8	10.2
Plot 5					
10 cm	10.8	12.2	13.3	10.9	11.8
30 cm	10.4	12.2	14.3	10.9	12.0
60 cm	9.1	10.8	12.1	11.1	10.8
Plot 6					
10 cm	11.3	13.2	15.4	11.6	12.9
30 cm	10.2	12.5	14.1	11.7	12.2
60 cm	9.2	11.1	12.7	11.9	11.2
Plot 7					
10 cm	11.4	12.5	14.5	10.2	12.2
30 cm	10.5	13.3	15.7	12.6	13.0
60 cm	8.7	11.5	14.2	12.9	11.9
Plot 8					
10 cm	11.5	12.2	13.8	8.9	11.6
30 cm	9.5	11.3	12.8	10.8	11.1
60 cm	10.0	11.5	12.6	11.9	11.5
Plot 9					
10 cm	10.9	13.1	15.9	10.7	12.6
30 cm	9.4	11.6	13.2	10.8	11.2
60 cm	10.1	11.6	12.6	11.6	11.5
Plot 10					
10 cm	12.4	15.0	18.8	13.5	15.0
30 cm	10.7	13.0	15.5	14.1	13.3
60 cm	10.5	11.8	14.8	13.5	12.6

	June	July	Aug.	Sept.	Average
Plot 11					
10 cm	13.5	19.4	20.1	12.2	16.3
30 cm	15.2	20.0	23.3	15.8	18.7
60 cm	14.0	17.2	20.0	14.9	16.6
Plot 12					
10 cm	14.9	20.6	20.7	10.4	16.8
30 cm	11.3	14.4	17.3	12.2	13.9
60 cm	10.8	13.4	16.6	14.1	13.7
Plot 13					
10 cm	13.7	18.8	18.5	11.3	15.7
30 cm	14.0	17.5	20.7	16.0	17.1
60 cm	12.1	14.9	18.4	14.4	14.9
Plot 14					
10 cm	15.6	20.4	21.0	12.7	17.4
30 cm	13.0	16.3	19.0	13.1	15.4
60 cm	12.0	14.6	17.9	14.1	14.6
Plot 15					
10 cm	15.8	21.5	20.6	11.6	17.4
30 cm	14.1	17.3	21.4	12.2	16.4
60 cm	13.1	15.5	18.7	14.9	15.6
Plot 16					
10 cm	14.4	18.4	18.5	12.2	16.0
30 cm	12.1	14.7	15.7	11.7	13.5
60 cm	12.7	14.9	16.7	13.8	14.5
Plot 17					
10 cm	12.2	15.6	16.8	11.0	13.9
30 cm	12.3	15.0	17.3	13.1	14.4
60 cm	9.6	11.4	13.8	11.3	11.6
Plot 18					
10 cm	14.5	20.1	21.3	12.7	17.2
30 cm	13.3	16.6	19.1	12.7	15.5
60 cm	13.8	17.2	19.4	14.0	16.2
Plot 19					
10 cm	14.1	16.3	19.0	12.4	15.6
30 cm	11.5	13.6	15.6	11.3	13.1
60 cm	11.5	13.5	15.7	12.3	13.3
Plot 20					
10 cm	13.2	14.6	16.1	9.9	13.5
30 cm	10.4	12.5	14.0	11.1	12.1
60 cm	9.4	11.1	12.6	10.8	11.0

D5: SOIL PROFILE DESCRIPTIONS*

Plot 1 (Control site): 40 km north of Trail.

Horizon 1 (0-3 cm)	A thin layer of decomposing coniferous litter, merging with:
Horizon 2 (3-6 cm)	A very dark greyish brown (10YR 3/2) friable loam with a weakly developed medium crumb structure. Roots are common and of fine to small size. Sharp even boundary to:
Horizon 3 (6-30 cm)	Yellowish brown (10YR 5/6) gravelly loam of loose consistence and fine crumb structure. Roots are common in this horizon. Rounded pebbles 1-20 cm in length are abundant. Gradual transition to:
Horizon 4 (30+ cm)	Olive brown (2.5YR 4/4) gravelly sandy loam of loose consistence and fine crumb structure. Rounded pebbles 1-20 cm in length are common. Roots are absent from this zone.

Plot 5: 14.5 km north of Trail.

Horizon 1 (0-15 cm)	Decomposing coniferous litter. The fine roots of the ground cover are common. Gradual transition to:
Horizon 2 (15-25 cm)	Greyish brown (10YR 5/2) loam with a moderate sub-angular blocky structure giving peds ½-1 cm in size and of brittle consistence. Roots up to 5 cm diameter common. Gradual transition to:
Horizon 3 (25+ cm)	Light yellowish brown (2.5Y 6/4) sandy loam of similar structure and consistence to horizon 2. Roots rare. Coarse fragments are absent from the entire profile.

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*The profile descriptions follow the nomenclature outlined in Soil Survey Staff (1951) field handbook.

<u>Plot 10</u>: 3 km north of Trail.

Horizon 1 (0-8 cm)	Organic debris absent from the surface of this very dark grey (10YR 3/1) gravelly loam. The soil here exhibits a weakly developed medium crumb structure and is of loose consistence when dry. Small roots are present. Gradual transition to:
Horizon 2 (8-20 cm)	Dark yellowish brown (10YR 3/4) gravelly loam of similar structure and consistence to the overlying horizon. Pebbles 1-10 cm in length are common. Small roots present. Gradual transition to:
Horizon 3 (20+ cm)	Pale olive (5Y 6/3) gravelly sandy loam in which pebbles 1-15 cm in length are common. This horizon is of similar structure and consistence to that above. Roots are absent.

<u>Plot 15</u>: 9 km south of Trail.

Horizon 1 (0-2 cm)	Organic debris is absent from the surface of this dark greyish brown (10YR 4/2) gravelly sandy loam. The structure of this horizon is a weakly developed fine crumb. Consistence is loose when dry. Roots and pebbles are absent. Gradual transition to:
Horizon 2 (2-36 cm)	Yellowish brown (10YR 5/8) gravelly sandy loam of medium crumb structure. Consistence is loose when dry. Roots and pebbles absent. Gradual transition to:
Horizon 3 (36+ cm)	Yellowish brown (2.5Y 6/4) gravelly loamy sand. Structure and consistence is similar to that of the overlying horizon. Pebbles 1-5 cm in length are present. Roots are absent.

Plot 20: 23 km south of Trail.

Horizon 1 (0-4 cm)	Well decomposed layer of coniferous and deciduous litter giving a dark brown (7.5YR 3/2) colour to the surface soil. Gradual transition to:
Horizon 2 (4-30 cm)	Yellowish brown (10YR 5/4) sandy loam of weakly developed sub-angular blocky structure giving peds ½-1 cm in size. Consistence is loose. Roots up to 3 cm were common. Gradual transition to:
Horizon 3 (30+ cm)	Light yellowish brown (2.5Y 6/4) loamy sand of similar structure and consistence to horizon 2. Roots are absent. Coarse fragments are absent from the entire profile.

APPENDIX E: SULPHUR DIOXIDE DATA

E1: Atmospheric sulphur dioxide levels during the period May 24th to October 11th 1971
- a) Method
- b) Calculations
- c) Results

E2: Long term atmospheric sulphur dioxide data
- i) Birchbank recorder, 10.5 km north of Trail
- ii) Columbia Gardens recorder, 9.0 km south of Trail
- iii) Northport recorder, 30 km south of Trail

E1: ATMOSPHERIC SULPHUR DIOXIDE LEVELS DURING THE PERIOD MAY 24TH TO OCTOBER 11TH

a) Method*

1. With the aid of a little distilled water the contents of the sulphation plate are removed to a beaker.
2. 20 ml of sodium carbonate added, contents stirred and allowed to stand for 3 hours with occasional stirring.
3. Beaker placed in 100°C water bath for 30 min, cooled and 10 ml distilled water added.
4. Mixture filtered and residue washed with distilled water and filtrate diluted to 50 ml.
5. 10 ml of diluted filtrate added to 5 ml 0.7 N hydrochloric acid and 10 ml distilled water.
6. 2 ml of acidified sample from step 5 added to 8 ml distilled water in a test-tube. Procedure repeated twice.
7. One scoop of "sulfaspend reagent" added to one tube from step 6--the SAMPLE. One scoop of reagent added to a third tube containing 10 ml distilled water--the STANDARD BLANK. All three tubes shaken.
8. The SAMPLE and the SAMPLE BLANK (from step 6) are read on a spectrophotometer at 450 nm against the STANDARD BLANK.

b) Calculations*

1. Equivalent sulphur dioxide content found by:

$$\text{SAMPLE absorbance} - \left(\begin{matrix}\text{SAMPLE BLANK}\\ \text{absorbance}\end{matrix} + \begin{matrix}\text{STANDARD BLANK}\\ \text{absorbance}\end{matrix}\right)$$

and the value read against a standard curve obtained by dilutions of the "sulfate standard".

2. Sulphation rate, $SO_3/cm^2/day$ calculated by:

$$\text{Sulphation rate} = \frac{AB}{CDE}$$

Where A = g SO_4 of sample stock taken from the standard curve,
B = ratio of SO_3 to SO_4 = 0.833,
C = fraction of filtrate used to produce the turbidity = 0.016,
D = exposure time in days = 28,
E = area of sulphation plate = 18 cm^2.

Therefore: $$\text{Sulphation rate} = \frac{A(2.88)}{28}$$

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*Based on manufacturer's instructions.

c) <u>Results</u> (mg $SO_3/cm^2/day$)

	May 24th-June 21st	June 21st-July 19th	July 19th-Aug. 16th	Aug. 16th-Sept. 13th	Sept. 13th-Oct. 11th	Average value excl. July 19th-Aug. 16th
Plot 1	0.10	0.17	0.06	0.09	0.06	0.11
Plot 2	0.13	0.21	0.09	0.12	0.12	0.15
Plot 3	0.18	0.09	0.03	0.10	0.18	0.14
Plot 5	0.11	0.18	0.05	0.19	0.13	0.15
Plot 6	0.22	0.30	0.07	0.26	0.28	0.27
Plot 8	0.35	0.34	0.08	0.30	0.29	0.32
Plot 10	0.40	0.48	0.07	0.38	0.48	0.44
Plot 11	0.38	0.37	0.06	0.33	0.34	0.36
Plot 13	0.33	0.27	0.03	0.23	0.29	0.28
Plot 15	0.23	0.15	0.07	0.14	0.24	0.19
Plot 16	0.14	0.10	0.04	0.12	0.16	0.13
Plot 18	0.13	0.09	0.04	0.10	0.17	0.12
Plot 20	0.09	0.08	0.05	0.06	0.08	0.08

E2: LONG TERM ATMOSPHERIC SULPHUR DIOXIDE DATA*

i) Birchbank recorder, 10.5 km north of Trail (data recorded in hours)

Year	Time rec. not op.	Zero rdgs.	Trace to 0.10 ppm	0.11 to 0.20 ppm	0.21 to 0.30 ppm	0.31 to 0.40 ppm	0.41 to 0.50 ppm	Over 0.50 ppm	Max. ppm	Av. SO_2 ppm
1951	288.7	5569.3	2090.0	571.3	167.7	51.3	12.7	9.0	0.71	-
1952	145.0	5954.7	1823.7	626.7	157.0	48.7	14.0	13.5	0.95	-
1953	105.0	5457.3	2543.0	479.0	108.7	41.7	13.7	16.7	1.31	-
1954	22.3	6348.0	2029.3	286.7	47.7	16.7	6.7	2.7	0.69	-
1955	57.2	5690.7	2378.5	511.3	89.3	22.0	7.0	4.0	0.69	-
1956	68.7	5723.0	2391.3	475.0	80.0	28.0	9.3	8.7	1.01	-
1957	164.3	6181.7	1943.7	285.3	58.0	17.7	6.7	2.7	0.67	-
1958	33.3	6124.3	2018.0	445.7	119.7	45.0	17.0	17.0	1.01	-
1959	58.7	6519.0	1927.3	207.0	32.3	8.7	5.3	1.7	0.76	-
1960	61.3	6321.0	2076.0	255.3	40.0	17.3	6.7	6.2	0.91	-
1961	37.0	6182.7	2001.3	439.3	67.3	22.3	5.7	4.3	1.35	-
1962	63.3	5811.3	2361.3	415.3	71.7	20.3	11.0	5.7	0.74	0.022
1963	7.3	6324.7	2097.0	271.7	38.3	13.3	7.0	4.7	0.81	0.016
1964	98.7	5651.7	2674.0	291.0	49.3	12.7	4.3	2.3	0.61	0.012
1965	0.0	5756.0	2307.3	513.0	99.7	47.7	17.3	19.0	1.71	0.025
1966	15.0	5783.3	2447.0	400.7	86.0	22.3	3.7	2.0	0.86	0.021
1967	405.0	5736.0	2054.0	434.0	103.3	17.7	6.0	4.0	0.68	0.021
1968	591.0	5369.2	2033.7	604.8	126.5	29.8	17.8	11.2	1.22	0.030
1969	163.0	5193.0	2388.5	690.0	211.5	61.0	30.0	23.0	1.72	0.039
1970	57.0	5271.5	2626.5	606.5	150.0	33.5	8.0	7.7	0.90	0.032

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*Data courtesy of Cominco Ltd.

ii) Columbia Gardens recorder, 9.0 km south of Trail (data recorded in hours)

Year	Time rec. not op.	Zero rdgs.	Trace to 0.10 ppm	0.11 to 0.20 ppm	0.21 to 0.30 ppm	0.31 to 0.40 ppm	0.41- to 0.50 ppm	Over 0.50 ppm	Max. ppm	Av. SO_2 ppm
1941	52.9	4695.3	2319.0	962.3	397.9	168.7	84.2	80.0	1.89	-
1942	84.8	4353.3	2643.3	1050.0	374.8	160.3	56.5	45.5	1.43	-
1943	93.0	4246.2	3374.5	762.8	168.2	71.7	24.3	19.3	1.04	-
1944	163.8	5155.8	2862.7	463.7	93.0	24.0	12.3	8.7	0.91	-
1945	233.8	6112.8	2019.2	297.2	65.0	17.7	8.7	5.7	0.81	-
1946	114.8	6075.3	2195.1	305.5	52.7	11.3	1.7	3.7	0.99	-
1947	66.5	6435.9	1960.3	241.7	39.7	12.0	2.7	1.3	0.66	-
1948	106.6	5363.3	2962.4	290.7	47.7	9.0	2.7	1.3	0.69	-
1949	161.7	5557.2	2772.8	241.4	22.0	3.7	0.7	0.7	0.74	-
1950	56.1	5699.8	2576.1	344.8	55.7	19.2	6.0	2.0	0.67	-
1951	132.2	5774.7	2532.5	285.2	26.8	5.7	1.0	2.0	0.83	-
1952	71.2	6416.8	2059.5	197.5	27.7	5.7	2.0	0.7	0.57	-
1953	42.6	6850.1	1743.8	100.3	14.3	5.7	2.3	0.8	0.60	-
1954	25.5	5094.6	3333.5	274.9	25.5	3.6	1.4	1.0	0.67	-
1955	86.3	5302.6	2792.6	462.0	79.5	22.6	8.5	6.0	0.88	-
1956	30.8	6158.5	2124.8	330.5	85.5	27.0	14.0	13.0	0.78	-
1957	30.0	6248.0	1916.0	473.0	72.0	12.5	5.0	3.5	1.27	-
1958	63.0	5341.5	2417.5	612.0	200.0	64.5	37.5	24.0	1.50	-
1959	17.5	5786.5	2497.0	385.5	53.5	11.5	5.5	3.0	0.74	-
1960	13.5	5813.0	2445.0	380.5	93.5	25.0	8.5	5.0	0.84	-
1961	96.0	6093.5	2086.0	397.0	60.0	11.0	8.0	8.5	1.28	-
1962	10.5	5824.0	2305.5	502.0	83.5	27.0	5.5	2.0	0.73	0.026
1963	40.0	6330.0	1840.5	433.5	67.5	19.5	6.0	10.5	1.35	0.022
1964	51.5	6417.0	1817.0	374.0	81.0	27.0	9.0	7.3	1.78	0.021
1965	59.5	5863.0	2002.0	594.5	145.5	62.0	23.5	10.0	0.98	0.032
1966	81.5	5695.5	2158.5	596.5	135.0	56.0	19.5	17.5	0.90	0.032
1967	68.0	6022.0	2077.0	520.5	50.5	12.5	2.5	7.0	1.04	0.027
1968	527.0	5968.5	1852.0	351.5	61.5	14.0	6.0	3.5	0.91	0.021
1969	36.0	5514.0	2321.0	723.0	123.0	27.0	11.5	4.5	-	0.031
1970	53.0	5880.5	2256.0	457.5	84.5	17.0	7.5	4.0	0.82	0.025

iii) <u>Northport recorder, 30.0 km south of Trail (data recorded in hours)</u>

Year	Time rec. not op.	Zero rdgs.	Trace to 0.10 ppm	0.11 to 0.20 ppm	0.21 to 0.30 ppm	0.31 to 0.40 ppm	0.41 to 0.50 ppm	Over 0.50 ppm	Max. ppm	Av. SO_2 ppm
1941	112.3	5834.7	2319.2	373.0	93.0	16.5	7.3	2.0	0.63	-
1942	353.3	555.3	2186.8	463.0	154.2	36.7	24.3	3.7	0.59	-
1943	152.8	5666.7	2382.3	333.3	157.5	44.7	16.7	6.0	0.87	-
1944	95.8	6892.7	1682.3	141.2	21.7	3.0	1.3	0.0	0.42	-
1945	106.8	6994.8	1488.5	137.2	27.9	3.7	1.3	0.0	0.50	-
1946	321.3	6643.3	1628.5	148.2	16.0	2.3	0.3	0.0	0.42	-
1947	317.5	6798.5	1592.0	50.5	1.7	0.0	0.0	0.0	0.25	-
1948	1244.2	4969.3	1764.5	58.0	4.0	0.0	0.0	0.0	0.27	-
1949	99.1	6257.4	2296.3	80.7	19.8	3.0	2.0	1.7	0.64	-
1950	190.8	6170.3	2205.0	186.3	7.0	0.7	0.0	0.0	0.34	-
1951	60.0	6699.3	1894.8	100.7	4.7	0.3	0.0	0.0	0.33	-
1952	83.8	6680.0	1943.2	72.3	4.3	0.0	0.3	0.0	0.41	-
1953	122.9	6786.1	1787.7	54.3	9.0	0.0	0.0	0.0	0.22	-
1954	100.8	6655.2	1528.0	26.0	0.0	0.0	0.0	0.0	0.19	-
1955	59.9	7094.4	1628.3	62.7	4.7	0.0	0.0	0.0	0.24	-
1956	91.3	6792.3	1849.3	49.7	1.3	0.0	0.0	0.0	0.23	-
1957	288.3	7042.7	1411.7	17.3	0.0	0.0	0.0	0.0	0.20	-
1958	150.7	6348.3	2148.7	101.7	9.7	1.0	0.0	0.0	0.35	-
1959	139.0	6647.0	1934.3	39.0	0.7	0.0	0.0	0.0	0.22	-
1960	5.0	7000.8	1743.2	29.0	5.3	0.7	0.0	0.0	0.34	-
1961	4.3	6768.3	1934.7	44.3	7.0	1.3	0.0	0.0	0.37	-
1962	82.7	6981.0	1651.3	39.0	5.3	0.7	0.0	0.0	0.36	0.006
1963	34.0	7254.0	1460.7	8.7	1.7	0.0	0.0	0.0	0.35	0.004
1964	68.3	7394.0	1293.3	26.7	1.7	0.0	0.0	0.0	0.26	0.005
1965	58.7	7358.7	1268.7	55.0	12.0	4.3	2.7	0.0	0.45	0.007
1966	0.0	5380.7	910.7	52.7	2.0	0.0	0.0	0.0	0.28	0.006
1967		Recorder not operated from Sept. 24th 1966 to Sept. 16th 1968								
1968	470.0	1797.0	298.3	3.7	0.0	0.0	0.0	0.0	0.16	0.004
1969	329.0	6707.7	1630.3	35.0	7.0	1.0	0.0	0.0	0.32	0.010
1970	469.3	6647.7	1583.3	56.3	3.3	0.0	0.0	0.0	0.24	0.010