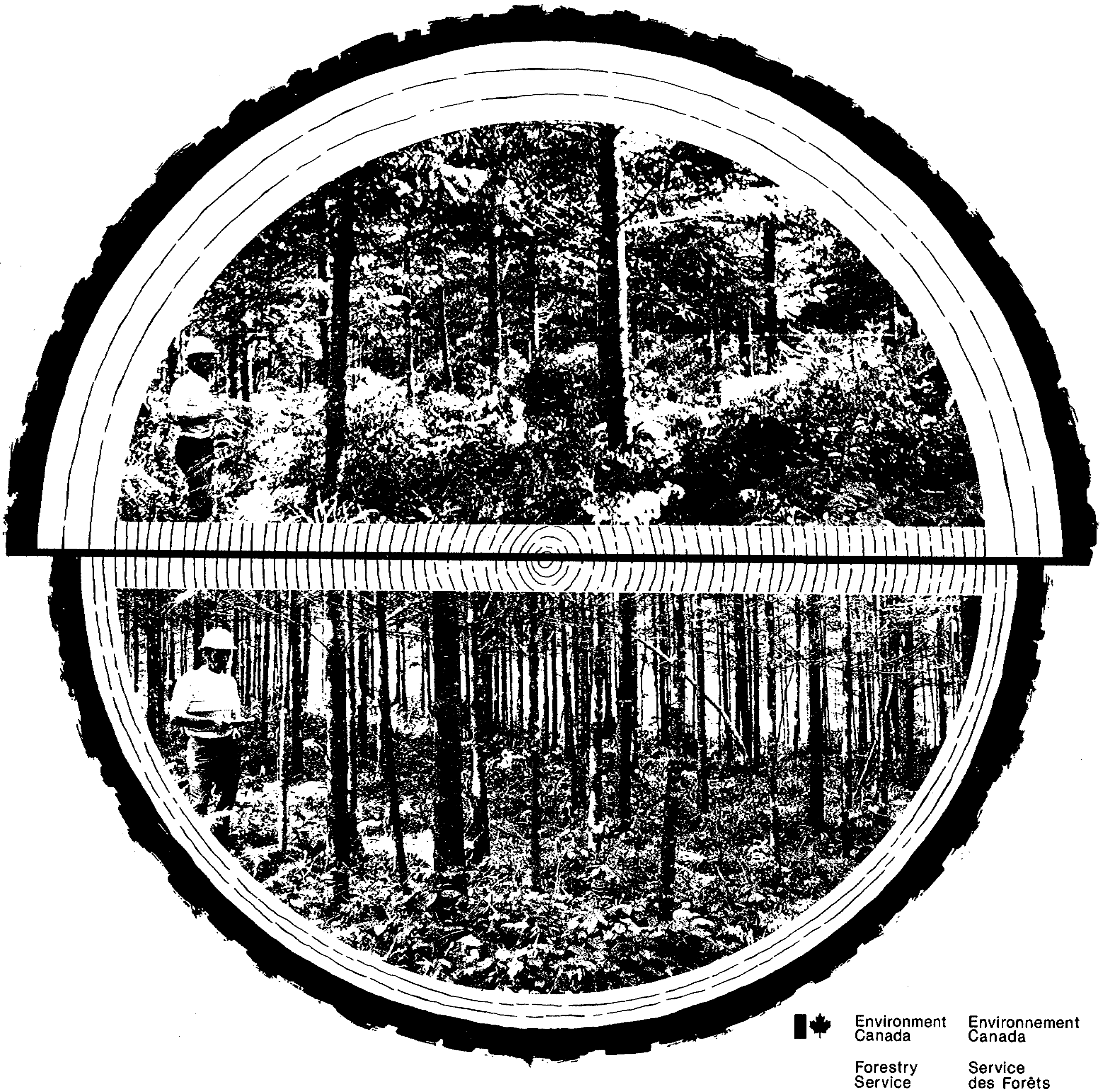
Fertilization & Thinning Effects On a Douglas-Fir Ecosystem At Shawnigan Lake: An Establishment Report

EDITED BY M. CROWN AND C.P. BRETT



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ABSTRACT

Establishment of a muitidisciplinary research project, initiated in 1970, to study the effects of thinning and nitrogen fertilization on a 24-year-old Douglas-fir (*Pseudotsuga menziesii* Mirb., Franco) stand near Shawnigan Lake, B.C., is described. The site is characterized by edaphic factors, climate, vegetation, stand history and growth at the time of treatment. Experimental design, plot layout and treatments are given in detail. Component studies of tree growth, tree physiological conditions, water relations, atmospheric conditions, understory vegetation, soil chemistry, soil fauna, and soil microflora are described. By studying these biologicat relationships, the project proposes to improve our capability in predicting effects of thinning and fertilization under different site and stand conditions. This publication provides a comprehensive background reference for future progress reports and publications.

Key words: tree growth, simulation, physiology, undergrowth, nutrient cycling, soil fauna, soil microflora.

Resume

Les auteurs decrivent la mise sur pied d'un project de recherche multidisciplinaire, qui debuta en 1970, sur les effets d'éclaircies et de fertilisations a l'azote dans un peuplement de Douglas (Pseudotsuga *menziesii* (Mirb.) Franco) âgé de 24 ans près de Shawnigan Lake, C.-B. Ils caracterisent fa station parses facteurs edaphiques, son climat, sa vegetation, l'historique et la croissance du peuplement a l'epoque du traitement. Ils decrivent en detail le design experimental, le plan de la parcelle et les traitements. Ils decrivent aussi les études de la croissance des arbres, l'état physiologique des arbres, les rapports avec l'humidite, les conditions atmospheriques, la vegetation du suus-etage, la chimie du sol, la faune du sol et sa microflore. Par l'étude de ces relations biologiques, les auteurs veulent améliorer leurs moyens de prédire fes effets des eclaircies et de la fertilisation en differentes conditions de station et de peuplement. Cet article sert de référence d'ensemble et de base pour de futurs rapports de progrès et articles.

Mots clés: croissance des arbres, simulation, physiologie, vegetation du sous-étage, cycles de nourritures, faune du sol, microflore du sol.

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An Establishment Report

Edited by M. Crown and C.P. Brett

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1.0 INTRODUCTION

Expanding demands for wood, accelerated removal of lands formerly reserved for timber production, and impending regional shortages of important species, such as Douglas-fir (*Pseudotsuga* ***menziesii*** Mirb. Franco) (Manning and Grinnell, 1971), have resulted in the urgent necessity for improved silvicultural practice to maintain or enhance wood yields. In recognition of this need, the British Columbia Forest Service formed a Forest Productivity Committee to study the effects of thinning and nitrogen fertilization on stand yields across a range of sites. Fertilization with nitrogen is favored because of the acknowledged nitrogen deficiency in coastal soils of the Pacific Northwest. Fertilizer trials in B.C. have produced variable results, but have shown that substantial increases in yield and reductions in rotation age are possible. In support of the Forest Productivity Committee's program, and in response to public concern over environmental quality, the Pacific Forest Research Centre undertook a multidisciplinary research project PC-23 - The management of coastal Douglas-fir, western hemlock ***(Tsuga** heterophylla* (Raf.) **Sarg)** ecosystems. The main portion of the project to date is established in Douglas-fir at Shawnigan Lake, B.C. (Figs. 1 and 2).

The studies on the Shawnigan Lake site represent the first step in the project. The site is representative of only a smalt part of the coastal British Columbia

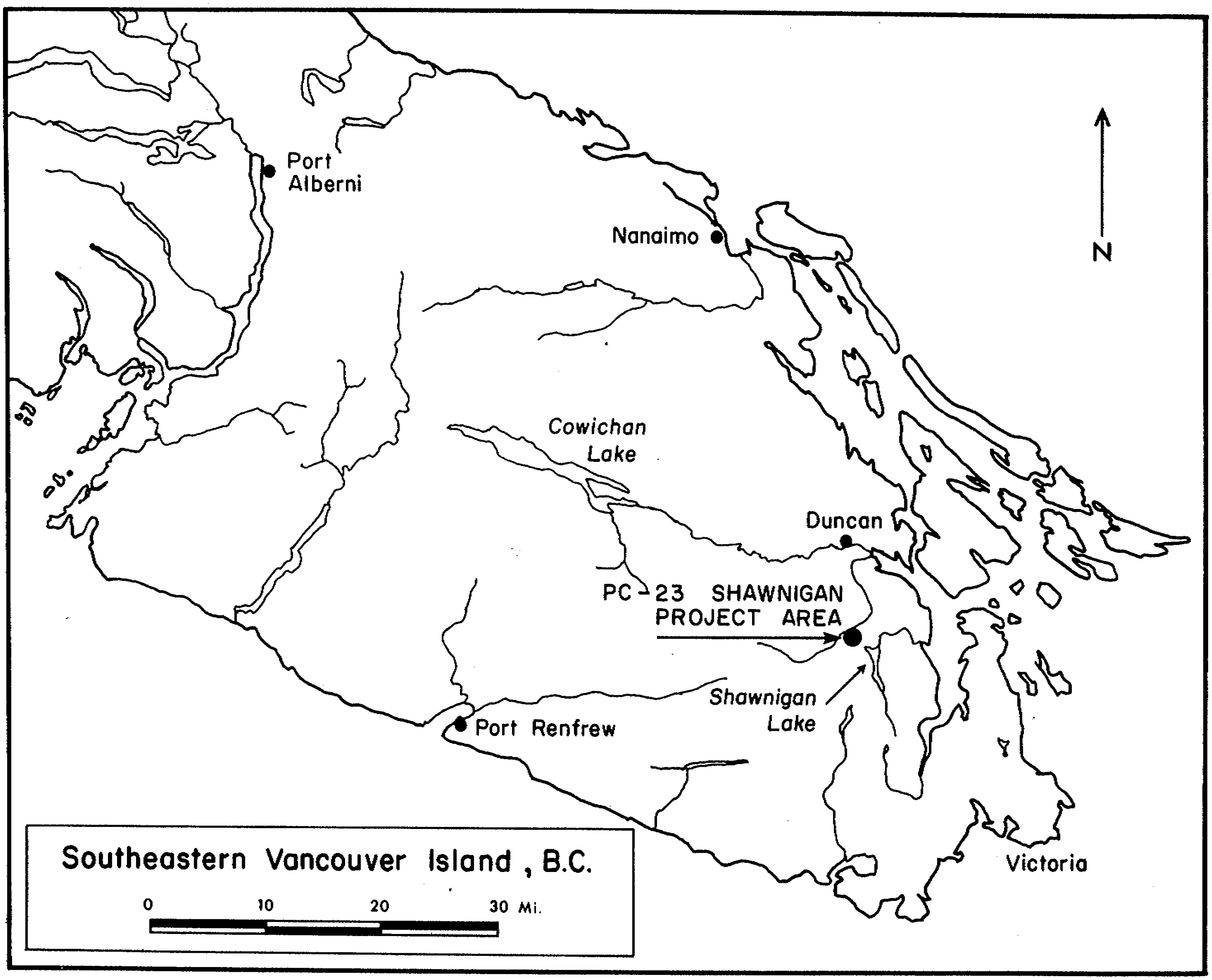

Figure *I* — **Project** location **map**

forest, but it is well suited as a learning site for developing methodology and knowledge which wilt provide guidelines for other studies throughout the coastal forest.

The overall objective of the project is to achieve a better understanding of tree growth processes and to develop effective and environmentally acceptable thinning and fertilization practices designed to increase wood yields (Brett, 1972). More specifically, the objectives are to:

(1) define growth response of coastal Douglas-fir and western hemlock trees and stands to various levels and combinations of thinning and fertilization treatments;

(2) develop ecosystem and growth models and other means of predicting treatment response under different stand and ecological conditions;

(3) identify tree, stand and ecological conditions affecting treatment response;

(4) determine the rote of understory vegetation in nutrient cycling, soil water relations and tree growth response;

(5) identify and explain changes in soil properties, and soil microflora and soil fauna populations and relate these changes to nutrient cycling;

(6) determine the effects of fertilization and thinning on hydrometeorological parameters;

(7) evaluate impact of the treatments on environmental quality;

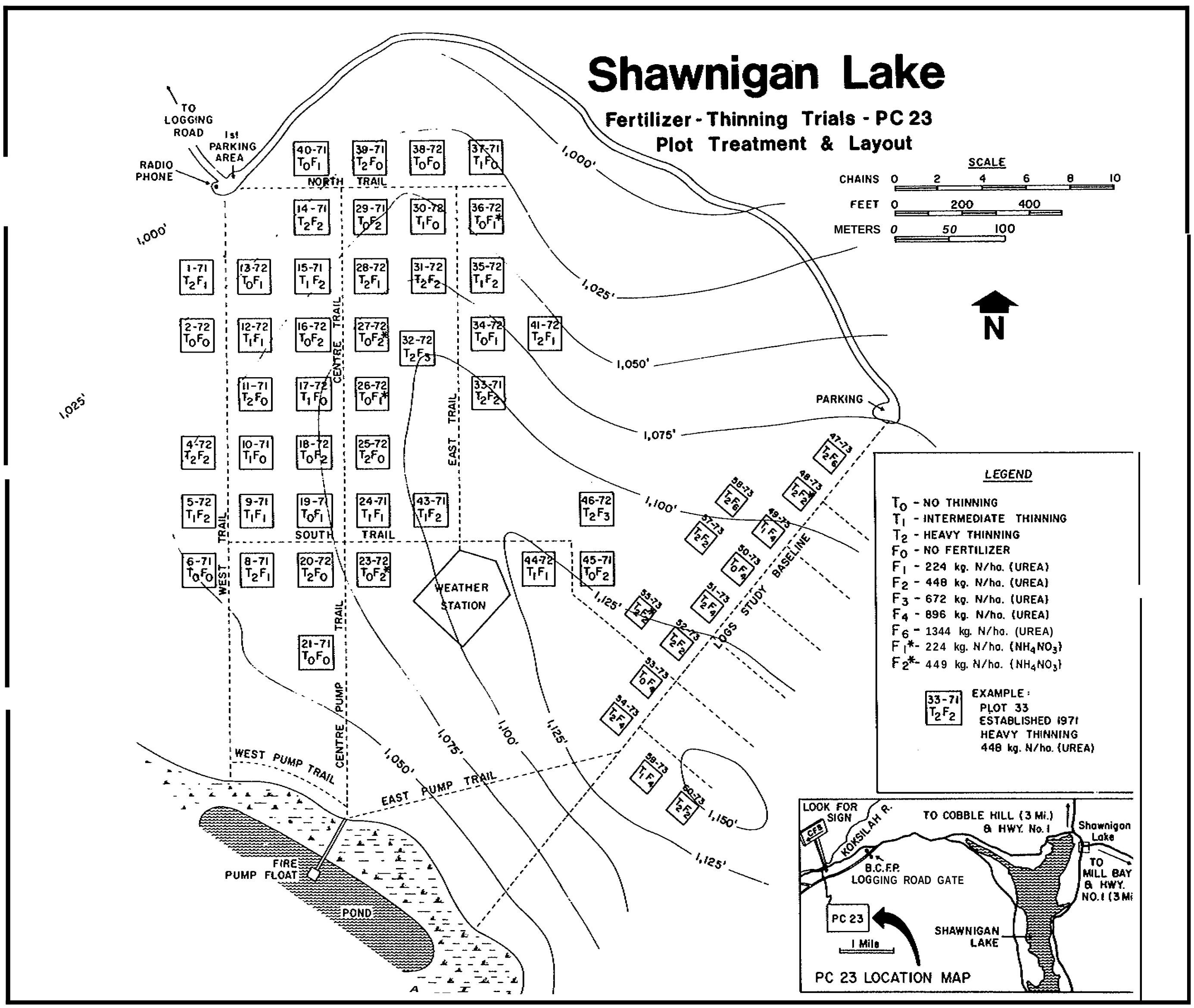

Figure 2 — **Shawnigan** lake, plot **treatment** and layout

(8) prescribe management practices for enhancement of productivity of coastal Douglas-fir/western hemlock forests without adverse effects on environmental quality.

The individual studies now in progress at Shawnigan Lake, in support of these objectives, and the scientists responsible are:

PC-23-003 Pilot fertilization - thinning trials of coastal Douglas-fir and western hemlock (C.P. Brett* & M. Crown).

PC-23-I20 Predicting growth and yield through individual tree models of inter-tree competition and growth (J.D. Arney** & R. Quenet).

PC-23-006 The physiology of growth of Douglas-fir in relation to nitrogen fertilization and thinning (H. Brix).

PC-23-169 The role of undergrowth in intensively managed Douglas-fir ecosystems (P.K. Diggle).

PC-23-005 Nutrient distribution in a young Douglas-fir ecosystem (B. Webber).

PC-23-094 Nitrogen movement and urea induced transformation in forest soil (B. Webber).

PC-23-109 The role of soil fauna in tree nutrition in relation to thinning and fertilization (V.G. Marshall).

PC-23-134 The soil microflora and biotic processes in managed forest land (J.A. Dangerfield).

* C.P. Brett - project leader until - Dec./1972.

** J.D. Arney - study leader until - Oct./1973.

Other studies under the project, not reported here, are being conducted elsewhere and will complement the thinning and fertilization trials at Shawnigan Lake.

These studies are:

PC-23-001 Response of thinned and unthinned Douglas-fir to fertilization at different ages, rates and seasons (Y. Lee).

PC-23-002 Fertilization of dense juvenile western hemlock (Y. Lee - in co-operation with industry).

PC-23-004 Soil nutrient-foliar nutrient relationships as determined by site quality (8. Webber).

PC-23-080 Levels of Growing Stock (LOGS) study of Douglas-fir (P.K. Diggle at Campbell River and Shawnigan).

PC-23-184 Advice and services in forest fertilization and thinning (M. Crown).

PC-23-170X By Contract - Effect of stand treatment on hydrometeorological parameters (Dr. T.A. Black, contractor; H. Brix, contract officer).

PC-23-191X By Contract - Effect of stand treatment on mineral weathering and nutrient cycling (Dr. L. Lavkulich, contractor; V.G. Marshall, contract officer).

2.0 APPROACH

The Shawnigan Douglas-fir ecosystem can be divided conveniently into four subsystems: 1) producers (green plants), 2) consumers (animals), 3) decomposers (micro-organisms), and 4) abiotic components (environmental factors). Since the project is concerned primarily with maintaining and enhancing wood yields, emphasis is being placed on studying the producer, decomposer and abiotic sub-systems. A simplistic ecosystem flow chart (Fig. 3) shows the interrelations between the studies and the internal systems.

The individual studies (see Introduction, Description of Core Study and Component Study Descriptions) cover three major areas: 1) defining and understanding basic interrelations, 2) monitoring and analyzing responses, and 3) constructing, integrating and verifying mathematical models relating basic relationships to responses. Defining and understanding basic interrelations is essential in developing predictive techniques. There are too many variables in the abiotic sub-system to establish trials for all sets of conditions. However, through understanding how environmental components affect nutrient cycling, water budgets, microorganism populations and activities, tree physiology and growth, and other aspects of the ecosystem, it should be possible to predict tree response under different conditions. The monitoring and analyzing of changes in soil chemical conditions, nutrient status, microorganism activity and tree growth, will provide reference points for developing functions between basic interrelationships and ecosystem responses. Predicting response to fertilization and thinning will be undertaken through mathematical modelling, the success of which wilt depend on an adequate understanding of the system. The models will, therefore, be developed and tested continually throughout the fife of the project.

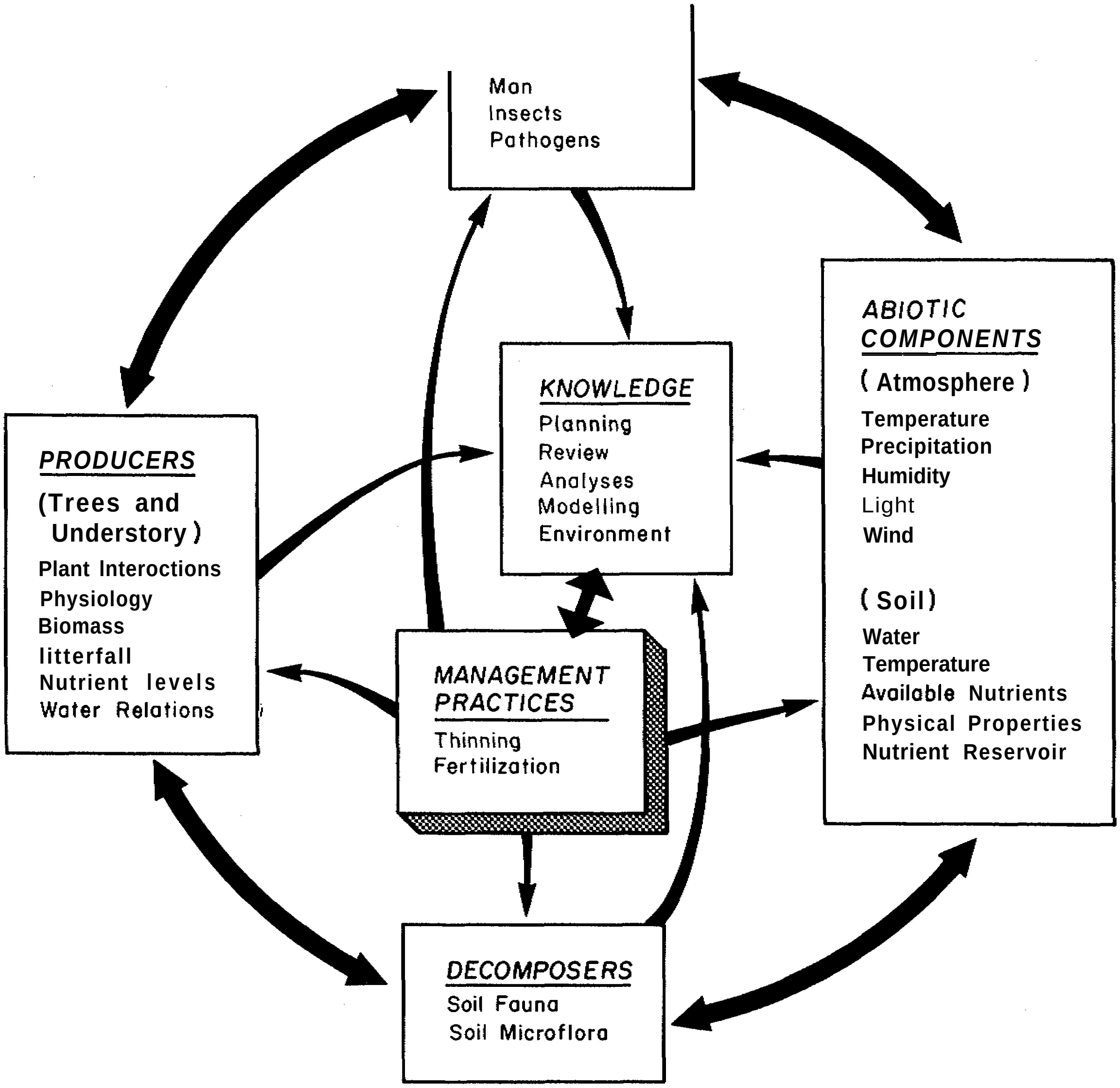

Figure 3 — Flow chart of ecosystem showing the areas of study being undertaken

3.0 DESCRIPTION OF SHAWNIGAN LAKE SITE

3.1 EDAPHIC FACTORS

Physiography

Southeastern Vancouver Island (Fig. 1) is characterized by a narrow strip of low lying, gently sloping terrain extending along the eastern coast and flanked on the west side by the Vancouver Island Mountain Range (Holland, 1964). The lowlands constitute a portion of the Georgia Depression which has risen above current sea level to an elevation of approximately 300 m (984 ft.), with hills and monadnocks rising to 600 m (1970 ft.). Differential erosion of sedimentary rocks and deposition of glacial and fluvioglacial material has left a gently undulating surface dissected by numerous streams of variable sizes.

The site on which the fertilization-thinning experiments are being conducted comprises the top of a well-rounded knoll, approximately 335 m (1,099 ft.) in elevation, rising about 60 m (197 ft.) above the basal peneplain. To the north and east, the terrain consists of low knobby to rolling rounded hills intersected by the Koksilah River. The river flows in a northeasterly direction about 1.6 km (1.0 miles north of the study site). The Shawnigan Lake system is about 4.8 km (3.0 miles to the east). The adjacent terrain to the south and west is more rugged, with rocky hills and mountains greater than 600 m in elevation. A shallow lake, possibly a remnant of a melt-water channel (Halstead, 1968), approximately 8 ha (19.8 ac) in size, is situated on the south side of the study area and drains in a northwesterly direction to the Koksilah River.

Bedrock geology

Bedrock of southeastern Vancouver Island consists of a mixture of volcanic rocks with granitic intrusions and some sedimentary rocks (Clapp, 1917). The oldest known rocks are the sedimentary Leech River slaty schists and the Malahat volcanics, presumably of late carboniferous age. During the upper Triassic and lower Jurassic periods, another vulcanism gave rise to the formation known as the Vancouver volcanics. Conformably associated with this vulcanism is the Sutton limestone formation. Also conformable with the Vancouver volcanics is the Sicker series consisting of metamorphic, volcanic and overlying sedimentary rocks. All of these rock types have been metamorphosed, deformed and intruded by batholiths composed of Wark gabbro and diorite gneiss.

The study area occurs on the northern edge of a batholith. The principal rock type of this formation is a gabbro-diorite, which is dark greenish, medium to coarse grained and of a gneissic texture (Clapp, 1917). The primary minerals are mostly feldspar and hornblende, but quartz, augite, biotite, calcite, magnetite, ilmenite, titanite and apatite occur in varying amounts, and some are impregnated with pyrite. Most primary minerals have been fractured, crushed, foliated and partly recrystallized to form secondary minerals such as uralite, biotite, chlorite, epidote, serpentine, muscovite, sericite, kaolin and limonite. The material is very resistant to erosion and weathering; consequently, rugged outcroppings remain after glaciation, except where they are covered by drift.

North of the batholith, and adjacent to the study area, the older and more easily eroded Vancouver volcanics occur. The main rock types of this formation are andesites, with some basalts and labradorite andesites, which occur in flow, fragmental and injected forms consisting of amygdaloids, porphyries, pillow-lavas, tuff-breccias, slaty and cherty tuffs and andesite porphyrites (Clapp, 1917).

Surficial Geology

The topography of southeastern Vancouver Island has been modified by glaciation; the most recent major one, termed the Fraser glaciation, occurred about 15,000 years ago. During the early stages of the Fraser glaciation (Fyles, 1963; Halstead, 1968), the Cowichan Ice Tongue formed and moved down the Cowichan Valley. Although glacial ice did not reach the Shawnigan study area during this stage, ice jamming caused meltwater to back up the Koksilah River and flow out of various outlets to Shawnigan and Sooke lakes (Halstead, 1968), which possibly influenced the surficial materials of the study area.

During the major episode of the Fraser glaciation, termed the Vashon Stade, a massive accumulation of ice moved down the Georgia Depression in a southerly direction, overriding everything except a few peaks above 1400 m (4,593 ft) (Fyles, 1963; Halstead, 1968). The ice mass was approximately 1500 m (4,921 ft) thick at its maximum and persisted to approximately 10,000 years ago. These glaciers scoured most areas clean, but left some moraine and ablation material as it receded, although much of this material was subsequently altered in many places by meltwater.

The Shawnigan Lake study site was not mapped in Halstead's (1966) surficial geology survey.

The area has a moderately deep deposit of till capping the bedrock. Based on the smooth well-rounded appearance of the knoll and the scarcity of prominent bedrock outcrops on nearby hills, the origin of the till is presumably ground moraine, composed of a mixture of material brought down from the west by the Cowichan ice Tongue, and material moved in from the north by the continental ice mass. Currently, extremely compact till of undetermined depth lies under loose till 50 to 75 cm (20 to 30 inches) thick. A few rock outcrops occur along the lower slopes.

Soils

The soils of the study area, developed on coarse-textured till, composed of a mixture of volcanic and granitic rock fragments, are shallow, coarse textured, well-drained and underlain by impermeable basal till. Profile development is through podzolization, and is weakly expressed with essentially no A, horizon and little color change throughout, except for organic staining near the surface. The organic mantle is thin, usually less than 2 cm (0.8 inch), and much of this is recently deposited litter. Fermentation and humus layers are not distinguishable. The area was burned over prior to planting, which undoubtedly influenced the organic layers.

Soils were classified as Orthic Dystric Brunisols (Canada Soil Survey Committee, 1974). These soils are similar to the Shawnigan series as described by Day, Farstad and Laird (1959).

A representative profile, based on six soil pits, is given in Appendix I. Variations occur in horizon thicknesses and color, but these are of minor significance. The amount of gravel varies from 31 to 84% (Appendix II), but there is no consistent pattern evident within or among the profiles. The proportions of sand, silt and clay in the fraction less than 2 mm varies, generally with an increase in clay in the lower part of the profile. Some profiles lacked the Bm_2 horizon; in these, the Bm_1 is thicker. Soil depth to the C_1 horizon varies between 45 (17.7 inches) and 60 cm (23.6 inches), except for one profile which had a depth of 88 cm (34.6 inches).

The soils are porous and retain little water. Moisture equivalent (1/3 atmospheres) is usually highest (about 24%) in the top mineral horizon, apparently due to the organic matter content, and decreases to about 18% in the lower horizons. One sample pit near the top of the knoll had a significantly tower moisture equivalent than the other sample pits, but there was no apparent explanation for this. Water-holding capacity at 15 atmospheres is approximately 50% of the moisture equivalent for most samples. These amounts of water retention are similar to average sandy loam soils (Buckman and Brady, 1963); however, they represent only the amount of moisture retained by the 2 mm fraction and would be lower if the total soil volume were considered.

The carbon to nitrogen ratio is around 15:1, except in the top mineral horizon, which is as much as 35:1. Carbon and nitrogen percentages are generally considered to be low for forest soils and the ratio was somewhat lower than optimal for tree growth (25:1); however, there are no adequate guidelines to assess this. The amounts and the ratio are similar to other soils developed on coarse textured till of southern Vancouver Island (Day, Farstad and Laird, 1959). Except for the high amount of exchangeable hydrogen, other exchangeable cations are low compared to agricultural standards (Appendix II) and are similar in amount to the Shawnigan series, which Day et *al.* (*loc. cit.*) rate as being low in inherent fertility. The total exchange capacity is relatively high #or coarse textured soils of Vancouver Island (Day *et al., loc. cit.*), but dominance of hydrogen reduces the natural fertility. This may be ameliorated by the addition of fertilizers or lime.

3.2 CLIMATE

The climate at the PC-23 site is transitional between the Cool Summer Mediterranean Climate (Koppen's-Csb) and the Marine West Coast Climate (Koppen's-Cfb) (Day et *al., loc. cit.*).

A weather station, set up in a 0.45 ha (1.10 ac) clearing provides precipitation, temperature, humidity, and solar radiation and wind speed and direction records. A tabulated statement of measurements taken is given in Appendix V. Data collected are extracted and summarized in English and metric units by Climate and Data Services, Resource Analysis Unit, of the Environment and Land Use Committee Secretariat of British Columbia.

Precipitation and temperature data from the PC-23 site for 1971 and 1972 closely resemble those from the Department of Transport (DOT) station at Shawnigan Lake (Table I). More comprehensive site specific data will be given in future progress reports; meanwhile, data (Day *et al., loc. cit.*) from the Shawnigan lake (DOT) station are provided below to characterize the general climatic conditions of the site. Appendices III and IV provide a basis for regional comparison.

Precipitation:-	**mm**	**inches**
Mean annual	1090	42.9
4 months June - Sept.	122	4.8
2 months July - Aug.	41	1.6
Temperature:-	°C	°F
Mean annual	8.9	48
4 months June-Sept.	15.6	60
2 months July - Aug.	17.2	63
Duration of the vegetation period -		237 days
Duration of frost-free period -		168 days
Day degrees above 5.6°C (42°F) in the vegetation period -		2815
Water deficiency during the vegetation period [7.6 mm (3 inch) - storage]		9.3

3.3 VEGETATION

The study site is situated in the wetter (Madrono-Douglas-fir) Subzone of the Coastal Douglas-fir Biogeoclimatic Zone of Krajina (1969), and the Strait of Georgia Section of the Coast Forest Region of Rowe (1972). In this vegetation zone, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the most

Table 1 — Precipitation and temperature comparisons, PC-23 site vs. Shawnigan Lake (DOT) station

A - Precipitation averaged for 1971 and 1972 (monthly means).

Location	J		F		M		A		M		J		J1		A		S		O		N		D		(Annual)	
	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches	mm	inches
PC-23 site	261	10.29	196	7.72	145	5.73	71	2.79	22	0.87	50	2.00	45	1.78	21	0.82	85	3.36	58	2.28	138	5.44	292	11.50	1386	54.59
Shawnigan Lake (DOT)	212	8.35	173	6.83	216	8.52	57	2.26	24	0.93	44	1.74	38	1.49	20	0.77	84	3.31	59	2.32	139	5.49	295	11.65	1363	53.70

B - Temperature averaged for 1971 and 1972 (monthly means).

Location	J		F		M		A		M		J		J1		A		S		O		N		D		(Annual)	
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
PC-23 site	0.6	33	2.2	36	6.1	43	7.8	46	12.2	54	12.8	55	17.8	64	17.8	64	12.2	54	10.0	50	4.4	40	-1.1	30	8.3	47
Shawnigan Lake (DOT)	1.1	34	3.3	38	4.4	40	6.7	44	12.2	54	13.3	56	17.8	64	18.3	65	12.2	54	8.9	48	5.6	42	0.6	33	8.9	48

prevalent species, both successionally as a pioneer and as a climax, on normal to drier sites. Other species commonly encountered include western red cedar (*Thuja plicata* Donn), western hemlock (***Tsuga** heterophylla* (Raf.) Sarg.), grand fir (***Abies** grandis* (Dougl.) Lindl.), lodgepole pine (*Pinus contorta* . Dougl.), western white pine (*Pinus monticola* Dougl.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), madrona (***Arbutus** menziesii* Pursh), red alder (*Alnus rubra* Bong.) and bigleaf maple (*Acer macrophyllum* Pursh).

Current forest cover consists of a mixture *of* planted and natural Douglas-fir, with a small proportion **of** western hemlock, western white pine, lodgepole pine and western red cedar from natural sources. **Red** alder occurs in wetter areas, usually depressions, and a few madrona are widely scattered on **dry** areas.

Salal (*Gaultheria shallon* Pursh), Oregon grape (*Mahonia nervosa* Nutt.) **and** bracken (*Pteridium aquilinum* (L.) Kuhn) dominate the present understory vegetation. **Also** present in varying amounts are twinflower (*Linnaea borealis* L.), wild rose (*Rosa* sp.), trailing blackberry (***Rubus** ursinus* Cham & Schlecht), willow (*Salix* sp.), prince's pine (*Chimaphila umbellata* (L.) Bart.), bunchberry (*Cornus canadensis* L.), starflower (*Trientalis latifolia* Hock.), ox-eye **daisy** (*Chrysanthemum leucanthemum* L.), lupine (*Lupinus* sp.), swordfern (*Polystichum munitum* (Kaulf.) Presl), bedstraw (*Galium* sp.) and the **moss** *Eurynchium oreganum* (Sull.) Jacq.

3.4 STAND HISTORY

Stand origin

The study area, previously forested with a stand ***of*** naturally occurring Douglas-fir, was burned **in** 1925, salvage logged in 1927, regenerated naturally to Douglas-fir and reburned in 1942, leaving a site devoid of slash and with little humus. **A** unique feature of the area was the preponderance of lupines that came in as ground cover prior to planting. The area was planted to 2-0 Douglas-fir stock in the spring of 1948. Seedlings used originated from seed registered as B4/KE/45. This seed was collected below 152 m (500 ft) elevation, in the Courtenay-Campbell River area of Vancouver Island, in 1945. It was sown in Green Timber Nursery, Surrey, B.C., in 1946.

Survival data (Bamford, 1973) for the total plantation give an indication of the proportion *of* natural to planted trees that were originally present.

	Planted trees /ha(ac)	Naturals /ha(ac)	Total/trees/ha(ac)
194%	2189 (886)	1164 (471)	3353 (1,357)
1st year survival	2056 (832)	1448 (586)	3504 (1,418)
3rd year survival	2026 (820)	1927 (780)	3953 (1,600)

At the time of establishment (1948), the species composition was Douglas-fir 80%, western red cedar 14%, western hemlock 3%, and other species 3%.

Seed collections were made on Vancouver Island in 1943 and 1945, indicating that these were the cone-crop years in that period. It is, therefore, most likely that the Douglas-fir naturals present at the time of planting were of this origin; the additional Douglas-fir naturals in the 3rd year survival data were probably detayed germinants of 1945 origin. Thus, the natural component of the stand could be considered to be within 1-3 years of the age of the planted trees. Site index is 21 m (68 ft) at 50 years (B.C.F.S., 1970).

Silvicultural or other treatments were not carried out in the stand until the project was initiated in 1970, at stand age 24. At that time, the average tree had a d.b.h. of 7.8 cm (3.1 inches) and a height of 8.6 m (28.4 ft).

Insects

At the start of the project, the stand was lightly infested with blackheaded budworm, Acleris *gloverana* (Wlshm.). These populations have remained low and have shown no evident response to fertilizer treatment. Blackheaded budworm feeds preferentially on hemlock, and only in periods of severe epidemic would the insect heavily attack Douglas-fir.

In the summer of 1972, bark beette feeding activity became evident in the thinned ptots. Species of the following genera were present: ***Pseudohylesinus***, *Scolytus*, *Trypodendron*, and a ***Hylastes-Hylurgops***, as well as ***Dendroctonus pseudotsuga*** (Hopk.). Of these, *P. nebulosus* (Lec.) was most common. These populations had moved into the area in response to thinning, and were feeding on and breeding in slash left in the plots. There was concern that the progeny, upon emerging from the slash, might attack live trees being used for individual tree studies. However, the populations apparently remained confined to dead material on the ground, as no attacks on living trees within the plots were noted. Nevertheless, in thinning trials, the possibility of bark beetle attack on standing trees does exist, and beetle populations will continue to be monitored to determine whether control measures are warranted.

In 1973, populations of the Douglas-fir woolly aphid, *Adelges cooleyi* (Gillette), appeared for the first time on the trial site. At present, the incidence of infestation appears to be higher on fertilized plots than on unfertilized areas. This insect is becoming a major pest of juvenile Douglas-fir, and has the capacity to develop rapidly into a serious infestation (Wood and Koot, 1973). Tree mortality is not likely to result, but feeding activity of heavy infestations could affect studies of growth response.

Disease

The only disease of consequence found in the plantation was ***Poria weirii*** Murr. root rot. Scattered mortality caused by ***Armillaria mellea*** (Fr.) Kumm. was noted, along with minor occurrences of *Rhabdocline* needle blight.

Poria weirii infection centres, of varying sizes, are distributed throughout the plantation; the most severely infected area faces the small lake to the south. A detailed survey of the whole plantation was not attempted, but Appendix VI indicates generally the distribution of the infection centres.

Disease incidence was assessed in all locations designated for plot establishment. Again, the only disease of consequence was ***P.*** *weirii* root rot. Where root rot was found in proposed plot areas, the plots were relocated to exclude the disease. An exception was a supplementary ammonium nitrate plot, number 36.

A continuing check is made in the plots for root rot infection centres not apparent at the first examination. Where the disease is found, the trees are uprooted to reduce the possibility of further spread of the fungus.

4.0 DESCRIPTION OF CORE STUDY

PC-23-003 Pilot fertilization-thinning trials of Coastal Douglas-fir and western hemlock (C.P. Brett and M. Crown).

The objective of the study was to measure volume growth response of managed stands to nitrogen fertilization and thinning treatments, and to provide and service treated study areas for related multi-disciplinary studies. The study was planned in close collaboration with other members of the project

Table 2 — Summary of fertilization and thinning treatments by year and plot number

Thinning	Year	Fertilization, treatments, kg N/ha (lb N/ac): 0	224 (200)	448 (400)	672 (600)	896 (800)	1344 (1200)
		F_0	F_1	F_2	F_3	F_4	F_6
		Plot numbers, Nitrogen as Urea.					
NONE T_0	1971	21	19 40	29 45			
	1972	2 38	13 34	16 18			
	1973					50 53	
I N T E [illegible] T_1		10 37	9 24	15 43			
	1972	17 30	12 44	5 35			
	1973					49 59	
HEAVY T_2	1971	11 39	1 8	14 33			
	1972	20 25	28 41	4 31	32 46		
	1973			52,57 & 60		51 54	47 58
		Plot numbers, Nitrogen as Ammonium Nitrate					
NONE T_0	1972		26 36	23 27			
HEAVY T_2	1973			48 55			
1971 = 18 plots		1972 = 24 plots 1973 = 13 plots		Total = 55 plots			

team and in consultation with provincial and industrial cooperators. It constitutes the main medium through which other component studies are integrated, and from which basic mensurational data on plot response to treatments are derived.

4.1 EXPERIMENTAL DESIGN, TREATMENTS, PLOT SIZE

Main experiment (1971,1972)

The basic experiment consists of a completety randomized design comprised of three fertilization levels and three thinning schedules (see below) giving nine treatment combinations. Each treatment was replicated twice and the entire experiment was repeated in each of two successive years (1971 and 1972) (Table 2 and Fig. 2).

a) Fertilization (nitrogen*)
   1. F_0 - control
   2. F_1 - 224 kgN/ha (200 lb N/ac)
   3. F_2 - 448 kgN/ha (400 lb N/ac)

* Applied as "Forest Grade" urea (46%N.j

b) Thinning
   1. T_0 - no thinning (control) (Fig. 4)
   2. T_1 - intermediate thinning (approx. 1/3 b.a. removed) (Fig. 5)
   3. T_2 - heavy thinning (approx. 2/3 b.a. removed) (Fig. 6)

Each treated plot is 0.08 ha (0.2 ac) and is surrounded by a 10.06-m (33ft) wide buffer zone. Mensurational data are collected from 0.04 ha (0.1 ac) sub-plots in the centre of the treated plots.

Subsidiary trials (1972 and 1973)

Subsidiary trials were initiated in the second and third years of the basic experiment to extend the range of nitrogen levels and to compare the effects of forms of nitrogen by applications of ammonium nitrate in addition to the urea treatment plots (Table 2).

In 1972 - Six subsidiary plots, 0.08 ha, with 10.6 m buffer zones were established.

In 1973 - Thirteen subsidiary plots, 0.04 ha (0.1 ac), with 10.06 m buffer zones were established.

4.2 PLOT ESTABLISHMENT

Following plantation location on aerial photographs and a base map, a starting point was selected near the NW corner of the stand and it was marked off with a staff compass into 100.58 m (5 chain) strips, running in a N-S direction. Levels were taken on each strip and tied back to the start point for topographical mapping.

The area between strips was divided into units of 50.29-m sq (165-feet sq). All units were inspected by a silviculturalist, a pathologist and an entomologist to determine their suitability in terms of stand uniformity, tree density, size and condition, prevalence of disease and insect populations; unsuitable units were rejected. On the remainder, 0.08 ha plots with 10.06-m-wide buffer zones were established with sides perpendicular to cardinal directions. Following the establishment of permanent plot centres and temporary plot corner posts, all trees in plots and buffer zones were pruned to a height of 1.83 m (6 ft) to improve access.

A similar procedure was followed in 1973 for the establishment of the 0.04 ha plots with 10.06-m-wide buffer zones.

4.3 THINNING CRITERIA AND METHODOLOGY

Thinning criteria in order of importance were:

1. a range of stand densities, from open-grown trees to closed canopies;
2. even spacing of residual trees;
3. maximum ± 5% difference in average plot b.a. and d.b.h. within each thinning level;
4. retention of maximum number of potential crop trees;
5. adequate tree representation across a range of diameter classes;
6. retention of Douglas-fir plantation trees, i.e., elimination of advanced natural regeneration or 'wolf' trees, where possible.

Following plot establishment, stem mapping and tree measurement, notions of open-grown and medium density stands were developed. Theoretical intermediate and heavy thinnings were applied first on stem maps of representative plots and then in the field. Residual spacing of trees, b.a., d.b.h. and number of trees were determined after marking each sample thinning level and were checked against tentative initial prescriptions. Some adjustments were made, primarily to ensure an effective release of residual trees in the intermediate thinning level. From these activities, residual stand target levels were set. These are compared with actual plot averages in Table 3.

Each year, plots to be thinned were marked according to the foregoing prescriptions, followed by a subjective marking of corresponding buffer zones. In the 1973 trials, both plot and adjacent buffer zones were prepared for thinning in the same manner. Tree marking and final checking of base thinning levels were followed by felling, treatment of all stumps with borax to prevent infection by *Fomes annosus* (Fr.)

Plot statistics:

Site Index	— 20 m (65 ft) in 50 yr
Stems/ha (ac)	— 4,695 (1900)
Initial avg d.b.h. cm (inches)	— 7.87 (3.10)
Basal area m^2/ha (ft^2/ac)	— 25.96 (113.09)
*Competitive Stress Index (c.s.i.)	— 430 units

*Section 5.1

Established 1972. Photo: Oct., 1973.

Figure 4 — T_0 - No thinning (control) - Plot number 38

Plot statistics:

Site Index - 19 m (62 ft) in 50 yr

	Before thinning	After thinning
Stemslha (ac)	4,596(1860)	2,076(840)
Avg d.b.h. cm (inches)	7.56 (2.98)	9.07 (3.57)
Basal area m^2/ha (ft^2/ac)	22.73(99.02)	14.00(60.97)
Competitive Stress Index (c.s.i.)	426 units	233 units

Established 1971. Photo: Oct., 1973.

Figure 5' — T_1 - **Intermediate** thinning (approx. 1/3 b.a. **removed) -** Plot number 15

Plot statistics:
Site Index - 20 m (65 ft) in 50 yr

	Before thinning	After thinning
Stems/ha (ac)	4,818 (1,950)	914 (370)
Avg d.b.h. cm (inches)	7.29 (2.87)	10.16 (4.00)
Basal area m^2 /ha (ft^2 /ac)	22.29 (97.11)	7.67 (33.40)
Competitive Stress Index (c.s.i.)	455 units	142 units

Established 1971. Photo: Oct., 1973.

Figure 6 — T_2 - **Heavy** thinning **(approx.** 2/3 b.a. removed) - Plot number 14

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Table 3 — Residual thinned-stand targets and actual averages for the 1971 plots

Thinning treatment	Number of trees /ha(ac)	b.a. m^2/ha(ft^2/ac)	d.b.h. cm(inches)	Competitive Stress Index(c.s.i.)*
None (control)				
T_0 - actual	4250(1720)	23.1(100.8)	7.8(3.1)	429
Intermediate				
T_1 - target	1961(794)	15.6(68.0)	9.7(3.8)	
T_1 - actual	1923(778)	14.5(63.3)	9.4(3.7)	240
Heavy				
T_2 - target	902(365)	8.4(36.6)	10.7(4.2)	
T_2 - actual	914(370)	8.3(36.1)	10.5(4.1)	144

* Section 5.1 and Appendix VIII

Karst., and measuring total tree height and height to live crown of felled trees. All branches were lopped; stems were cut into short sections and left in situ on the plots and buffer zones. Permanent tree numbers were fixed to all residual trees (except willow) in excess of 2.54 cm (1.0 inches) d.b.h.

A local volume table was prepared from the stem analysis of 71 trees removed in thinnings, plus additional measurement of 35 standing trees. These trees were selected at random from all the plots to cover the range of d.b.h. height and initial Competitive Stress Index (c.s.i.) (Arney, 1973) found in the plots.

4.4 FERTILIZATION CRITERIA AND METHODOLOGY

Fertilization criteria in order of importance were:

1. even spread of precise amounts of required fertilizers;
2. fertilizer to be applied during snow-free, cool, moist weather before end of wet winter season;
3. all fertilizer applications to be carried out in shortest time possible.

Each plot, along with its buffer zone ("gross plot"), was treated as one. These "gross plots" were marked into 2.44 m (8 ft) strips, in both N-S and E-W directions. The fertilizer was pre-weighed and carefully applied by trained crews, using "Cycione" spreaders, to these cross strips.

In this manner, using teams of 10 to 14 men, fertilizer treatments were completed in 2.5 working days in 1971 and less than 2 working days in 1972 and 1973 (see Appendix VII for specific details of precipitation and temperature during and following fertilization operations).

4.5 MEASUREMENTS AND TREE DESCRIPTION

Measurements made were:

1. D.b.h. and stem diameters, using diameter tapes to an accuracy of 0.254 mm (0.01 inches).
2. Tree heights, using height poles to an accuracy of 15.2 cm (6 inches).
3. Volume sample trees, diameters and heights at 2.54 cm (1 inch) taper steps to a minimum 7.62 cm (3 inch top), and tree height from three years prior to treatment.
4. Stem mapping in the plots and inner 5.03 m (16.5 ft) of the buffer zones, to an accuracy of ± 15.2 cm (6 inches). Initially this was done on an azimuth and distance basis from plot centres, using a plane table and engineering tape. For greater accuracy and overall efficiency, all stem mapping was checked, using right-angle prisms and engineering tapes.

Descriptive data collected were:
Tree species; crown class - dominant, co-dominant, intermediate suppressed; condition alive, dead, diseased or damaged, and height to live crown.

4.6 ELECTRO/MECHANICAL MEASUREMENT OF DIAMETER INCREMENT

An electro-mechanical dendrometer (Fig. 7) was developed to facilitate measurement of stem response at ½ tree height above breast height on

Figure 7 — Electro-mechanical **dendrometer band and** precision nullohmmeter

sample trees being studied under PC-23-006, and to provide data for interim volume response calculations. The device consisted of a 2.54 cm (1 inch) stainless steel dendrometer band and rotary potentiometer mounted on a specially designed polystyrene frame. tt functioned to an accuracy of .159 mm (.00625 inch). Leads enabled readings of upper stem growth from the ground with a precision nullohmmeter. The devices, attached to 6 trees (see PC-23-006) in each of 55 plots, were read **on** a weekly basis during the growing season.

4.7 FIRE PROTECTION

Installation of fire protection facilities was completed in 1973 (Appendix IX). **A** fire protection plan was prepared, assuming that there would be 3-5 men at the site on an average and that shortage of manpower **would** have to be compensated for by providing facilities that were capital intensive.

5.0 COMPONENT STUDY DESCRIPTIONS

5.1 PC-23-120 PREDICTING GROWTH AND YIELD THROUGH INDIVIDUAL TREE MODELS OF INTER-TREE COMPETITION AND GROWTH - (J.D. ARNEY AND R.V. QUENET).

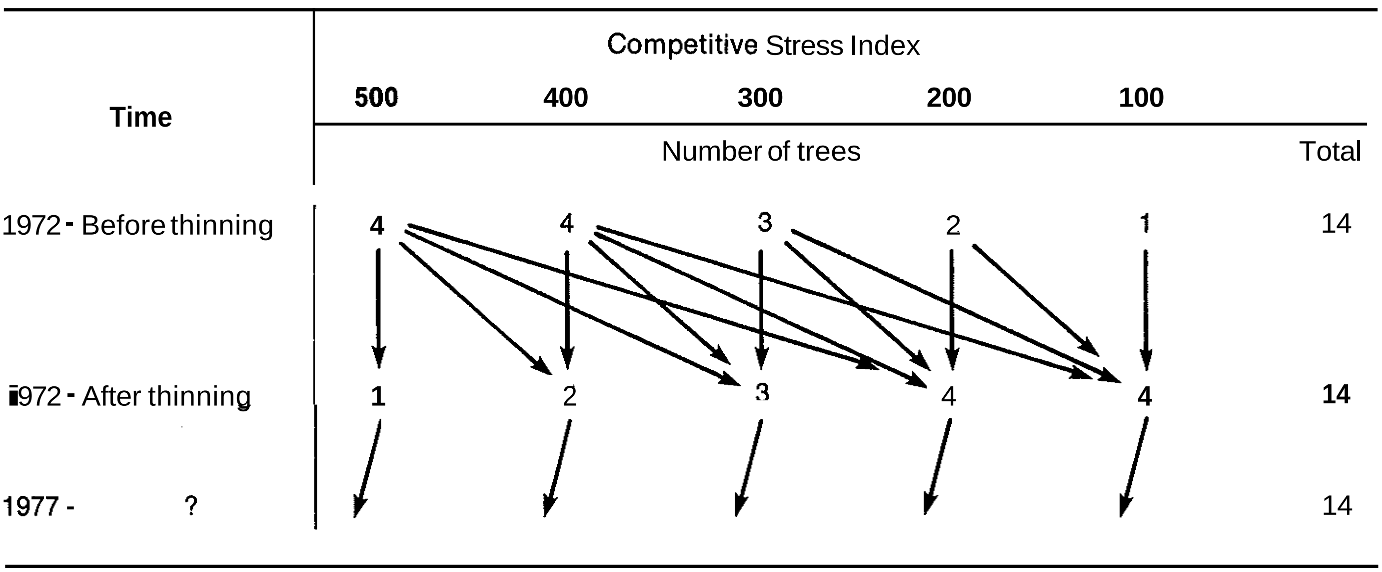
The objective of this study was to develop a stand growth model based on relationships describing individual tree growth and growth response **as** a function of inter-tree cumpetition, stand condition and cultural treatment, for the purpose of predicting growth and yield of managed stands.

Strategy

Conventional plot installations provide well-defined stand growth and yield estimates for the particular sites and treatment schedules investigated. However, they require continuous maintenance throughout most of a rotation and are not readily extrapolated to other treatment schedules. To provide more exact information about growth capacities, **to** obtain this information within a decade, and to extrapolate and interpolate to other management schedules, a new biologically based approach must replace large plot installations. The approach should not only provide a basis for managed stand growth and yield prediction, but should also be a stable research too! for intensive investigations of **how** trees grow under any stand condition, natural or imposed.

This approach should be derived from detailed components of **growth** and development of individual trees. Height, diameter and volume growth will be predicted from inputs of potential for growth (present stem and crown dimensions) and environmental constraints (present age, site index, and degree of surrounding competition). If the expression of these constraints is biologically meaningful and present tree size **is** well defined, any stand manipulation that causes a response in volume increment should be reflected in the constraint values. Component based models are capable of providing a framework in which precise quantitative relationships can be used to characterize the processes of stand development. The real value of such models is in predicting yields from stands managed in ways yet undocumented in actual stands.

To stratify individual trees into groups by potential growth response, an individual tree competition index, Competitive Stress **Index** (c.s.i.), was developed (Arney, 1973), which incorporates features of previous expressions of inter-tree competition (Krajicek *et al.,* 1961; Newnham, 1964; Gerrard, 1967; Bella, 1969).



Sampling Theory and Design

The design for a given installation is based on stratified sampling. The population of N trees is first divided into sub-populations of $N_1, N_2, \ldots N_x$ trees, respectively. These sub-populations are non-overlapping, and together they comprise the whole population, so that $N_1 + N_2 \ldots + N = N$.

It may be possible to divide a heterogeneous population into sub-populations, each of which is internally homogeneous. If each stratum is homogeneous, a precise estimate of any stratum mean can be obtained from a small sample in that stratum. These estimates can then be combined into a precise estimate for the whole population (Cochran, 1963).

At the Shawnigan Lake installation (one age class and site class), it was originally planned to use the design, relative to initial c.s.i., and change in c.s.i. (Δc.s.i.) due to thinning as shown.

All experimental units (trees) in the design were replicated four times, resulting in 56 trees measured for each fertilizer treatment represented at Shawnigan, *i.e.,* F_0, F_1 and F2. This method was referred to as Stratified Sampling by Competitive Stress as classified, using c.s.i. values determined for each tree by stem-mapping.

Regression analysis on 2-year d.b.h. increment showed tree size to be a highly significant variable. Consequently, tree size was added to the stratification procedures for selecting volume sample trees, and the method referred to as Stratified Sampling by Size and Competitive Stress was adopted for core study **PC-23-003.** The sampling procedure consists of grouping individual trees by fertilizer treatment, d.b.h. class, initial c.s.i. in 100 unit classes and thinning release classes of 100 units of c.s.i., and selecting two volume sample trees at random for each stratum so defined.

Height, diameter, form and volume responses of the volume sample trees will be used to derive and modify quantitative relationships for use in the component based distance dependent individual tree growth model.

5.2 PC-23-006 THE PHYSIOLOGY OF GROWTH OF DOUGLAS-FIRIN RELATION TO NITROGEN FERTILIZATION AND THINNING - (H. BRIX)

The objective of this study was to find criteria for prediction of growth responses of thinned and unthinned forest stands to nitrogen fertilization by providing knowledge of the physiological mechanism of the response and associated environmental conditions.

Strategy

Studies by other scientists within this project are designed *to* investigate factors influencing the availability of applied nitrogen to the tree. This study attempts to clarify the physiological mechanisms by which improved nitrogen nutrition and thinning increases stern growth. These physiological studies are being undertaken to aid in the prediction of growth effects of thinning and fertilization under different stand and site conditions.

The processes of photosynthesis and respiration account for 90% or more of net dry matter production. A major part of the study, therefore, deals with changes in environment and tree conditions, following fertilization and thinning, that affect the photosynthetic capacity and respiration of trees and stands.

It is important to clarify whether fertilization affects the photosynthetic capacity by influencing (1) the amount of leaves produced, (2) the photosynthetic efficiency of the leaves, or (3) both. In the first case, only stands *with* leaf masses below the optimum will benefit from fertilization. In the second case, it is necessary to study how much the effect of nitrogen nutrition on the photosynthetic efficiency depends on factors such as light, temperature and water. The efficiency should be studied for leaves of different ages, and at different times, following fertilization.

Effects of stand thinning will be studied, with special emphasis on conditions affecting photosynthesis and respiration, such as water and mineral status of trees, light intensity and temperature in tree crowns, and production of leaves and their distribution within the stand.

Methods

A detailed account of the growth response to treatment is a prerequisite #orexplaining growth. Weekly stem circumference increments will be observed for some years following treatment, at breast height (bh) and at ½ tree height above bh for trees *of* initial uniform size. Six trees were selected in each plot, giving 12 trees per treatment in each treatment year. Vernier scale dendrometer bands were fitted at bh. In the 1971 and 1972 installations, **4.4 cm (1.75** inch) wide aluminum bands, inscribed with scale readings *to* 0.25 mm (0.01 inch) in stem circumference, were used. In the 1973 installations, **1.9** cm (0.75 inch) stainless steel bands were used; they were provided with printed decal scales giving vernier readings to 0.1 mm (0.004 inch) in stem diameter. To facilitate measurements at ½ tree height, dendrometer bands equipped with rotary potentiometers (developed by C.P. Brett and associates) were installed (Fig. *7)*. Height growth will be measured on a yearly basis.

Trees in the T_1 treatment were released in two ways: half were released from tree competition to the south, and half to the north. The two groups of trees will thus receive the same degree of release from root competition but different crown release with respect to light intensity, thereby providing some means of evaluating the importance *of* light conditions in growth response to thinning.

Size and numbers of leaves and branches will be measured for each year, 5 years after treatment. Effect of nitrogen fertilization on photosynthetic efficiency and on rate of respiration has already been studied for a 2-year period, using material from study plots in the Greater Victoria Watershed (Brix and Ebell, 1969; Brix, 1971, 1972). These plots will continue to be used to provide information on CO_2 gas exchange. Effects of fight intensity and branch water potential on photosynthesis for fertilized and unfertilized trees have been compared (Brix, 1971,1972) and studies of temperature effect for these trees are underway. The Shawnigan Lake plots will be used for field measurements of CO_2 exchange to test results obtained in the laboratory.

In addition to studies of photosynthetic capacity of trees with respect to leaf masses and their efficiency, environmental and internal conditions of trees affecting rates of CO_2 exchange will be investigated. This will be done on all T_0F_0, T_0F_2, T_2F_0 and T_2F_2 plots.

Tree water potential will be measured with the pressure bomb at monthly intervals during the growing season for at least 3 years following treatment. Diurnal changes of water potential will also be recorded under low and high soil moisture stress. To explain tree water potentials, measurements will be made of soil water potential (Wescor Inc. soil psychrometers), stem sap velocity (heat pulse method) and stomatal resistance (diffusion porometer method). A total of 116 soil psychrometers have been placed in the main rooting zone at ***20.3*** cm (8.0 inch) depth; additionally **24** at 10.2 cm (4.0 inch) and 24 at **40.6** cm (16.0 inch) depths. Light intensity in the photosynthetically active spectrum will be sampled in different crown positions in thinned and unthinned stands (Lambda Instrument ***Co.*** quantum sensor and meter) and evaluated from studies of light intensity - photosynthesis relationships. Crown and soil temperatures will be studied in relations to stand thinning.

Total nitrogen of leaves will be analyzed from samples collected yearly in the middle and at the end of the growing season (early July and September). Studies will be made to discern whether growth responses to treatments are better related to some leaf amino acids than to total leaf nitrogen concentration.

5.3 PC-23-169 THE ROLE OF UNDERGROWTH IN INTENSIVELY MANAGED DOUGLAS-FIR ECOSYSTEMS- (P.K. Diggle).

The objective of this study was to determine the interrelationships between the undergrowth and the tree overstory in thinned and fertilized Douglas-fir stands.

Strategy and design

Undergrowth, as an ecosystem component, utilizes applied nutrients and soil water and plays a major role in nutrient cycling. Elucidation of the degree of competition which the undergrowth exerts on the tree overstory through its usage of nutrients and water, and patterns of nutrient cycling will be important in explaining and predicting tree growth response to thinning and fertilization programs.

Initial investigation of undergrowth species distribution, composition and relative abundance was carried out in four thinning/fertilizer combinations from 1971 treatments. These plots were among the first established; consequently, the undergrowth had longer to react to changed stand conditions. Treatment combinations selected represent four extreme conditions: T_0F_0, T_0F_2, T_2F_0 and T_2F_2.

To sample undergrowth on these four treatments, a systematic grid of $1m^2$ subplots was laid out in the 0.08 ha treatment plots. The number of subplots was varied according to undergrowth variability, with a minimum of 25 per treatment. On each subplot, the percentage of area occurring as bare soil, rock and litter, and covered by plant species was estimated. Plant cover was estimated by species down to a minimum of 5%. Species comprising less than 5% of the cover were given an arbitrary 1%. For the two most abundant species, salal and bracken, the average height of dominant and codominant plants was also recorded.

To provide an estimate of undergrowth biomass for the four treatments, a sample number of subplots were clipped, separated by species and prepared for weighing and nutrient analysis.

To obtain a preliminary indication of gross undergrowth effect on tree growth, all undergrowth in one 1973 T_2F_2 plot (0.04 ha) was removed in early spring by dipping, fotlowed in summer by spot spraying new sprouts with Paraquat.

Elements of study design are still under development and refinement and analysis of results to date suggest certain changes. In particular, a non-destructive technique for biomass estimation is required, as is an effective method of measuring plant vigor, e.g. leaf color and size, plant size and shape.

5.4 PC-23-005 NUTRIENT DISTRIBUTION IN A YOUNG DOUGLAS-FIR ECOSYSTEM - (B.D. Webber).

Silvicultural treatments such as fertilization and thinning influence nutrient cycling and, therefore, have an effect on tree and stand growth. The objective of this study was to determine biomass and nutrient distributions in Douglas-fir and the effects that silvicultural treatments have upon such distributions.

Strategy

Because a large number of samples are required for studies of this nature, initial biomass and nutrient relationships will be developed, using the easily measurable stand parameters of diameter and height. Since a cyclic system is being studied, it will also be necessary to monitor stand parameters which change rapidly as a result of treatment. Two such parameters to be monitored are nutrient status of the standing crop and quantity and quality of litterfall.

Design

Pretreatment biomass and nutrient sampling will be carried out using diameter and height as independent variables. Thirty-seven trees will be randomly selected from the thinned trees in the 1972 installation. These trees will be fractionated into current and older foliage, branches, wood and bark. Nutrient analysis will be carried out on the above components.

For foliar nutrient status, four plot buffer trees in each treatment combination will be permanently marked and sampled (Table 4).

Samples will be taken in March 1972, October 1972, October 1973 and October 1974. Current foliage will be analyzed for nitrogen, phosphorous, potassium and calcium content.

Litterfall sampling will be carried out in the treatment combinations shown (Table 5).

In each treatment combination there will be ten 0.61 m x 0.61 m (2 ft x 2 ft) sample screens.

Samples will be collected on a monthly basis during the snow free period. They will be aggregated by plot, and analyzed for nitrogen, phosphorous, potassium, calcium and magnesium.

5.5, PC-23-094 NITROGEN MOVEMENT AND UREA INDUCED TRANSFORMATION IN FOREST SOILS - (B.D. WEBBER).

The application of a fertilizer to forest soils affects not only ptant growth, but also many soil properties and processes. The nature and extent of such effects on forest soils is not clearly understood. The objective of this study was to determine the effect of urea fertilization on forest soil properties, including translocation and leaching losses of major cations and the subsequent effect on nutrient cycling.

Table 4 — Sampling plan for foliar nutrient status

Thinning Regime	fertilization Regime							
	F_0	F_1	F_2	F_3	F_4	F_6	F_1*	F_2*
	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot
T_0	2(72)	34(72)					26(72)	23(72)
T_1	17(72)	12(72)						
T_2	25(72)	28(72)	4(72) 57(73)	32(72)	51(73)	58(73)		55(73)

* Ammonium nitrate

Table 5 — Sampling plan for litterfall

Thinning Regime	Fertilization Regime									
	F_0		F_1		F_2		F_3		F_2*	
	Plot	(Year)	Plot	(Year)	Plot	(Year)	Plot	(Year)	Plot	(Year)
T_0	2	(72)			18	(72)			23	(72)
T_1	17	(72)	12	(72)						
T_2	20	(72)	28	(72)	4	(72)	32	(72)		

Table 6 — Fertilization and thinning regimes showing lysimeter installation by plot and year

Thinning Regime	Fertilization Regime									
	F_0		F_1		F_2		F_3		F_6	
	Plot	(Year)	Plot	(Year)	Plot	(Year)	Plot	(Year)	Plot	(Year)
T_0	2	(72)			18 23	(74) (74)				
T_1	10	(71)	24	(71)	43	(71)				
T_2	25	(72)			4	(72)	32	(74)	58	(73)

Strategy and **design**

In soils of mature temperate forest ecosystems, nutrients are contained in a relatively closed cycle, with losses occurring primarily by cation leaching through the soil profile. Cation movement out of these ecosystems is generally low because of a low anion content.

Fertilization and thinning will alter conditions to allow for a greater production of anions, a concomitant increase in cation mobility and accentuated nutrient toss. Thinning will also modify the variables controlling the ionic concentration, such as temperature and water, and will affect the ionic concentration directly by the addition of ions to the forest floor via precipitation and litterfall. These processes may be accompanied by accelerated soil respiration, which leads to increased anion (primarily bicarbonate) production. fertilization will have a more direct effect through addition of mobile anions and cations to the forest floor. There wilt also be the indirect effect on soil pH and pH dependent cation exchange capacity.

Since most loss will occur through leaching, a monitoring of soil water should serve to indicate the magnitude of the changes. In this study, soil and soil water parameters directly related to the major pathways and impact of urea fertilization (Appendix X) will be monitored.

Plots representing a variety of fertilizer and thinning treatments were selected (Table 6) for installation of a tension lysimeter system (Appendix XI) at three depths (below surface, 10 cm (3.9 inches) and 30 cm (11.8 inches)). By applying a 0.1 atmosphere tension, soil water samples were collected from all selected plots and depths. The parameters monitored were: pH, conductivity, quantity flow, total nitrogen, ammonium nitrogen, nitrate nitrogen, calcium, magnesium, potassium and bicarbonate ions. Additional samples were also collected for soil pH determination at the three specified depths.

5.6 PC-23-109 THE ROLE OF SOIL FAUNA IN TREE NUTRITION IN RELATION TO FERTILIZATION AND THINNING - (V.G. MARSHALL).

Since some soil animals are important plant pests, while others are vital in maintaining soil fertility, the advent of forest fertilization and thinning warrants an understanding of the consequences of these silvicultural practices on the soil fauna. The objectives of this study were to: determine the effects of fertilizers and thinning on natural soil faunal populations, ascertain the role of the fauna in nutrient cycling, and indicate means of manipulating faunal populations to favorably influence tree growth.

Strategy and design

The interrelationships of soil fauna, fertilization, organic matter decomposition, nitrogen cycling and tree growth are shown in Appendix XII. Fertilizers affect fauna directly by its adjuncts, production of noxious substances and changes in physical and chemical properties of the soil and indirectly through increases in the micro- and macroflora. Soil flora is "grazed" by fauna or it may act as a physical conditioner of the litter, rendering it more palatable to fauna. Reciprocally, fauna spreads spores and clears away antibiotic producing fungi, thereby facilitating fungal succession. Fauna may also immobilize nutrients.

Various approaches are being taken, including studies on numbers, biomass, distribution of dominant animal species and CO_2 production in fertilized and unfertilized plots. Gut content analysis is being used to determine food of the fauna and ^{15}N-tagged fertilizers to trace the source of the food and the quantity of nitrogen immobilized. Other experiments with fertilizers and soil-faunal exclusion techniques will determine the impact of soil-animals on litter decomposition. Meteorological data will be used to interpret soil faunal information.

Soil Faunal Censusing: This will provide data for the evaluation of numbers, biomass and distribution of the fauna. Sampting will be carried out in the buffer strip of selected plots, thinned to different stocking and fertilized with various types and rates of fertilizers (Table 7).

Utilizing the results of preliminary sampling, Pearson and Hartley power function tables (Scheffé, 1959) were used to calculate the minimum number of samples required to show significant differences between fertilization and thinning treatments on nematodes, enchytraeids, coltembolans and mites.

CO_2 evolution: Carbon dioxide production in the field will be measured by the "respiration bell" technique (Witkamp, 1966).

Gut content analysis: Representative species will be dissected and their gut content will be examined for type of food (Poole, 1959).

^{15}N Studies: Urea tagged with ^{15}N will be applied to pot experiments and the extracted fauna will be analyzed for quantity of N immobilized. Similar trials will be carried out in the field.

Litter decomposition: Litter bags of 3 mesh sizes, containing titter from the experimental site, will be

Table 7 — List of soil faunal investigations

(for details of thinning and fertilizer treatments see Tables 2 and 3 and Appendix VIII)

Investigation	Plot No.	Kg N/ha Urea	Fertilizer Application	Sampling Started
CO_2 measurement	10	T_1F_0 - Control	1971	1971
"	24	T_1F_1 - 224	"	"
"	43	T_1F_2 - 440	"	"
"	2	T_0F_0 - Control	1972	1972
"	51	T_2F_4 - 896	1973	1973
"	47	T_2F_6 - 1344	"	"
Litter decomposition	20	T_2F_0 - Control	1972	1972
"	31	T_2F_2 - 448	"	"
"	46	T_2F_3 - 672	"	"
Faunal censusing	10	T_1F_0 - Control	1971	1971
"	24	T_1F_1 - 224	"	"
"	43	T_1F_2 - 448	"	"
"	2	T_0F_0 - Control	1972	1972
"	4	T_2F_2 - 440	"	"
"	18	T_0F_2 - 448	"	"
"	25	T_2F_0 - Control	"	"
"	32	T_2F_3 - 672	"	"
"		F_{4w} - 1120	"	"
"		F_{5w} - 2240	"	"
"	52	T_2F_2 - 448	1973	1973
"	50	T_0F_4 - 896	"	"
"	49	T_1F_4 - 896	"	"
"	51	T_2F_4 - 896	"	"
"	58	T_2F_6 - 1344	"	"
"	23	T_0F_{2*} - 448	1972	1972
"	48	T_2F_{2*} - 448	1973	1973

F_{4w} and F_{5w} = G. Wallis' plots 9, 17, 18 and 2, 3, 6, respectively.

* Ammonium nitrate.

heat sterilized and then replaced in the field. At 6-month intervals, four **bags** of each mesh size from each fertilizer treatment will be removed to determine weight losses, associated soil fauna, and nutrient status of the litter (e.g. Crossley and Hoglund, 1962; Curry, 1969).

5.7 PC-23-134 THE SOIL MICROFLORA AND BIOTIC PROCESSES IN MANAGED FOREST STANDS - (J.A. DANGERFIELD).

Microorganisms are capable of fixing large amounts of chemicals, responsible to a large degree for litter decomposition and capable of making insoluble materials available to the plant roots. Therefore, the objectives of this study were to determine the effect of forest management practices on soil microbiotic activity; to determine the importance of changes in microbial activity as retated to forest productivity, and to develop guidelines for achieving desirable changes in microbiotic activity.

Strategy

Since nutrient avaiiabitity is controlled in part by the rate of transformation from the unavailable to the available nutrient pool, the ability of the microflora to degrade complex soil organic components can **be** a major factor determining conversion rate. This is particularly true for nitrogen. Management practices that affect microbiat activity by changing soil temperature, moisture, pH and quantity and composition of litterfall could affect nutrient supply. It is therefore necessary to become familiar with the influences of any treatment on microorganisms if we wish to identify stand and ecological conditions affecting treatment response or to explain observed effects.

Table 8 — Sampling plan **for** microbiological characterization **of plots within the** Shawnigan installation

PC-23-134

Year of Plot Installation	Plot Number and Treatment	Remarks
1971	45(T_2F_2) 33(T_2F_2) 11(T_2F_0)	Will consider these for complete micro-biological and soil enzyme characterization in the 1974 growing season. Also respiration, ammonification and nitrification.
1972	2(T_0F_0) 4(T_2F_2) 18(T_0F_2 urea) 23(T_0F_2 NH_4NO_3) 25(T_2F_0)	Complete soil microbiological and enzyme characterization commencing Fall 1972 and extending through 1973 and 1974 growing season. Also respiration, ammonification and nitrification.
1973	48(T_2F_2 NH_4NO_3) 52(T_2F_2 urea)	Characterized as in the 1972 plots but only for summer of 1973.
	51(T_2F_4) 47(T_2F_6)	Limited microbiological and soil enzyme characterization for the summer of 1973. Also respiration, ammonification and nitrification.

In all these plots, the four sides of the buffer zone are sampled.

In the initial phases, a variety of approaches will be considered which will allow the selection of a suitable methodology for studying other sites. The approaches taken wilt include an estimation of total organism numbers and the potential of the mixed so l flora to perform selected organic and inorganic transformations; a monitoring of selected soil enzyn e levels, and measurement of soil respiration under controlled conditions. It is hoped to provide a link between number or activity of microorganisms and the soil enzymatic activity.

Design

Plots representing extremes of fertilizer and thinning treatment (Table 8) are sampled in early May, mid-July, early October and mid-February, which roughly approximate spring, summer, fall and winter.

Microbiological characterizations are performed on four composite samples collected from the buffer zone of each plot. Each composite sample is made up of 15 randomly selected 5-cm (1.97 inch) diameter soil cores.

Enzymatic analysis is performed on the above composite samples plus a fifth composite which is collected at the same time from the buffer strips. Respiration, nitrification and ammonification are determined on 15 individual 5-cm diameter cores randomly distributed throughout the buffer zone of each plot.

Microbiological Characterizations

Microbiological characterization will be achieved by using a most probable number technique. This involves sample dilution to extinction and the use of probability tables to finally determine organism numbers of specified capabilities. The capabitities of interest are fisted below:

1. Total number of bacteria capable of growth on Basal Salts media (MPN technique with 1 ml inoculum).
2. Total number of bacteria capable of growth on Basal Salts plus growth factor and amino acid supplements at pH 7.0, pH 6.0 and pH 5.0 (MPN technique with 1 ml inoculum).
3. Total number of actinomycetes capable of growth on chitin agar (plate count technique with 0.1 ml inoculum).
4. Total number of fungi capable of growth on phytone yeast extract agar (MPN technique with 0.1 ml inoculum).
5. Total number of yeast capable of growth on modified Sabaround agar at pH 4.0 (plate count technique with 0.1 ml inoculum).
6. Bacterial potential for ammonification (MPN technique with 1.0 ml inoculum).
7. Bacterial potential for cetlulose hydrolysis (MPN technique with 1.0 ml inoculum).
8. Bacterial potential for phytin hydrolysis (MPN technique with 1.0 ml inoculum).
9. Bacterial potential for gelatin hydrolysis (MPN technique with 1.0 ml inoculum).
10. Bacterial potential for starch hydrolysis (MPN technique with 1.0 ml inoculum).
11. Bacterial potentiat for urea hydrolysis (MPN technique with 1.0 ml inoculum).
12. Bacterial potential for phenolic degradation (MPN technique with 1.0 ml inoculum).
13. Fungal potential for cellulose hydrolysis (MPN technique with 0.1 ml inoculum).
14. Fungal potential for phytin hydrolysis (MPN technique with 0.1 ml inoculum).
15. Fungal potential for chitin hydrolysis (MPN technique with 0.1 ml inoculum).
16. Fungal potential fur phenolic degradation (MPN technique with 0.1 ml inoculum).

In addition to the foregoing microbiological assays to be performed on a routine basis, assays will be included periodically to determine the number of nitrifiers present and the potential for denitrification.

Enzymatic Analysis

A number of colorimetric techniques adopted from the literature are used here. The enzymes monitored are: cellulase, protease, phytase, phenol oxidase, urease and dehydrogenase.

Respiration

The evolved CO_2 was trapped in 5 M KOH and back titrated with acid of known normality. Nitrification and ammonification was measured by extracting samples with 2N KC1, distilling off the various nitrogen fractions into barium hydroxide, and titrating with standarized sulfuric acid.

6.0 SUMMARY

The multidisciplinary research studies at Shawnigan Lake, B.C. are part of a project on management of coastal Douglas-fir/w. hemlock ecosystems. They are undertaken to obtain a better understanding of nitrogen fertilization and thinning effects on growth and yield of coastal Douglas-fir stands in order to identify effects of these treatments on the ecosystem and on factors controlling growth responses. This will aid in predicting treatment effects under different stand and ecological conditions. This report describes the Shawnigan Lake site, treatments applied and plot establishment, together with objectives, strategy and interrelationships of component studies. It is intended to provide a background for future progress reports, and study results are not included.

The study area is located on top of a well-rounded knoll, approximately 335 m in elevation. The bedrock is composed of metamorphosed volcanic rock intruded by a batholith (Wark gabbro and diorite gneiss). This is capped by a moderately deep deposit of till, which is presumably ground moraine. The soils are classified as Orthic Dystric Brunisols and are shallow, coarse textured, well drained and underlain by impermeable basal till. There is essentially no A_e horizon and only a thin (usually less than **3** cm) organic mantle. The soil depth to C_1 horizon varies between 45 and 60 cm. Water holding capacity, C/N ratio and percentage of C and of N are low. Amounts of exchangeable cations are low, except for hydrogen. The climate is transitional between the coot summer Mediterranean and Marine West Coast Climate. The site is in the Wetter (Madrona-Douglas-fir) Subzone of the Coastal Douglas-fir Biogeoclimatic Zone of Krajina (1969) and the Strait of Georgia Section of the Coast Forest Region of Rowe (1972). The site index is 21 m at 50 yr. Current forest cover is a mixture of planted and natural Douglas-fir, with a small proportion of other conifers (western hemlock, western white pine, lodgepole pine and western red cedar), and red alder in wet depressions. The understory is dominated by **salal,** Oregon grape and bracken. The area was planted to 2-0 Douglas-fir in the spring of **1948,** following a heavy burn in 1942 which left a clean site with little humus. Some Douglas-fir were established naturally since **1943.**

Trials of component studies were integrated in a core study that provided for plot establishment and maintenance and for measurement and analysis of votume growth responses. The basic experiment consisted of a 3 x 3 randomized plot design comprising 3 levels of N fertilization (0,224 and **448** kg N, as urea, per ha) and 3 levels of thinning in which zero (To), approximately 1/3 (T_1) and 2/3 (T_2) of the basal area was removed. Treatments were replicated twice in each of 2 years (1971 and 1972) in plots of **0.08** ha surrounded by 10 m wide buffer zones. Subsidiary trials, established in 1972 and 1973, extended the range of nitrogen levels to 1344 kg N/ha and compared ammonium nitrate and urea effects. In 1970, the stand age was 24 years. At that time the average tree had a d.b.h. of **7.8** cm and a height of **8.65** m. The average stand statistics for 1971 plots, immediately after thinning, for the T_0, T_1 and T_2 treatments, respectively, were:

4250,1923 and 914 for number of treeslha; 23.1, 14.5 and 8.3 for b.a. m^2/ha; 7.8, 9.4 and 10.5 for d.b.h. cm, and **429,240** and **144** for c.s.i.

The seven component studies seek to identify changes in soil, vegetation and atmosphere in response to treatments and analyze relationships among these factors, together with their functional role in tree growth. A knowledge and understanding of treatment and environmental impact on nutrient cycling, water budgets, microorganism populations and activities, competition among trees and with understory, and physiological conditions of trees are sought to provide input into mathematical models that will predict growth response under various stand and ecological conditions. Six studies deal with nitrogen and thinning effect on (1) the physiology of the trees and regimes of light, water and temperature; (2) undergrowth and its role in the ecosystem; (3) nutrient distribution in the ecosystem; (4) nitrogen movement and transformations in the soils; (5) soil fauna and their role in tree nutrition, and (6) soil microflora and biotic processes. The seventh study is designed to develop a predictive stand growth model based on relationships describing individual tree growth and growth response as a function of inter-tree competition, stand condition and cultural treatment.

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9.0 APPENDICES

APPENDIX I - A representative soil profile description for the Shawnigan Lake site.

Bm_1 0-15 cm (0-5.9 inches	Dark reddish brown (5 YR 3/4) moist, dark brown (7.5 **YR 414)** dry gravelly sandy loam with about 60% **by** weight gravel and very weak granular to subangular blocky structure. Illuvial organic material is accumulated. Lower horizon boundary is gradual, not clearly defined. Roots are common. Horizon depth is 12.5 to 18 cm. pH 5.6 in water, **4.8** in $CaC1_2$.
Bm_2 15-35cm **(5.9-13.8** inches)	Dark yellowish brown (10YR **4/4)** moist, yellowish brown (10YR **5/4)** dry gravelly **sandy** loam with about 70% gravel by weight and very weak subangular btocky structure. **Sand** and gravel grains are stained with iron oxides. Lower boundary is smooth and indistinct. Horizon thickness is 10 to 23 cm. Few roots. pH 5.5 in water, **4.6** in $CaC1_2$.
BC 35-45 cm (13.8-17.7 inches)	Essentially the same as the Bm_2 horizon, but has a higher percentage **of** rocks greater than 10 mm in diameter, about **45% by** weight **as** compared to 30% for the Bm_2, and **has** an abrupt lower boundary- Horizon **is** 10 to 23 cm **thick,** sometimes lacking. Routs are often matted in the lower boundary **of** this horizon and the top **of** the C_1 horizon.
C_1 45-75 **cm (17.7-29.5** inches)	Light yellowish brown (2.5Y 4/4) moist, **(5Y 6/4)** dry), mottled gravelly sandy loam containing cemented chunks of **till.** Zone of maximum soil water discharge when saturated. Horizon **is 24 - 32** cm thick. Lower boundary is abrupt. pH 5.6 **in** water, 4.7 in $CaC1_2$.
C_2 75+ **cm** (29.5 + inches)	Light yellowish brown (2.5Y **414** moist, 6/2 dry) compact massive gravelly **sandy** loam till. Extremely hard and impermeable to roots and water. pH 5.5 in water, **4.6** in $CaC1_2$.

APPENDIX 11 **SOIL ANALYSIS----SHAWNIGAN LAKE**

		Coarse Material (Size & percent)				Moisture (percent)		Texture (percent)			Color		pH		Horizon Depth (inches)
Plot	**Horizon**	≥10mm	5 to ≤10mm	2 to ≤5mm	≤2mm	15 Atm.	1/3 Atm.	Sand	Silt	Clay	Dry	Wet	H_2O	$CaCl_2$	
1	Bm-1	29	13	20	38	7.40	16.40	51.4	37.0	11.6	7.5YR-4/4	5YR-3/4	5.8	4.9	0-5
	Bm-2	24	12	28	36	5.77	11.80	60.8	30.0	9.2	10YR-5/4	10YR-4/4	5.8	4.9	5-11
	BC	40	13	18	29	5.47	8.80	67.8	25.0	7.2	10YR-5/4	10YR-4/4	5.7	4.9	11-18
	C--1	45	14	15	26	3.85	4.90	72.4	19.0	8.6	5Y-6/4	2.5Y-4/4	5.7	5.0	18-30
	c--2	—	—	—	52	2.75	4.50	79.4	17.0	3.6	2.5Y-6/2	2.5Y-4/4	5.5	—	30+
2a	Bm-1	34	10	23	33	8.82	23.00	59.4	31.0	9.6	7.5YR-5/4	5YR-3/4	5.5	4.7	0-7
	Bm-2	39	19	19	23	7.96	10.00	54.4	30.6	15.0	10YR-5/3	10YR-4/3	5.5	4.5	7-11
	BC	25	11	19	45	11.36	18.80	59.4	25.6	15.0	2.5Y-6/4	2.5Y-5/4	5.4	4.7	11-20
	C	—	—	—	48	9.11	14.70	59.4	32.0	18.6	2.5Y-5/4	2.5Y-4/4	5.5	4.7	20+
2b	Bm-1	13	9	17	61	11.25	29.20	46.8	40.0	13.2	10YR-5/3	10YR-3/4	5.4	4.8	0-6
	Bm-2	49	10	13	28	11.35	26.90	52.0	33.6	14.4	10YR-5/3	10YR-3/4	5.4	4.6	6-10
	Bm-3	57	7	10	26	10.51	20.30	52.0	31.0	17.0	10YR-5/4	10YR-4/3	5.5	4.6	10-18
	BC	13	7	11	69	8.42	18.20	52.6	29.4	18.0	2.5Y-6/4	2.5Y-5/4	5.8	4.8	18-22
	C	—	—	—	48	10.14	21.20	54.4	27.6	18.0	2.5Y-6/4	2.5Y-5/4	6.0	4.9	22+
3	Bm-1	30	13	20	37	8.50	20.30	66.0	25.6	8.4	10YR-5/4	10YR-4/3	5.5	4.6	0-7
	Bm-2	27	15	20	38	5.56	16.30	59.4	27.6	13.0	2.5Y-6/4	2.5Y-4/4	5.4	4.6	7-16
	BC	34	18	18	30	5.86	14.50	67.0	23.0	10.0	5Y-6/3	2.5Y-5/4	5.3	4.6	16-21
	C--1	16	11	19	54	8.11	16.10	51.0	31.0	18.0	2.5Y-6/4	2.5Y-5/4	5.4	4.4	21-25
	c--2	—	—	—	45	8.36	15.80	72.4	18.0	9.6	5Y-6/3	2.5Y-4/4	5.6	4.6	25+
4	Aej	28	14	20	38	8.84	21.90	53.0	35.0	12.0	10YR-5/2	10YR-3/2	5.7	4.8	0-7
	Bm-1	44	16	17	23	8.88	18.70	73.0	20.6	6.4	10YR-5/3	10YR-4/3	5.8	4.9	7-15
	Bm-2	33	18	19	30	8.30	16.20	58.6	26.0	15.0	2.5Y-5/4	2.5Y-5/4	5.8	4.8	15-30
	BC	40	17	15	28	9.82	17.80	49.0	28.4	22.6	2.5Y-5/4	2.5Y-5/4	5.5	4.5	30-35
	C--1	47	25	12	16	12.71	——	51.4	29.0	19.6	2.5Y-5/4	2.5Y-4/4	—	—	35-39
	c--2	—	—	—	36	9.96	19.30	57.6	27.0	15.4	5Y-6/3	5Y-5/3	5.3	—	39+
5	Aej	15	19	19	47	9.48	22.90	58.8	26.0	15.2	10YR-6/3	10YR-5/4	5.6	4.8	0-6
	Bm	41	17	14	28	16.73	24.90	42.4	28.4	29.2	10YR-5/6	10YR-4/4	5.5	4.5	6-15
	BC	17	10	14	59	16.37	25.90	43.8	25.0	31.2	10YR-5/6	10YR-4/4	5.5	4.6	15-24
	C	—	—	—	44	8.15	14.40	61.6	14.4	24.0	2.5Y-6/4	2.5Y-5/4	5.5	4.6	24

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APPENDIX II con't. . . . . SOIL ANALYSIS---SHAWNIGAN LAKE

Plot	Horizon	Exchangeable Cations (m.equiv/100g) Calcium	Magnesium	Potassium	Sodium	Hydrogen	Total Exchange Capacity	Carbon	Nitrogen	Oxalate Extraction % Aluminum	Oxalate Extraction % Iron	Dithion Extraction % Aluminum	Dithion Extraction % Iron
1	Bm-1	1.34	0.14	0.14	0.06	11.44	13.13	2.43	0.07	0.73	0.28	0.35	2.04
	Bm-2	0.97	0.11	0.11	0.05	7.51	8.74	0.88	0.06	0.62	0.16	0.47	1.83
	BC	0.41	0.05	0.07	0.05	6.85	7.44	0.73	0.05	0.70	0.18	0.39	1.42
	C--1	0.57	0.07	0.06	0.05	6.24	6.99	0.63	0.03	0.65	0.19	0.29	0.86
	c--2	0.27	0.02	0.02	0.04	5.14	5.83	0.31	0.02	0.70	0.19	0.18	0.65
2a	Bm-1	1.48	0.35	0.14	0.06	14.23	16.27	2.08	0.09	0.67	0.30	0.48	1.69
	Bm-2	1.30	0.36	0.11	0.08	12.50	14.65	1.43	0.09	0.61	0.17	0.35	1.25
	BC	1.35	0.57	0.06	0.14	10.02	12.14	0.46	0.04	0.68	0.13	0.38	1.79
	C	3.14	1.75	0.08	0.15	14.50	19.60	0.25	0.02	0.32	0.15	0.12	1.49
2b	Bm-1	2.25	0.51	0.18	0.52	7.73	11.20	3.63	0.10	0.55	0.27	0.41	1.61
	Bm-2	1.43	0.42	0.14	0.13	15.26	17.37	2.07	0.10	0.67	0.24	0.53	1.64
	Bm-3	1.07	0.36	0.12	0.19	13.22	14.88	1.31	0.08	0.77	0.20	0.55	1.81
	BC	1.72	0.59	0.07	0.09	9.06	11.53	0.45	0.03	0.43	0.08	0.32	1.60
	C	3.80	1.40	0.07	0.13	6.06	11.46	0.33	0.03	0.22	0.09	0.21	1.57
3	Bm-1	1.03	0.27	0.21	0.07	13.08	14.65	1.09	0.07	0.54	0.13	0.24	1.80
	Bm-2	0.35	0.19	0.10	0.07	9.27	9.88	0.72	0.07	0.63	0.14	0.52	1.20
	BC	0.34	0.08	0.09	0.07	11.78	12.36	0.60	0.05	0.62	0.11	0.46	0.81
	C--1	0.48	0.16	0.08	0.10	11.94	12.76	0.74	0.05	0.72	0.12	0.48	1.33
	c--2	4.74	1.45	0.09	0.11	9.57	15.95	0.59	0.03	0.28	0.13	0.23	1.23
4	Aej	3.46	0.59	0.32	0.08	12.16	16.62	1.41	0.10	0.36	0.17	0.31	0.94
	Bm-1	2.18	0.12	0.22	0.08	11.54	14.14	1.34	0.06	0.73	0.28	0.70	1.59
	Em-2	1.88	0.14	0.14	0.08	8.19	10.42	0.59	0.05	0.60	0.14	0.47	1.34
	BC	0.93	0.23	0.13	0.08	9.07	10.44	0.59	0.05	0.62	0.12	0.46	1.20
	C--1	1.53	0.42	0.17	0.12	16.43	18.66	1.35	0.07	0.72	0.15	0.52	1.15
	c--2	1.16	0.32	0.12	0.10	11.54	13.24	0.96	0.06	0.49	0.11	0.42	0.92
5	Aej	2.12	0.42	0.38	0.04	11.35	14.32	1.18	0.06	0.38	0.25	0.44	1.48
	Bm	1.53	0.31	0.35	0.08	16.47	18.74	1.15	0.08	0.79	0.23	0.92	2.44
	BC	1.62	0.60	0.23	0.10	16.05	18.59	1.02	0.07	0.73	0.31	0.54	2.49
	C	0.51	0.23	0.11	0.09	8.73	9.66	0.31	0.03	0.55	0.16	0.51	1.46

APPENDIX III

CLIMATIC DATA FOR SOUTHEAST VANCOUVER ISLAND*

	Elevation (ft)	Precipitation inches: Mean Annual	Precipitation inches: 4 mos. June–Sept.	Precipitation inches: 2 mos. July and August	Temperature (°F.): Mean Annual	Temperature (°F.): 4 mos. June–Sept.	Temperature (°F.): 2 mos. July and August	Sunshine Hours: Annual
SAANICH PENINSULA AREA-- OOL MEDITERRANEAN CLIMATE								
Victoria	228	27.1	3.4	1.1	50	58	60	2192
Dom. Observatory	730	27.2	3.1	1.1	50	62	64	
Cordova Bay	112	32.1	3.7	1.3	49	58	60	
James Island	176	27.5	3.5	1.3	50	60	62	
Pat Bay Airport	53	33.6	4.2	1.6	49	59	61	
Sidney	200	30.7	4.0	1.5	49	60	62	2038
Fender Island	200	30.2	4.2	1.6				
Average		29.8	3.7	1.4				
Range		27.1–33.6	3.1–4.2	1.1–1.6				
SAANICH PENINSULA TO COMOX LOWLAND--TRANSITIONAL CLIMATE								
	125	46.1	4.7	1.4	49	58	59	
	455	42.9	4.8	1.6	48	60	63	
	175	35.5	4.4	1.7	49	61	63	1805
	28	39.3	4.7	1.8	50	62	65	
	36	38.0	4.6	1.7	49	60	62	
	40	41.4	4.9'	1.7	--	--	--	
	100	37.9	5.5	2.0	50	61	64	
	104	42.5	6.9	2.1	47	58	61	1832
	60	33.8	5.3	2.0	50	62	65	
Parksville	300	31.9	5.2	2.2	46	57	59	
Denman Island	180	50.4	5.8	2.0	--	--	--	
Comox Airport	75	46.3	5.9	2.7	48	59	61	
Cape Lazo	125	41.8	5.5	2.2	48	59	62	
		40.6	5.1	1.9				
		31.9–50.3	4.4–5.9	1.4–2.7				
TERRITORY ADJACENT TO THE COASTAL PLAIN--MARITIME CLIMATE								
Cowichan Lake	58	74.8	7.2	2.3	49	60	63	1454
Alberni (Beaver Creek)	300	68.5	6.7	2.4	49	61	64	
Cameron Lake	600	57.6	6.3	2.1	--	--	--	
Cumberland	523	57.8	7.8	3.0	48	60	62	
Courtenay	150	55.5	7.3	[illegible]	--	--	--	
Campbell River	50	55.7	7.5	3.3	--	--	—	
Average		61.6	7.1	2.7				
Range		55.5–74.7	6.2–7.5	2.2–3.3				

*Source - Soil Survey of Southeast Vancouver Island Gulf Islands, British Columbia. J.H. Day, L. Farstad and D.G. Laird, 1959.

CLIMATIC FACTORS AFFECTING PLANT GROWTH ON SOUTHEAST VANCOUVER ISLAND**

	Cool Mediterranean Climate		Transitional Climate						Maritime Climate			
	Sidney	Victoria	Sooke	Shawnigan Lake	Duncan	Ganges	Nanaimo	Cape Lazo	Jordan River	Cowichan Lake	Alberni	Cumberland
Altitude above mean sea level (ft)	100	228	125	455	28	35	85			545	300	523
Mean annual temperature (°F.)	49	50	49	48	51	49	50			49	49	48
Yearly precipitation (inches)	30.3	26.9	45.4	42.1	38.6	37.3	37.2	42.1	71.2	73.1	67.8	57.6
Beginning of vegetative period	Mar. 8	Feb. 26	Mar. 6	Mar. 22	Mar. 2	Mar. 8	Mar. 10	Mar. 23	Mar. 13	Mar. 15	Mar. 15	Mar. 23
End of vegetative period	Nov. 22	Dec. 4	Nov. 20	Nov. 15	Nov. 22	Nov. 20	Nov. 21	Nov. 6	Nov. 24	Nov. 15	Nov. 15	Nov. 10
Duration of vegetative period (days)	259	281	259	237	265	257	256	228	256	245	245	232
Mean date last frost in spring	Mar. 31	Feb. 28	Apr. 21	May 2	May 4	Apr. 7	Apr. 12	Apr. 13	Apr. 4	Apr. 26	May 12	May 14
Mean date first frost in fall	Nov. 16	Dec. 7	Oct. 27	Oct. 17	Oct. 6	Nov. 4	Nov. 3	Oct. 24	Nov. 5	Oct. 19	Oct. 10	Oct. 11
Duration of frost-free period (days)	230	282	189	168	155	211	205	194	215	176	151	150
Day degrees above 42°F. in vegetative period	2976	3014	2723	2815	3434	2995	3269	2795	2263	2970	3376	2837
Precipitation during vegetative period (inches)	14.7	15.6	21.7	16.7	19.6	17.7	18.6	16.1	34.5	31.9	30.2	24.4
Water deficiency during vegetative period (3-inch storage)	10.2	10.6	8.4	9.3	9.7	9.3	8.6	9.0	3.7	6.0	5.7	5.8
Mean date of drought point—												
(2-inch storage)	May 26	May 18	June 7	June 7	June 8	June 5	June 8	June 4	July 2	June 26	July 1	June 18
(3-inch storage)	June 8	June 2	June 19	June 19	June 21	June 14	June 22	June 14	July 13	July 6	July 9	July 3
(4-inch storage)	June 19	June 13	July 1	July 1	July 1	June 29	July 3	June 24	July 24	July 15	July 18	July 13

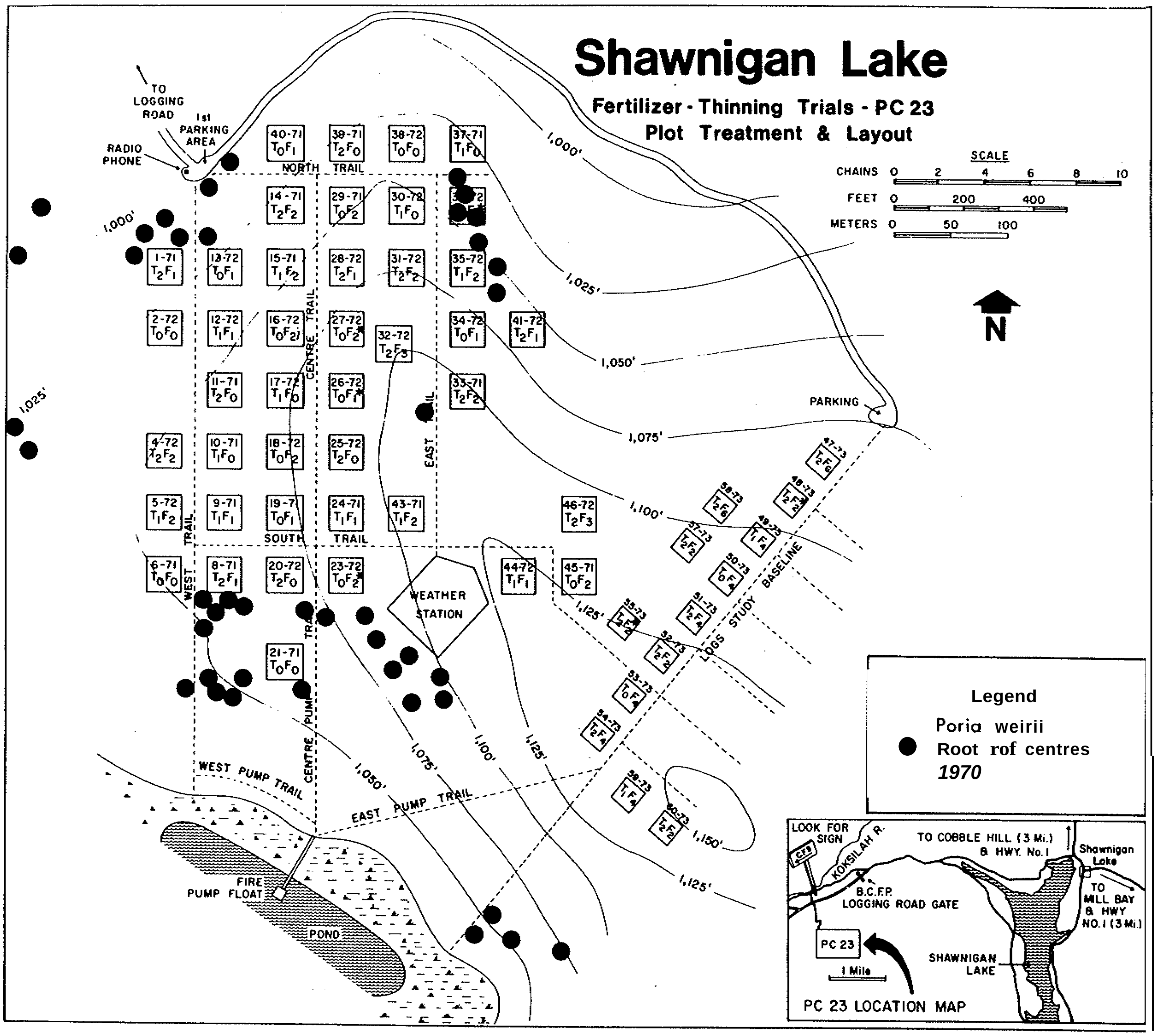
*Vegetative period is considered as the period during which the mean temperature is at or above 42°F.

** Source - Soil Survey of Southeast Vancouver Island and Gulf Islands, British Columbia. J.H. Day, L. Farstad and D.G. Laird, 1959.

APPENDIX V. Meteorological data collected, time of recording and instruments used.

Measurements taken	Time Period Measured	Instruments Used
1) Temperature (°F) Daily: max, min, mean Monthly avg: max, min, mean	All year	Hygrothermograph plus max and min check thermometers
2) Humidity (%) Daily: max, min, mean Monthly avg: max, min, mean	All year	Hygrothermograph
3) Solar Radiation (Langley) Total daily and monthly	April - Oct.	R-401 Solar Radiation Recorder - Weather Measure Corporation
4) Precipitation (inches) (a) Total daily and monthly	April - Oct.	Cassella-Recording Rain guage
(b) Total monthly	Nov. - March	Total precipitation gauge
5) Wind speed and direction Average Hourly (mph)	All year	No. 470 - Science associates, all purpose wind recording system.

Appendix VI - Poria weirii root rot centres.



APPENDIX VII - Precipitation and temperature at the time of fertilization 1971-1973.

Year	Fertilization Dates	During Fertilization Period										During the 14 days following Fertilization									
		Precipitation		Temperature								Precipitation		Temperature							
				min		max		mean						min		max		mean			
		cm	inches	°C	°F	°C	°F	°C	°F			cm	inches	°C	°F	°C	°F	°C	°F		
1971	March 25th-30th	9.60	(3.78)	0.7	(33.3)	6.9	(44.5)	3.8	(38.9)			5.16	(2.03)	1.2	(34.1)	10.1	(50.2)	5.7	(42.2)		
1972	March 20th-23rd	0.86	(0.34)	6.2	(43.1)	11.8	(53.2)	9.0	(48.2)			5.99	(2.36)	5.1	(41.2)	13.1	(55.6)	9.3	(48.4)		
1973	March 20th-21st	NIL	(NIL)	-0.2	(31.6)	9.8	(49.6)	4.8	(40.6)			1.98	(0.78)	1.5	(34.7)	11.0	(51.8)	6.2	(43.2)		

APPENDIX VIII - Plot Statistics - PC-23-003

Treatment	Year	Plot #	Site Index BCFS - 50 YRS		Before Thinning Stems				b.a.		c.s.i.	After Thinning Stem		Avg d.b.h.		b.a.		c.s.i.
									m2/ha.	ft^2/ac.	units	/ha.	/ac.	cm	inches	m^2/ha.	ft^2/ac.	units
	1971	6	24	78	5189	2100	7.48	2.95	28.01	122.02	510							
	1971	21	21	68	5090	2060	7.78	3.06	27.10	118.04	482							
	Average		22	73	5140	2080	7.63	3.00	27.56	120.03	496							
	1972**	2	21	68	4732	1915	7.58	2.98	24.41	106.32	489							
	1972	38	20	65	4695	1900	7.87	3.10	25.96	113.09	430							
	Average		21	67	4714	1908	7.73	3.04	25.19	109.71	460							
T_0F_1	1971	19	22	71	3954	1600	8.17	3.22	23.44	102.08	411							
	1971	40	22	73	3188	1290	8.73	3.44	22.04	96.00	389							
	Average		22	72	3571	1445	8.45	3.33	22.74	99.04	400							
	1972	13	21	67	4608	1865	8.07	3.18	27.04	117.80	476							
	1972	34	21	68	3002	1215	8.86	3.49	22.15	96.50	352							
	Average		21	68	3805	1540	8.47	3.34	24.60	107.15	414							
T_0F_2	1971	29	18	56	4769	1930	6.90	2.72	19.42	84.61	410							
	1971	45	20	67	3311	1340	8.01	3.16	18.82	81.96	373							
	Average		19	62	4040	1635	7.46	2.94	19.12	83.28	392							
	1972	16	19	62	3335	1350	8.24	3.24	19.79	86.23	384							
	1972	18	20	64	3360	1360	8.18	3.22	20.41	88.93	373							
	Average		20	63	3348	1355	8.21	3.23	20.10	87.58	379							

** data in 1972 & 1973 plots liable to minor alteration as verification proceeds.

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APPENDIX VIII (con't), Plot Statistics - PC-23-003

Treatment	Year	Plot #	Site Index BCFS - 50 YRS m.	Site Index BCFS - 50 YRS ft.	Before Thinning Stems /ha.	Stems /ac.	Avg d.b.h. cm.	Avg d.b.h. inches	b.a. m^2/ha.	b.a. ft^2/ac.	c.s.i. units	After Thinning Stem /ha.	Stem /ac.	Avg d.b.h. cm.	Avg d.b.h. inches	b.a. m^2/ha.	b.a. ft^2/ac.	c.s.i. units
T_1F_0	1971	10	21	70	4151	1680	7.04	2.77	19.81	86.31	405	1829	740	8.80	3.47	12.51	54.48	227
	1971	37	23	75	5337	2160	7.62	3.00	28.16	122.65	526	2051	830	9.84	3.87	16.69	72.69	253
	Average		22	72	4744	1920	7.33	2.88	23.98	104.48	466	1940	785	9.32	3.67	14.60	63.58	240
	1972	17	21	68	3780	1530	7.88	3.10	22.23	96.82	429	1976	800	9.65	3.80	15.78	68.72	259
	1972	30	20	66	3867	1565	8.61	3.39	25.35	110.44	440	1927	780	10.02	3.94	16.14	70.30	247
	Average		21	67	3824	1547	8.25	3. 25	23.79	106.63	435	1952	790	9.84	3.87	15.96	69.51	253
T_1F_1	1971	9	23	76	3509	1420	8.63	3.40	23.58	102.72	432	1656	670	10.07	3.96	14.12	61.53	241
	1971	24	20	64	3435	1390	8.00	3.15	19.44	84.69	369	1977	800	9.45	3.72	14-82	64.57	248
	Average		21	70	3472	1405	8.32	3.28	21.49	93.70	400	1816	735	9.76	3.84	14.47	63.05	244
	1972	12	21	69	3447	1395	9.17	3.61	26.51	115.47	451	1865	755	10.16	4.00	16.57	72.20	247
	1972	44	20	64	3891	1575	8.28	3.26	23.38	101.86	432	1976	800	9.76	3.84	15.64	68.15	241
	Average		21	67	3669	1485	8.73	3.44	24.95	108.67	432	1921	778	9.96	3.92	16.11	70.18	244
T_1F_2	1971	15	19	62	4596	1860	7.56	2.98	22.73	99.02	426	2076	840	9.07	3.57	14.00	60.97	233
	1971	43	21	68	3608	1460	7.93	3.12	20.92	91.13	401	1952	790	9.47	3.73	15.11	65.83	236
	Average		20	65	4102	1660	7.74	3.05	21.82	95.08	414	2014	815	9.27	3.65	14.56	63.40	234
	1972	5	21	70	3953	1600	8.82	3.47	28.30	123.28	468	1939	785	9.94	3.91	16.24	70.72	259
	1972	35	21	70	3360	1360	8.60	3.38	22.76	99.14	432	1964	795	9.81	3.86	16.12	70.20	264
	Average		21	70	3657	1480	8.71	3.43	25.53	111.21	450	1952	790	9.88	3.89	16.18	70.46	262

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APPENDIX VIII (con't), Plot Statistics - PC-23-003

Treatment	Year	Plot #	Site Index BCFS - 50 YRS		Before Thinning						c.s.i.	After Thinning						c.s.i.
					Stems		Avg d.b.h.		b.a.			Stem		Avg d.b.h.		b.a.		
			m.	ft.	/ha.	/ac.	cm.	inches	m^2/ha.	ft^2/ac.	units	/ha.	/ac.	cm.	inches	m^2/ha.	ft^2/ac.	units
T_2F_0	1971	11	20	67	4398	1780	7.43	2.92	23.05	100.41	428	890	360	10.52	4.14	8.19	35.66	145
	1971	39	19	62	4473	1810	7.16	2.82	20.72	90.28	410	890	360	10.28	4.05	7.72	33.64	138
	Average		19	64	4436	1795	7.30	2.87	21.88	95.34	419	890	360	10.40	4.10	7.96	34.65	142
	1972	20	20	65	3014	1220	9.44	3.72	24.11	105.02	432	840	340	11.08	k.36	8.48	36.95	147
	1972	25	18	59	3101	1255	8.00	3.15	17.41	75.84	377	926	375	10.49	4.13	8.29	36.09	146
	Average		19	62	3058	1238	8.72	3.44	20.76	90.43	405	883	358	10.79	4.25	8.39	36.52	147
T_2F_1	1971	1	20	67	4151	1680	7.70	3.03	21.53	93.79	426	988	400	10.31	4.06	8.54	37.22	147
	1971	8	22	74	3706	1500	9.00	3.54	26.70	116.33	464	890	360	10.93	4.30	8.64	37.64	142
	Average		21	70	3928	1.590	8.35	3e28	24.12	105.06	445	939	380	10.62	4.18	8.59	37.43	144
	1972	28	20	64	4670	1890	7.41	2.92	22.57	98.32	445	939	380	10.41	4.10	8.22	35.80	138
	1972	41	21	69	3311	1340	8.26	3.25	20.23	88.14	353	889	360	10.84	4.27	8.62	37.55	148
	Average		21	67	3991	1615	7.84	3-09	21.40	93.23	399	914	370	10.63	4.19	8.42	36.68	143
T_2F_2	1971	14	20	65	4818	1950	7.29	2.87	22.29	97.11	455	914	370	10.16	4.00	7.67	33.40	142
	1971	33	20	66	2545	1030	8.94	3.52	17.68	77.03	346	914	370	10.92	4.30	9.02	39.30	148
	Average		20	66	3682	1490	8.56	3.20	19.98	87.07	400	914	370	10.54	4.15	8.34	36.35	145
	1972	4	20	66	4682	1895	7.52	2.96	24.12	105.08	449	864	350	10.86	4.27	8.31	36.21	129
	1972	31	20	66	3385	1370	8.07	3.18	19.66	85.62	400	901	365	10.73	4.22	8.49	37.00	143
	Average		20	66	4034	1633	7.80	3.07	21.89	95.35	425	883	358	10.80	4.25	8.40	36.61	136

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APPENDIX VIII Plot Statistics - PC-23-003

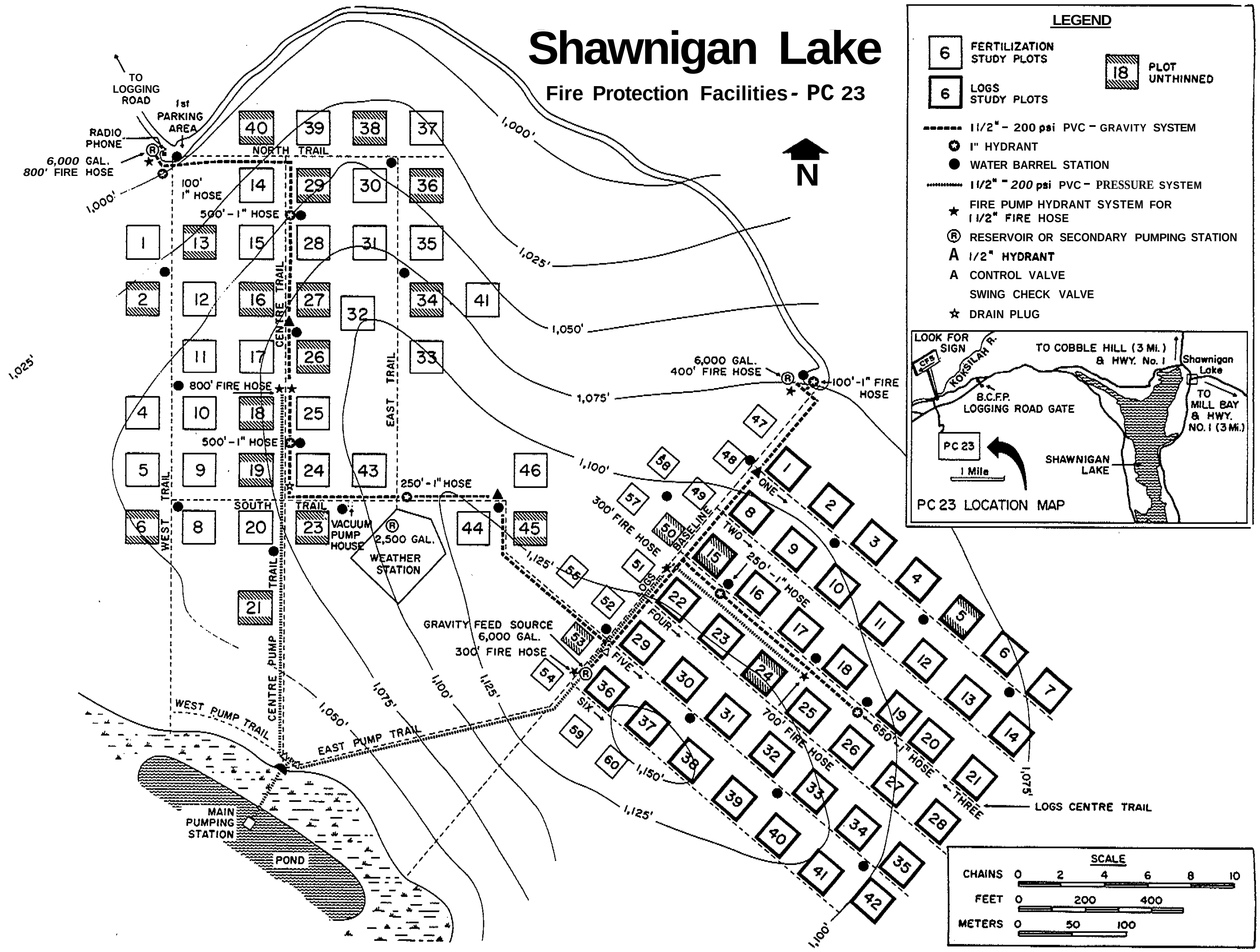
Treatment	Year	Plot #	Site Index BCFS - 50 YRS m.	Site Index BCFS - 50 YRS ft.	Before Thinning Stems /ha.	Before Thinning Stems /ac.	Before Thinning Avg d.b.h. cm.	Before Thinning Avg d.b.h. inches	Before Thinning b.a. m2/ha.	Before Thinning b.a. ft^2/ac.	Before Thinning c.s.i. units	After Thinning Stem /ha.	After Thinning Stem /ac.	After Thinning Avg d.b.h. cm.	After Thinning Avg d.b.h. inches	After Thinning b.a. m^2/ha.	After Thinning b.a. ft^2/ac.	After Thinning c.s.i. units
T_2F_2	1973**	52	21	67	3038	1230	9.07	3.57	22.90	9'9.74	395	814	330	11.12'	4.38	8.34	36.34	142
	1973	57	20	64	2446	990	9.80	3.86	20.82	90.66	357	740	300	11.68	4.60	8.14	35.46	144
	1973	60	18	59	3680	1490	8.52	3.36	23.74	103.44	414	840	34.0	10.89	4.29	8.04	34.98	130
	Average		19	63	3054	1236	9.13	3.60	22.48	97.94	389	798	324	11.23	4.42	8.18	35.60	139
T_2F_3	1972	32	18	60	3669	1485	7.72	3.04	19.78	86.15	378	877	355	10.44	4.11	8.07	35.15	138
	1972	46	21	70	3583	1450	8.63	3.40	23.40	101.95	414	901	365	10.61	4.18	8.26	35.98	125
	Average		20	65	3626	1468	8.17	3.22	21.59	94.05	396	889	360	10.53	4.15	8.17	35.57	132
T_2F_4	1973	51	20	64	2644	1070	9.82	3.87	22.14	96.40	373	814	330	11.43	4.50	8.56	37.30	147
	1973	54	18	60	4176	1690	8.16	3.21	24.90	108.44	458	864	350	11.22	4.42	8.70	37.90	141
	Average		19	62	3410	1780	8.99	3.54	23.54	102.46	416	840	340	11.33	4.46	8.64	37.60	144
T_2F_6	1973	47	18	60	4664	1880	8.09	3.28	27.68	120.60	476	840	340	10.99	4.33	8.34	36.30	133
	1973	58	19	63	4176	1690	8.11	3.19	25.14	109.50	430	840	340	11.32	4.46	8.74	38.12	134
	Average		19	62	4410	1786	8.10	3.19	26.42	115.26	453	840	340	11.16	4.40	8.54	37.22	134
T_0F_4	1973	50	21	69	3088	1250	9.54	3.75	24.96	108.72	388							
	1973	53	18	59	4052	1640	7.96	3.13	23.40	101.94	412							
	Average		20	64	3570	1446	8.75	3.44	24.18	105.34	400							
T_1F_4	1973	49	21	67	3904	1580	8.68	3.42	26.72	116.38	452	1902	770	10.01	3.94	15.80	68.80	234
	1973	59	19	61	4620	1870	8.12	3.20	27.12	118.10	478	1952	790	10.02	3.94	16.10	70.16	239
	Average		20	64	4262	1726	8.40	3.31	26.92	117.24	465	1928	780	10.02	3.94	15.96	69.48	237

APPENDIX VIII (con't), Plot Statistics - PC-23-003

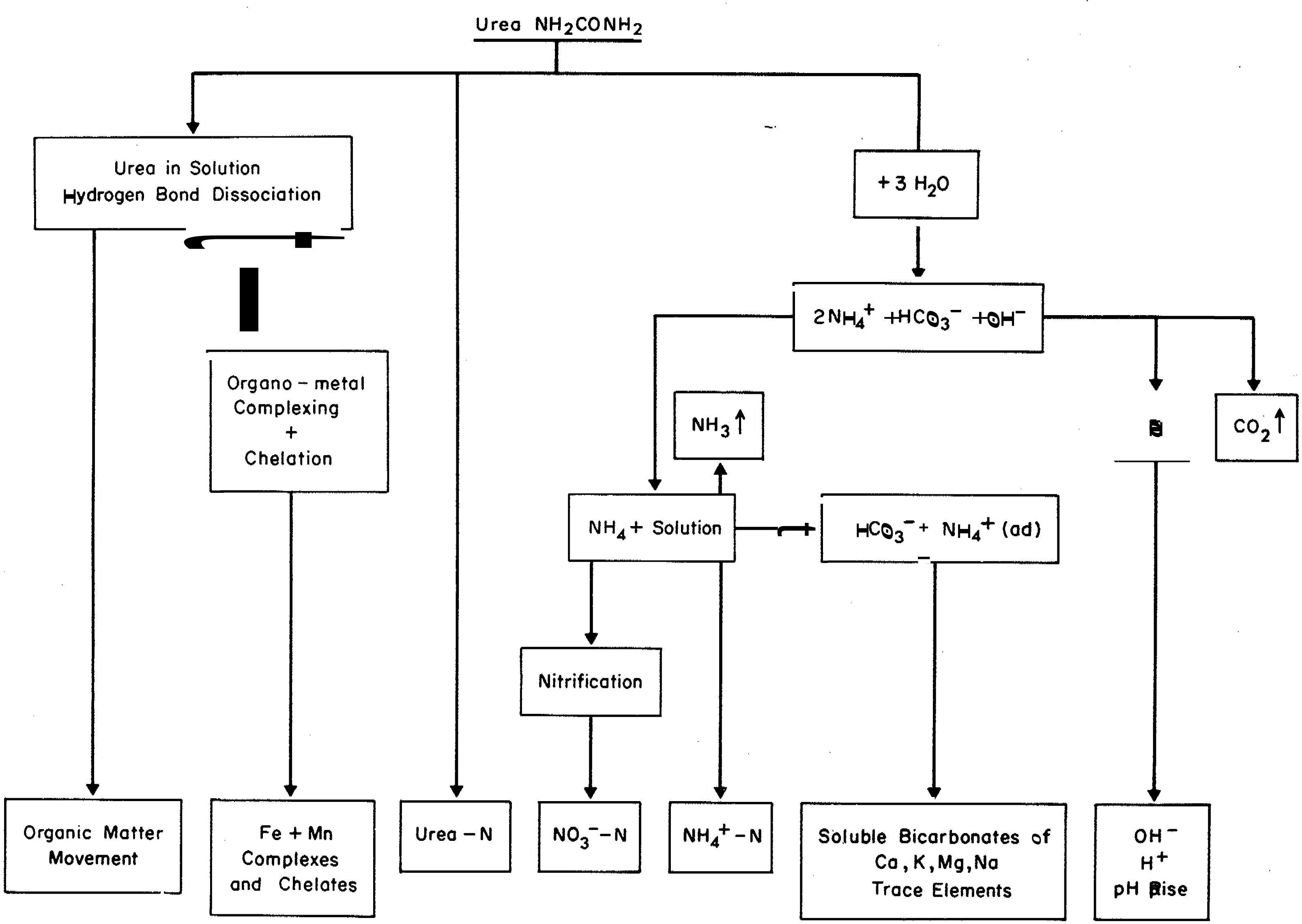
Treatment	Year	Plot #	Site Index BCFS - 50 YRS		Before Thinning Stems		Before Thinning Avg d.b.h		Before Thinning b.a.		Before Thinning c.s.i.	After Thinning Stem		After Thinning Avg d.b.h.		After Thinning b.a.		After Thinning c.s.i.
			m.	ft.	/ha.	/ac.	cm.	inches	m^2/ha.	ft^2/ac.	units	/ha.	/ac.	cm.	inches	m^2/ha.	ft^2/ac.	units
T_0F_1*	1972	26	18	59	3632	1470	7.29	2.87	16.94	73.78	458							
	1972	36	21	68	3459	1400	8.52	3.35	22.80	99.33	390							
	Average		20	64	3545	1435	7.91	3.11	19.87	90.51	374							
T_0F_2*	1972	23	21	70	3644	1475	8.25	3.25	22.90	99.76	407							
	1972	27	17	57	3966	1605	7.48	2.94	20.21	88.02	406							
	Average		20	64	3805	1540	7.87	3.10	21.56	93.89	407							
T_2F_2*	1973	48	19	63	4842	1960	7.42	2.92	24.80	108.02	467	988	400	10.23	4.03	8.50	37.02	136
	1973	55	21	67	2644	1070	9.54	3.75	21.42	93.28	373	840	340	11.50	4.53	9.02	39.30	142
	Average		20	65	3744	1516	8.48	3.34	23.12	100.66	420	914	370	10.87	4.28	8.76	38.16	139

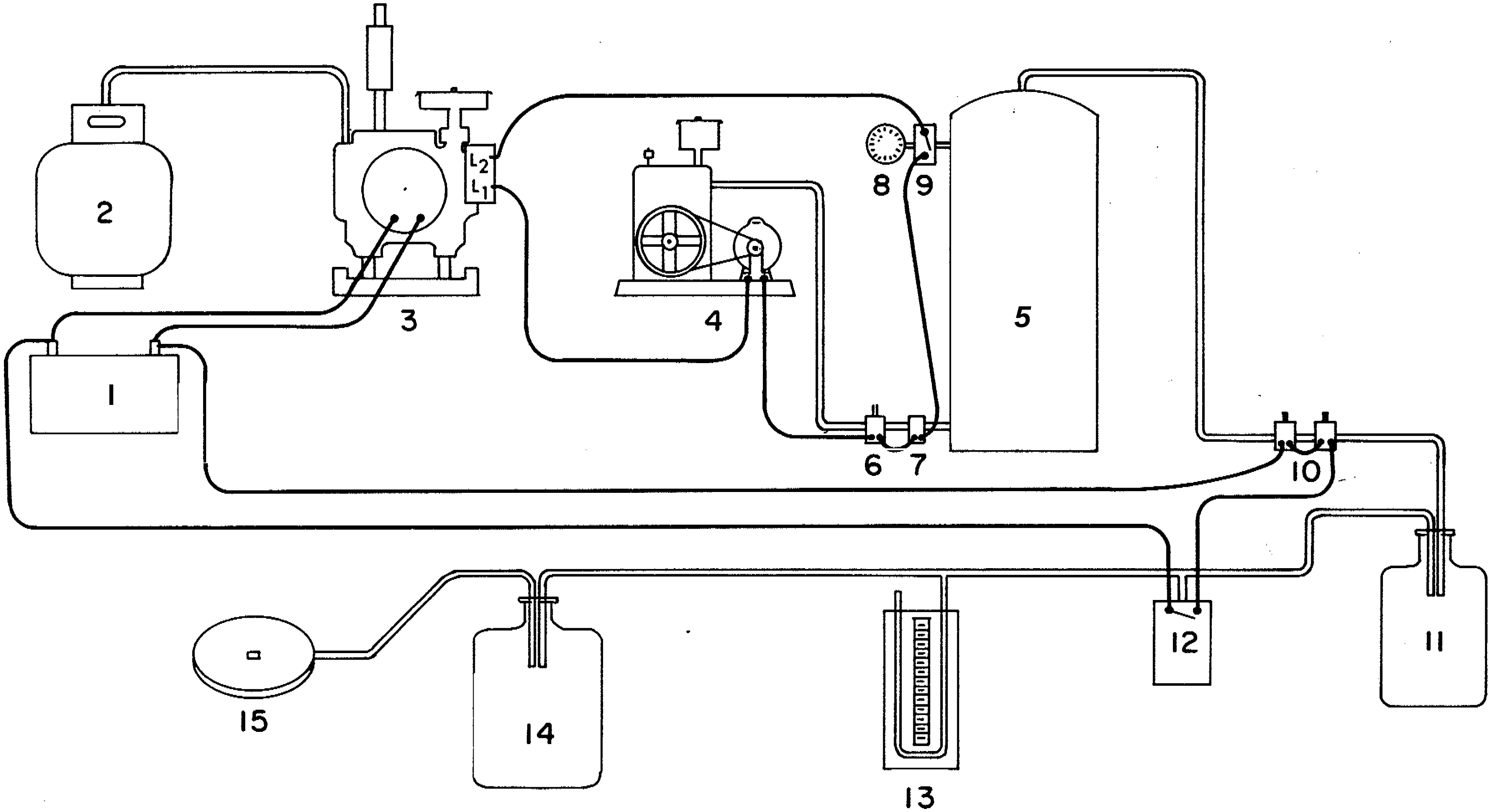
* Ammonium nitrate

APPENDIX IX - **Fire** protection **facilities.**



APPENDIX X - Typical urea transformation in forest soil.

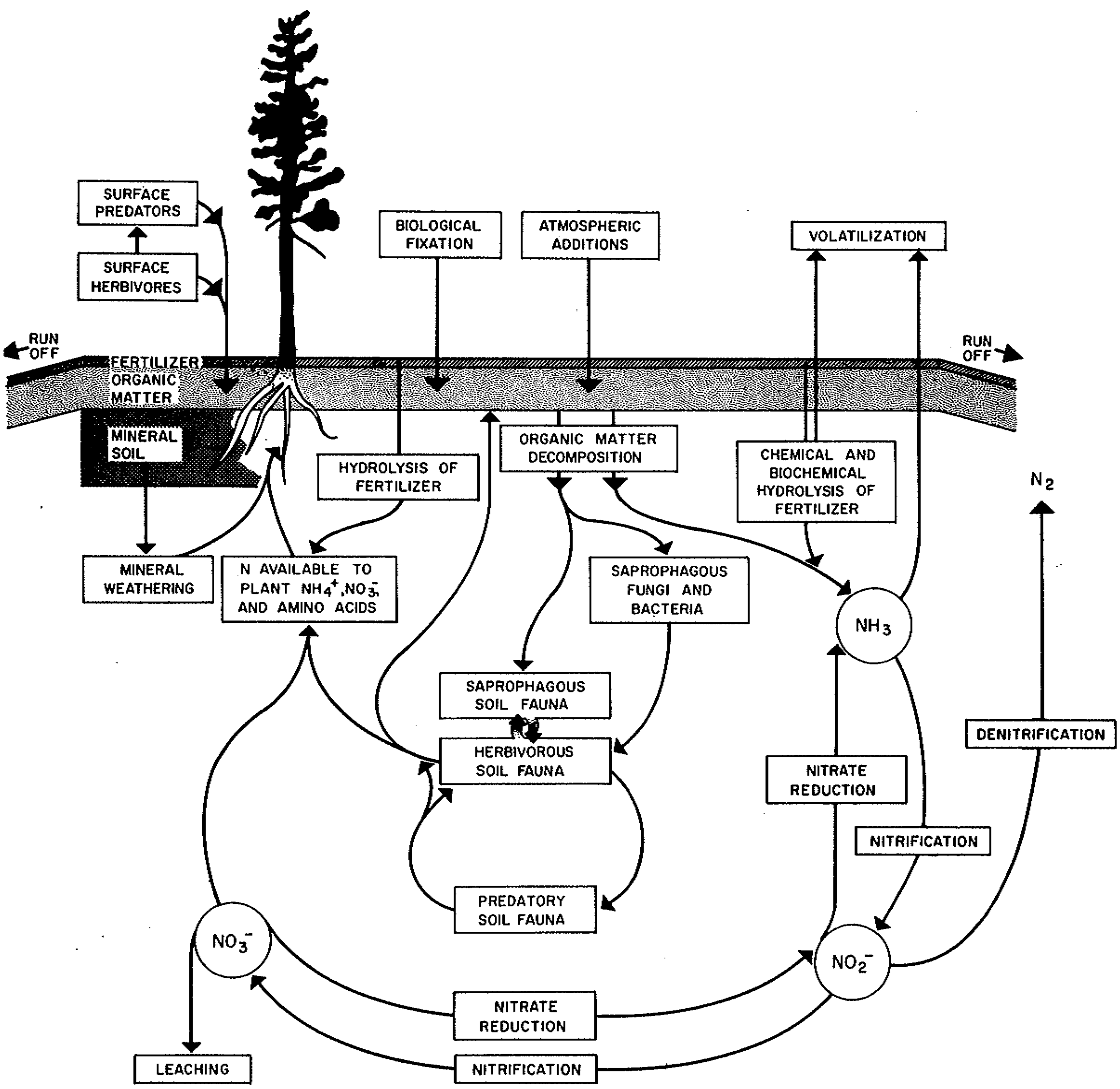




APPENDIX XI Schematic diagram, lysimeter vacuum system Shawnigan Lake

1. Battery 12 v (electric start-generator power supply-regulation solenoids)
2. Propane gas (generator fuel)
3. 3500 w auto start 120 v generator
4. High vacuum-volume pump (120 v)
5. 250 gal vacuum storage tank
6. N.O.-N.C. 2-way solenoid (120 v)
7. N.C. 1-way solenoid (120 v)
8. Vacuum gauge (30 in Hg)
9. Vacuum regulation switch (20 in Hg differential 120 v controls generator start-stop and vacuum storage volume)
10. N.C. solenoids in series (12 v)
11. Vacuum buffer bottle (5 gal)
12. Vacuum regulation switch (controls #10 and regulates vacuum to 1/10 atmospheres in feed lines)
13. U-tube manometer
14. Vacuum supply-leachate storage bottle (5 gal)
15. Lysimeter plate

Appendix XII. The **role** of soil fauna and flora in **relation** to nutrient cycling, **particularly** nitrogen, **in** the forest **ecosystem,**



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