ASSESSMENT STUDIES OF SUBSTRATE AND VEGETATION ON FIVE PAST-PRODUCING MINE-SITES IN B.C.

by

JOHN BRAILSFORD BINNS

B.Sc., The University of Newcastle upon Tyne, 1969
M.Sc. Royal School of Mines, 1981

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Department of Resource Management Science.

The University of British Columbia
Vancouver, Canada

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ABSTRACT

Mine reclamation is a long-term process but few long-term (>15 years) assessment studies are carried out. Considerable effort has gone into test-plot experiments to design revegetation programs prior to termination of mine production but little is known from the results of this work of the long-term effect of competitive interactions between seeded species themselves and between seeded and immigrating native species during the progression to a natural vegetation for that site.

The present study revisited and repeated benchmark scientific studies carried out at five mine-sites during the period 1973-1978. The mine-sites were Bull River mine, Coal Creek mine, Cumberland No. 4 mine, Pinchi Lake mine and Texada Iron mines. They were in different biogeoclimatic locations and at each mine, sample sites were located on different waste materials. On-site studies carried out during the 1993 field season included substrate observation and sampling, and visual observation of plant species and percent cover. Substrate samples were later analysed in the laboratory for soil nutrients. The graphical presentation of data honours the original data and is an effective way of assessing the development of substrate health and plant succession.

Results show that if sufficient attention is paid to improving land-form then over a long period natural regenerative processes can accomplish remarkable results. Moisture deficiency will restrict growth to deep rooting, drought tolerant species and result in slow encroachment. This may require intensive management if erosion is likely.

This type of study performed by staff with interdisciplinary training or experience can be used to make economical long-term assessments of site rehabilitation. They would not in any way replace the detailed quantitative monitoring conducted at critical phases early in the decommissioning process. However, as a complement, such studies could

provide data for predicting long-term development on newer sites. In addition, they are an ecologically acceptable alternative to assessments of "productivity" on sites where rehabilitation is slow.

Table of contents

List of Tables

List of Figures

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Chapter 1

INTRODUCTION

1.1 Aim of the Research

The main aim of the research was to assess the changes in substrate and vegetation on mine-sites with different growing conditions to assess the current state of rehabilitation and to define the limiting factors (if any) to development of a natural plant community on that site. Also, an analysis of the differences between reclaimed and unreclaimed sites would offer insights into those reclamation management practices that are most beneficial to the development of the plant community on that type of site. The evaluation studies were carried out by repeating previous substrate and vegetation assessment studies on five past-producing mine-sites in B.C.

1.2 The nature of mining disturbance

Land disturbed by mining or similar activities is an inevitable part of the development of civilisation. We inherit a large area from the past and the disturbance of ecosystems continues to the present for by far the greatest proportion of the needs and comforts of civilisation come ultimately from the ground, in the form of mineral ores, building materials and fossil fuels (Bradshaw, 1983). Mining in its broad sense refers to the exploration, location, extraction, processing and eventual refining of those materials and its activity inevitably disturbs the ecosystem containing those minerals. The impact of the disturbance depends on numerous factors associated with the location of the mineral deposit, its size and the mineral(s) contained.

The volume of material handled has become enormous; for example, in the U.S.A. in 1988, 3.3 billion tons of material was handled at non-fuel mines (Young, 1993).

For new mines, although land cannot be restored to its original condition, it can be reclaimed so that the land is equally capable of supporting acceptable land uses. There are now legislated requirements for reclamation of the mine-site and mining is regarded as a "temporary use of the land".

Also, the requirement for new metal mines is being partly offset by the promotion of recycling and substitution of other materials. As an example, of the common metals, aluminum and lead are extensively recycled and glass optical fibre is substituting for some of the uses of copper.

1.3 Definition of reclamation

At an underground mine surface disturbance is minimised as only ore is brought to the surface and a large proportion of the tailings can be returned underground to stabilize the underground workings. In comparison, a modern open-pit mine/concentrator complex leaves a large pit, the waste rock not processed is piled in large dumps and at least 95% of the material processed remains, as tailings in slurry form, to be disposed of. Such a mining operation leads to the disturbance of the original ecosystem, thus reclamation can be considered as the process of reconstruction of an ecosystem, albeit not the same as the original one. Unless topsoil is removed and retained during the mining operation the resulting substrate is essentially skeletal and can be compared to the material remaining following natural processes such as the retreat of a glacier or volcanic activity (Bradshaw, 1983). For this reason, retention of topsoil is now a requirement for modern mining operations. The immediate area of land disturbed by mining is relatively small and the mine-site may be compared to an island of drastically altered biophysical conditions within a sea of different surroundings. However, since ecosystems are connected through various natural phenomena e.g. the hydrological cycle, the potential impact of mining extends beyond the actual mine-site. The altered conditions at the mine-site include particle size, pH conditions, nutrient availability, toxic substances, slope angle and stability, compaction and bulk density, access roads, groundwater and engineered structures.

Revegetation or its ecological analog, the eventual re-establishment of a substrate and a natural plant community, is merely a single component of the decommissioning process of a mining operation and the reclamation of the land to a land-use compatible with the surrounding land.

1.4 Reclamation legislation

Although the Mines Act regulating the operation of mines and quarries was first introduced in B.C. at the turn of the century, reclamation was only included as a legal requirement in 1969. This legislation in B.C. was introduced to regulate the large open-pit coal mines being brought into production at that time in south-eastern B.C. The new mines were located in the steep topography of the Elk Valley district where the land is important as a winter range for ungulates, primarily elk. Previous mining operations in the area had either been underground or small surface workings whereas the new operations were to be open-pit operations mining 3-5Mt of coal per year involving the removal of 5-10Mt per year of waste to be stacked in large dumps on the side of the valley. Similar operations were being introduced in Alberta in the early 1960's and Alberta introduced legislation with similar intent.

In the U.S., federal mining legislation was introduced as the Surface Mining Control and Reclamation Act (SMCRA) in 1977. The intent of the U.S. legislation was fundamentally different from that of B.C. and Alberta in that it set detailed targets for reclamation performance which were embodied in the Act itself. In addition, the Act established a reclamation program funded by fees levied per unit of coal mined to rehabilitate land and water resources adversely affected by pre-Act coal mining (Jackson, 1991). This Act has the advantage of clarity but it lacks flexibility. Alberta and B.C. used a less precise Act with accompanying Regulations (Alberta) and Code, in the case of B.C.

1.5 Comparison of Alberta and B.C. reclamation legislation

The first provincial legislation specifically dealing with reclamation was passed in Alberta in 1963, the Surface Reclamation Act.(SRA) The act set minimum standards for cleanup and recontouring of the land, established field enforcement staff and provided for reclamation certificates. In 1973 the Alberta Land Surface Conservation and Reclamation Act (LSCRA), parts 1 and 2 were passed. Its purpose was to minimize adverse impact, to ensure that reclamation was completed and to designate the type of operation where development and reclamation approval was required. The Act covered coal mines, oil sand schemes and sand and gravel pits. In 1978, part 3 of the Act was proclaimed, which listed the operations for which reclamation standards were enforceable under the Act and in 1980 a set of minimum standards was developed for part 3 disturbances. In 1991 Alberta introduced the omnibus environmental bill, the Environmental Protection Act, which continues the thrust of the government's efforts towards environmental protection, proactive reclamation and public participation (Powter and Chymko, 1991).

Parallel with the regulatory control, the government established the Reclamation Research Technical Advisory Committee (RRTAC) composed of academic and government researchers whose aim was to research better ways to achieve reclamation in Alberta. The result was a prodigious amount of research specifically aimed at the establishment of substrate and vegetation in dry alpine conditions.

In 1969 the existing B.C. Mines Act was amended to require reclamation for major coal mines and hardrock metal mines. In 1973 the legislation was amended to include coal exploration, mineral exploration, sand and gravel pits and quarries. In 1984, the ministry published mine reclamation guidelines which set broad reclamation standards and set a maximum reclamation bond of $2500/ha (BCMEMPR, 1991). The Act was amended in 1990 and was accompanied by the "Health, Safety and Reclamation Code" of which part 10 provides general standards for structures and equipment cleanup, waste dumps, watercourses, pit walls, tailings ponds, spillways, roads, metal uptake, toxic chemicals and acid generating material, as well as a monitoring program to demonstrate that reclamation objectives were being met (BCMEMPR, 1992). Section 10 of the Act removed the $2500/ha limit and established the posting of a reclamation security to be determined by the chief inspector as a condition for issue of a Reclamation Permit. It is the Reclamation Permit which embodies site-specific requirements for reclamation standards.

The B.C. Technical and Research Committee on Reclamation (TRCR) first became active in the early 1970's in response to a demonstrated need in British Columbia mining for greater government-industry communication in the area of environmental protection and reclamation. Membership is drawn from the corporate sector (several of the large mines are represented); Ministry of Energy, Mines and Petroleum Resources; Mining Association of British Columbia; Ministry of Environment, Lands and Parks and British Columbia universities. Since 1975, TRCR has sponsored an annual reclamation symposium to foster the exchange of information and ideas on reclamation. Good reclamation practice is promoted by the annual competition for reclamation awards. Initially, much research work was done by companies concerning the revegetation of the large new coal mines. More recently, its main technical focus has been on dump and impoundment stability and acid rock drainage (ARD), the latter now recognised as the greatest problem facing operators of metal mines around the world.

The difference in emphasis between RRTAC and TRCR reflects the strong agricultural base in Alberta where land conservation is a priority within industrial development while historically land stewardship has few roots in B.C. (Smyth, 1995). Currently, in B.C., there is little government funding for soil or vegetation research, which are the priorities in Alberta, while problems with ARD are given a higher priority in B.C.

1.6 Reclamation objectives of the legislation

In contrast to the U.S., both the Alberta and B.C. Acts are flexible in terms of reclamation targets. B.C. still sets the standard of land productivity on reclaimed areas as;

> "not less than existed prior to mining on an average property basis unless the owner, agent or manager can provide evidence which demonstrates to the chief inspector the impracticality of doing so."

In practice, there is abundant opportunity for regional disparity because of local differences in interpretation of productivity.

Alberta requires that the land be returned to "equivalent capability". This is defined to mean that after reclamation, the ability of the land to support various land uses is similar to the ability that existed before disturbance, but that the ability to support individual land uses will not necessarily be equal after reclamation. In order for development to be sustainable those characteristics of the land which determine the ability to sustain various uses must be returned. The critical features are landscape form (slope), drainage, and soil quality and quantity (Powter and Chymko, 1991).

Both Alberta and B.C. leave room for innovative approaches to reclamation, recognising that reclamation is site specific.

Lavkulich (1991) expressed the objectives of reclaiming a mine site as developing a sustainable water cycle, nutrient cycle, energy flow and biological succession in addition to the general requirement that the site is non-polluting and blends into the geographic setting. In particular, the objectives as defined by Lavkulich are sustainable cycles, not end-points of productivity, but positive trends.

Both the above definitions of ecosystem reconstruction imply that reclamation is a combination of visual aesthetics, geotechnical stability, hydrology, environmental chemistry, promotion of soil formation and animal and plant ecology.

1.7 Perceptions of environmental stewardship

Four points of view of the record of environmental stewardship by the mining company on a site are possible, depending on the stakeholder, and these are unlikely to be convergent.

1. The local community
2. Public interest groups (First Nations, hunters, environmental group)
3. The mining company
4. The regulator

This illustrates the problem facing government in meeting their commitment to coordinated land-use planning based on a consensual approach. The resultant uncertainty is one of the major problems facing the mining industry in B.C. today.

1.8 The Reclamation discipline

In order to reconstruct ecosystems economically which are self-sustaining, it is clear that a large number of different operations have to be carried out correctly so that properly functioning ecosystem processes will occur. There is no single overriding principle to be observed. This is important, since it goes against reductionist tendencies in ecology (Bradshaw, 1983). However, in order to define reclamation end-points for a reclamation permit or define a monitoring program, objective measurable criteria are required to avoid as much subjective bias as possible.

The preceding discussion of legislation requiring reclamation highlights one important point; mining had been going on for a long time before reclamation was required. Thus the "reclamationist" has many challenges in rehabilitating those orphan sites where environmental damage pre-dates reclamation legislation. However, such reconstruction of ecosystems has been undertaken successfully at many sites. An example is freshwater ecosystems and the case of previously acidified lakes where a raising of the pH from <5 to neutral has allowed a recovery in the stability of the aquatic food web (Locke and Sprules, 1994).

The reclamation profession must therefore concern itself with both rehabilitation of past damage as well as ensuring that the standards of current reclamation are maintained. In addition research must continue to improve the standards of reclamation in the future.

1.9 The Reductionist/Disciplinary approach

The importance of the quality of the substrate remaining or subsequently developed on the site compared to the original soil has long been recognised. Therefore, rigorous studies have been made of the physical and chemical properties of the waste, tailings and other disturbed material which were to be revegetated. In addition, propagation studies have been carried out to determine an appropriate revegetation strategy (Lavkulich et al., 1976; Como et al., 1978; Cominco Ltd., 1973). Unfortunately, no follow-up assessment studies have been performed since these studies to complement the baseline studies and measure the development of energy or nutrient cycling sensu Lavkulich on the disturbed areas.

Considerable research has focussed on the amendments required for a substrate to produce the maximum yield of seeded agronomic cultivars. The imperative was to restore vegetation, e.g. on sites subject to wind or water erosion or to demonstrate "productivity" of forage crops on decommissioned tailings surfaces. Two major disadvantages may be noted with these revegetation studies:

1. The studies were conducted in plots often 1m x 1m in size. Although the plot experiments would be rigorously designed in terms of their statistical validity the small plots failed to take into account the effects of competition, invasion and migration which would apply on a large site.

2. Usually not enough time had elapsed to determine whether or not the agronomic cover would sustain itself and if not, what the likely succession of immigrating species would be. This would depend on which of the processes of Facilitation, Tolerance or Inhibition, as outlined by Connell and Slatyer (1977), was dominant.

Other studies have investigated both the substrate and vegetation on disturbed mine lands and measured the resulting improvement in substrate nutrient capital associated with combinations of certain grass or leguminous species, whether colonized or introduced. However, the procedure has been to compare mine-sites of different age in order to investigate relationships between age and substrate nutrients or vegetation (Roberts et al., 1981; Skousen et al., 1994; Li and Daniels, 1994).

Few B.C. studies are available which examined the development of substrate and vegetation on the same sites and none were found which were conducted over a time period long enough to assess the long-term trend in energy and nutrient cycling and biological succession.

A common difficulty with all the literature on substrate or vegetation research is a lack of visual presentation of quantitative data. A colour photograph of good quality may be an excellent tool for assessing the overall status of reclamation of the scene in the photograph but it cannot be used to assess species richness or percent cover of a species. Usually, in vegetation studies, species lists are given in a table with the percent cover for each species. It is difficult to gain an impression of how biological succession is progressing from these tables.

1.10 Interdisciplinary studies as a reclamation research tool

The extensive research work described above can be used as a tool in the reclamation planning of existing and future mines which may have the same type of waste materials. These studies provide valuable snapshots of current conditions or limitations to rehabilitation and may propose courses of action to be followed. However, as previously mentioned, assessment of reclamation is partly perception and depends on an overall impression of the site. Revegetation is only part of the decommissioning process and as such, whether achieved entirely naturally or with assistance, it cannot make up for deficiencies in other parts of the process. This is particularly true at older sites for it is by examining older sites that we can determine what "building blocks" of successful ecosystem reconstruction can and cannot be achieved by nature in a human time frame. This will help set priorities for reclamation of both abandoned sites and active sites. It suggests that a more integrated or holistic approach will be useful in assessing the degree of "success" of reclamation of a particular site. However, it is important that such a study include the objective measurements necessary to measure compliance with standards and avoid regional inconsistencies in regulation.

As an example, the access to a site may be the single most important factor impeding the fulfilment of the land use objective as wildlife habitat. The mine itself may be reclaimed to a high standard but the mine access road has allowed hunters into the area. The increase in killing capability of both recreational and subsistence hunters has far outstripped the regulatory, moral or traditional impediments to his harvest.

1.11 Components of a reclamation assessment study

An assessment study must address the following criteria in order to determine if a site meets the requirements of ecosystem reconstruction:

Table 1.1 Summary of reclamation assessment studies

CRITERIA	FEATURES TO BE STUDIED
visual	Removal of all non-biodegradeable debris. Does site blend in with its surroundings? Are there gaps in rehabilitation?
landform	Stability, compaction, recontouring.
water cycle	Erosion, substrate physical properties, surface moisture retention capacity, integrity of watercourses for extra run-off, surface water quality monitoring, groundwater quality monitoring.
energy cycle	Substrate chemistry assessment, organic matter, soil fauna, microbial activity.
nutrient cycle	Substrate chemistry assessment, deficiences and toxicities.
biological succession	regular vegetation assessment studies, terrestrial and aquatic ecological studies.
Land use capability	Access, compliance with reclamation permit standards. Terrestrial and aquatic ecological studies.

Assessment implies that this is a parameter which can be observed visually and only needs to be measured quantitatively (assessed) on an infrequent basis. Monitoring implies that the parameter is critical and should be monitored regularly during operations and immediately post-closure until stability is reached.

1.12 Reasons for lack of long-term studies in B.C.

A multi-disciplinary study, consisting of seven components, is expensive, even for a single currently operating site. For this reason, the available research studies have inevitably focussed on a subset of the criteria. The onus is on the mining company to demonstrate that their reclamation plan is effective but on the other hand there is understandable reluctance on the part of the company to commit to what they perceive as a very expensive exercise.

When considering a reclamation inventory of past-producing mines, the only survey of closed mines in B.C. (Steffen, Robertson and Kirsten et al., 1992), focussed on their potential for discharging ARD. Also, the statistics currently gathered by the Reclamation Section of the Mine Review and Permitting Branch, Mineral Resources Division of the Ministry and published annually are compiled from figures submitted by industry and are limited in scope.

Repeating vegetation studies only is of limited value because of the short term variation in ephemeral species. This might be because the measurements were made at a different time of the year or moisture conditions were different from one study to another. Soil, by comparison, is a medium which integrates the local geology, topography, climate and biology over time and changes little in physical properties during the year. Although microbial activity will change with temperature and affect the C/N balance, this is not nearly as significant as potential changes in vegetation. Combined substrate and vegetation studies are therefore the minimum required to assess the development of water, energy and nutrient cycling and the development of biological succession.

1.13 Benefits and goals of the research

It is important for both regulators and mining companies to demonstrate to the public that indeed, mining has been a temporary use of public land for mines which are now closed and returned to public ownership. The best way to do this is to advertise the successful reclamation of a mine-site by long-term evaluation of the same site in order to show how the process of ecosystem reconstruction has progressed. Also, reconstruction of an ecosystem is very expensive and difficult to achieve in a short time. It is better to develop the tools to assess how, with appropriate early management on a site initially denuded of vegetation, natural regeneration processes will, given time, promote a natural plant community. This time will vary significantly from site to site.

These relatively simple assessment studies are not intended to replace the intensive monitoring studies that take place immediately post-closure.

The practical goals of the research effort were:

1) to assess the progress made towards rehabilitation and define any factor(s) limiting revegetation of the five study sites.

2) to demonstrate a practical, effective methodology and field procedure for assessing substrate and vegetation changes and presenting the results.

If such studies could be made economically, this might encourage their use to demonstrate reclamation of past-producing mine-sites.

Chapter 2.

STUDY SITES

2.1 Criteria for choice of site

The criteria for choice of site were based on the main objective of measuring the long-term development of substrate and vegetation on B.C. mine-sites.

The primary requirement was that a previous benchmark study had been established 10-15 years ago which could be repeated to observe the change with time.

A second requirement was that the sites should be in different biogeoclimatic conditions. In addition, different geological conditions would be ensured by the choice of both coal and metal mines. To test the influence of site management both reclaimed and un-reclaimed sites were chosen. The study sites were chosen by a study of the literature, advice from individuals and reconnaissance site visits to 26 sites. Once the criteria had been satisfied the following sites were chosen. The location of the study sites is shown in Figure 2.1.

Bull River copper mine, near Cranbrook.(BR)

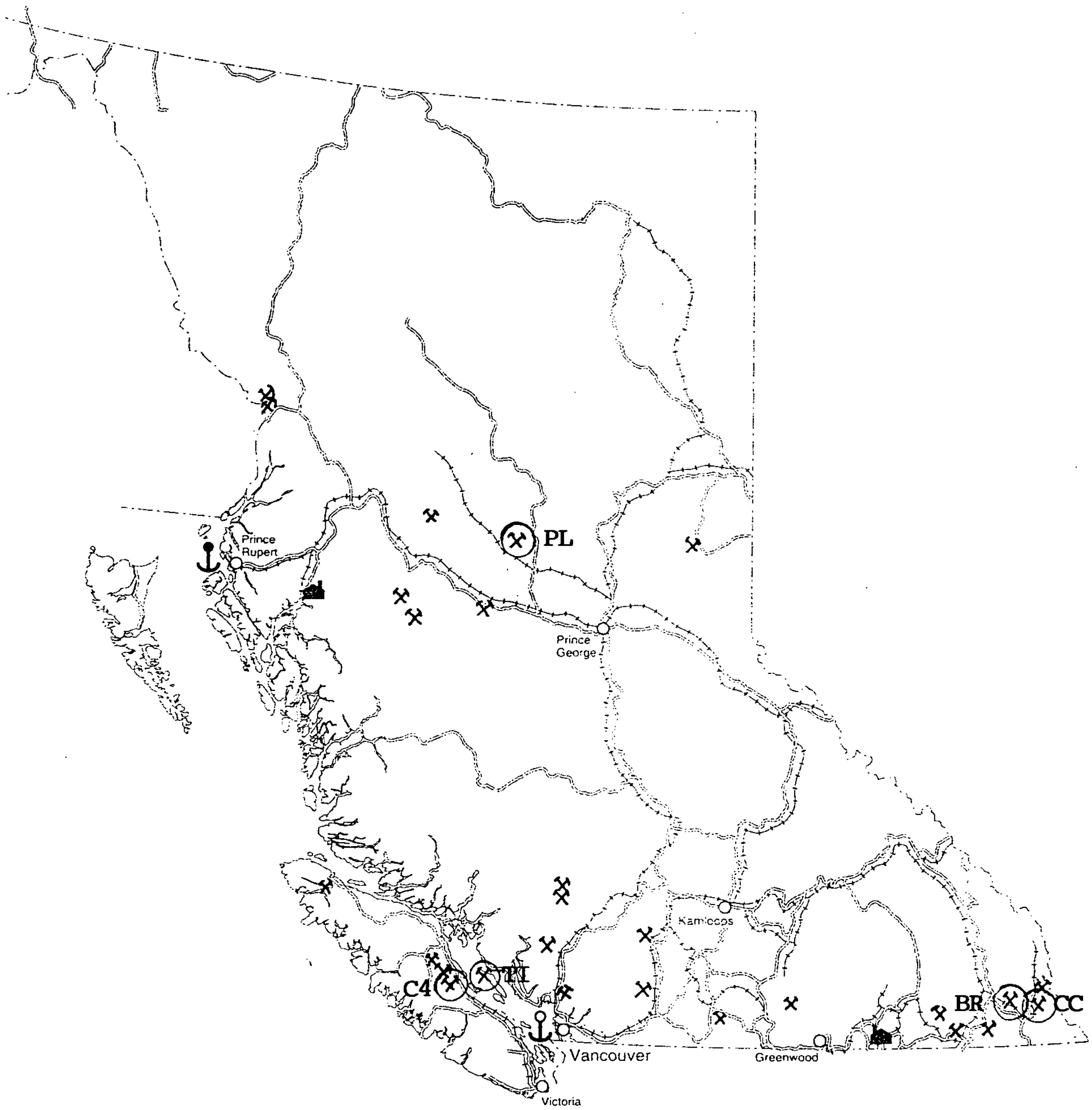
Coal Creek collieries, near Fernie.(CC)

Cumberland No. 4 coal mine, near Courtney.(C4)

Pinchi Lake mercury mine, near Fort St. James.(PL)

Texada Iron mines on Texada Island, near Powell River.(TI)

Bull River is currently under further exploration with no public access. Careful work by the current operators has resulted in little disturbance and it is still fenced to avoid grazing. Coal Creek and Cumberland are inactive but open to public access while Pinchi Lake is both inactive and inaccessible to the public. The Texada Iron mine-site is now part of a large active limestone quarrying operation and not open to public access. Table 2.1



LEGEND

- Kitimat Smelter
- Trail Smelter
- Ridley Island (Prince Rupert) Port
- Point Roberts / Vancouver Port
- Railroads
- Highways / Exploration Roads
- Reconnaissance site
- Study site

BR Bull River
CC Coal Creek
C4 Cumberland No. 4
PL Pinchi Lake
TI Texada Iron

Fig. 2.1 Location of reconnaissance and study sites (adapted from BCMEMPR (1993b) summarizes the five study sites and Table 2.2 describes the salient biophysical conditions at each site.

Table 2.1 Summary of study sites

MINE-SITE	MINE TYPE	AREAS STUDIED	RECLAMATION
Bull River	Open pit	waste dumps, pit, tailings	recontoured, ferti-lized, seeded
Coal Creek	U/G	waste dumps, settling pond	none
Cumberland No.4	U/G	waste dump	none
Pinchi Lake	Open pit, U/G	tailings pond	fertilized, seeded
Texada Iron	Open pit, U/G	tailings, waste dumps	none

Table 2.2 Comparison of biophysical conditions at the sites.

	BULL RIVER	COAL CREEK	CUMBERLAND No. 4 MINE	PINCHI LAKE	TEXADA IRON
Biogeoclimatic zone	IDF xw	ICH dw	CWH mm	SBS mh	CDF mm
Elevation (m)	930-1070	1020	160	715	5-120
Aspect	SW	E-W	W	S	S
Area disturbed (ha)	40	130	15	82	130
Years undisturbed	10	35, 50	>70	14	>30
Total annual precipitation (mm)	500	1130	1570	495	875
Max. distance to seed source (m)	450	150	150	200	200

Biogeoclimatic zones are described according to the B.C. Ministry of Forests (1991). Precipitation/Temperature graphs for the five sites are given in Figure 2.2 (Bull River) and Figure 2.3.

Bull River mine 946m 5.5°C 499.15mm
(1971-73, 1975)

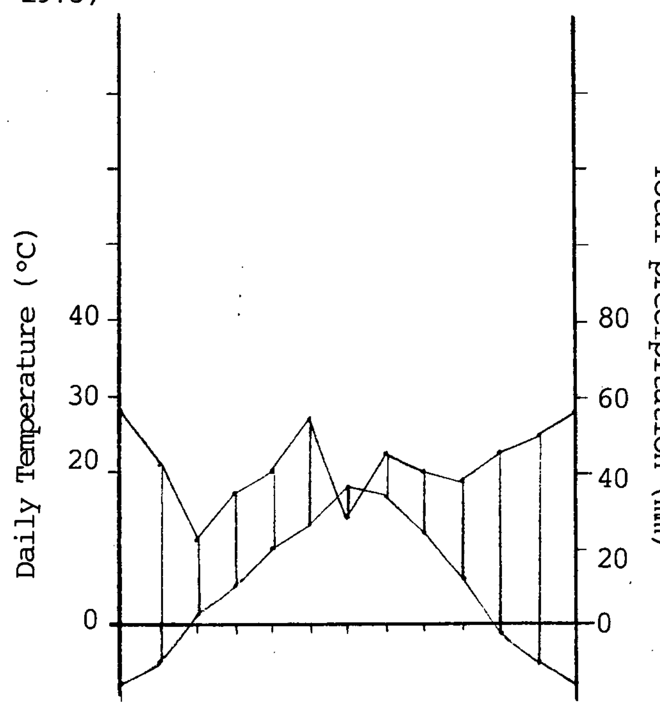
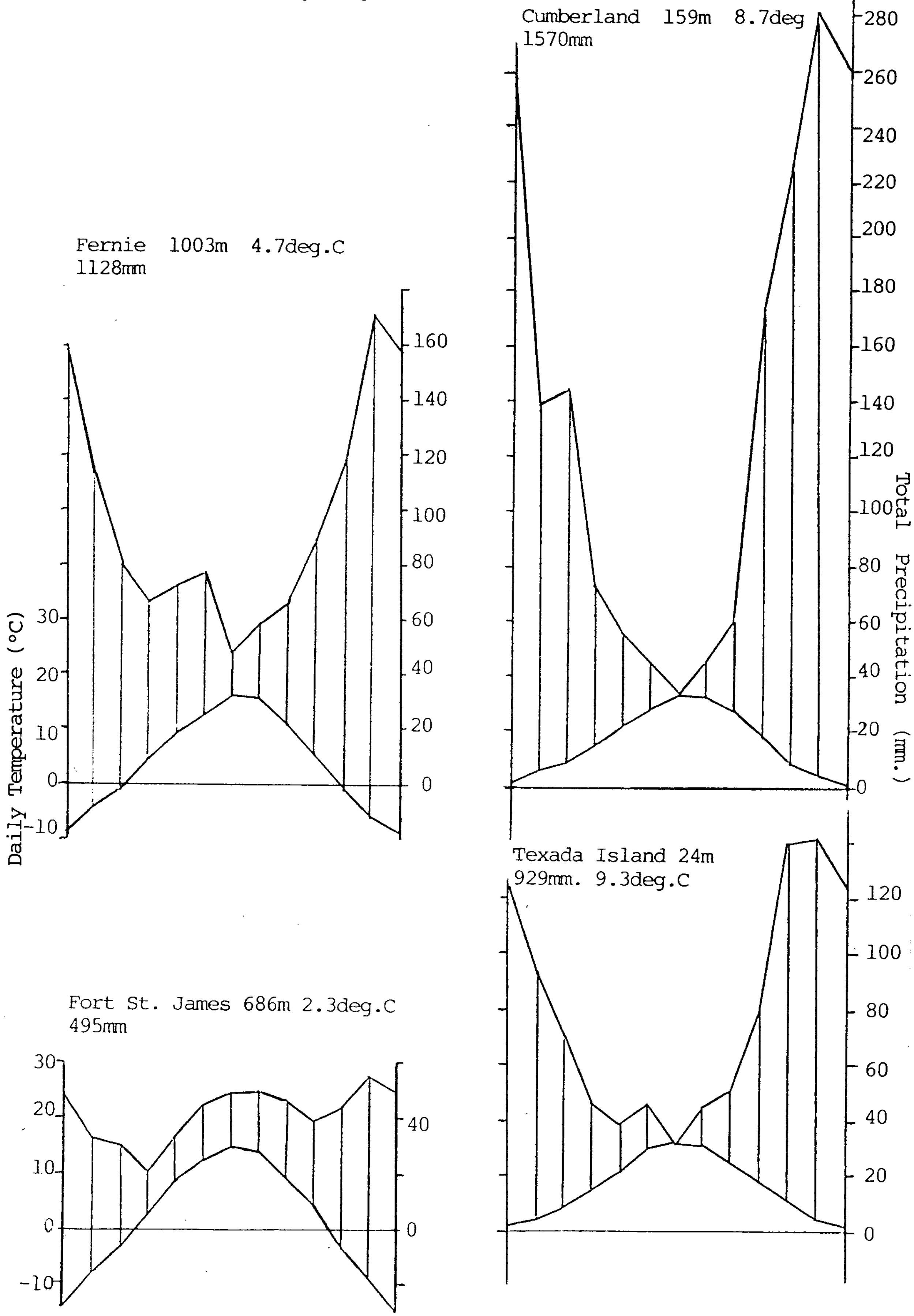


Figure 2.2 Bull River: Temperature and precipitation data

Fig.2.3: Temperature and precipitation data.



2.2 Benchmark studies

2.2.1 B.C. Ministry of Energy, Mines & Petroleum Resources (MEMPR)

Vegetation assessment surveys were carried out at Bull River (BCMEMPR, 1979), Pinchi Lake (BCMEMPR, 1978b) and Texada Iron (BCMEMPR, 1978a) by A. Nicholson and J. Singleton. These studies involved the visual estimation of plant species and percentage cover of each species on 3-5 contiguous quadrats of 1m or 4m square on a particular area defined by a vegetation/substrate association. They are consistent between sites in that they were carried out by the same people. They were reported in preliminary form but never published by the ministry.

2.2.2 University of British Columbia

A number of studies were carried out by the Department of Soil Science, University of British Columbia from 1976-1978. The aim of the studies was the characterization of mine spoils, examining both waste rock and tailings in order to provide type references for planning reclamation at the mines studied and other mines with similar types of waste. This was the pioneer work done in the province on ARD and metal (molybdenum) uptake in forage crops. In addition, weathering studies on mine spoils (using the soxhlet apparatus) showed the importance of weathering and resulting leachate on reclamation of mine spoils. Based on the studies made under this program, recommendations were made for improving the "mine-soil" as part of a revegetation strategy at a number of B.C. mines (Lavkulich et al., 1976, Como et al., 1978). In these studies the researchers carried out a comprehensive characterization of spoil material and vegetation. Also, an ecological survey was carried out at each site including an inventory of species present.

Errington (1975), studied the revegetation of the Cumberland coal mines as part of his Ph.D. thesis on revegetation of disturbed sites in British Columbia. In fact, his vegetation inventory combines both Cumberland No.4 and No.5 mines and so can only be used in a qualitative sense with the 1993 vegetation assessment at No.4 mine.

2.3 Study sites

2.3.1 Bull River

This open-pit copper mine was the first mine to be both commissioned and closed under the 1969 legislation requiring reclamation of mine-sites. The mine-site lies above the Bull river on the south facing flank of the Bull river valley about 23km west of Fernie. The biophysical conditions at the site are given in Table 2.2 and the temperature/precipitation pattern for the mine is given in Figure 2.2. The climate is characterized by low snowfall and high winds. Because of the southwest aspect and exposure, evapotranspiration produces a severe moisture deficiency in summer. Brunisols and Luvisols are the characteristic soils over glacial till overburden. The Canada Land Inventory defines the lower elevations in the valley as important winter concentration ranges for ungulates.

The ore deposit consisted of copper, with minor silver and gold, occurring primarily as sulphides within a vein stockwork in sedimentary rocks of the Precambrian Aldridge Formation. A total of 750 000t of ore was produced from two small open-pits from 1970-72 with the waste from the second pit being used to fill the first. Run-of-mine waste was stored on wrap-around dumps while ore was trucked to the on-site concentrator where, following conventional milling and the addition of lime before flotation, the product was a copper concentrate with silver and gold contained as credits. Tailings were alkaline and stored in a lined impoundment from which the till overburden was retained for a future cover.

The mine ceased production prematurely in 1972 and resloping and fertilizing/seeding started immediately and continued through the 1973 and 1974 growing seasons. A total of 40 ha were disturbed and subsequently reclaimed (BCMEMPR, 1979). No. 1 pit was partially backfilled and allowed to fill with water and a sand beach has been made. Waste dump surfaces were re-contoured and smoothed followed by seeding and fertilizing directly on to the dump material. The seed mixes are detailed in table 2.3 and include grasses and alsike clover but no alfalfa.

Table 2.3 Bull River seed mixes

mix 1	mix 2	mix 3
25% crested wheatgrass	n/a alsike clover	25% crested wheatgrass
20% tall wheatgrass	n/a crested wheatgrass	20% tall wheatgrass
20% timothy	n/a slender wheatgrass	20% timothy
15% slender wheatgrass	n/a tall fescue	15% slender wheatgrass
10% Canada bluegrass	n/a tall wheatgrass	10% tall fescue
10% hard fescue	n/a timothy	5% alsike clover
		5% Canada bluegrass

Although no trees or shrubs were planted on the site, islands of natural vegetation were left intact in the center and eastern sections of the site. From a distance, the site blends in well with the surroundings thanks to the resloping but at closer view, the sparse vegetation on the site contrasts with the surrounding vegetation. There is little invasion of native plants into the rather sparse, predominantly agronomic grass cover; nevertheless there is no evidence of water erosion, although some wind erosion occurs during high winds.

A study was carried out by MOE in 1974-1975 (Stanlake et al., 1978), which focussed primarily on patterns of ungulate usage of the site. This study found that wildlife were crossing the site, using the vegetation islands as refuge.

In 1976-77, a vegetation assessment was made on six substrate/vegetation units (BCMEMPR, 1979). Tall fescue showed the most consistent growth on all plots. The other seeded species, namely alsike clover, crested wheatgrass, slender wheatgrass and tall wheatgrass were to be found in various combinations in all areas along with the tall fescue and clover. In addition the authors expressed the concern that invading sweet clover might become a nuisance.

2.3.2 Coal Creek

The narrow Coal Creek valley lies 2 km east of Fernie, oriented east-west. Physiographic features of the area are given in Table 2.2 and the seasonal precipitation and temperature pattern for Fernie is given in Figure 2.3. However, the local ICH zonal characteristics on the sides of the valley are determined by aspect and thus moisture conditions. The background vegetation in the valley bottom is dominantly Douglas fir, white spruce and aspen with snowberry and Douglas maple. Soils of the area are dominantly Dystric or Eutric Brunisols or Brunisolic Gray Luvisols (Como et al., 1978).

Outcropping seams of metallurgical grade coal in Coal Creek were mined from the Coal Creek Colliery by the Crows Nest Pass Coal Company from 1898-1943. Underground methods were used and coal was hand sorted before being hauled away by rail. Several thousand tonnes of waste, produced either as development muck, waste from coal sorting or ash from combustion for heating purposes, were disposed of along the narrow valley bottom. In addition to the mine installations at the eastern end of the valley, there was also a town-site.

In 1943 the Elk River Colliery was opened just to the west of the old Coal Creek Colliery workings. This more modern mine included a coal washing plant which separated the coal from waste by gravimetric means with the waste water being led through a series of 4 settling ponds to allow suspended solids, mainly fine coal, to precipitate before the flow was directed into Coal Creek, a tributary of the Elk river. This operation continued in production until 1958 when the mine was closed for economic reasons. The disturbed area for the two mines totals 130ha covering the valley bottom eastward for 3km from the old railway bridge at the west end of the settling ponds. The sites assessed were all in the first kilometre from the bridge.

No formal revegetation has been recorded but some informal seeding and recontouring was carried out by Westar during their exploration in the valley (Milligan, 1993). Natural revegetation is complete except for coal waste, steep slopes and tracks; the area is tidy and any foreign debris is not from the mining operations. Current vegetation is dominated by cottonwood with snowberry and weedy herbs. In high moisture areas near the creek, alder is dominant. Some shifting of spoil piles has been carried out primarily for recreation purposes but the site is relatively undisturbed and much evidence of mining activity can be seen in the colour of the substrate on unvegetated slopes, old concrete foundations and unfamiliar contours. It is obvious that the land surface everywhere consists largely of coal mine waste and a prominent pile of coal waste has been resloped for a moto-cross climb feature. Considerable work has been done recently by Shell Canada, the previous corporate parent of Crows Nest Industries, to make safe the old entrances and installations and reslope and seed steep areas to prevent erosion. The current land use is recreation and hunting, principally by local residents. Shell freely allows public access and the area is visited by car, motorcycle and on foot.

The 1977 study by the UBC Soil Science Department (Como et al., 1978), carried out comprehensive characterization studies on 1) forested, 2) grassland and 3) settling pond sites as follows:

physical properties of spoil

chemical analysis of spoil

chemical analysis of vegetation

mineralogy of spoil

Plant species growing within a 5m radius of the soil pit and also those growing in the vicinity were identified.

In 1993 the three sites were relocated as closely as possible from the aerial photograph presented in the report; three substrate samples were taken from each site and species occurrence was recorded on three plots on each site.

2.3.3 Cumberland No. 4 mine

The Cumberland No.4 mine was an underground coal mine located 3 km west of Cumberland on Vancouver Island. The biophysical conditions are given in table 2.2 and the temperature/precipitation pattern for Cumberland is given in figure 2.3. Physiographically the site lies in the lee of a 50m high scarp along the eastern shore of Lake Comox. This feature provides both shelter and a good seed source and the site has returned naturally to a mature hemlock/cedar forest cover. The primary colonization by alder is still visible on the road edges. The current land use is as a recreation area including swimming and picnicking by the lake and riding on moto-cross machines.

The Cumberland No. 4 mine workings were accessed by an inclined shaft collared at the base of the scarp, 200m north of the inflow of Coal Creek. As its nomenclature indicates, the mine was one of a number of operations centred on Cumberland in the Comox coalfield. The mine operated from 1898-1936 and produced over 6.5Mt of clean steam coal. Coal was brought to the surface in cars hauled by cable and tipped on to tables for hand sorting. From there it was taken by rail to the loading port of Union Bay. Any waste material that remained on surface was piled between the lake and the bluff. The run-of-mine waste delivered by train from the incline shaft was spread in linear piles advancing away from the incline collar by using an advancing track on top of the dump 2-6m high (Weir, 1993). The lake level has since been raised by the construction of the Puntledge Dam; the mine waste now forms the lake bed on the eastern shore of the lake and the dumps now occupy an area of about 15 ha between the lake edge and the bluff.

The area is now covered with a second growth stand dominated by hemlock of diameter at breast height (dbh) 37-75cm with an open understorey dominated by mosses. The exact age of the dumps is unknown but they were abandoned before 1924 and all regeneration of vegetation is entirely natural (Weir, 1993). Seed dispersal across the dump has been aided by the height of the bluff and the dump has remained unmarked by moto-cross riders because of the steep side to the dump adjacent to the road.

The spoil area was studied previously in 1973 (Errington, 1975), with a transect of 17 contiguous 4m x 4m measurement quadrats running westward from the road and perpendicular to the waste piles. This traverse was relocated in this study as closely as possible and repeated with five 5mx5m quadrats along its length. Three substrate samples were taken for analysis.

2.3.4 Pinchi Lake mine

The Pinchi Lake mercury mine is situated on the north-east side of Pinchi Lake about 30km northwest of Fort St. James. The mine-site lies in gently rolling terrain from lake level at an elevation of 720m to 885m in the Sub Boreal Spruce zone. The area soils are dominated by Luvisols, reflecting the glaciated terrains. Biophysical conditions are given in table 2.2 and the temperature/precipitation pattern for Fort St. James is shown in figure 2.3. The area lies on the Interior Plateau in the rainshadow of the coastal mountains and has a humid continental climate with precipitation (495mm) distributed fairly evenly throughout the year. Winters are long and cold and the annual frost free period is 70-75 days. The Canada Land Inventory classified the area as having best physical capability for "limited big game range".

The mine operated during World War 2 and later from 1968-1975 as an underground and open-pit operation when 1100 tpd of mercury ore were mined and milled. Following crushing and grinding the ore was conditioned with lime before flotation. The concentrate was fed to the propane powered roaster and mercury was produced by condensing the roaster flue gases and bottled in the traditional 76lb flasks. Coarse tailings were used as back-fill underground with the remainder pumped as a slurry behind a tailings impoundment. Following settling of the solids the water was reclaimed by gravity to the mill for re-use. The total site disturbance is 82 ha of which 24 ha is occupied by the tailings impoundment, including dykes (Gardiner and Stathers, 1980).

Extensive reclamation research work has been carried out on the spoil material to test various reclamation techniques during mining before suspension of operations and details are contained in well documented annual reports (Gardiner, 1975, 1979, 1980, 1982, 1983; Gardiner and Stathers, 1976, 1977, 1978; Gardiner et al. 1981). Waste rock and tailings have been characterized and these tests showed that they are strongly alkaline, non-saline, very low in organic matter and essential plant nutrients nitrogen, phosphorus and in the case of tailings, potassium. Cation exchange capacities were higher than would be expected for a soil of similar texture and organic matter content. Extractable heavy metal contents were similar to normal agricultural soils. Both waste rock and tailings had low moisture retention capacities. Rigorous propagation tests were carried out using different legume and seed mixes and fertilizer types and application rates both in growth chambers and on test plots. These showed that grass and legume species grew satisfactorily on waste rock and tailings, provided a properly balanced supply of primary plant nutrients was made available (Cominco, 1973). Test plots of conifer and shrub seedlings were established in a tailings research plot area in the northeast corner of the tailings pond (Gardiner, 1975).

Since operations were suspended in 1975 the mine area has been actively reclaimed while under care and maintenance status. The area has been classified as having best physical capability for "limited big game range" and the reclamation objectives were for the disturbed land to be stabilised and rehabilitated to a use and appearance compatible with surrounding disturbed land. The general reclamation approach was to improve plant growth conditions on disturbed sites to encourage development of self-sustaining native or naturalized plant communities by initially establishing a vegetative cover of suitably adapted legume and grass species and by application of fertilizers and other site improvement techniques (Stathers and Gardiner, 1979).

Vegetation is a dense sward of alfalfa on waste rock and grasses and clover on the tailings impoundment. Revegetation was carried out by helicopter seeding and fertilizing in May, 1978 with a mix of alfalfa 30%, alsike clover 20%, creeping red fescue 25%, Canada bluegrass 15% and red top 10% accompanied by N13:P16:K10 fertiliser although coverage was uneven in some areas (Gardiner, 1978). An application of maintenance fertilizer over all areas was carried out in June, 1979. Also in 1979, 1000 lodgepole pine seedlings were planted to accelerate tree establishment for screening purposes (Gardiner, 1980). In addition, an assessment was made of the invasion of native shrubs species on to all test plots, including tailings, in 1977 (Gardiner and Stathers, 1978) and areas where seed germination was poor were re-seeded by hand broadcasting in May, 1980. Observations showed that legume dominated vegetation growing on unprepared waste rock and tailings continued to sustain satisfactory growth without annual application of fertilizer but grass dominated vegetation deteriorated once fertilizer was discontinued. As a result there was a concern that vegetation on the tailings pond would deteriorate to the point where reseeding might be desirable. Therefore, in 1980, maintenance fertilizer was discontinued on several disturbed areas revegetated in 1978 including the tailings impoundment and ore storage areas. However, on the tailings pond and ore storage areas, test strips each 3.7m wide, were fertilized to determine the effect of extra fertilizer application. Results from paired $1m^2$ test plots on four strips on the tailings pond show a reduction in cover from 79-60%, an increase in litter cover and a 50% drop in above-ground biomass without fertilizer. In addition, nutrient analysis of vegetation showed that nutrient content of both the fertilized and unfertilized plots was below the suggested nutrient contents for grass and legumes grown on range and pasture soil. The corresponding results for the legume dominated vegetation in the ore storage area showed a reduced effect (Gardiner et al, 1981). Later observations on the tailings pond confirmed that creeping red fescue and redtop was being replaced by alsike clover and that the population of volunteer poplar and willow was increasing. Foxtail barley and alkaligrass were growing well in seasonally inundated areas and bullrushes and willow populated the fringes of permanent pond areas (Gardiner, 1983; Gardiner, 1984).

In 1993 the tailings pond was sustaining a variety of vegetation and bird and animal life. Its contours make its previous use obvious and the presence of the concrete decant tower is notable but on final closure this would be replaced by a permanent spillway.

In 1978, a survey by MEMPR assessed vegetation by species and percentage cover on marked plots on all the disturbed site types (MEMPR, 1978b). These were the measurements which were to be relocated and repeated. Unfortunately, only the traverse of sampling plots across the tailings pond could be reliably relocated for this investigation and thus the 1993 study focussed on the tailings pond. Two stakes marking plots from the 1978 traverse were found and the traverse was repeated (PL1) but with plots 50m apart. Two further traverses, PL2 and PL3, were established across the pond with plots 50m apart. A small pit was dug and a substrate sample taken at each plot and a soil pit was completed at a background site.

2.3.5 Texada Iron mines

Texada Iron Mines is located on the SW coast of Texada Island about 14 km southwest of Vananda. The mine complex is on a steep south facing rocky slope rising from sea level to 250m with a narrow beach. Biophysical conditions are given in Table 2.2 and the temperature/precipitation pattern for Texada Island is shown in Figure 2.3. The main physiographic features of the site are mild winters, warm summers, moderate precipitation and exposure to onshore winds. There is considerable mist and fog during the winter months (Diggon, 1993). The soils are predominantly Humo-Ferric Podzols averaging one metre deep.

The mines operated principally from 1952-1976. Production was from four small open-pits from 1952-1965 but full underground production started in 1964 (Texada Mines, 1973). The orebody is a magnetite skarn type with a monzonite stock intruding Quatsino limestones overlain by andesitic volcanic flows (BCMEMPR, 1993a). During underground mining, annual ore production was about 1.1Mt. Following milling, both an iron (magnetite) and copper concentrate were produced and shipped directly to Japan. Tailings were deposited in the sea by a wooden flume. From April, 1969 production was almost entirely from underground operations with little new surface waste disposal, except for a small area of tailings. The exceptions were the small "Anomaly A" orebody which was developed underground with an access road, stockpile and adit and the salvaging of ore from the bottom benches of the Paxton pit (Texada Mines, 1973). A total of 130 ha of land has been disturbed.

At the close of operations in 1976 the property was sold and became a limestone quarrying operation with the dock, loading, workshop and office facilities continuing in use and any infrastructure not required was removed. Only post-1969 disturbances relating to the Anomaly "A" workings and the lower Paxton bench recovery were reclaimed. About 1Mt of tailings, largely covered with stockpiled limestone, remained along the shore. The four open pits remained as well as 18.6Mt of waste rock terraced into 16m(50ft) benches with slopes at the natural angle of repose. In addition, dense waste rock was used for creating stockpile areas and dock facilities (Texada Mines, 1973). No attempt at reclamation has been made and all revegetation reflects natural regeneration over 25-30 years. The mine property on the plateau to the north is now active as a limestone quarry and some areas of the iron mine are used as storage for the limestone product and in addition dump material from the iron mine is occasionally marketed as rip-rap or aggregate.

The alkalinity of the waste rock (pH=8, n=16), compaction, limited moisture retention and sterility in nitrogen and organic C make it a difficult site for plant recolonization. In addition magnetite, crystalline limestone, volcanics, monzonite and skarn, when silicified, are highly resistant to weathering. Unsilicified volcanics appears to have been weathered most rapidly.

Vegetation is sparse, mainly Douglas fir on exposed dry sites and alder where moisture is less limiting and at the break of slope on the dumps where moisture tends to collect. Douglas fir occurs more frequently but is sparse and often has a "skirted" appearance from heavy browsing (Lavkulich et al., 1976). However, Douglas fir described as 2m in 1978 is now 10m tall and cone bearing. Cedar are very heavily browsed and arbutus have not propagated beyond isolated individual seedlings away from the arbutus stand at the western end of the mine-site. Herbs are typical weedy species found on dry sites. Much of the bench tops have been compacted for haulage purposes and the only species occurring consistently is poverty oatgrass.

There is much evidence of deer whose east to west traverses across the mine complex are well travelled. There are no predators for either deer or squirrels, both being introduced species.

The 1976 study was carried out by the UBC Soil Science Department while the mine was still active (Lavkulich et al., 1976). Comprehensive characterization studies of spoil material and vegetation from the tailings pond, North Paxton dump, Lower Paxton dump and Yellow Kid dump were completed and background values were also measured. Studies were as follows:

mine waste physical properties,

mine waste chemical and mineralogical properties, water chemical quality,

chemical analysis of plant tissue from mine site,

greenhouse mine waste fertility studies.

ecological survey of disturbed and background areas

In 1978, a survey by MEMPR assessed vegetation by species and percentage cover on marked quadrats on 7 site units and of these the stakes for TI2,4,6,7 were relocated by the author.

The 1993 study repeated vegetation studies at the seven 1978 sites. Substrate samples representative of different substrate/vegetation combinations were taken at sites TI2,5,6 from the 1978 survey and TI8 which was as close as possible to the Yellow Kid dump site from the 1976 survey.

Chapter 3

METHODS

3.1 Field methods

3.1.1 Logistics

3.1.1.1 Reconnaissance phase

The reconnaissance phase of the research from June to August 1993 involved visiting 28 mine-sites in order to gather background information and find suitable sites for further study. As well as evaluating reclamation status at the mine, the visit involved testing of any surface water for pH, conductivity, temperature and dissolved oxygen using the ICM model 51501 water analyser. Where the pH was below 5.0 then SO_4^{2-} concentration was measured using a HACH sulphate analyser. Numerous 35mm photographs were taken for later reference. This reconnaissance phase involved preliminary plant identification and aquiring useful identification guides. "Trees, shrubs and flowers to know in British Columbia" (Lyons, 1991) was used as a general guide. For the respective regions, "Indicator plants of coastal British Columbia" (Klinka et al, 1989); "Some common plants of the sub-boreal spruce zone" (Pojar et al, 1982) and "A guide to some common plants of the southern interior of British Columbia" (Angove and Bancroft, 1983) were used. Plants which could not be identified in the field were stored in a plant press for later identification at the UBC herbarium.

The reconnaissance sites, listed below, are shown in figure 2.1:

Beaverdell
Bell Copper
Bralorne
Britannia Copper
Bull River
Byron Creek Collieries
Coal Creek Collieries
Craigmont
Cumberland Collieries

Endako
Emerald
Equity Silver
Giant Nickel
Granduc
HB
Highland Valley Copper
Island Copper
Jersey
Mt. Washington
Pinchi Lake
Pioneer
Premier Gold
Quintette Coal
St. Eugene
Silver Queen
Similco
Texada Iron

3.1.1.2 Site study phase

Upon completion of the reconnaissance, five sites were selected as representative sites for further study. Each site study lasted 1-2 weeks and this phase lasted from August to November 1993. Identification of species was, at times, hampered by the lateness of the season particularly at Coal Creek at an elevation of 1100m. Species identification was confirmed by reference to "Flora of the Pacific Northwest" (Hitchcock and Cronquist, 1991). Considerable time was spent in relocating plots from the previous MEMPR surveys where plots were marked with wooden stakes. Successful relocation depended on description of the site, the quality of the location maps and the type of stakes used to mark the plots. The 1" x 2" x 18" wooden stakes used by the MEMPR teams at Pinchi Lake and Texada Iron, being short and with a small aluminum tag stapled firmly to the top were found the most easily. Although easily hidden because of their short length, they could be located more easily than longer ones which, if they were ever found, were usually lying on the ground. At Texada Iron the original MEMPR stakes, still in the ground, were found for sites 4,6 and 7 of the 7 sites measured in 1978. The others were relocated within 20m of their plotted position on a location map with sufficient planimetric detail to place their position. No markers from the UBC study were found and the location map had insufficient detail to relocate their position accurately. At Pinchi Lake the MEMPR stakes were very difficult to find on a featureless tailings pond and only 2 of the original 6 stakes were found; the positions of the rest were extrapolated. At Bull River, no MEMPR stakes were found standing. One wooden stake of the same type used at Texada Iron and Pinchi Lake was found lying down at the plotted position of plot BR3-3 with only the staples remaining. This stake was 2ft long and easier for wildlife to knock over. At Coal Creek, the UBC location map was an air photo so that the plotted locations could be relocated within 25m, even though no stakes were found. At Cumberland, there was no location map from the previous study, but the author of the previous study (J.C. Errington) kindly went with me to the site and confidently identified the position of the end of his traverse to within 50m. Based on the experience of relocating stakes the current study used only cedar/fir 1" x 2" x 18" stakes with 2"x4" aluminum tags stapled to the top.

3.1.2 Site measurements

3.1.2.1 Plot description

Measurements were made on the basis of "site units", which represents a particular combination of substrate and vegetation, and each such site unit would be represented by 1-5 plots, often contiguous. The site units established by previous studies were followed and, if necessary, added to. The aim of sampling each site unit is to assess all the different growing conditions on the mine-site. In this way there would be no gaps in the evaluation of limitations to or progress towards revegetation of the site.

At each plot, located or established, the reclamation site inventory procedure described in MEMPR (1985) was followed. This is a subset of the "Ecosystem description in the field" procedure (Ministry of Environment, 1990), modified for mine-sites, and consists of guidelines for describing the physical conditions of the plot and a vegetation inventory. The centre of the plot was defined by the stake from the previous survey and the area of 5m x 5m was defined with a 5m long strip of calico, wide enough to be clearly visible on photographs. The $25m^2$ size plot was chosen as being the maximum size of plot that could be assessed visually. The physical parameters estimated visually were as follows:

Table 3.1 Plot description parameters observed

SITE PARAMETERS	SUBSTRATE OBSERVATIONS
slope	pH (Helleborg-Truog)
aspect	wildlife pellet count
elevation	soil fauna (earthworms)
length upslope/downslope	Texture of fine material
moisture regime	coarse material- size
slope position macro	coarse material- shape
surface shape	coarse material- volume
slope position moisture	calcareousness (using dilute HCl)
exposure type	soil colour- Munsell charts
erosion	
drainage	

3.1.2.2 Vegetation assessment

The vegetation was assessed visually by estimating the percentage cover for each species in a plot. Data entry forms were made up with species lists based on the species previously present with new species being added as required. Common names were used for identification and all plants were identified to the species level where possible, except mosses. For shrubs and trees the canopy edge was taken as the area of cover and in such cases the total cover including understorey may exceed 100%. At Coal Creek, because of the lateness of the growing season, the species occurrence only was noted and not the percentage cover.

3.1.2.3 Substrate sampling

Where data from previous substrate sampling by UBC was available, as in the case of Coal Creek and Texada Iron, they were repeated with the sample being taken as closely as possible to the same location. Also, additional sites were selected to represent a particular substrate/vegetation combination. Cumberland No. 4 consisted of only one substrate/vegetation type, whereas Texada Iron had nine. At each sample location a hole was dug 30cm in diameter and 15 cm deep. The substrate material was sieved to minus 5mm and the undersize was split into 5 replicates which were stored in plastic bags open to air to prevent anaerobic conditions from developing. Sample numbers were marked both on the outside of the bag and on tags placed inside the bag. These samples were returned to the UBC soil laboratory for analysis. Where water bodies were accessible, field measurements of pH, electrical conductivity, dissolved oxygen and temperature were taken but no physical samples were retained.

3.1.2.4 Tree coring

At Coal Creek, Cumberland No. 4 and Texada Iron, where natural regeneration has occurred over a sufficient period of time to allow trees to grow, trees were cored with an increment borer to determine age.

3.1.2.5 Data quality

There was no way of monitoring the quality of the vegetation assessment data. Since the 1993 measurements were all carried out by the same person over a relatively short period of time, it was reasonable to assume that the 1993 data was internally consistent in terms of species identification and percentage cover. However, it was not valid to compare visual measurements of percentage cover made by two different people at different times on a plot of several square metres in size. For this reason, historical comparisons of the vegetation data were made using species occurrence data only, whereas the 1993 data were used to compare sites both by species presence and percentage cover.

3.2 Laboratory measurements

UBC Soil Science Laboratory facilities were used for all the laboratory measurements.

3.2.1 Sample preparation

Replicate samples were air dried and weighed. About 150g of the dried sample was then disaggregated before weighing and sieving to minus 2mm. The minus 2mm fraction was then weighed. This was then used to calculate the percent fines (<2mm material) of the whole sample.

3.2.2 pH determination

A pH determination was carried out using both water and 0.01M $CaCl_2$ using the procedure outlined by the American Society of Agronomy (1965) on 5 replicates of 47 samples using a Fisher Scientific pH meter. The sensor was immersed for a timed 2 minutes except where the organic matter content or colour of the material changed, then 5 minutes were allowed for equilibrium to be reached.

3.2.3 Total Nitrogen determination

The Nitrogen content of samples was determined using the Total Kjeldahl Nitrogen method. Initially, a test run was completed on 7 samples using both 0.5g and 1.0g sample weights. A blank, 2 duplicates and a standard were added to the run. Based on the results for the carbon rich samples from Coal Creek a sample weight of approximately 0.3g was used for Coal Creek and 1.0g elsewhere. All 5 replicates were analysed for the 9 samples from Coal Creek to see if the variation in the results warranted the analysis of all the replicates or not. Based on the consistency of the N results from Coal Creek and the similarity in consistency between the pH results from Coal Creek and other sites, only a single replicate was used for the N determination at the other sites. The Total N determination does not differentiate between organic N available to plants and geological or indigenous N present in host rocks.

3.2.4 Organic Carbon determination

It was originally intended to use the Walkley-Black titration method for determining organic C on sites where carbonate was known to be present e.g. Texada Iron, so that inorganic C would not interfere and for internal consistency the same method would be used throughout. However, the sample size required to complete the Walkley-Black titration successfully on the highly carbonaceous material from Coal Creek was so small (<0.05g) that the accuracy of the method was questionable. For this reason and also the fact that the previous UBC determinations used Leco Total C at both Coal Creek and

Texada Leco Total C was used as well as Walkley-Black at those sites. One replicate per sample was used for the organic C determinations. The 21 Leco Total C measurements were done by Martin Hilmer (Soil Science Technician) after preparation by the author; all other laboratory work was performed by the author.

3.2.5 Data quality

The precision of the laboratory measurements of pH, %N, organic C and Total C was verified by performing duplicate measurements on approximately 10% of the samples. The difference in duplicate measurements was always less than 10% when duplicate measurements were made without delay. The pH duplicate measurements were made 2 months later and there were some differences greater than 10%. In these cases both the duplicate and the original measurement were repeated. The accuracy of the results was monitored by comparing with the value of pH and total C for laboratory "standard" soil. To test whether or not replicates were required for substrate samples, the <5mm substrate material was divided into 5 replicates for all 47 substrate samples and all 5 replicates were analysed for pH in water and $CaCl_2$. For pH data the standard deviation was always less than 5% of the mean of the replicate values. Only the replicates for the 9 samples for Coal Creek were analysed for percent N. The acceptable lack of variation in these replicates was used as evidence that the use of a single replicate was justified instead of creating a special "composite" sample for the C and N determinations. The data quality of the laboratory experiments is considered satisfactory.

3.3 Data processing

3.3.1 Data entry

All field data were entered manually on to coding sheets. At the end of the field season two computer data files were constructed, one for the environmental data and another for the vegetation for all five mine-sites. The intention was to use SYSTAT (Wilkinson, 1990) both to calculate statistical measures for the data and to present the data graphically. Since SYSTAT is not designed for easy editing and file manipulation, LOTUS 123 was used for file processing, following which the files were translated from LOTUS into SYSTAT format.

3.3.2 Data processing

Species occurrence data was compiled including both the historical and 1993 data. Presence of a species was indicated by a "1" and absence by "0". The file contains historical data for 17 site units representing a unique substrate/vegetation combination on the 5 mine-sites. In 1993 these 17 site units were repeated and 4 were added; each site unit is made up of 1-5 measurement plots resulting in 77 plots for 21 site units. Species richness has been compiled for the 1993 data. The species occurrence data from the plots on each site unit are combined to give the number of species which occur one or more times on each site unit. The species richness count for the 21 site units assessed in 1993 is combined with the count for the 17 site units previously measured to give a species richness file comparing the historic and current counts as well as tyhe 4 extra sites. The list of 94 species in these two files does not include the forbs and bryophytes which were identified in the historical study but not in 1993. These have been added to the life-form groupings separately for the historical species richness data. However, a table will be presented for each site in Chapter 4 giving a complete listing of all species identified in both the historic and 1993 studies, organized by life-form.

The percent cover data file contains data from the 21 site units at the 5 mine sites (77 plots) where the actual percentage coverage of species were measured. The value of cover given for each site unit is the mean of the percent cover for the plots on that site unit.

Although common names have been used throughout, Table 4.12 gives the common and scientific name for all species identified in 1993, organised by life-form.

All the laboratory results from the substrate samples were compiled into a LOTUS spreadsheet for calculation of averages and standard deviations for the 5 replicates of 47 substrate samples (235 samples).

Data have been collected and compiled as in Table 3.2.

Table 3.2 Summary of data collection and compilation

	BULL RIVER	COAL CREEK	CUMBERLAND No. 4 MINE	PINCHI LAKE	TEXADA IRON	TOTALS
No. of historical site units repeated in 1993	5	3	1	1	7	17
No. of site units added in 1993	-	-	-	2	2	4
No. of 1993 vegetation plots	19	9	5	21	23	77
No. of 1993 substrate samples	6	9	3	22	7	47

3.3.3 Data presentation

The aim was to present the results in a graphical format with the following purposes:

-To portray changes in plant community structure which would reflect biological succession.

-To show analytical data from substrate samples which would most illustrate the development of water, energy and nutrient cycling.

-To be organized so that data from several site units could be presented together for comparison purposes.

The procedure adopted was to group the plant species (94) into 5 life-forms as follows:

woody species(trees and shrubs)

herbs and flowers (includes ferns)

native grasses and legumes

agronomic grasses and legumes

mosses (includes liverworts and lichens)

A mine-site plant community is an immature plant community which is changing and the groupings are designed to reflect the most important characteristics of that change. The dominant component of most plant communities in B.C. are trees and shrubs. Since they are rarely planted their recruitment is a valuable indication of development of the plant community. Most reclamation plans involve seeding of agronomic grasses and legumes to provide rapid cover and to facilitate the development of water, energy and nutrient cycling. This is done by providing organic matter and soil N, reducing the bulk density and improving the soil structure. It is important to know how far this facilitation process has progressed by measuring the agronomic species that remain and the native grasses and legumes which are replacing them. A plant community also includes a number of more ephemeral species which may provide little cover but which are important in that their presence may be a valuable indicator of the edaphic conditions on the site. However they may only be identifiable for a short period each year and may cause wide variation in the total number of species identified by successive studies. They have been grouped as flowers and herbs. Mosses or bryophytes are the final component of the ground cover and this category includes liverworts and lichens.

To present the species richness and percent cover vegetation data for the five life-forms, stacked bar charts were used to identify the five life-form groups. In addition the stacked bar chart can be used in a relative sense for data by expressing the value as a percentage of the total.

In presenting analytical data on the substrate samples, box and whisker plots have been used. In contrast to the bar charts the variability in values between the plots on each site unit is depicted by the box and whiskers. The median value is the line within the box and the ends of the box represent the interquartile (± 25%) range. The "whiskers" or lines extending from the box ends show the lower and upper fences and any outlying data value is represented by an asterisk. For the organic N data at Coal Creek where 5 replicate samples were analysed a mean was calculated for each plot and used for the box plot display.

Chapter 4

RESULTS

The results of the field survey and laboratory determinations are given below. The first part of the chapter presents results or observations that have been grouped to compare data across all mine-sites. A summary of the relocation of plots from previous surveys is given in Table 4.1 and Table 4.2 is a key to relate the site units, given as unit numbers in the figures for visual clarity with the mine, site unit and plot numbers. The second part of the chapter discusses the mine-sites individually. There is an imbalance of data in favour of Pinchi Lake and Texada Iron because of the greater amount of information available. Where two values are given with the second in parentheses, the value in parentheses is the historic value.

Table 4.1 Relocation of plots from benchmark studies

NAME OF MINE	PREVIOUS STUDIES	SITE UNITS RELOCATED	COMMENTS
Bull River	MOE 1974-76 MEMPR 1978	none BR3-3	Good location map. Locations ± 25m.
Coal Creek	UBC 1977	none	No stakes but good air photo for location ± 25m
Cumberland #4	Errington 1973	none	location probably ± 50m
Pinchi Lake	Cominco studies MEMPR 1978	3 ex 6 on PL1	Tailings are featureless. Location ± 25m.
Texada Iron	MEMPR 1978 UBC 1977	sites 4,5,6,7 none	UBC location map poor

Hard-copy of the abridged field data is contained in the appendices as follows:

Appendix 1. Number of species data

Appendix 2. Species cover data

Appendix 3. Data from substrate sample analyses

Appendix 4. Plot description data

Appendix 5. Field plot description data

4.1 Comparisons across all mine-sites

Table 4.2 Key to correspondence between mine site units and site unit numbers on figures. (-H is the benchmark or historic measurement)

mine and site number	number of plots	site unit number on figures	SYSTAT case numbers
BR1	1,3,4,5,6	1	1-5
BR1-H	1	2	6
BR2	1-4	3	7-11
BR2-H	1	4	12
BR3	3,4	5	13-14
BR3-H	1	6	15
BR5	1-4	7	16-19
BR5-H	1	8	20
BR6	1-3	9	21-23
BR6-H	1	10	24
C4	1-5	11	25-29
C4-H	1	12	30
CCF-H	1	13	31
CCF	1-3	14	32-34
CCG-H	1	15	35
CCG	1-3	16	36-38
CCSP-H	1	17	39
CCSP	1-3	18	40-42
PL2	1-6	19	43-48
PL3	1-7	20	49-55
PL1	1-8	21	56-63
PL1-H	1	22	64
TI1	1	23	65
TI1-H	1	24	66
TI2	1-5	25	67-71
TI2-H	1	26	72
TI3	1-2	27	73-74
TI4	1-3	28	75-77
TI4-H	1	29	78
TI5	1	30	79
TI5-H	1	31	80
TI6	1,2,4	32	81-83
TI6-H	1	33	84
TI7	1-3	34	85-87
TI7-H	1	35	88
TI8	1-4	36	89-92
TI8-H	1	37	93
TI9	1	38	94

4.1.1 pH results

Figure 4.1 summarizes the results of the soil pH water analyses for the five mine-sites. At Bull River the pH values of >8 reflect the alkaline nature of the sedimentary rocks forming the waste material and also the till cover to the tailings pond which was stockpiled during construction of the lined tailings impoundment. At Cumberland No. 4 the pH of 5.2 is normal for a coniferous forest soil. At Coal Creek there is a drop in pH on all 3 sites from the previous study of at least half a pH unit but all current values are within the neutral range. At Pinchi Lake the alkaline pH value of the tailings reflects the alkaline nature of the host rocks and the addition of lime as a conditioner during beneficiation. At Texada Iron the alkaline values are consistent with the carbonate geology except for site 1 which is on the acid tailings.

4.1.2 Total Nitrogen content of substrate

Figure 4.2 summarizes the percent N results for all mine-sites. These values are Total N which may be expressed as the combination of geological N; unavailable to plants and consisting mainly of fixed NH_4^+ in micas and non-hydrolyzable N bound in coal and active N; consisting of hydrolyzable organic N and exchangeable N. Active N accumulates primarily in the 0-5cm interval associated with A horizon development (Li and Daniels, 1994).

The current survey used a composite sample from 0-15cm depth whereas the 1976-7 surveys at Coal Creek and Texada Iron took samples based on soil horizon. To allow comparison with the 1993 data, a weighted average of %N from 0-15cm has been calculated from the 1976-7 data. At Coal Creek, N content has increased at the Forested and Settling Pond sites to 0.75% and 1.0% respectively and decreased at the Grassland site

Figure 4.1 pH data from substrate samples

unit number	site	unit number	site
1	BR1	19	PL2
3	BR2	20	PL3
		21	PL1
11	C4		
		24	TI1-H
13	CCF-H	25	TI2
14	CCF	30	TI5
15	CCG-H	31	TI5-H
16	CCG	32	TI6
17	CCSP	36	TI8
18	CCSP-H	37	TI8-H

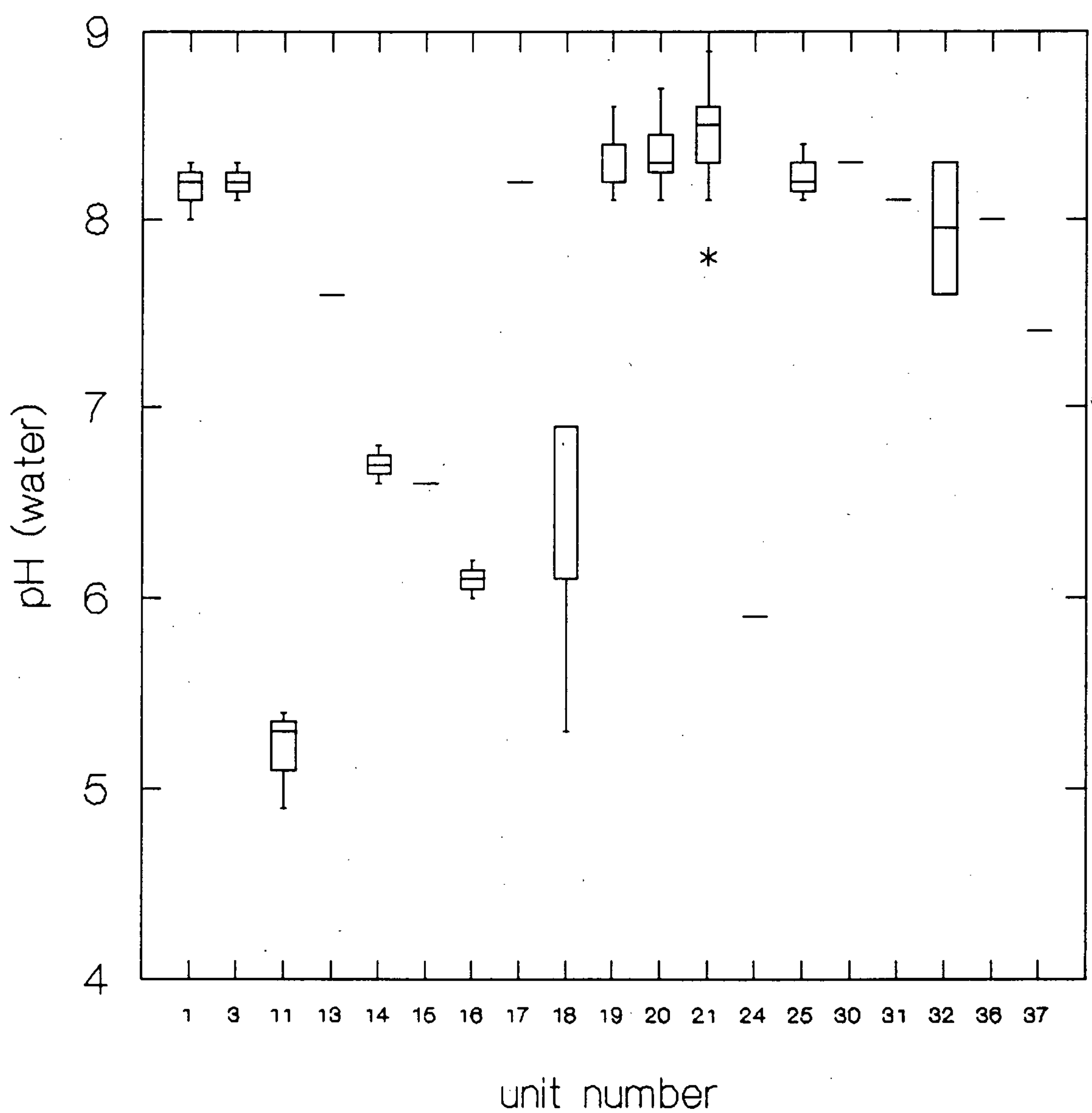
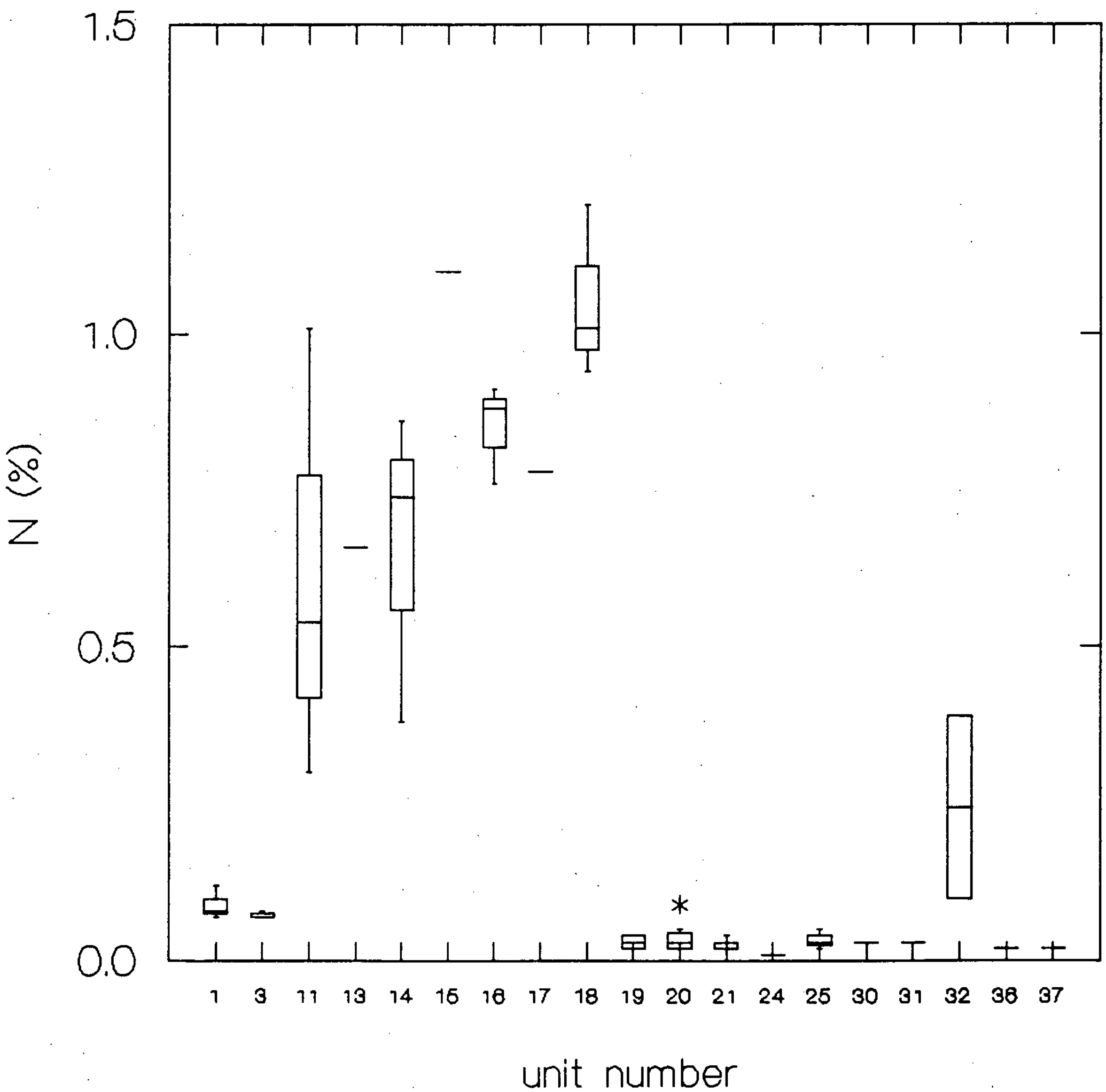


Figure 4.2 Percent Nitrogen data from substrate samples

unit number	site	unit number	site
1	BR1	19	PL2
3	BR2	20	PL3
		21	PL1
11	C4		
		24	TI1-H
13	CCF-H	25	TI2
14	CCF	30	TI5
15	CCG-H	31	TI5-H
16	CCG	32	TI6
17	CCSP	36	TI8
18	CCSP-H	37	TI8-H



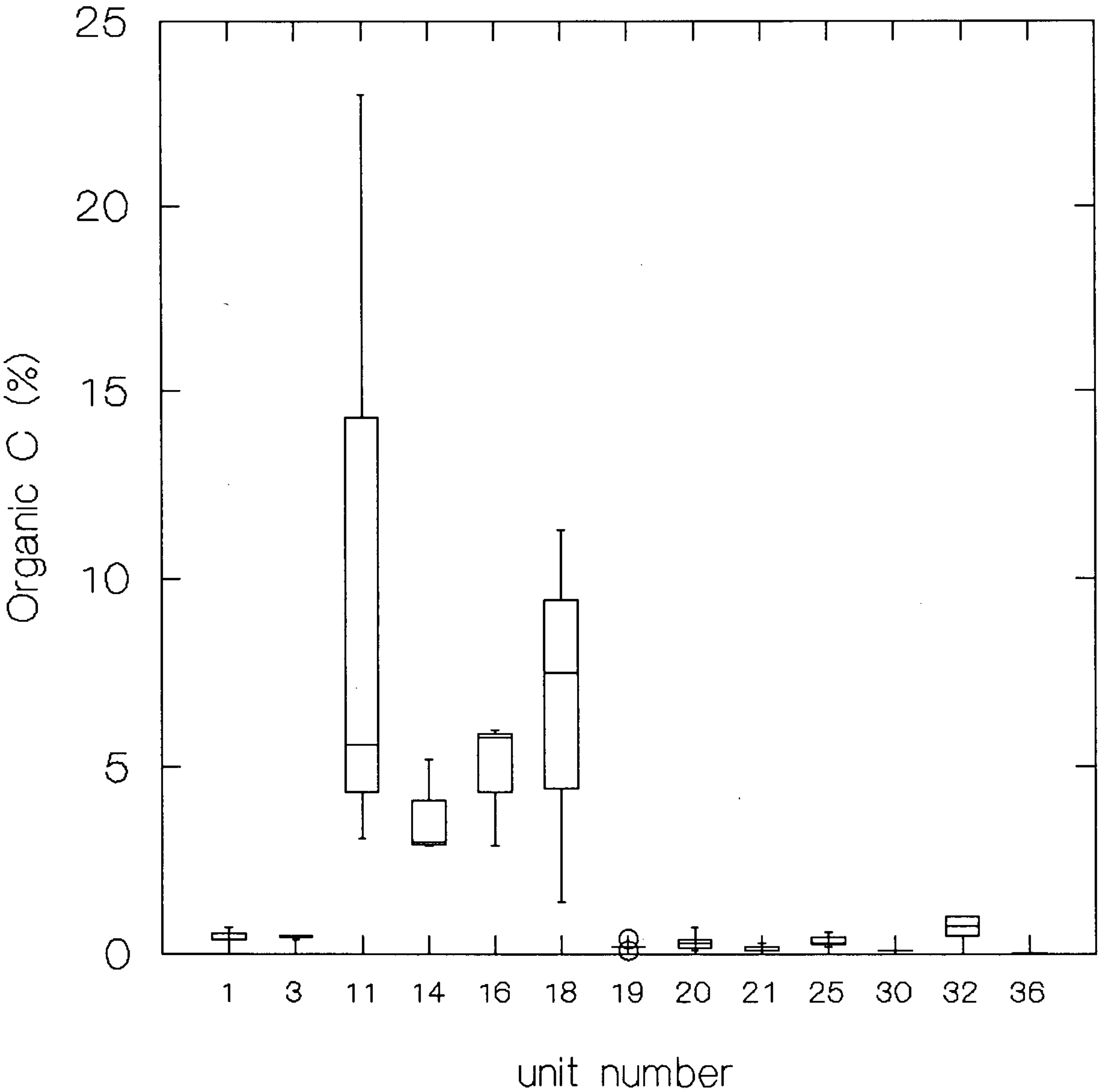
to 0.85%. The background value for this area is 0.04% (Kelley and Sprout, 1956). The median value of Total N at Cumberland No. 4 is 0.55% compared to a representative background value of 0.08%N given by Day et al. (1959). The mean value of 0.05%N at Pinchi Lake may be compared to a background value of 0.17%N on surface given by Runka (1972). There has been no change in the %N content from 1976 to 1993 at the two barren Texada Iron sites, TI5 and TI8 where values measured in 1993 were 0.05 % and 0.04%. Background values measured during the 1976 survey of A horizon were 0.202% for Paxton North (TI5) and 0.041% for Yellow Kid (TI8).

4.1.3 Organic Carbon content

Figure 4.3 summarizes the laboratory results for the Walkley-Black organic C determinations on the 1993 substrate data. The UBC substrate samples were analysed using the Leco Total carbon detection method and this data is not shown as a comparison. The 1993 samples which were analysed using the less aggressive Walkley-Black method show typical values for forest soils (Brady, 1990) at Coal Creek and Cumberland of about 5%. A background value on surface of 2.2%C (Walkley Black) has been given for Coal Creek (Kelly and Sprout, 1956) and 1.2%C for Cumberland (Day et al., 1959). All other sites have organic C content of 0.5% or less. The background value for Bull River is the same as that of Coal Creek. For Pinchi Lake a value of 2.3%C is given by Runka (1972). The only background value for Walkley Black organic C at Texada is 1.2%, the same reference as for Cumberland (Day et al., 1959).

Figure 4.3 Organic Carbon data (Walkley Black) for 1993 samples

unit number	site	unit number	site
1	BR1	19	PL2
3	BR2	20	PL3
		21	PL1
11	C4		
		25	TI2
14	CCF	30	TI5
16	CCG	32	TI6
18	CCSP	36	TI8



4.1.4 C/N ratio

Because of the close relationship between organic matter and the nitrogen content of soils and the definite proportion of C in organic matter, the ratio of organic C to total N is relatively constant in developed soils (Brady, 1990). Figure 4.4 shows the 1993 C/N ratio data for all sites. At Cumberland the median value is about 10.5 which is normal for a forest soil. (Brady, 1990) At Coal Creek the median values range from 6-7.5 with the highest value being on the forested site. At the three metal mining sites the nitrogen values are so low that the ratio is of questionable validity except for site TI6. Values vary from 2-8 except for the median C/N value of 12 at TI2.

4.1.5 Percent fines (<2mm)

Figure 4.5 summarizes the percent fines results for the 1993 data. In mine waste, values are usually low compared to soils but increase with time as weathering breaks down rock particles. Values were lowest at TI6, from 40-60%, reflecting the coarse nature of the uncompacted dump material. Similar material, compacted, at TI2 contained a median value of 65-70% fines. Other sites ranged from 70-95% with the highest value found for the sedimented coal particles on the settling pond site. The tailings at Pinchi Lake are all fines, any coarse material having been used for backfill underground.

Figure 4.4 C/N ratio for 1993 substrate samples

unit number	site	unit number	site
1	BR1	19	PL2
3	BR2	20	PL3
		21	PL1
11	C4		
		25	TI2
14	CCF	30	TI5
16	CCG	32	TI6
18	CCSP	36	TI8

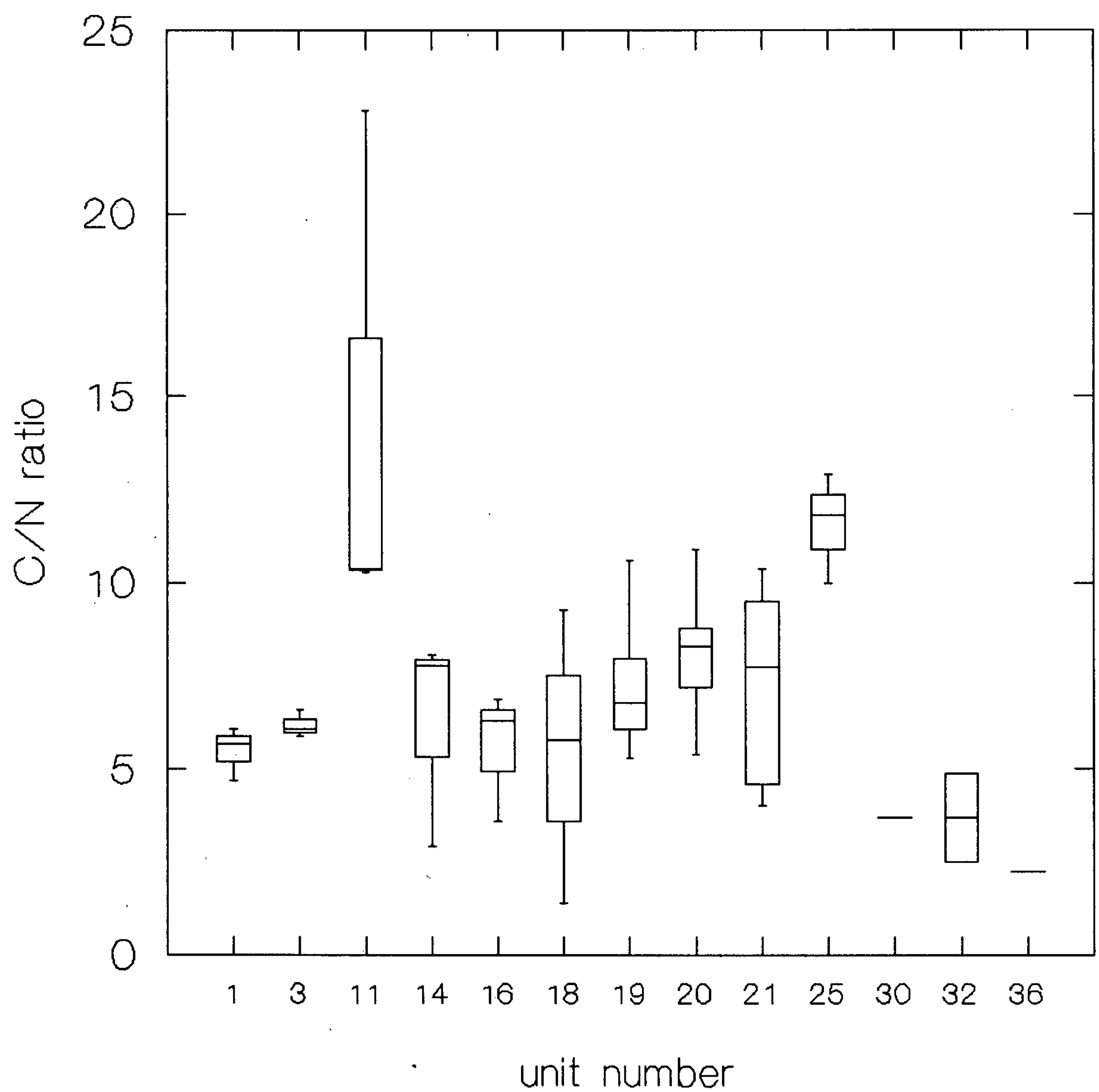
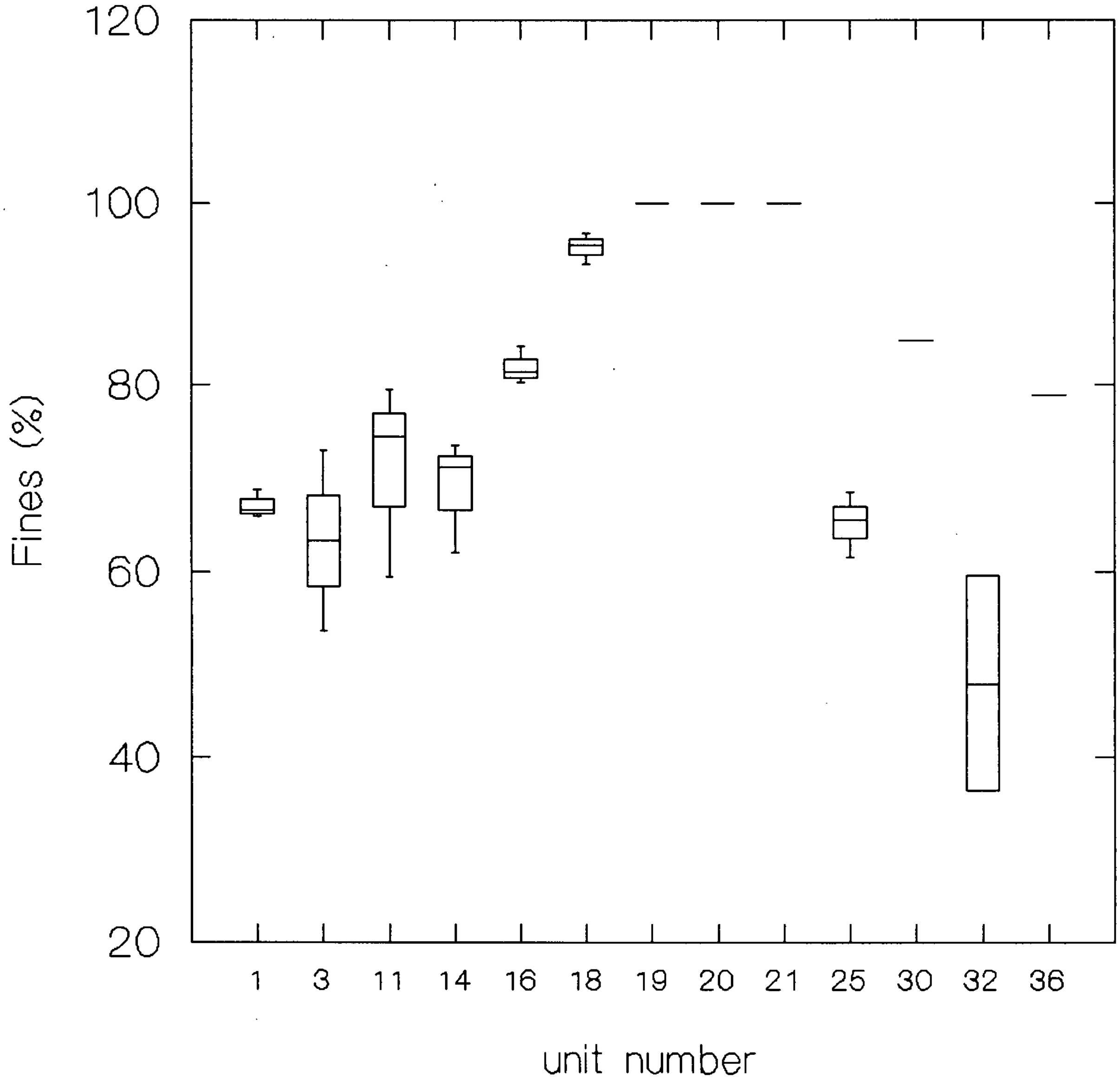


Figure 4.5 Percent fines for 1993 substrate samples

unit number	site	unit number	site
1	BR1	19	PL2
3	BR2	20	PL3
		21	PL1
11	C4		
		25	TI2
14	CCF	30	TI5
16	CCG	32	TI6
18	CCSP	36	TI8



4.1.6 Vegetation species richness for all sites

Figure 4.6 shows the number of species grouped into woody species, native grasses and legumes, flowers and herbs, mosses and agronomic grasses and legumes (where seeded) for each site unit reported historically and repeated in 1993 and the four new sites. It is notable that the largest number of species occurs at Cumberland; this is due to the fact that the the historical data from Errington (1975) includes woody species from both the No. 4 & 5 mines and that Errington identified many more mosses than the author. The other notable feature is that the high numbers of species at unit numbers 29(TI4) and 31(TI5) are made up largely of forbs, many of which are annuals and some of which are ephemeral, such that they would have been missed by the 1993 study which was made in September-October, late in the growing season.

Apart from the cases mentioned above, it can be seen that the greatest change in species richness has occurred at the two reclaimed sites, Bull River and Pinchi Lake.

At Bull River the number of agronomic species has been slightly reduced, volunteer woody species have appeared and there is a consistent increase in species richness from 1977 to 1993 except for site BR2. At Pinchi Lake the number of agronomic species has remained the same but recruitment of woody species has increased the number of species to 15(11). There is no correlation between number of species and percent cover.

4.1.7 Vegetation percent cover for all sites (1993 data)

Figure 4.7 shows percent cover for all sites; note that this was not measured at Coal Creek because of the lateness of the growing season. Vegetation cover varies from >100% at Cumberland and PL1 to practically bare on the haul road surface of TI5. Woody species provide a proportionally greater cover at Texada Iron than elsewhere. Both

Figure 4.6 Number of species data for all sites

unit number	site	unit number	site	unit number	site
1	BR1	13	CCF-H	23	TI1
2	BR1-H	14	CCF	24	TI1-H
3	BR2	15	CCG-H	25	TI2
4	BR2-H	16	CCG	26	TI2-H
5	BR3	17	CCSP	27	TI3
6	BR3-H	18	CCSP-H	28	TI4
7	BR5	19	PL2	29	TI4-H
8	BR5-H	20	PL3	30	TI5
9	BR6	21	PL1	31	TI5-H
10	BR6-H	22	PL1-H	32	TI6
11	C4			33	TI6-H
12	C4-H			34	TI7
				35	TI7-H
				36	TI8
				38	TI9

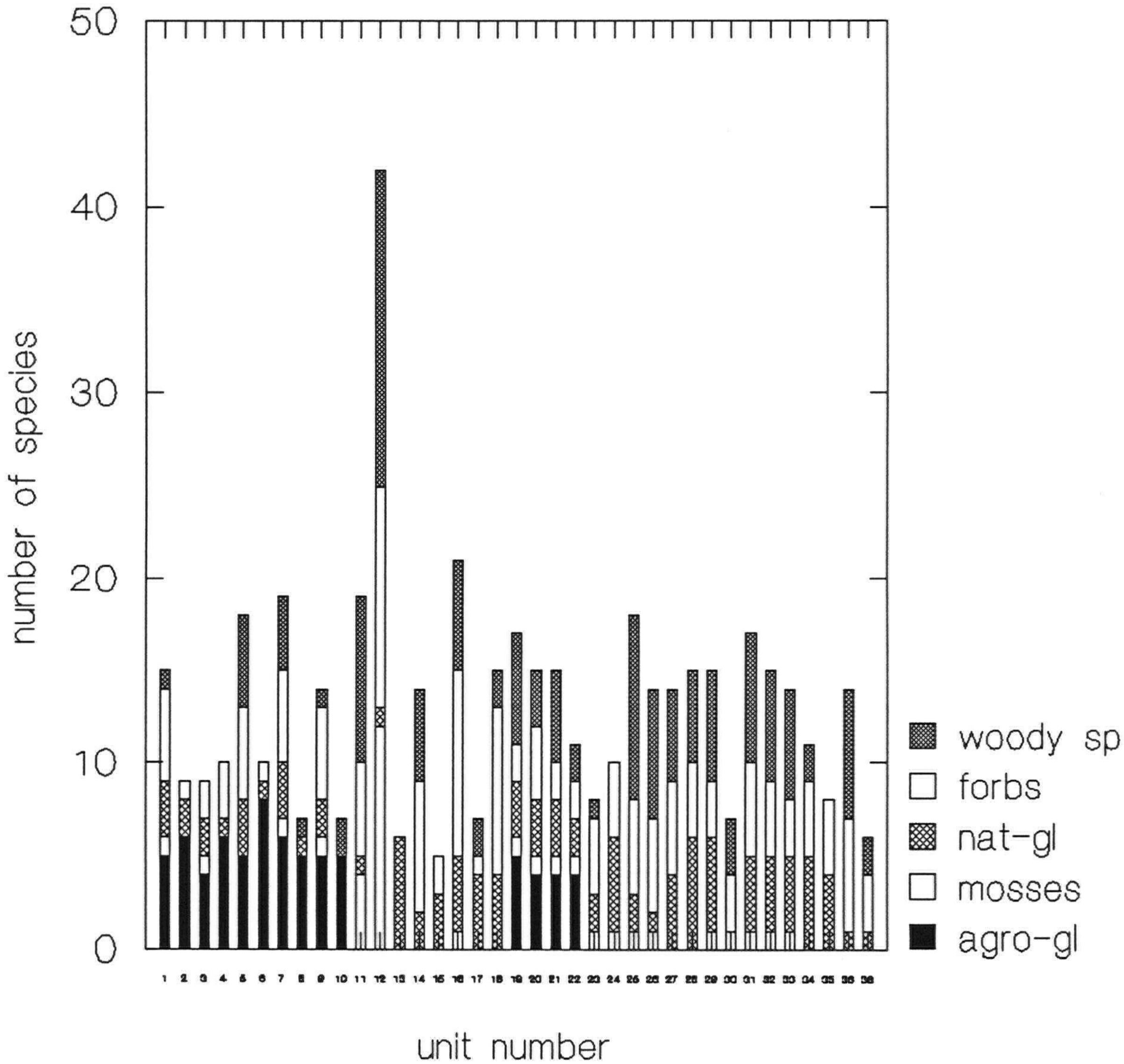
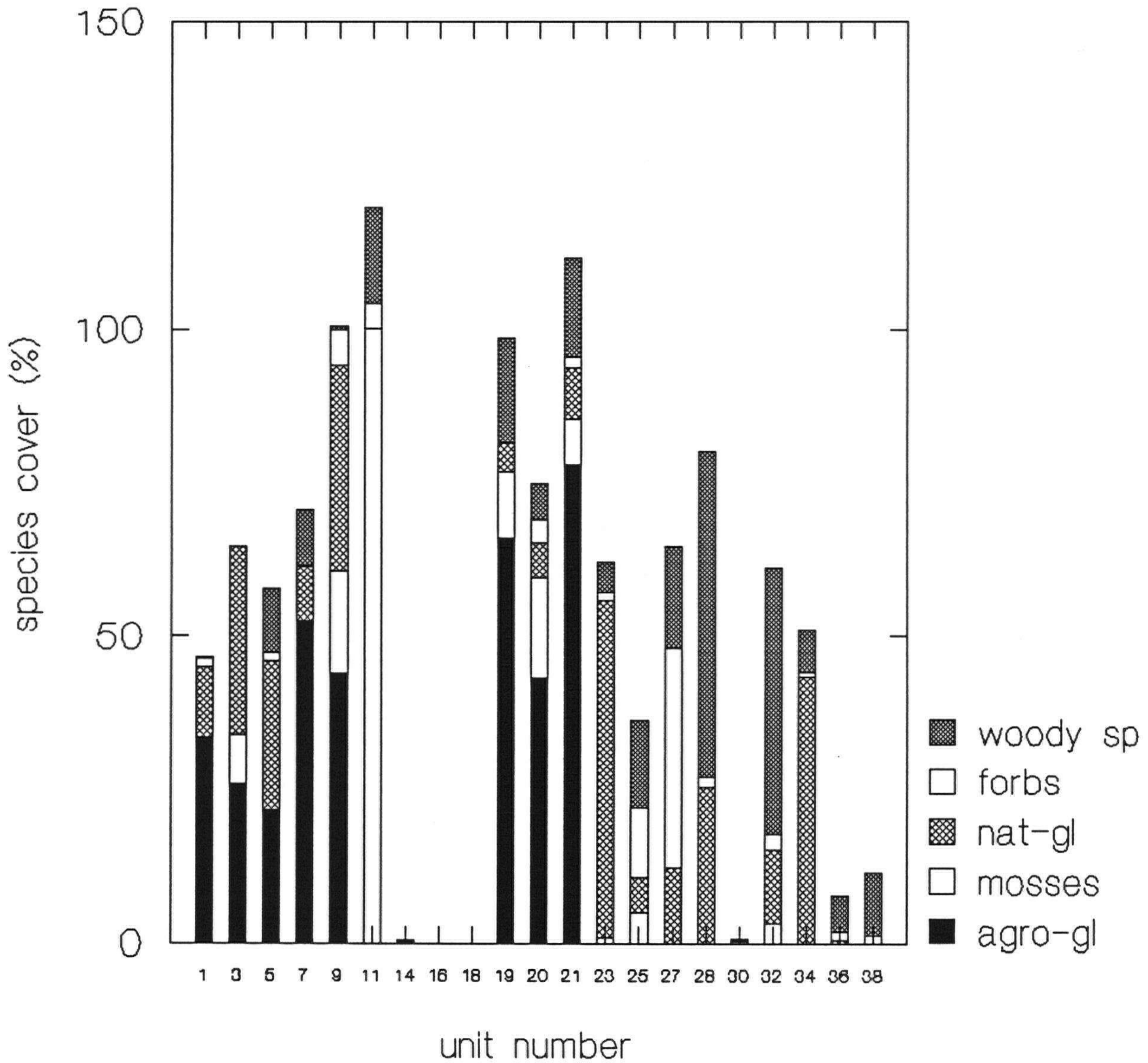


Figure 4.7 Species cover (%) for all sites (1993)

unit number	site	unit number	site	unit number	site
1	BR1	14	CCF	23	TI1
3	BR2	16	CCG	25	TI2
5	BR3	18	CCSP	27	TI3
7	BR5			28	TI4
9	BR6	19	PL2	30	TI5
		20	PL3	32	TI6
11	C4	21	PL1	34	TI7
				36	TI8
				38	TI9

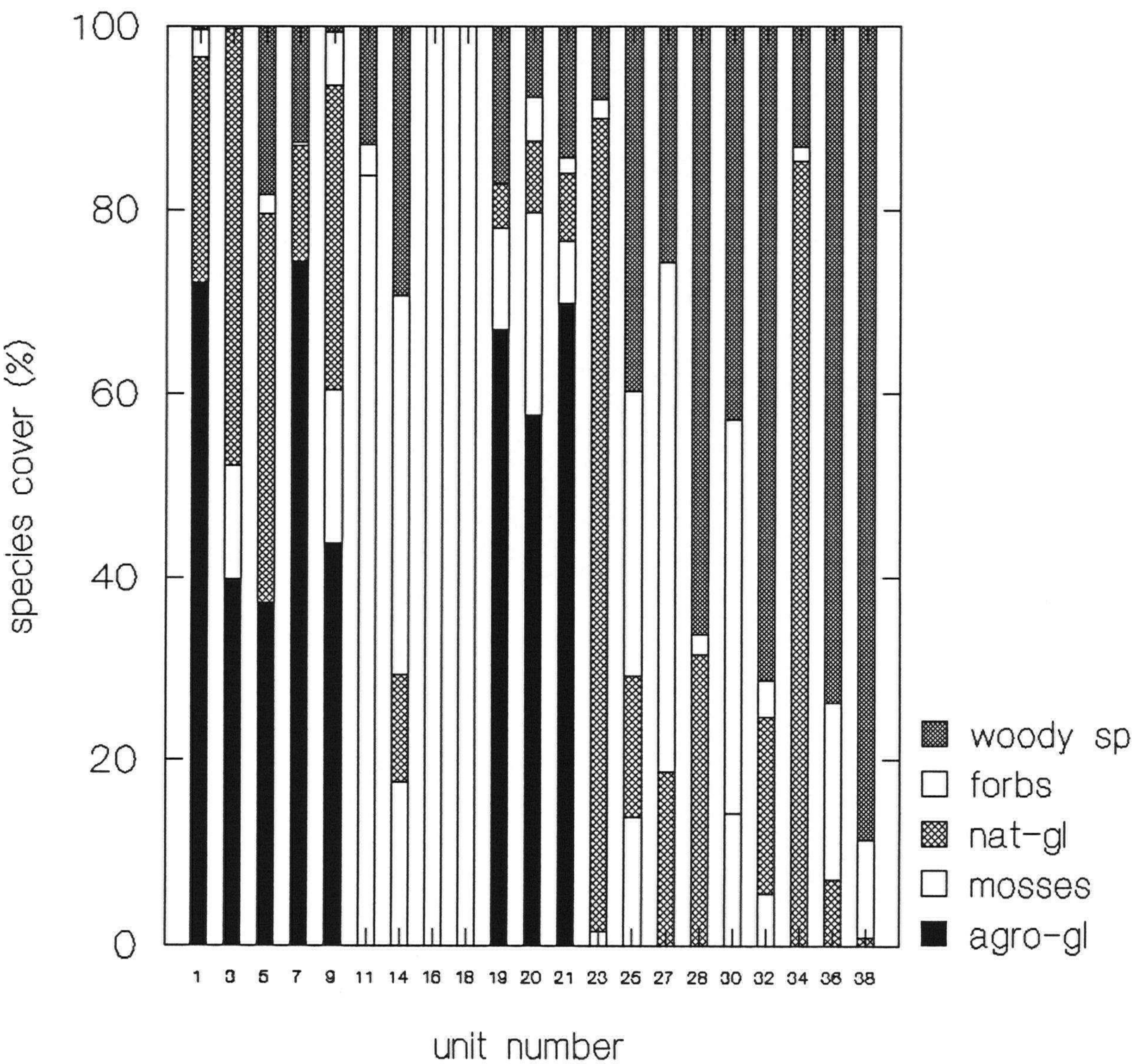


Bull River and Pinchi Lake were seeded, Bull River in 1973-75 and Pinchi Lake in 1979 but the cover is significantly higher at Pinchi Lake. The complete understorey at Cumberland is made up entirely of mosses in a Hemlock-moss association typical of the Coastal Western Hemlock zone.

Figure 4.8 shows the composition of the cover by life-form as a percentage of the total. It can be seen that the proportion of native grasses and legumes is greater at Bull River than Pinchi Lake; agronomics are dominant at Pinchi Lake and the proportion of woody species is similar. Variation in results is greater at Bull River, reflecting the variation in substrate/vegetation site units. At Pinchi Lake, the tailings material is the same, only the variation in particle size produces seasonal flooding which has reduced the cover on site unit 20 (traverse PL3).

Figure 4.8 Species cover (%) as percentage of total cover (1993)

unit number	site	unit number	site	unit number	site
1	BR1	14	CCF	23	TI1
3	BR2	16	CCG	25	TI2
5	BR3	18	CCSP	27	TI3
7	BR5			28	TI4
9	BR6	19	PL2	30	TI5
		20	PL3	32	TI6
11	C4	21	PL1	34	TI7
				36	TI8
				38	TI9



4.2 Results for individual mine-sites

4.2.1 Bull River (Figure 4.9)

Table 4.3 summarizes the description of site units at Bull River. Seed mixes are detailed in Table 2.3.

Table 4.3 Bull River: summary of site units

Site unit	Location	Material	Year and treatment	Comments
BR1	West dump	waste rock	1974 mix 1	5 plots. BR1-3,4,5 substrate sampled.
BR2	Tailings surface	stockpiled till	1972 mix 3	3 contiguous plots on level tailings. BR2-1,2,3 substrate sampled.
BR2	tailings impoundment slope	waste rock and till	1974 mix 3	2 plots (BR2-4,5) on impoundment slope 100m downslope from vegetation island.
BR3	edge of pits	waste rock	1974 mix n/a	2 plots on opposite sides of pit #2. Plot 3.3 stake relocated.
BR5	below top haul road	lightly disturbed	1974 mix n/a	4 plots along slope 50m downslope from natural vegetation
BR6	eastern dump, borrow pit	waste rock	1972,mix1 1975,mix2	3 plots on nutrient enriched and moist material.

Substrate samples were taken from BR1 and BR2. Despite the difference in provenance, substrate chemistry was very similar for the two materials. Median values were: pH 8.2, Total-N 0.08%, inorganic C 0.45% and C/N 5.8. There was no historic substrate analysis. Fines content was 65-70% with more variability in the till samples from the tailings pond.

It was observed that overall the dominant seeded species had changed from tall fescue to tall wheatgrass. Where tall wheatgrass appeared in any abundance it was dominant whereas bluegrass and clover were co-dominant. On sites BR2,3 & 6 about 50% of the cover was provided by an unidentified sod-grass with no seed heads which has been

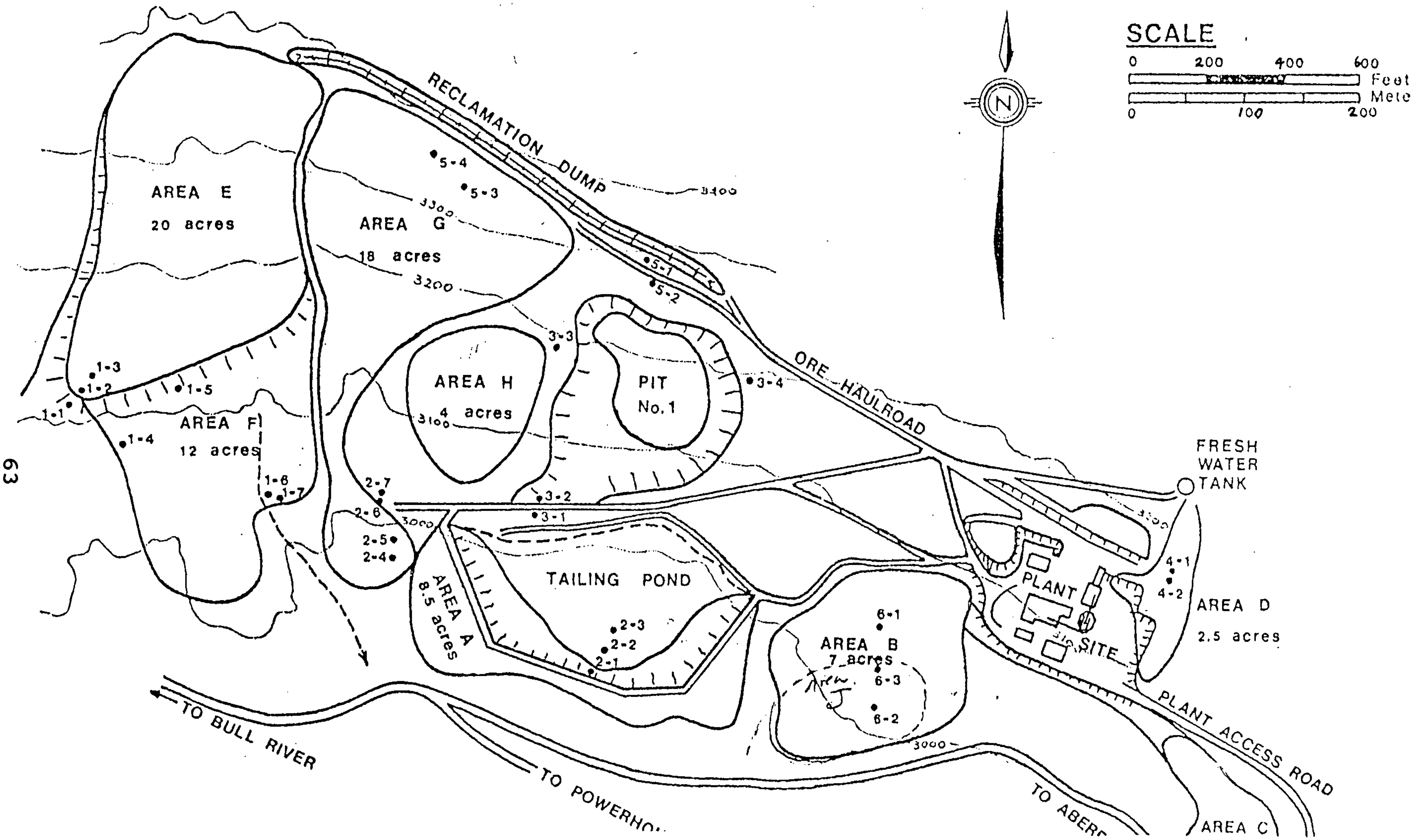


Fig. 4.9 BULL RIVER; Location of plots
(MEMPR, 1979)

arbitrarily assigned to the native grass and legume group. Sweet clover had invaded all sites but in very low numbers and although all the sites had an established grass/legume cover there was plenty of bare ground for colonisation by native species. BR3 & 5, occupying lightly disturbed ground were the only sites where significant woody species growth had occurred. Knapweed occurred on plots BR5-1 & 2, close to the northern perimeter of the mine-site.

The steep sided western waste dump areas, (BR1, pH 8.1) is very exposed and there was evidence of wind erosion during strong winds. On this site tall wheatgrass had replaced tall fescue as the most abundant species with fescue, timothy and clover also growing consistently on all sites with 45% mean total cover after 19 years. Mullein occurred on all sites and cinquefoil grew measurably on two sites (2%, 1%). No shrubs had invaded this material and the anticipated invasion by sweet clover had not materialised. Although mean cover was lowest on this site (45%), 15(9) species were represented. Native grasses and legumes had increased and wild strawberry was present on one plot.

On the tailings site (BR2, pH 8.2) where the surface material is retained till, seeded bluegrass and clover were co-dominant with the unidentified species. This was the only site where the number of species was reduced from 1977. There was evidence of mechanical disturbance and no shrubs had invaded the bare ground.

Figure 4.10 shows that, as expected, species richness was highest on the lightly disturbed areas, BR3 & 5 with 18(10) and 19(7) species respectively including several woody species (juniper, oregon grape, snowberry, saskatoon, soopalallie and wild rose). As well as having a seed bank stored in the lightly disturbed material the plots were less than 50m downslope from undisturbed vegetation on the perimeter of the mine-site. On

Figure 4.10 Bull River: number of species

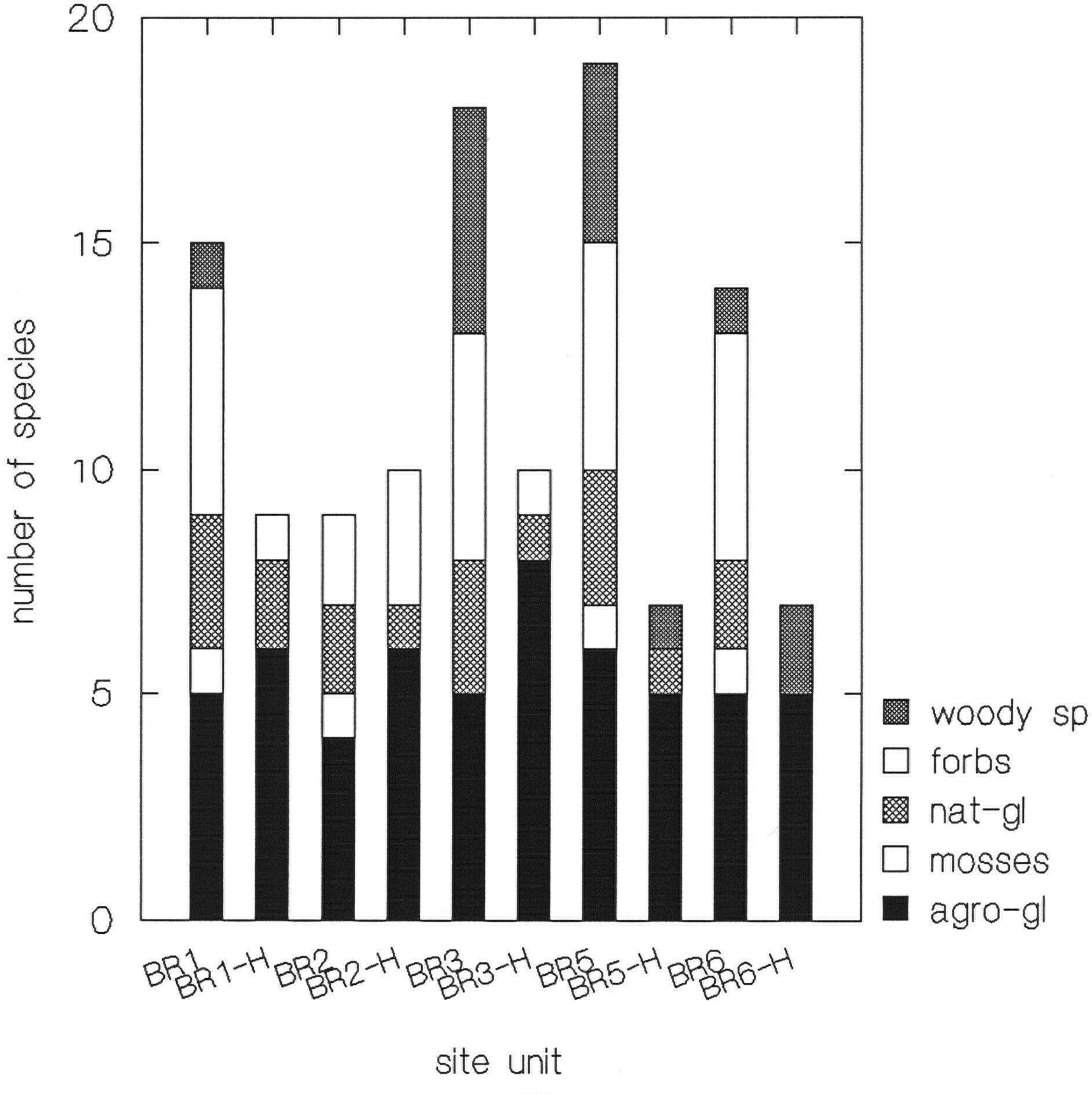
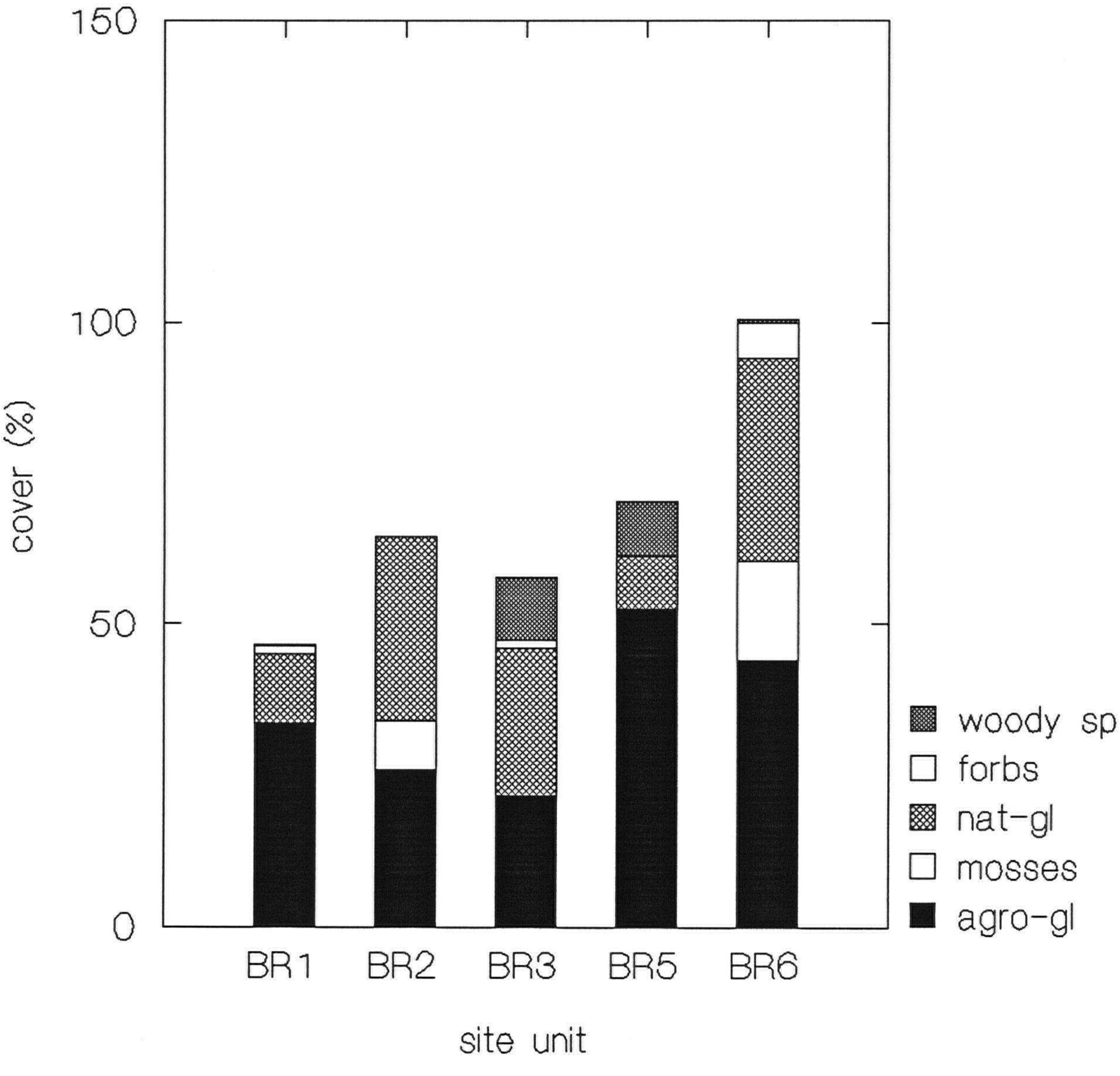


Figure 4.11 Bull River: percent cover



these site units, shrub growth was limited by browsing. Cover averaged 70% over the two sites units.

On the eastern dump area near the plant site (BR6), leakage from sewer/water lines had increased available moisture and nutrients. On all three plots cover was 100%, dominated by tall wheatgrass. The number of agronomic species remained the same (5) but total number of species had increased to 14(7). Although willow was present its contribution to cover was negligible and the cover was almost exclusively grasses whose thick sward limited further recruitment of woody species.

Table 4.4 Bull River: Species present in historical and 1993 studies

Life form	species present in previous study (MEMPR 1976-77)	species present in 1993 study
Woody species, trees and shrubs	aspen willow - - - - - - - -	- - birch cottonwood snowberry saskatoon berry soopalallie wild rose oregon grape juniper
Forbs, flowers and herbs	great mullein fireweed pearly everlasting yarrow red raspberry - - - - - -	great mullein - pearly everlasting yarrow - knapweed purple fleabane aster thistle wall lettuce ragwort
Native grasses and legumes	sweet clover - - moss	sweet clover cinquefoil vetch moss
Agronomic grasses and legumes	alsike clover dutch clover - tall fescue timothy crested wheatgrass slender wheatgrass tall wheatgrass smooth brome Canada bluegrass hard fescue redtop	alsike clover dutch clover alfalfa - timothy crested wheatgrass slender wheatgrass tall wheatgrass - Canada bluegrass hard fescue -
mosses (includes liverworts and lichens)	moss	moss

4.2.2 Coal Creek (Figure 4.12)

Table 4.5 summarizes the site units studied at Coal Creek in 1977 and repeated in 1993.

Table 4.5 Coal Creek: summary of site units

SITE UNIT	LOCATION	MATERIAL	COMMENTS
CCF, Forested	At base of slope. N side of creek 0+800m	base of old waste dump	3 plots. 100% cover of woody species (cottonwood, snowberry) with understorey of forbs and native grasses.
CCG, Grassland	On raised bank of railway 0+875m	combustion waste	3 contiguous plots. 100% cover of snowberry, forbs and native grasses.
CCSP, Settling pond	Second of four ponds 0+100m	fine coal	3 plots. 60% cover of shallow rooting weedy species and native grasses.

Substrate samples were repeated on all sites. Local coordinates are taken from the location map and are expressed as distance in metres east of the bridge.

CCF is a "forested" site, the remains of a run-of-mine waste dump constructed before 1943 but which since then has been largely removed for fill and levelled. The number of years since recent disturbance is unknown for this site (Diamond, 1993). This site could not be located exactly from the 1977 photographs since some trees had been felled, probably by campers. In 1977 the site had vigorous growth of aspen, cottonwood, sweet clover, red fescue and timothy. By 1993 the dominant tree species was cottonwood (up to 25m; dbh 37cm) although aspen and Douglas fir individuals were present less than 50m away. It was not possible to get an age from the poplar by coring but a Douglas fir growing on the side slope gave an age of 23 years. Snowberry, not encountered in 1977, was the dominant shrub in 1993. The main grasses present were bluegrass and wild rye. Substrate pH was 6.7 and the historical value of pH (given in parentheses) was (7.6) and

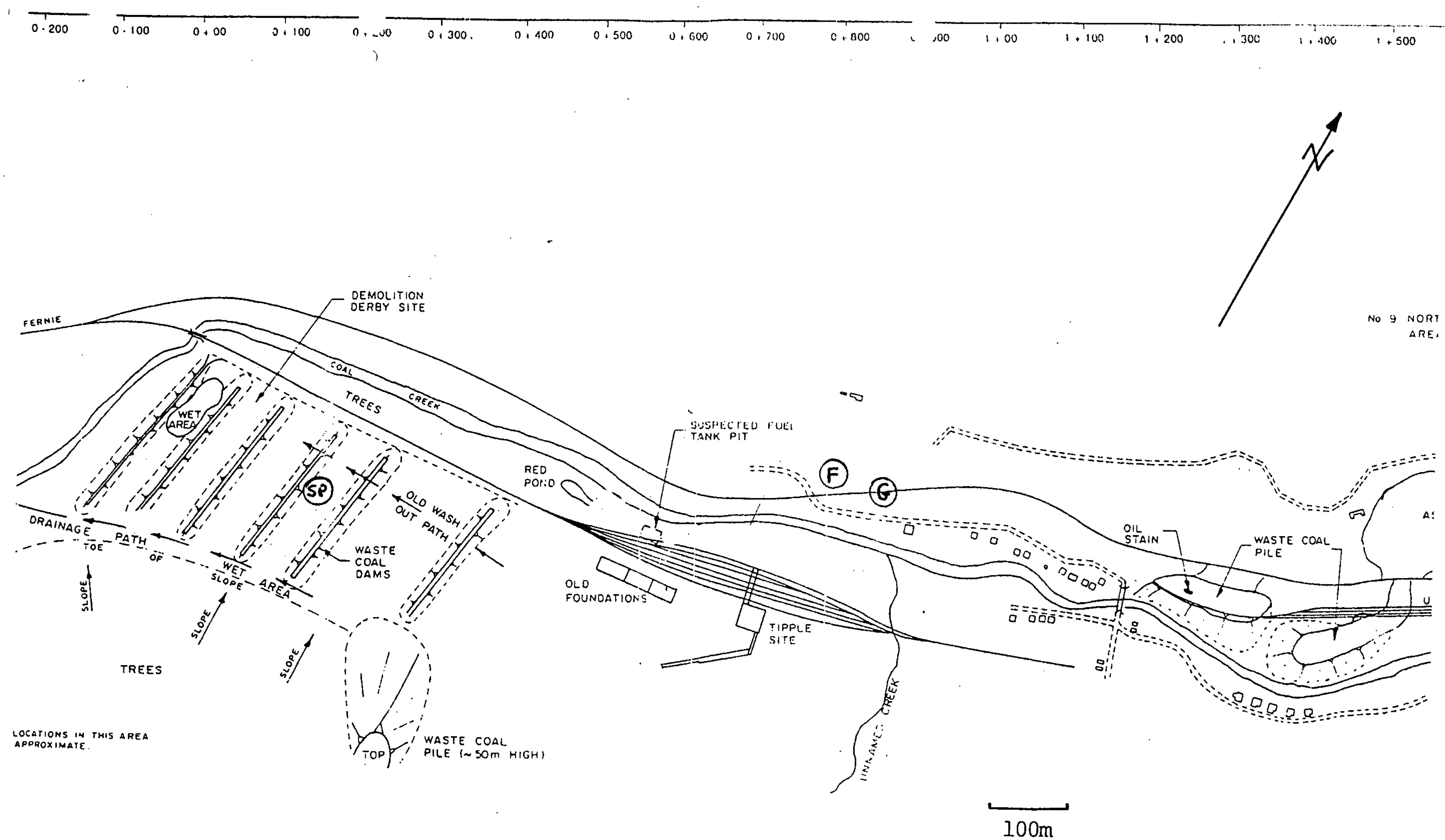


Fig. 4.12 COAL CREEK; Location of plots
(courtesy of Shell Canada Ltd.)

nutrient cycling was occurring. There had been no apparent change in the soil N content. The organic C content was 4% and the N content was 0.75% giving a median C/N ratio of 7.5. Soil structure was being improved by the presence of earthworms. The fines content was 70%.

CCG is an elevated "grassland" embankment used by the Coal Creek Colliery railway. At surface, the material consists largely of ash, probably a product of the steam generating plant. The colliery closed in 1943. In 1977 the plant cover was limited to more drought resistant weedy herb species and grasses. Bull thistle, bladder campion, sweet clover, fireweed and rabbit brush were common herbs and red top and fescue were dominant grasses. Problems of water stress were evident. In 1993 there was 100% cover and both aspen and cottonwood were established. The dominant shrub was snowberry with lesser saskatoon, Douglas maple and choke cherry. The main weedy herbs were fringed sage, fireweed, bull thistle and vetch. Dominant grasses were timothy, bluegrass and wild rye. This site had the largest species richness of all the five mine-sites in 1993 with 21(6) species occurring on the three contiguous plots. The pH was 6.1(6.6) and N content was reduced to a median value of 0.8%(1.15%). Organic C content was 6% giving a median C/N ratio of 6.5. Fines content was 80%. Earthworms were also present at this site.

Site unit CCSP is located on the second settling pond containing fine coal waste material from the Elk River Colliery washing plant. Although this site was re-sampled, it had not remained undisturbed, having been used for moto-cross and was not used for comparison purposes. N content was 1.0%(0.75%), Organic C content was 7.5% giving a median C/N ratio of 5.5. The fines content was almost 100%.

Figure 4.13 Coal Creek: number of species

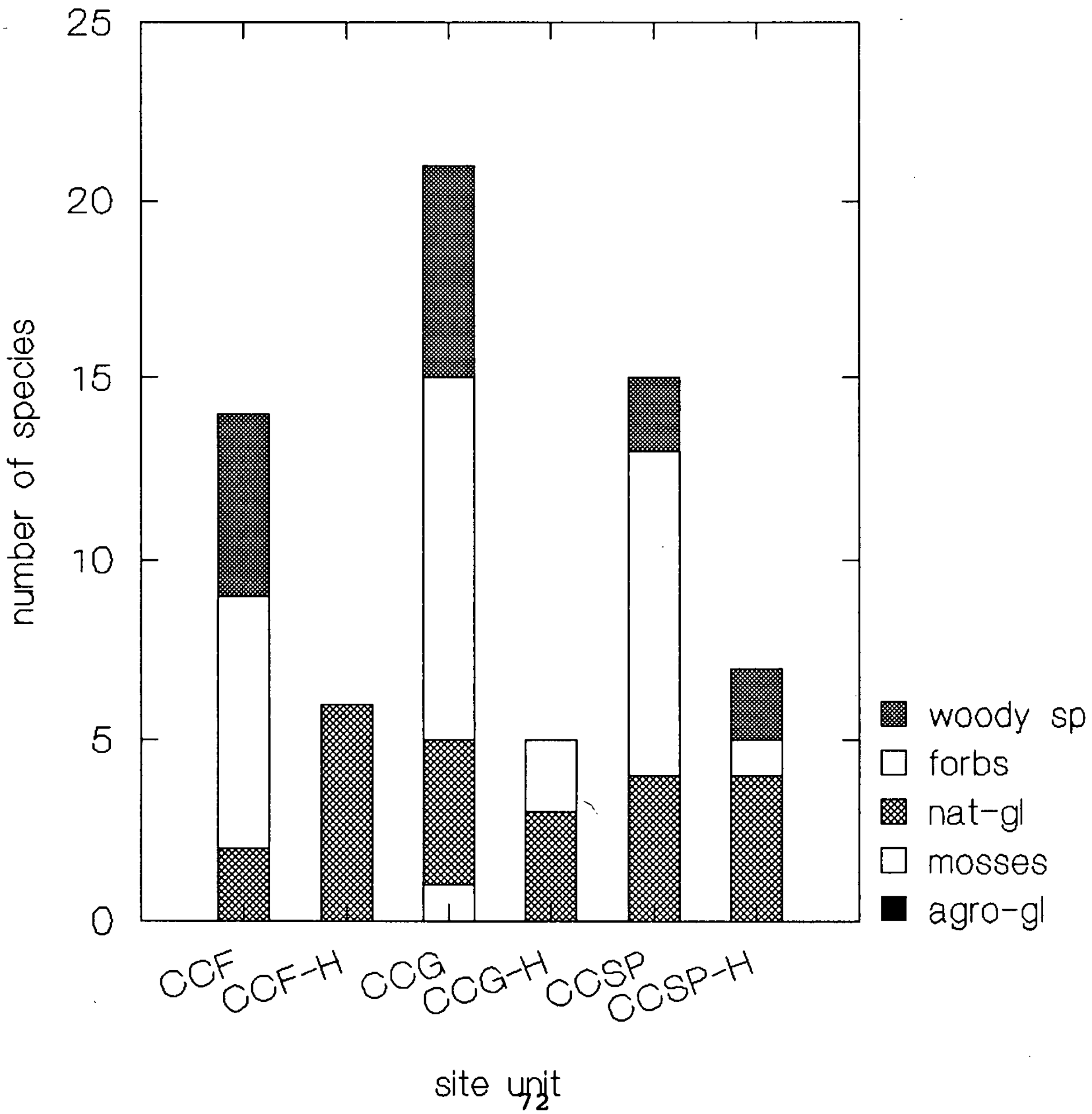


Table 4.6 Coal Creek: Species present in historical and 1993 studies

Life form	species present in previous study (Como *et al* 1977)	species present in 1993 study
Woody species, trees and shrubs	red osier dogwood	-
	white spruce	-
	aspen	aspen
	cottonwood	cottonwood
	lodgepole pine	-
	Douglas maple	Douglas maple
	saskatoon	saskatoon
	-	black choke cherry
	-	snowberry
Forbs, flowers and herbs	rabbit brush	-
	absinthium	fringed sage?
	shepherd's purse	-
	lambsquarter	lambsquarter
	small-flowered	-
	willowherb	-
	horsetail	horsetail
	ox-eye daisy	ox-eye daisy
	peppergrass	-
	butter and eggs	-
	plantain	-
	butterweed groundsel	-
	sow thistle	thistle
	dandelion	dandelion
	stinkweed	-
	yarrow	yarrow
	rockcress	-
	fireweed	fireweed
	heliopsis	-
	common mullein	mullein
	silverleaf phacelia	-
	bladder campion	-
	-	buttercup
	-	burdock
	-	arrow leafed balsam
	-	root
	-	aster
		strawberry
grasses and legumes	vetch	vetch
	yellow clover	golden clover
	dutch clover	dutch clover
	fan-leaf cinquefoil	-
	cinquefoil	cinquefoil
	sweet clover	sweet clover
	timothy	timothy
	red fescue	fescue sp.
	redtop	redtop
	bentgrass	-
	foxtail	-
	Canada bluegrass	Canada bluegrass
	-	blue wild rye grass
	-	Wheeler's bluegrass
mosses (including liverworts and lichens)	moss	moss

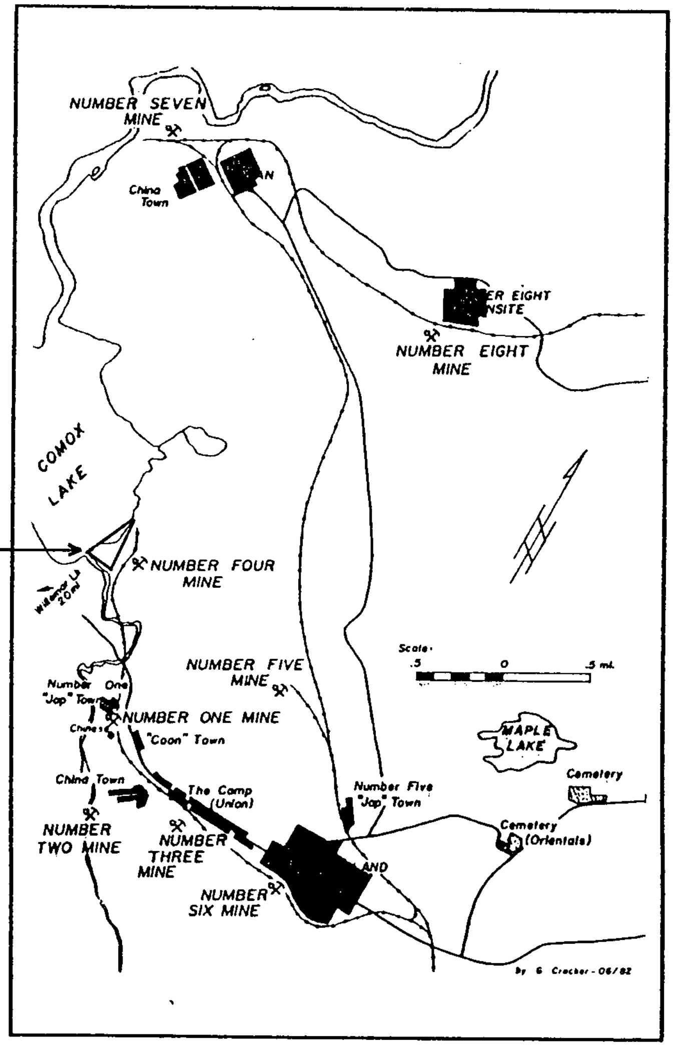
4.2.3 Cumberland No. 4 mine (Figure 4.14)

The 1973 study of 17 contiguous 4x4m transects was relocated to within 50m and was repeated using five 5mx5m plots spread out over the same distance (68m). The east end of the traverse is at the road at 350710E, 5499230N (NAD 1923). Any changes in vegetation were expected to be small since the vegetation was already well established in 1973 with one hemlock dating from 1928 (Errington, 1973).

Light decreases away from the road and the last plot was illuminated only by light from the canopy above (80% closure). Soils were well drained and dark coloured with a significant proportion of coal fragments. The pH was 5 (n=3). In 1993 there had been no change in the predominantly hemlock canopy noted previously but total ground cover, which had been as low as 36% in 1973, was 100%, except for the occasional footpath, the increase in cover being from mosses. Twinflower and huckleberry were still the co-dominant shrubs but their abundance decreased away from the road and on the last plot salal was dominant, followed by oregon grape. Rattlesnake plantain and wall lettuce (tall blue lettuce?) were still the dominant herbs. Although cover had increased significantly there was an apparent marked decrease in the species richness along the traverse. Part of this is the result of the species for No. 4 and 5 mines being combined in the previous survey and a large part of the decrease in the mosses life-form group is because the present author could identify few mosses.

Fines content was 78%, slightly higher than the forested site at Coal Creek and the median C/N ratio was 10 with 5.5% organic C and 0.55% N.

Cumberland No. 4
mine dump area.



The mines and towns of the Comox Valley Lynne Bowen "Boss Whistle"

Fig. 4.14 Location of study site
(Courtesy of Cumberland Museum)

Figure 4.15 Cumberland No. 4: number of species

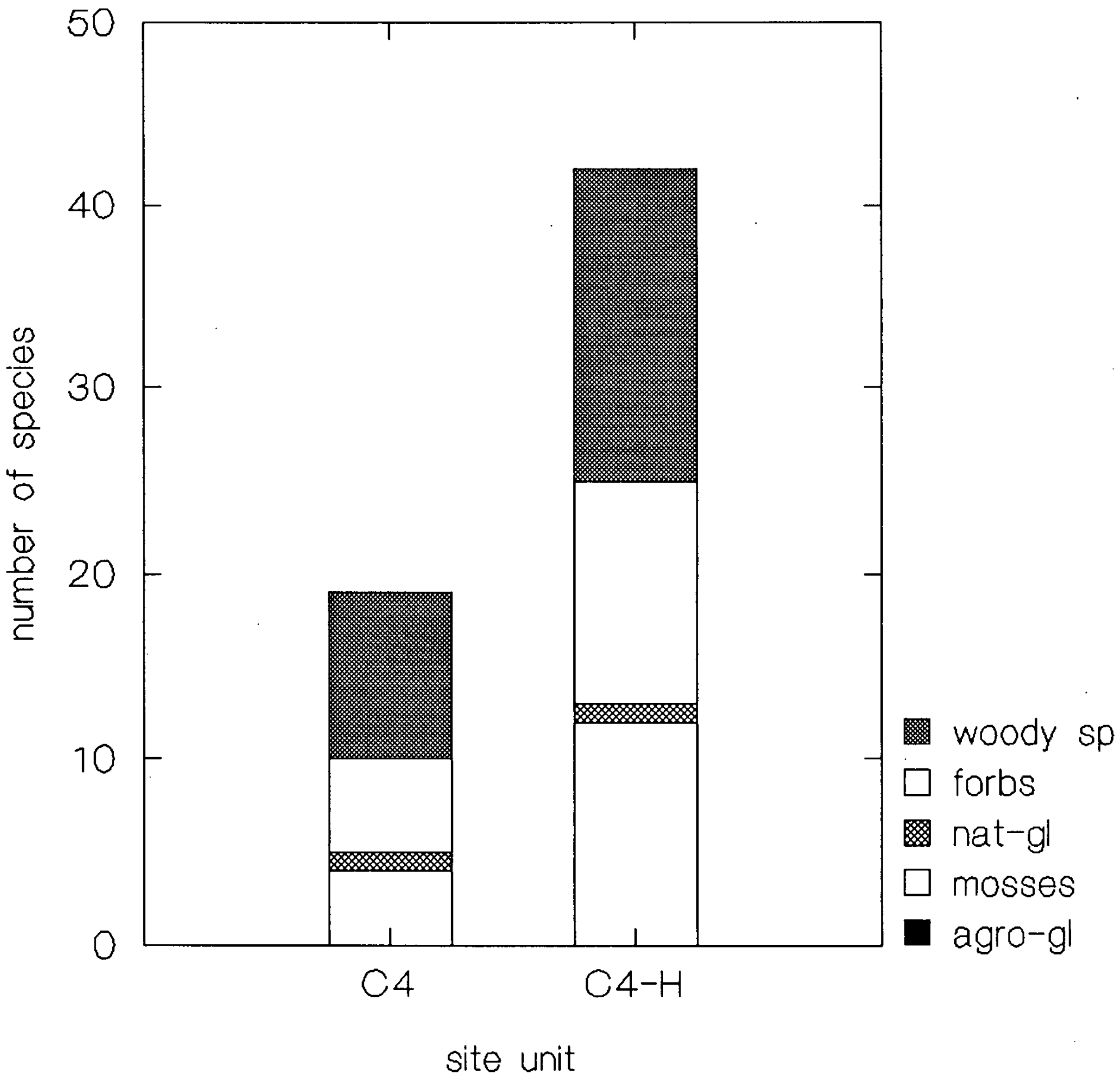


Figure 4.16 Cumberland No. 4: percent cover

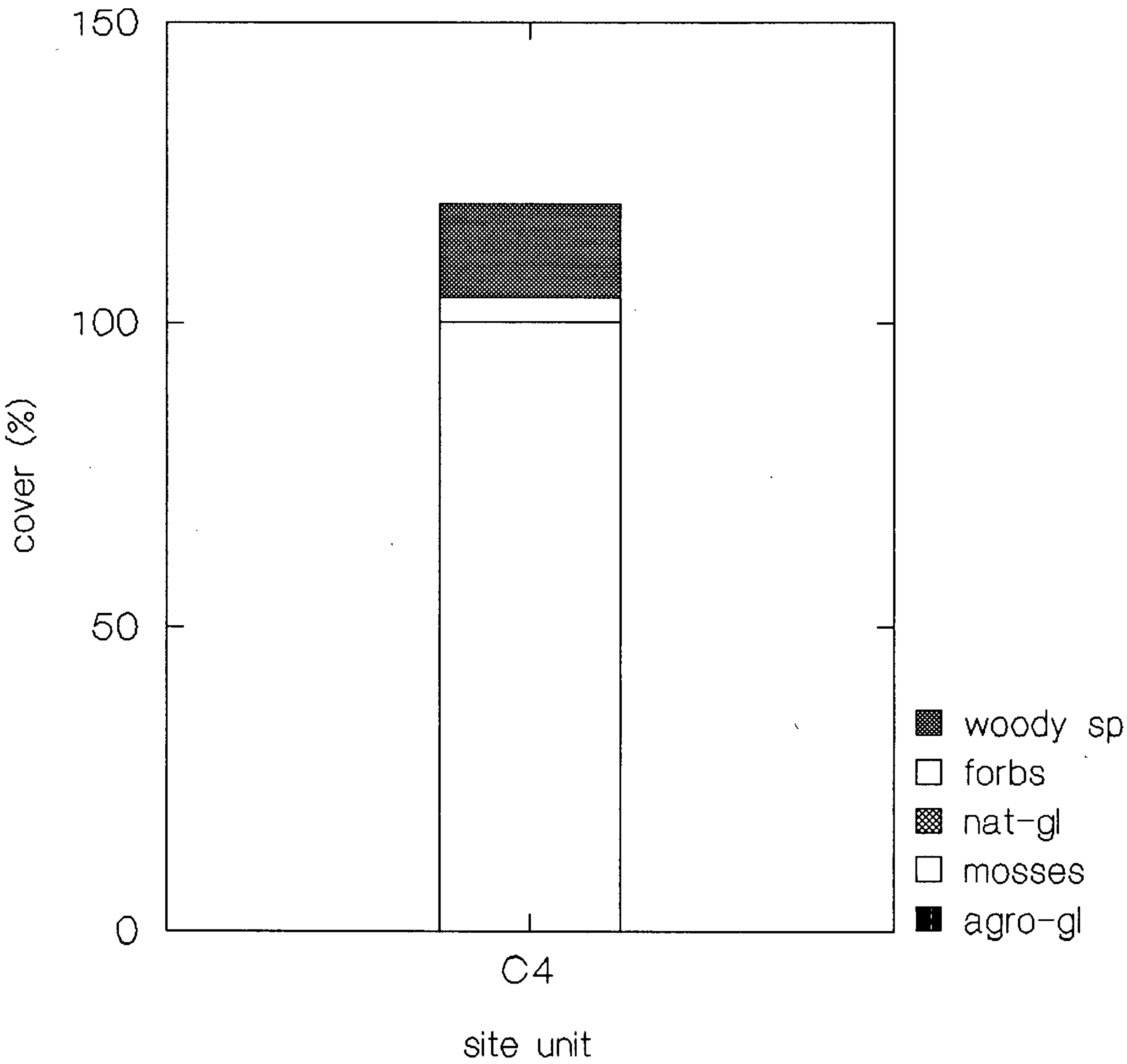


Table 4.7 Cumberland No. 4: Species present in historical and 1993 studies

Life form	species present in previous study (Errington, 1975)	species present in 1993 study
Woody species, trees and shrubs	-	grand fir
	red alder	red alder
	flowering dogwood	-
	sitka spruce	-
	monticola pine	monticola pine
	aspen	-
	cottonwood	-
	Douglas fir	-
	mountain ash	-
	red cedar	red cedar
	hemlock	hemlock
	saskatoon	-
	kinnikinnik	-
	salal	salal
	oregon grape	oregon grape
	stinkcurrant	-
	trailing blackberry	trailing blackberry
	huckleberry	huckleberry
Forbs, flowers and herbs	vanillaleaf	vanillaleaf
	sedge	-
	fireweed	-
	rattle-snake plantain	rattle-snake plantain
	lactuca biennis	-
	-	wall-lettuce
	wintergreen	-
	clasping twistedstalk	-
	trillium	-
	dock	-
	bracken	bracken
	sword fern	sword fern
	deer fern	-
Grasses and legumes	gramineae	fescue sp.
mosses (including liverworts, lichens)	Dichranum fuscescens	-
	Eurhynchium oreganum	Eurhynchium oreganum
	Hylocomium splendens	Hylocomium splendens
	Leucolepis menziesii	-
	Mnium spinulosum	-
	Plagiothecum undulatum	-
	Pohlia nutans	-
	Polytrichum juniperum	-
	Rhacomitrium canescens	-
	Rhizomnium glabrescens	-
	Rhytidiadelphus loreus	-
	Rhytidiadelphus triquetrus	Rhytidiadelphus triquetrus
	-	moss

4.2.4 Pinchi Lake mine

The location of the traverses on the tailings pond is shown in Figure 4.17 and is summarized in Table 4.8.

Table 4.8 Pinchi Lake: summary of site plot traverses.

SITE UNIT	LOCATION	COMMENTS
PL2	N330 line along east flank of west pond.	6 plots 50m apart from wet S end to dry N end.
PL3	N30 line along west flank of east pond	7 plots 50m apart from wet S end to the tailings research test plot area.
PL1	N110 across dry section of surface.	8 plots 50m apart repeating the 1978 traverse of 6 plots across the pond.

The 1978 MEMPR survey took place in summer after spring seeding. A northeasterly transect of 6 plots was sampled across the pond from the edge of the wet area in the SW corner to the drier area of coarse material at the tailings inflow. Legumes had established poorly and native alkali grasses grew vigorously in all plots initially, before seeded grasses could become established (BCMEMPR, 1978). Seeded grasses required maintenance fertiliser in 1979 to maintain vigour (Gardiner, 1980). When the maintenance fertiliser was discontinued after 1979, grasses died back allowing legumes to spread. Native woody species including cottonwood and willow grew on the inside and outside slopes of the impoundment dykes and two permanent areas of open water occupying about 4ha had formed (Gardiner et al., 1981). In 1977 the assessment by the Cominco agrologist of the presence of invading native species on the tailings pond noted cottonwood, aspen, willow and water birch as representing woody species and ticklegrass, bluegrass, fireweed, sedge, horsetail, alsike clover and red clover.

By 1993 the vegetative cover was 100% on all the dry sections of the tailings impoundment. Two permanent ponds were established, one on either side of the pond

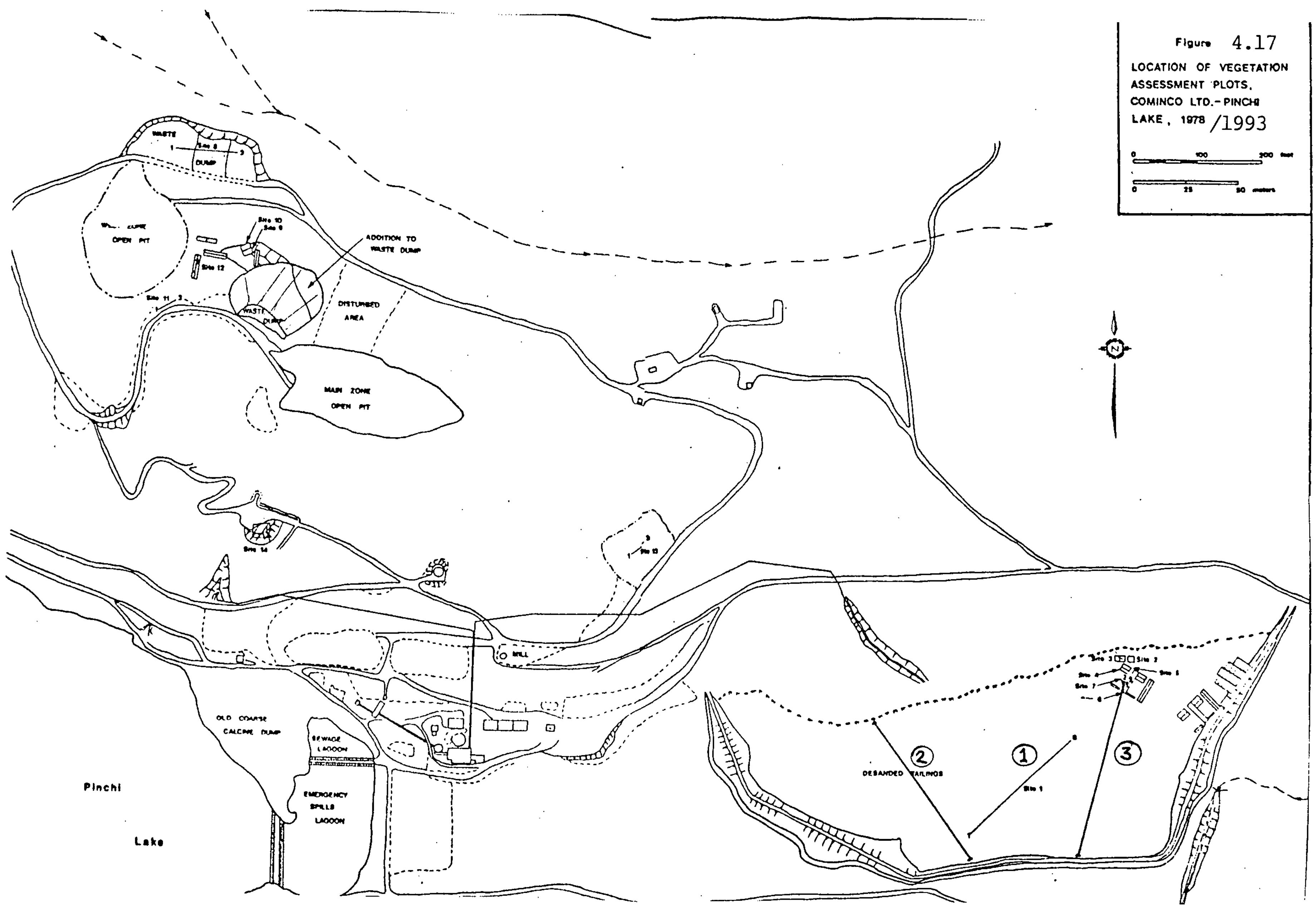


Figure 4.17
LOCATION OF VEGETATION ASSESSMENT PLOTS, COMINCO LTD.-PINCHI LAKE, 1978 /1993
0 100 200 feet
0 25 50 meters
WASTE DUMP
OPEN PIT
ADDITION TO WASTE DUMP
Site 12
WASTE DUMP
DISTURBED AREA
MAIN ZONE OPEN PIT
Site 14
MILL
OLD COARSE CALCINE DUMP
SEWAGE LAGOON
EMERGENCY SPILLS LAGOON
Pinchi
Lake
DESANDED TAILINGS
Site 1

reflecting the low gradient away from the tailings inlet point. A beaver lodge had been established on the western pond and was occupied in 1993. On the impoundment dykes constructed of waste rock, alfalfa was dominant, however on the pond, alsike clover and fescue were co-dominant and in 5 out of 6 plots on PL1 comprised at least 80% of cover. In the other plot (PL1-0) bluegrass and foxtail barley constituted 50% of the cover. Alfalfa occurred on all sites but was only measurable in the two plots with coarser, drier tailings material. Alkali grass was confined to the south and east edges of the pond where fine particle size creates seasonally inundated patches. Foxtail barley occurred mainly in wet patches on the perimeter of the pond but also occurred in pure stands in low lying areas elsewhere.

Figure 4.18 shows that the number of species along profile PL1 was 15(11) with the increase mainly due to deciduous woody species which provide more habitat and winter browse than forbs or grasses. In Figure 4.19 the lower overall percentage cover for traverse PL3 reflects the scant cover on the two quadrats at the south end of the profile where the surface is seasonally inundated as shown in figure 4.20.

Willow was the dominant shrub in the wet areas on the perimeter and was browsed by deer. Cottonwood, also browsed at the perimeter of the pond, occurred frequently all over the pond while birch, aspen and spruce individuals occurred mainly in the north-east corner. Moose were seen on the N side of the pond but there was no evidence that large wildlife were crossing the tailings pond. Although alder occurred elsewhere on the mine-site they did not occur in natural vegetation around the pond and so N-fixing species was limited to alsike clover.

In the reclamation research test plots, lodgepole pine and spruce planted as 1-0 seedlings in 1972 and fertilised, had attained 6m in height, while Douglas fir had perished.

Figure 4.18 Pinchi Lake: number of species

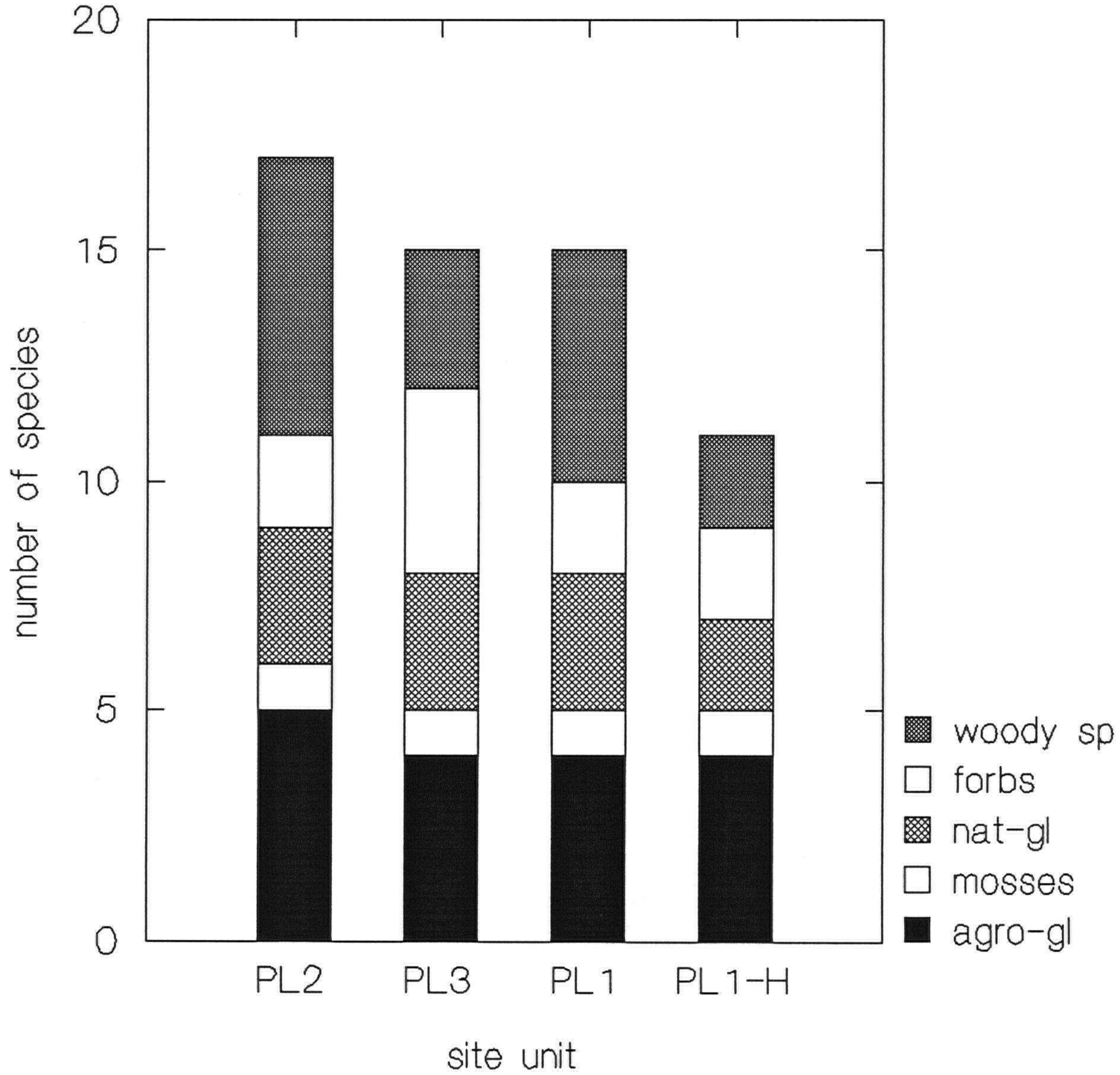


Figure 4.19 Pinchi Lake: percent cover

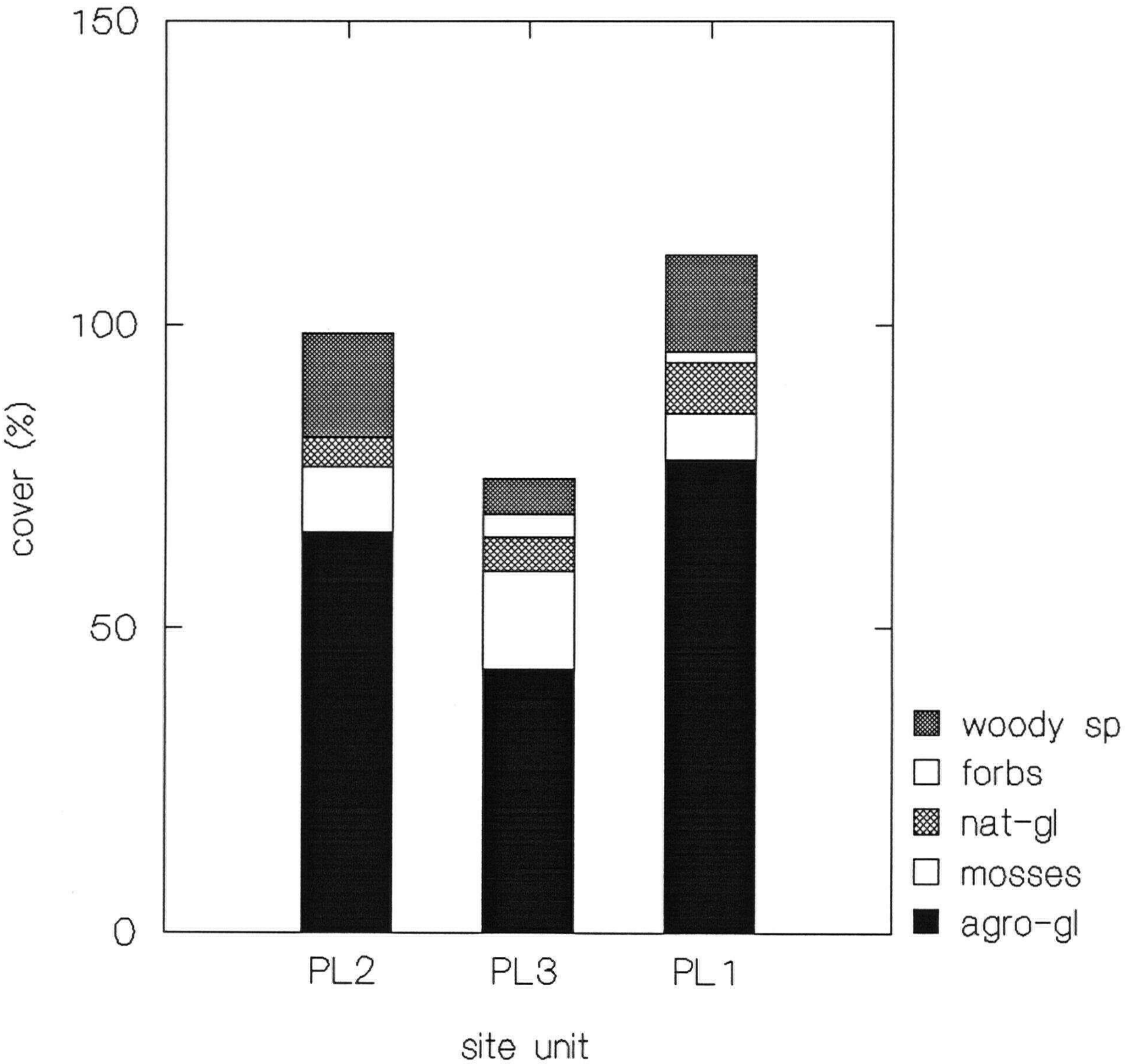
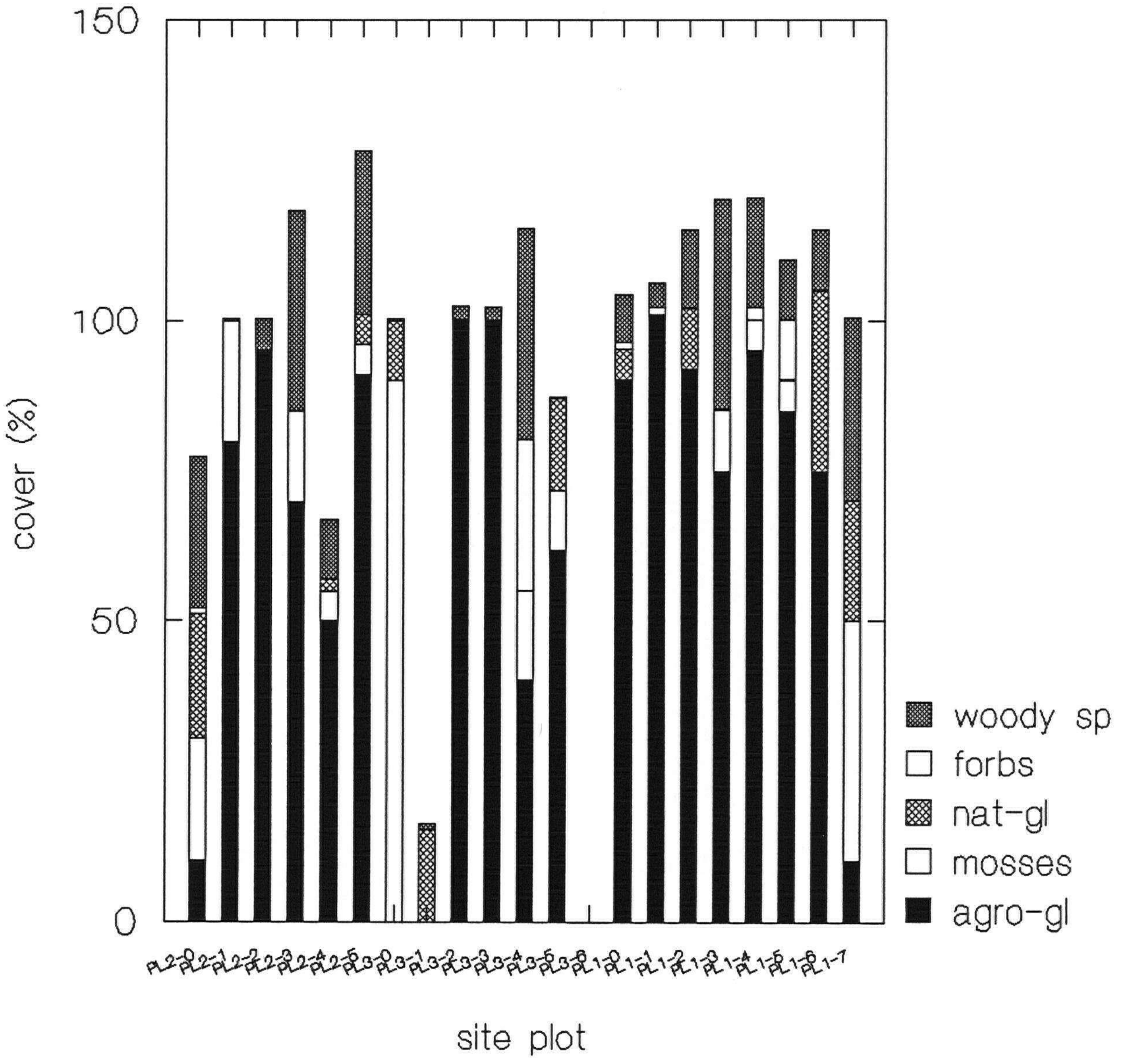


Figure 4.20 Pinchi Lake: percent cover for all plots on all traverses



Of the 300 lodgepole pine seedlings planted at the entrance to the pond in 1972, only a few stunted individuals survived. The tailings were alkaline (pH=8, n=25) as was the pond water (pH=8.6). Slightly higher values of N and organic C content consistently occur in wet areas where particle size is reduced, there was minimal vegetation and the ground is subject to seasonal flooding. The median N content for PL2,3 and 1 is 0.03% and the median organic C content is 0.31% for PL2 and 3 and 0.16% for PL1. These low values for N content make the ratio invalid.

The values given by Gardiner for raw tailings at Pinchi Lake were 0.5% organic matter which is equivalent to 0.35% organic C (determined colorimetrically by partial oxidation of organic matter with dichromate and sulphuric acid under specific conditions) and 2ppm NO_3^--N (determined colorimetrically using Brucine). The organic C determination is similar to the Walkley-Black technique used in 1993 but unless the oxidation conditions are known exactly it is unwise to compare them directly. Similarly the Brucine method extracted "active" N and was a much less aggressive attack than the Kjeldahl digestion which extracts all the N. This illustrates the problem in long-term studies of non-standardized analytical techniques.

Although a trend in substrate condition cannot be established without historic data using the same analytical procedure; nevertheless the presence of nutrient capital has been established and there is ample evidence from soil pits of nutrient cycling from the leaching of humus from the organic layer down into the rooting zone.

Table 4.9 Pinchi Lake: Species present in historical and 1993 studies

Life form	species present in previous study (MEMPR 1979)	species present in 1993 study
Woody species, trees and shrubs	cottonwood - - - - -	cottonwood willow white spruce birch aspen soopalallie
Forbs, flowers and herbs	horsetail broadleaved willowherb lambsquarters strawberry - - -	horsetail - - strawberry dandelion cat-tail sedge sp.
Native grasses and legumes	foxtail barley Nuttall's alkali grass weeping alkali grass -	foxtail barley Nuttall's alkali grass weeping alkali grass sweet clover?
Agronomic grasses and legumes	alfalfa alsike clover redtop creeping red fescue -	alfalfa alsike clover redtop creeping red fescue Canada bluegrass
mosses (including liverworts, lichens)	moss	moss

4.2.5 Texada Iron mines (Figure 4.21)

Figure 4.22 shows that in general terms the indicated number of species was less in 1993 than previously. However, where this was most notable on sites TI4 and TI5, the main decrease in species numbers was in the forbs group. The species missing in 1993 are shown in Table 4.11; they are mostly short-lived flowers and they may have been missing or unidentified because of lack of bloom later in the growing season. This table also shows that the number of woody species and native grasses has increased. There are no legumes present on the site and the only N fixing species is alder. Vegetation was still sparse, being mainly Douglas fir on dry exposed sites and alder at the bottom of dump slopes where moisture retention was better. However, there were abundant Douglas fir and alder mature seed trees present over the mine-site. The most common shrub species on the barren dumps were trailing blackberry and oceanspray and the dominant grass species on compacted dump material was poverty oatgrass. There was considerable wind erosion from the barren rock dumps caused by westerly on-shore winds which produced a fine white dust. The importance of micro-climate was shown by tiny Douglas fir seedlings growing in the shelter of small rocks where fines and moisture had accumulated.

The majority of the anomaly A, Prescott, Yellow Kid and Lake dump areas were inactive in 1993. Only the area to the east of the Paxton pit was being actively used for a screening unit processing limestone from a small quarry east of the Paxton pit. However, various sites were also in use for storage of both rock and equipment. Future changes in both contract and scheduling priorities for the quarry operation will mean that other areas become temporarily active as requirements for a particular waste product or storage space arise.

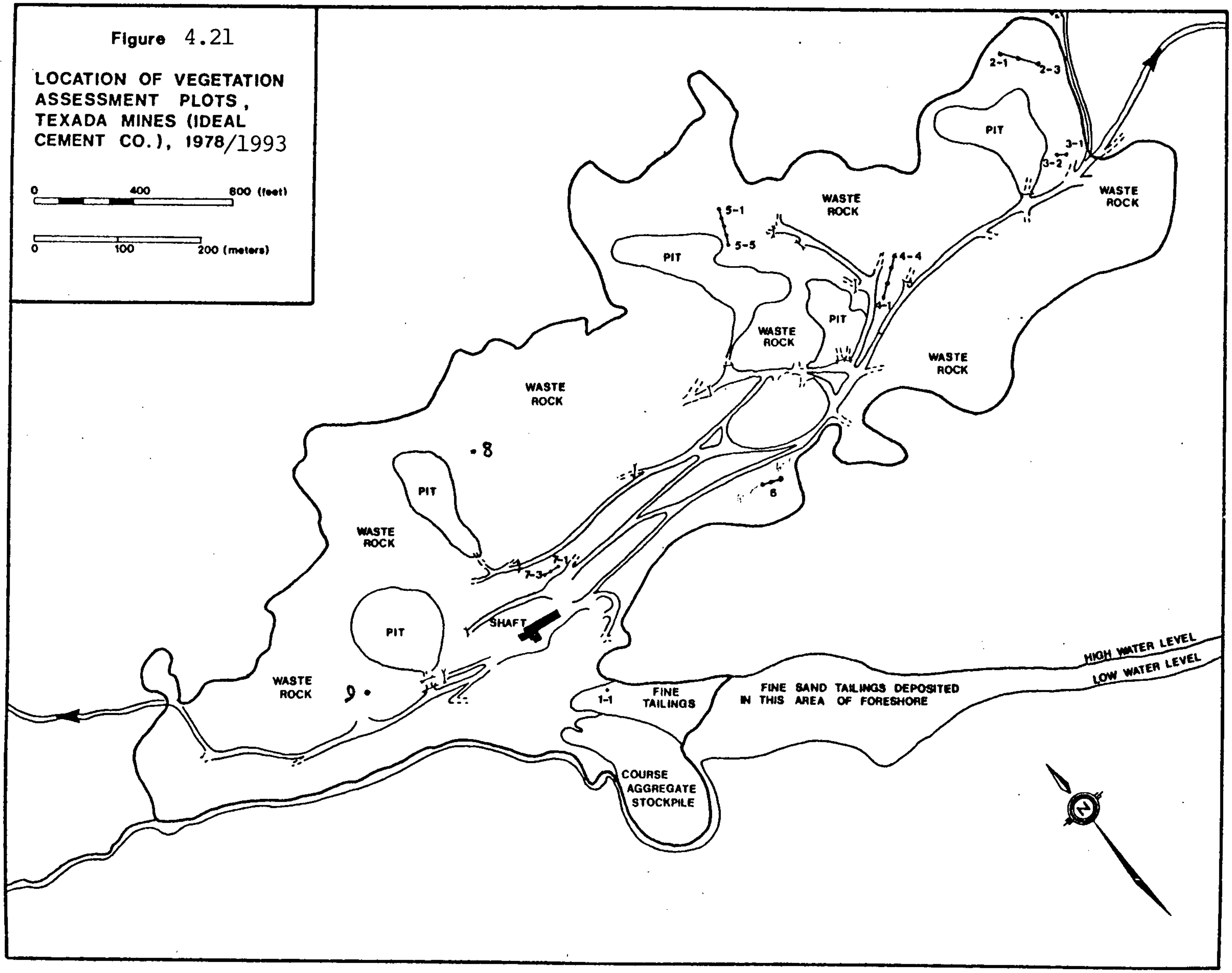


Figure 4.21

LOCATION OF VEGETATION ASSESSMENT PLOTS, TEXADA MINES (IDEAL CEMENT CO.), 1978/1993

Two previous surveys have made substrate/vegetation studies; a 1976 UBC Soil Science Department study (Lavkulich et al., 1976) focussed on characterization of the spoil materials and a 1978 MEMPR study (MEMPR, 1978a) established vegetation assessment plots on 7 substrate/vegetation units. The 1993 work located the marker stakes from 5 out of 7 of the 1978 sites and 2 more substrate/vegetation units were added; TI8 which corresponds as closely as possible with the Upper Yellow Kid Dump sampling point established by the UBC study and TI9 which is on a haul road occupying one of the Prescott dump benches on the exposed southwest facing slope to the west of the Prescott pit.

Table 4.10 Texada Iron: summary of site units

SITE UNIT	LOCATION	MATERIAL	ASPECT	COMMENTS
TI1	tailings beach	mine tailings	SW	1 plot at edge of tailings beach near break of slope.
TI2	bench on E Lake dump	volcanic waste	E	5 plots across dump bench used as haul road. Substrate sampled
TI3	base of S Lake dump	till	SE	2 contiguous plots on till sloughed from natural slope. Original site has been covered.
TI4	S Paxton dump slope	till covering	S	3 contiguous plots on dump covered with till.
TI5	East side of N Paxton pit	crystalline limestone	S	1 plot at edge of haulage road. Substrate sampled
TI6	Lower YK dump, below mine access road.	volcanic & igneous	SE	3 contiguous plots on flat topped dump of unconsolidated material. Substrate sampled.
TI7	middle YK dump	fine material, skarn	SE	3 contiguous plots along dump slope near mine office
TI8	upper YK dump bench	limestone, skarn	S	4 contiguous plots on third unconsolidated dump bench. Substrate sampled
TI9	W. Prescott dump	skarn	SW	1 plot at edge of haul road.

On site TI1 the previous plot could not be located and it was established according to the location map (BCMEMPR, 1979). In fact only a small portion of the tailings beach remains exposed, the rest having been covered with limestone and used as a stockpiling area. The tailings contain a high proportion of iron in the form of visible pyrite, which when oxidized from Fe^{2+} to Fe^{3+} in the presence of water, air and the bacteria belonging to the Thiobacillus genera releases H^+ to lower the pH, resulting in a more hostile environment for vegetation.

Site TI2 is a mixture of andesitic volcanics and limestone forming the flat surface of the NE Lake dump at the eastern edge of the mine-site. Plots TI2-1,2,3 are on the west side of the compacted haul road and TI2-4,5 are on the east side. A Douglas fir on plot TI2-1 was 14cm dbh and 6m tall. Plant coverage was patchy, averaging 45% with coverage fairly evenly divided among the five life-forms present and the plants are yellowish (Figure 4.23). Median pH was 8.2(8.0), N content was 0.03% and organic C content was 0.3% resulting rather fortuitously in a median C/N ratio of 12. The most common plant was trailing blackberry followed by black raspberry and fescue was the most common grass. The number of woody species had increased significantly to 10(6) with a similar number of forbs being absent in 1993. Alder was growing on the dump slope below the dump top but no alder was growing on the compacted dump top.

Site unit TI3 was not on the same material as in 1977 and so was not used in any comparison.

Site TI4 had a high percentage of cover (80%) with a 33cm dbh Douglas fir providing 40% of the cover on one plot and yorkshire fog, wild strawberry and trailing raspberry providing the next most common species. The core taken from the Douglas fir dated the tree at 17-18 years. There was no significant change in number of woody species

Figure 4.22 Texada Iron Mine: number of species

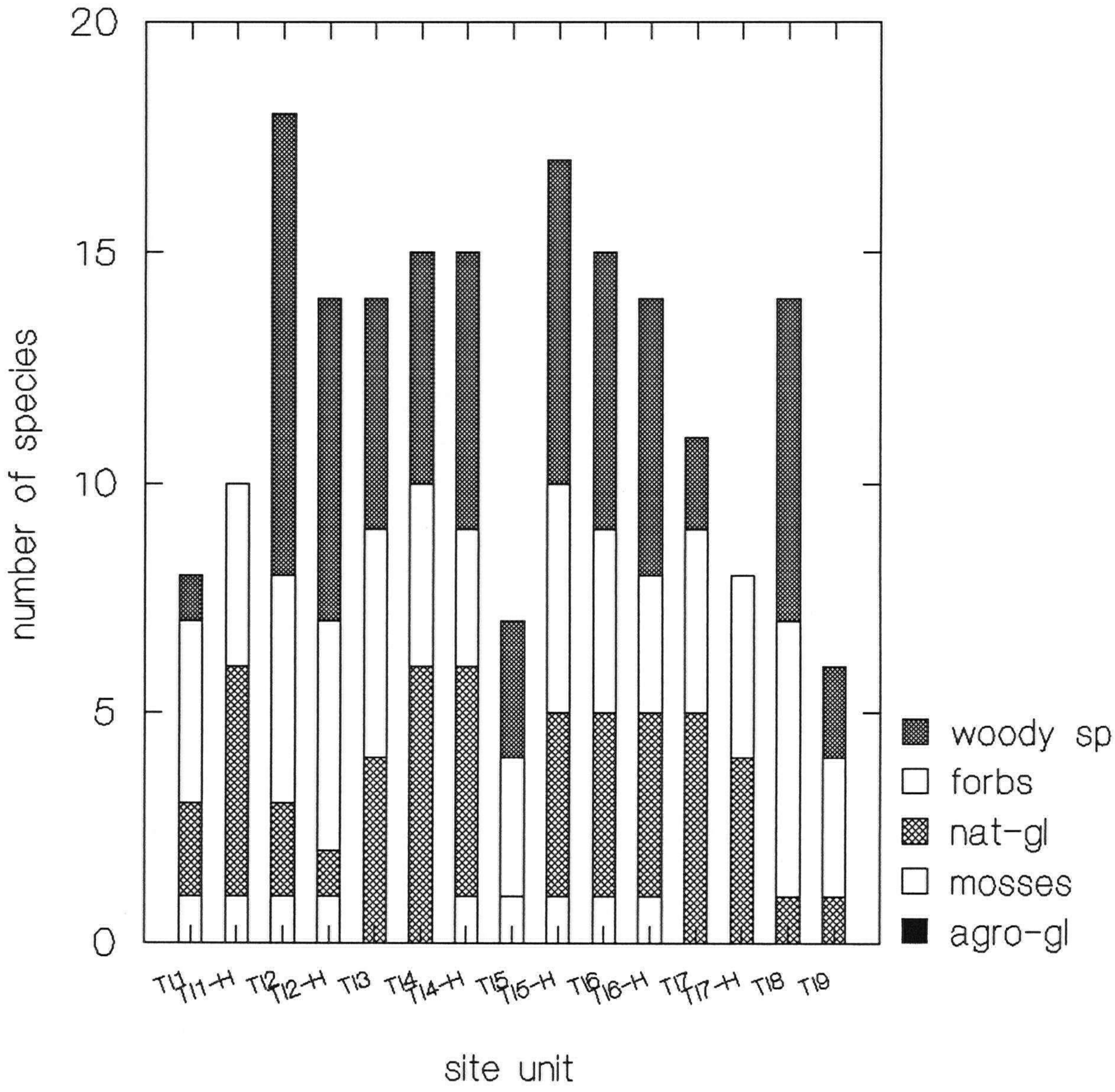
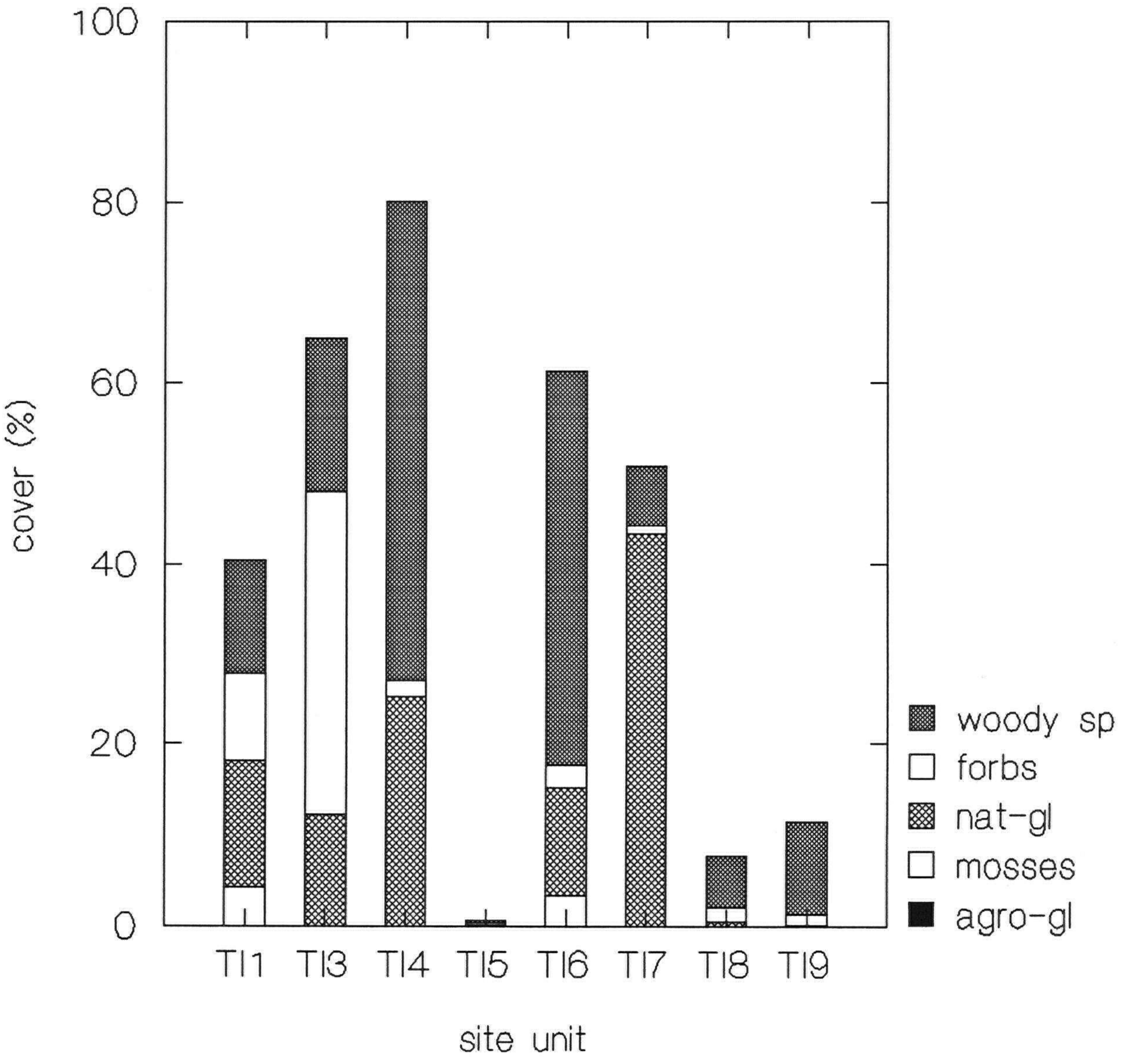


Figure 4.23 Texada Iron Mine: percent cover



or native grasses but the number of forbs had dropped to 4(14). However, in terms of vegetative cover, the cover from forbs is insignificant.

Site TI5 is a compacted haul road consisting primarily of crystalline limestone with a cover of only 1% consisting of trailing blackberry, weeds and moss. The previous plots were not re-located and it is likely that the 1993 plot was re-established in the wrong place , given the dramatic negative change in species richness and vegetative cover. The present owners kindly agreed to de-compact (with a bull-dozer ripper) a small area adjacent to the measured plot as a test of the influence of compaction onspecies propagation, without any other treatment.

TI6 is the only site unit where significant vegetative cover was found consistently over the whole site and nutrient cycling was in progress on coarse grained material where alder had seeded from nearby on to a dump composed of uncompacted intrusive and volcanics. The alder was vigorous, indicating that the site received considerable moisture seepage. Weathering of this material had occurred to produce material with 50% fines. There is ample evidence of surface litter decomposition, the pH is 7 and substrate nutrient capital was measured as a mean of 0.72% organic C and 0.25% N. In addition the presence of soil macrofauna was noted. There was no historical substrate measurement and although there was a significant gain in above-ground biomass from tree growth the number of woody and native grass species had not changed from the 1977 BCMEMPR study.

Site TI7 is on the 140° facing lower Yellow Kid dump slope adjacent to the mine office. Average cover was 57% of which 10% was provided by a 38cm dbh douglas fir (core dated at 21 years) and the remainder grasses; wild rye, drooping bromegrass and minor rat-tail fescue.

Site unit TI8 on the upper Yellow Kid dump was not included in the 1978 survey but was sampled as part of the UBC study. It is a site where dump material has been pushed over the dump crest leaving a surface of uncompacted crystalline limestone and skarn. Plots TI8-1,2,3 were on this material where the particle size was too large to yield a substrate sample whereas TI8-4 was 15m to the north on the compacted section of the dump where pH was 8.0(7.5) and the sample contained 79% fines. Percentage N remained unchanged at 0.02% and %C was 0.045. Although cover was low at <10%, 14 species were represented including an alder 3m tall and a rather chlorotic Douglas fir 2m tall. It is notable that on the small top bench of the Yellow Kid dump the main section compacted by truck haulage is barren of shrubs. The eastern section of the dump away from the pit which has not been compacted and has a poor moisture regime is covered with shrub alder 3-4m high.

Site unit TI9 was a single plot at the base of the slope on a compacted haul road on the west side of the Prescott pit to represent the exposed southwest facing western end of the mine complex. Douglas fir (2.5m and 0.8m tall), cedar (browsed to a stump) and arbutus (1.5m, normal vigour) occurred on the plot. This site was also chosen to test the influence of compaction and an area adjacent to the measured plot was ripped, without any other treatment.

Table 4.11 Texada Iron: Species present in historical and 1993 studies

Life form	species present in previous study (MEMPR 1978)	species present in 1993 study
Woody species, trees and shrubs	red alder	red alder
	Douglas fir	Douglas fir
	hemlock	hemlock
	lodgepole pine	lodgepole pine
	red cedar	red cedar
	-	arbutus
	-	Douglas maple
	-	juniper
	black gooseberry	black gooseberry
	oceanspray	oceanspray
	willow	willow
	red raspberry	-
	wild rose	wild rose
	red-flowering currant	-
	gooseberry	gooseberry
	snowberry	snowberry
	oregon grape	oregon grape
	-	black cap raspberry
Forbs, flowers and herbs	bird's eye pearlwort	-
	horsetail	horsetail
	dandelion	dandelion
	wild strawberry	wild strawberry
	blue-leaved strawberry	-
	cat-tail	cat-tail
	plantain	-
	thistle	thistle
	wall-lettuce	wall-lettuce
	yarrow	yarrow
	-	pearly everlasting
	Macoun's ragwort	Macoun's ragwort
	sedge	-
	fleabane	-
	sitka columbine	-
	chilean tarweed	-
	Hoelbell's rockcress	-
	American vetch	-
	purple crane's bill	-
	hairbell	-
	American wild carott	-
	sticky chickweed	-
	boreal sandwort	-
	fireweed	fireweed
	small flowered alumroot	-
	yerba buena	-
	-	ox-eye daisy
	-	bracken fern
	-	stinging nettle
Native grasses and legumes	smooth bromegrass	smooth bromegrass
	drooping bromegrass	drooping bromegrass
	fowl bluegrass	fowl bluegrass
	blue wild ryegrass	blue wild ryegrass
	poverty oatgrass	poverty oatgrass
	silver hairgrass	silver hairgrass
	rat-tail fescue	rat-tail fescue
	-	yorkshire fog
	-	bentgrass sp.
	-	wheatgrass sp.
	-	fescue sp.

mosses (including liverworts, lichens)	moss	moss

Table 4.12 Key to Common and Scientific names of species identified in 1993

Life form	Common name	Scientific name
Woody species (trees and shrubs)	poplar	populus tricocarpa
	alder	alnus rubra
	white spruce	picea glauca
	Douglas fir	pseudotsuga menziesii
	lodgepole pine	pinus contorta
	aspen	populus tremuloides
	arbutus	arbutus menziesii
	birch	betula sp.
	cedar	thuja plicata
	hemlock	tsuga heterophylla
	western white pine	pinus monticola
	grand fir	abies grandis
	Douglas maple	acer douglasii
	red osier dogwood	cornus stolonifera
	juniper	juniperus sp.
	cherry	prunus virginiana
	saskatoon berry	amelanchier alnifolia
	snowberry	symphoricarpus albus
	soopalallie	shepherdia canadensis
	willow	salix sp.
	oceanspray	holodiscus discolor
	blackberry	rubus ursinus
	raspberry	rubus leucodermis
	strawberry	fragaria sp.
	gooseberry	ribes lacustre
	huckleberry	vaccinium parvifolium
	wild rose	rosa gymnocarpa
	oregon grape	mahonia nervosa
	salal	gaultheria shallon
Forbs (flowers and herbs)	dandelion	taraxacum officinale
	horsetail	equisetum sp.
	cat-tail	typha latifolia
	sedge	carex sp.
	rush	juncus sp.
	lambs quarters	chenopodium album
	mullein	verbascum thapsus
	yarrow	achillia millefolium
	thistle	cirsium sp.
	pearly everlasting	anaphilis margaritacea
	ragwort	senecio sp.
	wall lettuce	laxctuca sp.
	aster	aster sp.
	fleabane	erigeron sp.
	knapweed	centaurea sp.
	rattlesnake plantain	goodyera oblongifolia
	vanillaleaf	achlys triphylla
	bracken fern	pteridium aquilinum
	sword fern	polystichum munitum
	bluebell	campanula rotundifolia
	daisy	leucanthemum vulgare
	fireweed	epilobium sp.
	fringed sage	artemisia frigida
	shepherd's purse	capsella bursa-pastoris
	buttercup	ranunculus sp.
	burdock	arctium lappa
	vetch	vicia sp.
	stinging nettle	urtica dioica

Native grasses and legumes	sweet clover dutch clover cinquefoil foxtail barley timothy bluegrass wildrye fescue rat-tail fescue yorkshire fog oatgrass soft brome downy chess bentgrass wheatgrass redtop alkaligrass unspecified grass	melitotus sp. trifolium repens potentilla sp. hordeum jubatum phleum pratense poa sp. elymus festuca sp. festuca myuros holcus lanatus danthonia spicata bromus mollis bromus tectorum agrostis sp. agropyron sp. agrostis alba puccinellia sp. gramineae
mosses (includes liverworts and lichens)	moss stepmoss goose necked moss oregon beaked moss	- hylocomium splendens rhytidiadelphus triquetrus eurhynchium oreganum
agronomic grasses and legumes	Canada bluegrass redtop tall wheatgrass slender wheatgrass crested wheatgrass pubescent wheatgrass int. wheatgrass tall fescue creeping red fescue hard fescue timothy alsike clover alfalfa	poa compressa agrostis alba agropyron elongatum agropyron trachycaulum agropyron sp. agropyron trichophorum agropyron intermedium festuca arundinacea festuca rubra festuca longifolia phleum sp. trifoleum hybridum medicago sp.

Chapter 5

DISCUSSION OF RESULTS

All assessments except those of energy and nutrient cycle were based on visual observations. This involved a certain amount of subjectivity based on the personal and professional bias of the observer. As already noted, there were large differences in the number of forbs identified between the two generations of vegetation surveys. On the other hand, quantitative measurements which monitor vegetation growth are usually done using either small metal quadrats 100 x 50cm or by measuring the growth along a steel wire left in the ground. Such techniques are considered objective enough to compare species richness and cover data measured by different people and are used for monitoring and compliance studies. Qualitative visual observations are unsuitable for monitoring compliance with productivity standards. However, for quantitative measurements the sampling area is so small that they are not representative of a site with a heterogenous natural plant community.

In evaluating the development of energy and nutrient cycling in the field, plant vigour was assessed and, where observed, symptoms of N and P deficiency were noted. Time and budget constraints limited analyses of the substrate to pH, organic C and Total N. Total N (Kjeldahl) is a very well known determination but it includes geological N which is not readily available to plants. This study used a single Total N determination from 0 to 15cm which does not necessarily reflect available N.

Also, in research of this nature where an attempt is made to compare current data with data that was collected 20 years ago, it is important to appreciate that such reports were compiled without the benefit of word processors or digital processing and graphics software. In the process of tracing the research that was made the author became keenly aware of the amount of historical data that was not published or cannot be found or has been discarded after individuals retired or were retrenched or departments were disbanded.

At Bull River the site blended visually into the general landscape and the resloping had improved landform stability. The low C/N ratio was more typical of a subsoil with a low organic content than a surface material. N mineralisation was taking place and some inorganic N may have been made available by hydrolysis or exchange of geologic N. Since N from the fertilizer applied in 1974 had long since been used or leached away the total-N resulted from a combination of indigenous and active N. The site geology referred to siderite and malachite, both carbonate minerals, and the pH >8 suggested that P fixation may have been occurring. However, although P was not measured in the substrate samples there was no evidence of P deficiency noted in the species identified. Organic matter was low, producing limited energy flow moderated by bacteria. No water samples were analysed but the high pH should have minimized copper solubility both from the point of view of groundwater and plant uptake.

The reason was not clear for the change in the dominant agronomic species from tall fescue to tall wheatgrass on site BR1. Clover persisted but its contribution to total-N was unknown since there was no benchmark measurement of this parameter. This site was very exposed to westerly winds and clover, with its shallow rooting system is limited by surface dryness. The average cover on this site was only 45%. Either arrival of native seed propagules was not taking place or the available nutrients and moisture regime were still insufficient to sustain propagation. On site unit BR6 with similar surface material, moisture was not limiting and cover was complete. Species richness had increased on all sites since the benchmark study, except BR2, but progress was very slow.

Luckily, a complete perimeter fence had saved the grass cover from grazing damage by local cattle. Deer and rabbit pellets on sites BR2,3 & 5 were evidence that wildlife were crossing the site using the island of vegetation left during mining and browsing of shrubs was evident near the perimeter of the site.

At Coal Creek the mining history was more obvious by the visual impact of black coal waste either on the waste piles or the settling ponds. Visually, these were gaps in the ecosystem reconstruction. Little recontouring had been done except recently and the unnatural contours were more visible in the relatively open vegetation than at Cumberland. The mine installations lined the narrow valley and the impact of these on groundwater were unknown. In particular, dark stains had been found in the soil at the site of a buried tank 20m south of the creek and the impact of this on groundwater or surface water during snowmelt was unknown.

At both CC-F and CC-G site units there was ample evidence of the progress of energy and nutrient cycling in the substrate sample chemistry and acumulation of an A horizon, particularly at site CC-F. Earthworms were present with a beneficial effect on soil structure on both sites. There was a highly significant consistent reduction in pH at all sites, reflecting the release of organic acids asssociated with the decomposition of litter and A horizon formation. This reduction in pH would also facilitate the propogation of certain coniferous species.

Natural regeneration of vegetation was complete apart from the areas of coal waste already mentioned. However open, grass areas, particularly the settling ponds and the waste coal piles were scarred by 4x4 trucks and moto-cross bikes tearing the surface layer.

Cumberland is an older site than Coal Creek (>70 years) without remnants of a townsite or washery. The only evidence of machinery was the concrete shell of the steam winding engine and fan house at the base of the bluff near the incline entry. There were no remnant piles of waste coal as at Coal Creek although at low water during summer the lake bottom at the shore showed its origin as mine and coal waste and the "stratigraphy" of the waste dump could be seen where Coal Creek had incised a cut through the waste on its way to the lake and also in the ends of the linear waste piles on the lake shore which attested to the provenance of the material. Otherwise the site blended with the surroundings and there were no other gaps in the ecosystem reconstruction process. The waste does not contain pyrite and did not appear to have negative impact on the water quality in the lake, it would certainly be less than the effect of recreational activities on and around the lake itself.

Revegetation on the site had been facilitated by primary colonisation by red alder and this successional process was in evidence at the road edges. Invasion of conifers had been readily effected by seeding from the bluff directly above the site. There had been little apparent change in the hemlock-moss vegetation since the benchmark survey, except an increase in the ground cover of mosses.

Ecosystem processes were functioning satisfactorily in the mature second growth vegetation. The pH (5.2) was normal for a coniferous forest soil and energy and nutrient cycling was evident.

Tailings are regarded as being very difficult to reclaim because of their sterility and low moisture holding capacity. At Pinchi Lake the tailings were very low in primary nutrients at the time of deposition and any immediate improvement in nutrient capital had been brought about by fertilizer. There had been considerable change in vegetation since the benchmark study and the vegetation was completely self-sustaining and included a number of native woody species. Energy and nutrient cycling had been sustained as evidenced by the formation of an A horizon and the leaching of organic matter down through the shallow rooting zone Subsequently, legume N fixation had contributed to the nutrient cycle. In particular, clover (Trifolium repens) was found to be the most effective of the legumes tested by Jefferies et al. (1981) in transferring N to a companion grass. However the symptoms of P deficiency, purplish tinges at the ends of the branches, were noted in a spruce about 2m high adjacent to the tailings test plots. The pH of the tailings was still >8 which would inhibit P release and was too high for the recruitment of coniferous species such as spruce and lodgepole pine. This explained the loss of practically all of the 300 lodgepole pine seedlings planted in 1972. However the release of organic acids associated with the A horizon development would eventually reduce the pH and facilitate the recruitment of local tree species for which a seed source was readily available nearby.

The grass/legume revegetation had been very successful in terms of cover. In addition willow and poplar had succeeded in germinating along strips where fortuitously, the seed density had been lower and the resulting grass sward was not so thick. Willow was providing forage at the edge of the tailings pond but there was no evidence from browsing or from pellets that wildlife were crossing the pond, presumably because there was not yet enough refuge.

The permanent ponds that had formed at the west and east ends of the impoundment had a pH of 9 and a high alkalinity because of dissolved Ca^{2+} from the addition of lime during beneficiation. This had the positive effect of reducing the solubility of heavy metals and buffering the pond pH. Aesthetically the ponds were a positive contribution to the landscape and provided a habitat niche. Although they were "perched" above the surrounding water table the structural integrity of the impoundment appeared sound and further build-up of hydrostatic head would be avoided by the lowering of the spillway elevation on permanent closure.

At Texada Iron the site was still active although not being mined and as such the process of ecosystem reconstruction was stalled except for isolated areas where natural regeneration of vegetation was taking place. This is a hostile site for revegetation because of the alkaline conditions, summer moisture deficiency and exposure to onshore winds.

On exposed westerly or south facing areas at Texada moisture deficiency was caused by evapotranspiration particularly during summer and exacerbated by the poor distribution of moisture-retaining fine material on surface. This was demonstrated by the behaviour of alder on site TI6 and the top bench of the YK dump. If the site was decompacted alder would propogate as long as a seed source was available. However on a sub-xeric site its productivity would be limited and it would grow in a shrub form. There had been minimal growth of shallow rooting species except in sheltered areas or shaded areas around trees where there was no surface moisture deficiency.

TI4 and TI7 were both dump slopes at the angle of repose. Part of the TI4 site of 3 contiguous plots was covered by till material from above so that at least the upper part of the slope was covered with till. The extensive cover (80%) had stabilised the slope and woody species provided two thirds of the cover. TI7 was a shorter dump slope in the middle of the YK dump with 3 contiguous plots partly in the shade of a large Douglas fir (dbh 38cm). Here the average cover was 40% but individual plots TI7-1 and TI7-2 had

50% cover thanks to the shade from the Douglas fir. Plot TI7-3 had only 30% cover and the slope was unstable.

There was a ready supply of seed available for the two main colonising tree species, Douglas fir and alder, since even the open areas of the YK dump were less than 200m from a seed source.

Chapter 6

CONCLUSIONS

At and immediately after closure of a mine-site, the major concerns are related to physical stability of the site with regard to public safety and chemical stability of leachates, effluents and surface and groundwater quality. Once the stability of the site has been confirmed using appropriate quantitative techniques, the adoption of cheaper, integrated studies to assess attributes whose rehabilitation takes place over a much longer term is more appropriate ecologically. It will also ease the burden on the mining company and as a result, ease the regulatory burden on the ministry. The fact that such studies are based on measuring change rather than absolute values makes them more relevant to heterogenous site conditions. The current study has demonstrated that objective assessments of energy and nutrient cycling and qualitative assessments of plant community development can be carried out in the field by one person and at reasonable cost.

In performing any long-term study one is always faced with the problem of differences in technique or analysis. This is particularly relevant in the case of analytical data from substrate samples. Because of this, it is readily apparent that different priorities should exist for characterization and long-term studies. For long-term studies it is particularly important to keep the number of parameters involving chemical analysis to a minimum, for technical and economic reasons. Analytical practices change and it is more realistic to restrict long-term measurements to the minimum necessary and to use only those which have widely accepted analytical techniques.

The determination of available N is expensive and not widely used; however Li and Daniels (1994) have proposed the use of "corrected-N" which is obtained by subtraction of total-N at 10 to 20cm from total-N at 0 to 5cm at each site. This is based on the findings that most of the available N was associated with organic matter accumulated in the A horizon and that most of the total-N below 10cm was geological in origin or "fixed" and unavailable to plants.

The substrate analysis would have benefited from a determination of P available to plants since P is critical for the future development of a plant community but is not always obvious from a visual inspection of vegetation and the species growing may not be P limited. The current standard methods for determination of available P by H_2SO_4/Na_2CO_3 extraction are well known and within the capabilities of any laboratory.

This study has preserved the integrity of the historical data with which comparisons have been made. This has meant that large variations in numbers of species exist between mine-sites or between successive studies on the same sites where these differences are artifacts caused by differences in the point in the growing season or the professional experience of the observer. For this reason a historical comparison of percent cover was not made. As a way of overcoming this problem for species richness data, the data presentation has been designed to preserve the maximum of information and isolate the source of the major variations. In doing so there has been no statistical manipulation of either the current or historical data. However the grouping of species and the clarity of the graphical presentation provides a practical, objective method of assessing vegetation succession. In addition, this type of assessment, which measures the development of a process rather than an endpoint, is more ecologically appropriate for substrate and vegetation and should be added to the usual "standards of productivity" as it takes into account that the speed of ecosystem reconstruction changes with biogeographic conditions.

The assessments have been made on 5 sites. Attention has been focussed on substrate and vegetation, but since these are part of an overall reclamation process, the rehabilitation status of other attributes has been assessed in terms of their progress or limiting effect on ecosystem reconstruction. This corresponds with the scheme of components of a reclamation study described in Table 1.1. Assessment of the visual, land-form, land use capability and hydrological cycle components was essentially subjective and based on a visual examination and the criteria used was the present state of rehabilitation compared to background. Assessment of energy and nutrient cycling was based on visual observation of substrate and rooting profile in the sampling pit and pH, total-N and organic C values of the substrate samples were compared with benchmark data and with measured background values or values from the literature. For vegetation, criteria used were the changes in composition of the plant community since the benchmark survey. No quantitative comparison has been made with the undisturbed vegetation. This is consistent with the assertion in Chapter 1.3 that reclamation is the reconstruction of an ecosystem, not the same ecosystem that existed previously.

Table 6.1 summarizes the conclusions regarding rehabilitation status for each component at the sites.

Table 6.1 Summary of rehabilitation status at all study sites

Key to status:

2	-satisfactory rehabilitation
1	-evidence of positive progress since the benchmark study.
0	-little or no development since the benchmark study
L	-Attribute is limiting progress towards rehabilitation.
n/a	-not applicable

RECLAMATION COMPONENT	BULL RIVER	COAL CREEK	CUMBERLAND No. 4 MINE	PINCHI LAKE	TEXADA IRON
Visual	2	1	2	2	0
Land-form	2	L	1	1	L
Land use capability	1	L	2	1	n/a
Hydrological cycle	L	1	2	2	L
energy cycle	1	2	2	1	0
nutrient cycle	1	2	2	1	0
biological succession	1	1	2	1	0

At Bull River, on sites BR-1 and BR-2, moisture loss through evapotranspiration appears to be the limiting factor in development of vegetative cover. More woody species are required to provide shade to shallow rooted ground cover and at the current rate of development it will be a long time before these sites achieve a cover of vegetation which will be satisfactory to eliminate wind erosion, sustain wildlife browsing and cattle grazing and be genetically diverse. The fencing should be maintained to prevent damage by cattle and the public. Sites on lightly disturbed ground are progressing satisfactorily towards development of a natural plant community and the pit lake is a positive feature.

At Coal Creek the land-form attribute is considered to be limiting the ecosystem reconstruction because of the unknown effects of the previous mining installations extending for 3km along the valley bottom along both sides of the creek. In addition, human recreational activity is a factor limiting rehabilitation by preventing the accumulation of organic material on waste coal dumps and the settling ponds. The settling ponds would benefit from the addition of some organic material, perhaps garden waste from the municipal dump only a few hundred meters away. Once this was applied it would need to be fenced.

The Cumberland site is considered reclaimed. Ecosystem processes are functioning and the question of whether or not the remaining concrete structure is a limitation to land use is purely subjective.

At Pinchi Lake the successful recruitment of native woody species in places where seeding density has been lower or wet conditions have been unsuitable for the agronomic cultivars marks the progress in development of a natural plant community. In addition, A horizon development reflects a sustained increase in nutrient capital and the release of organic acids. The balance between promoting an early vegetative cover and facilitating the recruitment of native species is an extremely difficult one. Evidence suggests that on the tailings pond, promotion of agronomics has been perhaps too successful. The 4 test strips where maintenance fertilizer was applied in 1980 were still completely free of recruitment of any native species after 13 years, in dramatic contrast to the surrounding sward. The decision not to apply maintenance fertilizer was correct. Any limitation to reclamation attributed to land-form because of the possibility of flooding would be removed by the disposal of the reclaim water line and decant tower and lowering of the permanent spillway elevation.

At Texada Iron the limiting factors to revegetation on exposed westerly or south facing areas at Texada are land-form, specifically compaction and moisture deficiency. The influence of compaction is demonstrated by the behaviour of alder on site TI6 and the top bench of the YK dump. Moisture deficiency is caused by evapotranspiration in exposed areas particularly during summer and exacerbated by the poor distribution of moisture-retaining fine material on surface. This means that revegetation of exposed, south-facing dump slopes will require recontouring before any revegetation treatment as shown by comparing TI4 and TI7, both of which are dump slopes at the angle of repose.

It is notable that all the sites studied are small in the sense that the distance of any point on the mine-site from undisturbed vegetation was usually less than 200m. Sites BR1 and BR2 at Bull River are the only sites where recruitment of native species is probably limited by distance to a ready seed source. This is an important consideration in the revegetation of large sites and successful development of a natural plant community on these sites will require provision for seed sources of woody species. This could best be achieved by leaving "islands" of vegetation intact as at Bull River, supplemented by transplanted rafts of natural vegetation or plantings of seedlings or cuttings, depending on the species. Where vegetation cannot be left intact as on a large tailings pond, development of natural vegetation will require extensive plantings or transplants of woody species. The approach will need to be tailored to the pH and particle size range of the material as well as the way it was deposited. However, Pinchi Lake is a good demonstration that natural vegetation can develop on alkaline tailings.

It is proposed that such studies would be useful to mining companies and regulators as follows:

1. This type of procedure could form the basis of an ecologically acceptable alternative to measurements of productivity.

2. To demonstrate that natural cycles and biological succession were initiated and sustainable without further inputs. This could reduce the length of time required to

continue treatment. Also, where public access is limiting rehabilitation a decision to eliminate an access road could be made earlier.

3. Besides providing an assessment tool for an individual site these studies provide a second benefit in that they can also be used as a research tool to assist in defining the site-specific conditions of the reclamation permit for new mines.

Chapter 7

RECOMMENDATIONS

1. Revegetation guidelines should require the evidence of the ability of a site unit to sustain natural cycles and biological succession without further management inputs as a complement to a definition of productivity.

2. At the same time, to be considered acceptable by regulators, these studies should be performed by a professionally accredited "reclamationist". This individual will usually be a geoscientist with interdisciplinary knowledge of both mining processes and the processes of reconstruction of an ecosystem.

3. The studies at Bull River, Coal Creek and Pinchi Lake should be repeated in 5 years. The annual reclamation inspection should assess the results of the decompaction experiments at Texada Iron.

4. Resources be provided within the ministry to maintain a reclamation database which not only contains more ecological data on mine-sites, but is capable of its analysis. This could form the basis for conditions of future mine reclamation permits.

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Appendix 1: number of species data

SITE$	UNIT	TOTSPC	WOODSPEC	FORBS	NATGL	AGROGL	MOSSES
BR1	1	15	1	5	3	5	1
BR1-H	2	9	0	1	2	6	0
BR2	3	9	0	2	2	4	1
BR2-H	4	10	0	3	1	6	0
BR3	5	18	5	5	3	5	0
BR3-H	6	10	0	1	1	8	0
BR5	7	19	4	5	3	6	1
BR5-H	8	7	1	0	1	5	0
BR6	9	14	1	5	2	5	1
BR6-H	10	7	2	0	0	5	0
C4	11	19	9	5	1	0	4
C4-H	12	42	17	12	1	0	12
CCF-H	13	6	0	0	6	0	0
CCF	14	14	5	7	2	0	0
CCG-H	15	5	0	2	3	0	0
CCG	16	21	6	10	4	0	1
CCSP-H	17	7	2	1	4	0	0
CCSP	18	15	2	9	4	0	0
PL2	19	17	6	2	3	5	1
PL3	20	15	3	4	3	4	1
PL1	21	15	5	2	3	4	1
PL1-H	22	11	2	2	2	4	1
TI1	23	8	1	4	2	0	1
TI1-H	24	10	0	4	5	0	1
TI2	25	18	10	5	2	0	1
TI2-H	26	14	7	5	1	0	1
TI3	27	14	5	5	4	0	0
TI4	28	15	5	4	6	0	0
TI4-H	29	15	6	3	5	0	1
TI5	30	7	3	3	0	0	1
TI5-H	31	17	7	5	4	0	1
TI6	32	15	6	4	4	0	1
TI6-H	33	14	6	3	4	0	1
TI7	34	11	2	4	5	0	0
TI7-H	35	8	0	4	4	0	0
TI8	36	14	7	6	1	0	0
TI8-H	37						
TI9	38	6	2	3	1	0	0

Appendix 2: Species cover data

SITEPLOT$	UNIT	WOODSPEC	FORBS	NATGL	AGROGL	MOSSES
BR1-1	1	0	0.1	2.1	28	0
BR1-3	1	0	0.2	8.1	52	0
BR1-4	1	0	5.1	20.1	17.1	0.1
BR1-5	1	0	0.2	11	40.2	0
BR1-6	1	1	1.1	16	30.2	0
BR1-H	2	0	0.1	12	24	0
BR2-1	3	0	0.1	8.1	5.1	0
BR2-2	3	0	0.2	41	24.1	10
BR2-3	3	0	0.2	55	35	0
BR2-4	3	0	0.2	25.1	30.2	15
BR2-5	3	0	0.1	25.1	35.1	15
BR2-H	4	0	0.3	0	28	0
BR3-3	5	0	1.3	5.1	28.1	0
BR3-4	5	21.2	1.1	44	15	0
BR3-H	6	0	0.1	6	34	0
BR5-1	7	15	0.2	5.1	45.1	0
BR5-2	7	20	0.3	15.1	60.4	0.1
BR5-3	7	1	0.3	5.1	45	0
BR5-4	7	0	0.2	10.1	60	0
BR5-H	8	0.1	0	1	25.2	0
BR6-1	9	0	0	20	30.1	50
BR6-2	9	2	17.2	60	22.1	0
BR6-3	9	0	0.1	20	80.2	0
BR6-H	10	0.2	0	0	38	0
C41	11	26	3	0	0	61
C42	11	31.1	12.2	0	0	100
C43	11	2.1	0.2	0	0	75
C44	11	5.1	1.1	0	0	60
C45	11	13.4	3.1	0	0	50.1
C473-H	12	71.2	2.2	0	0	5.1
CCF-H	13	0	0	0.6	0	0
CCF1	14	0.5	0.7	0.2	0	0
CCF2	14	0	0	0	0	0
CCF3	14	0	0	0	0	0
CCG-H	15	0	0.1	0.3	0	0
CCG1	16	0.6	1	0.4	0	10
CCG2	16	0	0	0	0	0
CCG3	16	0	0	0	0	0
CCSP-H	17	0.2	0.1	0.3	0	0
CCSP1	18	0.2	0.9	0.4	0	0
CCSP2	18	0	0	0	0	0
CCSP3	18	0	0	0	0	0
PL2-0	19	25.1	1.1	21	10.2	20
PL2-1	19	0.2	0	0.1	80	20
PL2-2	19	5.1	0	0	95.2	0
PL2-3	19	33.2	0	0	70.1	15
PL2-4	19	10.1	0	2	50	5
PL2-5	19	27.1	0	5	91.1	5
PL3-0	20	0.1	0.2	10	0	90
PL3-1	20	1	0	15.1	0	0.1
PL3-2	20	2.1	0	0.2	100.1	0

Appendix 2: Species cover data

SITEPLOT$	UNIT	WOODSPEC	FORBS	NATGL	AGROGL	MOSSES
PL3-3	20	2	0	0.2	100	0
PL3-4	20	35.1	25.1	0	40.2	15
PL3-5	20	0.1	0.1	15.1	62.1	10
PL3-6	20	0	0	0	0	0
PL1-0	21	8	1.1	5.1	90.2	0
PL1-1	21	4	1.1	0.1	101.1	0
PL1-2	21	13.1	0.1	10.1	92	0
PL1-3	21	35	0.1	0.1	75.2	10
PL1-4	21	18.3	2	0.1	95.1	5
PL1-5	21	10	10	0.1	85.1	5
PL1-6	21	10	0.1	30	75.1	0
PL1-7	21	30.2	0.1	20.1	10.1	40
PL1-H	22	0.2	0.2	13.1	3.8	0.1
TI1-1	23	5	1.3	55	0	1
TI1-H	24	0	47	42	0	10
TI2-1	25	33.1	12	10	0	5
TI2-2	25	0	12	10	0	5
TI2-3	25	0.1	12	5	0	10
TI2-4	25	38.3	17.2	1	0	0
TI2-5	25	0.3	3.1	2	0	5
TI2-H	26	4.5	5.2	0.1	0	1
TI3-1	27	22.2	40	12.2	0	0
TI3-2	27	11.2	32	12.2	0	0
TI4-1	28	70	1.2	32.2	0	0
TI4-2	28	47	2.2	40.3	0	0
TI4-3	28	42	2	3.3	0	0
TI4-H	29	8.1	8.1	21.6	0	2
TI5-5	30	0.3	0.3	0	0	0.1
TI5-H	31	0	0	0	0	0
TI6-1	32	69	0	0.1	0	0.1
TI6-2	32	7	5.2	0.1	0	0.1
TI6-4	32	55.1	2.1	35.1	0	10
TI6-H	33	50.7	5.6	22.5	0	13.3
TI7-1	34	10.1	0.3	50.1	0	0
TI7-2	34	10	2.2	50.2	0	0
TI7-3	34	0	0	30.2	0	0
TI7-H	35	0	3.4	22.9	0	0
TI8-1	36	21.3	5.2	0.1	0	0
TI8-2	36	1.1	0.4	1	0	0
TI8-3	36	0	0.1	1	0	0
TI8-4	36	0.3	0.2	0.1	0	0
TI8-H	37	0	0	0	0	0
TI9-1	38	10.1	1.2	0.1	0	0

Appendix 3: Data from substrate sample analysis

plot-id	rep. #	pH water	%N	% Org-C	C/N	av.%fines
BR 1-3	1	8.14				68.84
BR 1-3	2	8.09				
BR 1-3	3	7.95				
BR 1-3	4	8.00				
BR 1-3	5	8.00	0.12	0.73	6.08	
BR 1-4	1	8.20				65.91
BR 1-4	2	8.30				
BR 1-4	3	8.29				
BR 1-4	4	8.31				
BR 1-4	5	8.11	0.08	0.38	4.75	
BR 1-5	1	8.33				66.64
BR 1-5	2	8.32				
BR 1-5	3	8.33				
BR 1-5	4	8.23				
BR 1-5	5	8.20	0.07	0.40	5.71	
BR 2-1	1	8.24				53.55
BR 2-1	2	8.12				
BR 2-1	3	8.11				
BR 2-1	4	8.18				
BR 2-1	5	8.17	0.07	0.46	6.57	
BR 2-2	1	8.24				73.05
BR 2-2	2	8.34				
BR 2-2	3	8.38				
BR 2-2	4	8.44				
BR 2-2	5	8.16	0.08	0.46	5.75	
BR 2-3	1	7.92				63.31
BR 2-3	2	8.17				
BR 2-3	3	7.98				
BR 2-3	4	8.02				
BR 2-3	5	8.15	0.07	0.43	6.14	
CC F1	1	6.63	0.42			61.98
CC F1	2	6.52	0.34			
CC F1	3	6.43	0.38			
CC F1	4	6.66	0.37			
CC F1	5	6.71	0.38	2.96	7.79	
CC F2	1	6.43	0.76			71.18
CC F2	2	6.69	0.94			
CC F2	3	6.60	0.80			
CC F2	4	6.71	0.83			
CC F2	5	6.86	0.96	2.85	2.97	
CC F3	1	6.85	0.77			73.55
CC F3	2	6.79	0.64			
CC F3	3	6.80	0.96			
CC F3	4	6.72	0.70			
CC F3	5	7.01	0.64	5.19	8.11	
CC G1	1	6.13	0.88			81.35
CC G1	2	6.13	0.88			
CC G1	3	5.86	0.90			
CC G1	4	6.61	0.89			
CC G1	5	6.25	0.86	5.95	6.92	
CC G2	1	6.25	0.77			80.31

Appendix 3: Data from substrate sample analysis

plot-id	rep. #	pH water	%N	% Org-C	C/N	av.%fines
CC G2	2	6.16	0.70			
CC G2	3	6.03	0.84			
CC G2	4	6.03	0.72			
CC G2	5	5.86	0.79	2.86	3.62	
CC G3	1	6.38	0.96			84.29
CC G3	2	5.92	0.96			
CC G3	3	5.81	0.86			
CC G3	4	5.86	0.87			
CC G3	5	5.90	0.92	5.81	6.32	
CC SP1	1	6.76	1.20			95.37
CC SP1	2	7.05	1.22			
CC SP1	3	7.17	1.18			
CC SP1	4	6.60	1.23			
CC SP1	5	6.97	1.21	11.25	9.30	
CC SP2	1	6.96	0.99			96.70
CC SP2	2	6.80	0.88			
CC SP2	3	6.93	0.88			
CC SP2	4	6.71	0.95			
CC SP2	5	6.99	1.02	1.38	1.35	
CC SP3	1	7.14	1.28			93.32
CC SP3	2	7.27	1.18			
CC SP3	3	7.00	1.33			
CC SP3	4	6.42				
CC SP3	5	6.55	1.28	7.45	5.82	
C4-1	1	5.16				74.48
C4-1	2	5.28				
C4-1	3	5.36				
C4-1	4	5.42				
C4-1	5	5.10	0.54	5.56	10.30	
C4-2	1	5.40				79.50
C4-2	2	5.38				
C4-2	3	5.45				
C4-2	4	5.41				
C4-2	5	5.44	1.01	23.03	22.80	
C4-3	1	4.93				59.54
C4-3	2	4.81				
C4-3	3	4.82				
C4-3	4	4.85				
C4-3	5	4.83	0.30	3.13	10.43	

Appendix 4: Plot description data

SITEPLOT$	SITEUNIT	SLOPE	ASPECT	PELLETS	SOILFAUN	TOTCOVER
BR1-1	1	32	180	0	0	30
BR1-3	1	20	160	0	0	60
BR1-4	1	5	200	0	0	40
BR1-5	1	15	160	0	0	50
BR1-6	1	20	170	0	0	50
BR1-H	2					
BR2-1	3	10	1	0	0	10
BR2-2	3	1	1	2	0	75
BR2-3	3	1	1	1	0	90
BR2-4	3	15	180	11	0	70
BR2-5	3	15	180	7	0	65
BR2-H	4					
BR3-3	5	5	210	12	0	50
BR3-4	5	5	200	2	0	85
BR3-H	6					
BR5-1	7	20	180	4	0	50
BR5-2	7	18	180	5	0	75
BR5-3	7	20	180	9	0	50
BR5-4	7	20	200	10	0	70
BR5-H	8					
BR6-1	9	5	180	0	0	100
BR6-2	9	10	270	0	0	100
BR6-3	9	5	220	0	0	100
BR6-H	10					
C41	11	5	240	0	0	100
C42	11	30	240	0	0	100
C43	11	30	60	0	0	100
C44	11	25	60	0	0	100
C45	11	30	240	0	0	100
C473-H	12					
CCF-H	13					
CCF1	14	1	180	0	1	100
CCF2	14	1	180	0	1	100
CCF3	14	1	180	0	1	100
CCG-H	15					
CCG1	16	1	180	0	1	100
CCG2	16	1	180	0	1	100
CCG3	16	1	180	0	1	100
CCSP-H	17					
CCSP1	18	1	1	0	0	100
CCSP2	18	1	1	0	0	100
CCSP3	18	1	1	0	0	100
PL2-0	19	2	160	0	0	80
PL2-1	19	2	160	0	0	100
PL2-2	19	2	160	0	0	100
PL2-3	19	2	160	0	0	100
PL2-4	19	2	160	0	0	95
PL2-5	19	2	160	0	0	90
PL3-0	20	2	160	0	0	100
PL3-1	20	2	160	0	0	25
PL3-2	20	2	160	0	0	100

Appendix 4: Plot description data

SITEPLOT$	SITEUNIT	SLOPE	ASPECT	PELLETS	SOILFAUN	TOTCOVER
PL3-3	20	2	160	0	0	100
PL3-4	20	2	160	0	0	90
PL3-5	20	2	160	0	0	100
PL3-6	20	2	160	0	0	100
PL1-0	21	2	160	0	0	100
PL1-1	21	2	160	0	0	100
PL1-2	21	2	160	0	0	100
PL1-3	21	2	160	0	0	95
PL1-4	21	2	160	0	0	100
PL1-5	21	2	160	0	0	100
PL1-6	21	2	160	0	0	100
PL1-7	21	2	160	0	0	100
PL1-H	22					
TI1-1	23	1	170	0	0	60
TI1-H	24					
TI2-1	25	2	130	0	0	60
TI2-2	25	2	130	0	0	27
TI2-3	25	2	130	0	0	27
TI2-4	25	2	270	0	0	10
TI2-5	25	2	270	0	0	10
TI2-H	26					
TI3-1	27	2	180	0	0	100
TI3-2	27	2	180	0	0	100
TI4-1	28	40	140	5	0	100
TI4-2	28	40	140	0	0	100
TI4-3	28	40	140	0	0	100
TI4-H	29					
TI5-5	30	10	120	0	0	1
TI5-H	31					
TI6-1	32	5	240	0	1	70
TI6-2	32	5	240	2	1	10
TI6-4	32	2	240	0	1	100
TI6-H	33					
TI7-1	34	35	140	0	0	30
TI7-2	34	40	140	0	0	50
TI7-3	34	40	140	0	0	50
TI7-H	35					
TI8-1	36	2	130	1	0	25
TI8-2	36	2	130	0	0	1
TI8-3	36	2	130	0	0	1
TI8-4	36	2	130	2	0	1
TI8-H	37					
TI9-1	38	2	180	0	0	1

Appendix 5: Field plot description data

SITEPLOT	LENGTH_UP	LENGTH_DN	MOIST_REG	SLOPE_POS	SURF_SHAPE	SL_POS_M
BR1-1	20	20	9	2	4	1
BR1-3	5	5	8	4	7	1
BR1-4	1	20	9	1	1	1
BR1-5	50	25	7	4	1	2
BR1-6	5	5	6	5	1	1
BR1-H						
BR2-1	1	2	3	5	3	2
BR2-2	3	0	3	5	7	2
BR2-3	3	0	3	5	7	2
BR2-4	6	60	7	5	3	1
BR2-5	3	60	7	5	3	1
BR2-H						
BR3-3	150	30	7	4	3	1
BR3-4	25	100	7	4	2	2
BR3-H						
BR5-1	100	100	7	4	6	1
BR5-2	100	100	7	4	4	1
BR5-3	150	60	8	4	3	1
BR5-4	150	60	8	4	3	1
BR5-H						
BR6-1	15	30	5	4	3	3
BR6-2	10	15	3	5	3	5
BR6-3	0	20	5	5	3	2
BR6-H						
C41	0	3	4	6	3	1
C42	2	3	3	6	3	1
C43	3	4	4	6	3	1
C44	2	5	4	6	3	1
C45	2	2	3	6	3	1
C473-H						
CCF-H						
CCF1	10	10	4	6	7	3
CCF2	10	10	4	6	7	3
CCF3	10	10	4	6	7	3
CCG-H						
CCG1	12	12	8	6	1	1
CCG2	12	12	8	6	1	1
CCG3	12	12	8	6	1	1
CCSP-H						
CCSP1	2	3	4	6	7	3
CCSP2	2	3	4	6	7	3
CCSP3	2	3	4	6	7	3
PL2-0			2	7	7	4
PL2-1			3	7	7	4
PL2-2			3	7	7	4
PL2-3			3	7	7	4
PL2-4			3	7	7	4
PL2-5			3	7	7	4
PL3-0			2	7	7	4
PL3-1			2	7	7	4
PL3-2			3	7	7	4

Appendix 5: Field plot description data

SITEPLOT	LENGTH_UP	LENGTH_DN	MOIST_REG	SLOPE_POS	SURF_SHAPE	SL_POS_M
PL3-3			3	7	7	4
PL3-4			3	7	7	4
PL3-5			3	7	7	4
PL3-6			3	7	7	4
PL1-0			3	7	7	4
PL1-1			3	7	7	4
PL1-2			3	7	7	4
PL1-3			3	7	7	4
PL1-4			3	7	7	4
PL1-5			3	7	7	4
PL1-6			3	7	7	4
PL1-7			3	7	7	4
PL1-H						
TI1-1		0	7	6	4	3
TI1-H						
TI2-1		0	5	4	7	3
TI2-2		0	5	4	7	3
TI2-3		0	5	4	7	3
TI2-4		0	6	4	3	2
TI2-5		0	6	4	3	2
TI2-H						
TI3-1		0	5	4	4	3
TI3-2		0	5	4	4	3
TI4-1		8	5	4	3	1
TI4-2		8	5			
TI4-3			5			
TI4-H						
TI5-5		3	5	4	3	2
TI5-H						
TI6-1		2	4	4	3	1
TI6-2		2	4	4	3	1
TI6-4		2	5	4	3	2
TI6-H						
TI7-1		4	7	4	3	1
TI7-2		4	7	4	3	1
TI7-3		4	7	4	3	1
TI7-H						
TI8-1			7	4	3	2
TI8-2						
TI8-3						
TI8-4			6	4	3	3
TI8-H						
TI9-1			5	4	3	3

Appendix 5: Field plot description data

SITEPLOT	EXPOSURE	EROSION	TEXTURE_FN	CS_TEXT_SH	CS_TEXT_SZ	CS_TEXT_V
BR1-1	5	3	5	2	1	3
BR1-3	5	0	3	2	1	3
BR1-4	5	0	6	2	1	3
BR1-5	5	0	4	2	1	3
BR1-6	3	1	3	2	1	3
BR1-H						
BR2-1	5	0	2	2	2	4
BR2-2	4	0	5	2	1	3
BR2-3	4	0	3	2	1	3
BR2-4	4	0	5	2	1	3
BR2-5	4	0	4	2	1	3
BR2-H						
BR3-3	5	0	5	2	1	3
BR3-4	5	0	5	2	1	3
BR3-H						
BR5-1	5	0	4	2	1	3
BR5-2	5	0	4	2	1	3
BR5-3	5	0	5	2	1	3
BR5-4	5	0	6	2	1	3
BR5-H						
BR6-1	2	0	2	1	1	3
BR6-2	3	0	4	1	1	3
BR6-3	4	0	4	1	1	3
BR6-H						
C41	1	0	3	3	1	3
C42	1	0	4	3	1	3
C43	1	0	4	3	1	3
C44	1	0	4	3	1	3
C45	1	0	4	3	1	3
C473-H						
CCF-H						
CCF1	1	0	5	1	1	3
CCF2	1	0	5	1	1	3
CCF3	1	0	5	1	1	3
CCG-H						
CCG1	3	0	5	3	1	3
CCG2	3	0	5	3	1	3
CCG3	3	0	5	3	1	3
CCSP-H						
CCSP1	3	0	5			
CCSP2	3	0	5			
CCSP3	3	0	5			
PL2-0	3	0	9			
PL2-1	3	0	5			
PL2-2	3	0	5			
PL2-3	3	0	5			
PL2-4	3	0	4			
PL2-5	3	0	4			
PL3-0	3	0	9			
PL3-1	3	0	9			
PL3-2	3	0	4			

Appendix 5: Field plot description data

SITEPLOT	EXPOSURE	EROSION	TEXTURE_FN	CS_TEXT_SH	CS_TEXT_SZ	CS_TEXT_V
PL3-3	3	0	4			
PL3-4	3	0	6			
PL3-5	3	0	6			
PL3-6	3	0	5			
PL1-0	3	0	5			
PL1-1	3	0	5			
PL1-2	3	0	5			
PL1-3	3	0	5			
PL1-4	3	0	4			
PL1-5	3	0	6			
PL1-6	3	0	9			
PL1-7	3	0	6			
PL1-H						
TI1-1	2	0	6			
TI1-H						
TI2-1	3	0	3	2	1	3
TI2-2	3	0	3	2	1	3
TI2-3	3	0	3	2	1	3
TI2-4	3	0	3	2	1	3
TI2-5	3	0	3	2	1	3
TI2-H						
TI3-1	2	0		2	1	3
TI3-2	2	0		2	1	3
TI4-1	5	0				
TI4-2						
TI4-3						
TI4-H						
TI5-5	3	0	3	2	1	3
TI5-H						
TI6-1	2	0	3	2	2	3
TI6-2	2	0	3	2	2	3
TI6-4	1	0	3	2	2	3
TI6-H						
TI7-1	2	0	5	2	1	3
TI7-2	2	0	5	2	1	3
TI7-3	4	0	5	2	1	3
TI7-H						
TI8-1	4	0		2	3	4
TI8-2						
TI8-3						
TI8-4	4	0				
TI8-H						
TI9-1	4	0				