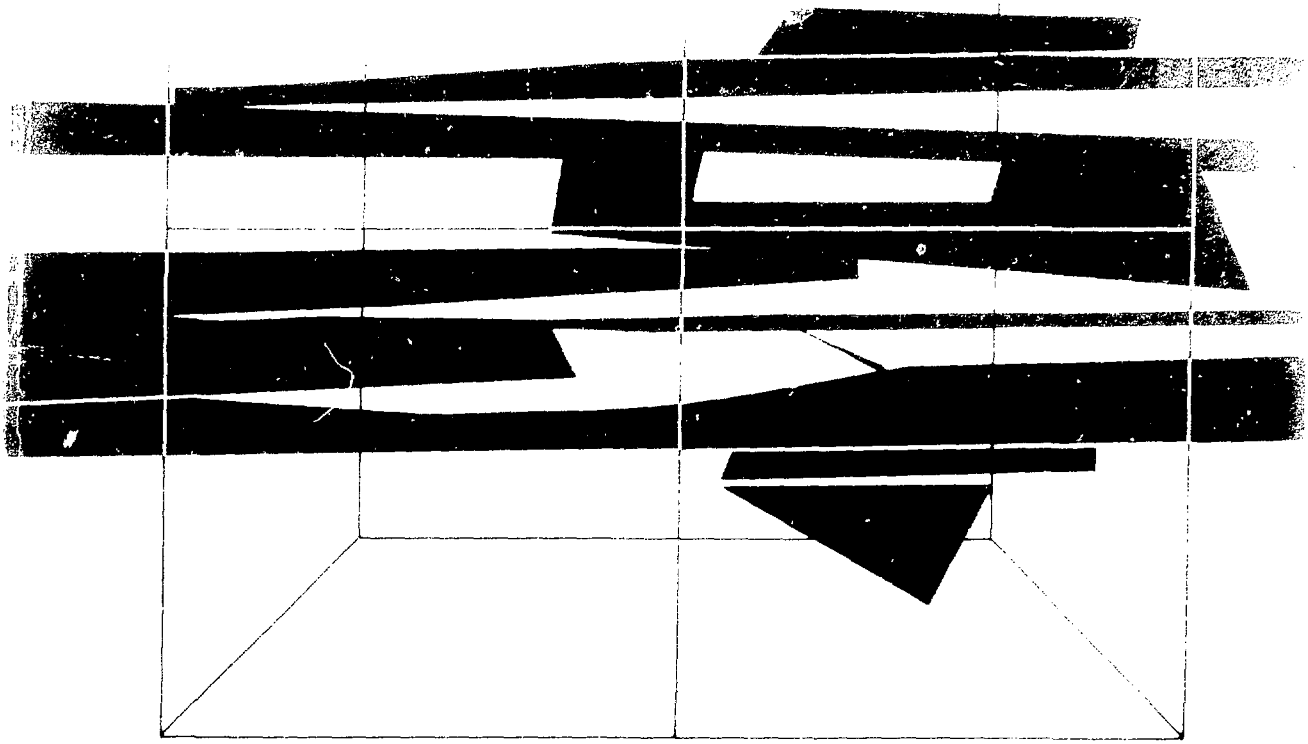
Long-term Ecological Behaviour of Abandoned Uranium Mill Tailings

2. Growth Patterns of Indigenous Vegetation on Terrestrial and Semi-aquatic Areas



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LONG-TERM ECOLOGICAL BEHAVIOUR OF ABANDONED URANIUM MILL TAILINGS

2. GROWTH PATTERNS OF INDIGENOUS VEGETATION ON TERRESTRIAL AND SEMI-AQUATIC AREAS

by

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for
Environment Canada,
Atomic Energy Control Board
Energy, Mines & Resources Canada

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ABSTRACT

Semi-aquatic and terrestrial areas on abandoned or inactive uranium mill tailings in Ontario were studied in order to identify the growth characteristics of the naturally invading species dominating these areas. Semi-aquatic areas of tailings sites have been invaded by cattails. These species formed wetland communities which varied in size, but all were essentially monocultures of *Typha latifolia, T. angustifolia*, or of the hybrids *T. glauca*. Sedges, *Scripus cyperinus* (wool-grass) and *Phragmites australis* (reed-grass), were found in transition zones between the cattail stand and the dry section of the tailings site. The expansion of the cattail stands appeared to be controlled by the hydrological conditions on the site, rather than the chemical characteristics of the tailings.

RÉSUMÉ

Les parties semi-aquatiques et terrestres de terrains abandonnés ou inutilisés de dépôt de résidus provenant du traitement de minerais d'uranium en Ontario ont été étudiées afin de déterminer les caractéristiques de croissance des espèces naturellement envahissantes, dominantes. Les terrains semi-aquatiques étaient envahis par les quenouilles. Celles-ci formaient des communautés plus ou moins grandes, constituées essentiellement d'une seule espèce: *Typha latifolia*, *T. angustifolia* ou l'hybride *T. glauca*. Le scirpe souchet, *Scripus cyperinus*, et le roseau *Phragmites australis* étaient présents dans les zones de transition entre le peuplement de quenouilles et la partie sèche du terrain. L'expansion des peuplements de quenouilles semble régie par les conditions hydrologiques plutôt que par les caractéristiques chimiques des résidus.

FOREWORD

Natural vegetation is invading the inactive/abandoned uranium mill tailings in Northern Ontario. A multi-year study was initiated in 1980 with the main objective to survey and identify the biota on the tailings in Bancroft and Elliot Lake areas of Ontario (Phase I) (EPS 4-ES-83-1). It was found that cattails (*Typhaceae*) stands colonized the semi-aquatic areas whereas trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*) were the dominant tree species on the terrestrial portions of the tailings. The objectives of the present investigation (Phase II) were to study the growth conditions and to assess the survival status of the ingressed vegetation under the prevailing ecological conditions. The project will eventually provide information of radionuclides transfer from tailings into the environment, and the data base will be used for future forecasting of potential environmental impacts. Again, it is hoped that the results of this study will be helpful to those involved in the management/regulatory aspects of the uranium mill tailings.

The research work was carried out under contract by Margarete Kalin of the University of Toronto. Funding for the project was jointly provided by the Atomic Energy Control Board, Environment Canada, and Energy, Mines and Resources Canada.

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Environment Canada

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The field work was accomplished in spite of rainstorms, mosquitos and blackflies, endured by Norm Cloutier, Will Gaherty and Dave Kay who collected data in the Elliot Lake area over a two year period. The students were hired by Rio Algom Limited and Denison Mines Limited for the summers of 1981 and 1982 to assist in the project. Without the dedication of the students and the financial commitment of the companies, this project could never have been fully realized.

I am especially grateful for the technical expertise of Guntis Brumelis and Norm Chudzinski who collected the data in Bancroft and completed all the work in the laboratory. Furthermore, I wish to acknowledge Norm's photographic expertise.

Special thanks are due to Katherine Frerot who prepared the report. I am indebted to Martin Smith for preparing maps and graphs as well as for reading drafts of the report. Caroline Caza deserves a special mention for many of her challenging questions which contributed throughout the years to the project. I am thankful for the encouragement I received during difficult periods of the project from J. Howieson and J. Coady. I also wish to thank A. Baweja who acted as Scientific Authority, and J. Wallach who provided editorial comments. In the final analysis, however, this report would never have been completed without the support of J.L. Yen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF MAPS

SUMMARY

Parameters of cattail growth such as density in the stand, height growth, reproductive development, and vegetative growth of the plants were studied in 13 cattail stands on the tailings over a two-year period. Data obtained were compared to five stands growing in non-tailings environments. The results led to the conclusion that cattails grow equally well in either environment, despite the extremely harsh growing conditions present on the uranium tailings. The only indication of stress on the plants was the higher number of fruits on the acidic tailings sites in the Elliot Lake area. The root zone of the cattails stands on the Elliot Lake and Bancroft tailings, however, were found to be respectively less acidic and more acidic than the surface region. These observations suggest that the roots have some control over the pH of their immediate environment.

Annual above-ground biomass production reflected the reproductive state of the cattail stands. In vegetative stands there were more leaves, whereas in reproductive stands, there were more stems and fruits. The biomass quantities of the cattails stands on tailings were in the same range as those of the control stands and were related in all cases to the stand density. Decomposition coefficients, determined after one year of biomass left to decay to litter, were found to be comparable to those in the control stands and to those reported in the literature. The total amount of litter in the tailings wetlands was determined from litter collections. Calculations concerning the anticipated quantity of litter in a cattail stand were based on a model. Decomposition coefficients and annual biomass input for the stands on the tailings were used to derive long-term litter accumulation values. These values were compared to the measured quantity of litter in each stand. Approximately half of the cattail stands have reached a 'steady state' on the tailings, where annual biomass input and decomposition are in equilibrium. The study of semi-aquatic areas on uranium mill tailings lead to the conclusion that the wetland communities are stable and growth will continue as long as the existing hydrological conditions prevail.

The basic growth characteristics of trembling aspen and white birch on uranium mill tailings were determined from the present study. The terrestrial areas of uranium mill tailings, where trembling aspens *(Populus tremuloides)* and white birch *(Betula papyrifera)* have colonized sections of inactive or abandoned tailings, exhibit diverse characteristics. Sites which have been revegetated with introduced grasses and legumes, such as Nordic in Elliot Lake and completely unamended sites in the Bancroft area (Auger and Bicroft Proper), both support tree stands. Trees have also colonized

uranium tailings both where the surface was only stabilized with limestone (Stanrock in Elliot Lake) and where sites were neutralized, fertilized and seeded once without further maintenance (Crotch in Elliot Lake). Regardless of the site condition and the time since amendment or abandonment, tree stands exhibited the same average height. Under all these site conditions, both trembling aspen and white birch grew and exhibited a net height increase per annum. Net growth occurred in all size classes of trees and ranged from 1 to 100 cm per year. The tree characteristics, however, reflected extremely poor site conditions, even on the sites which were fertilized annually. From the determinations of characteristics of selected stands in Bancroft and Elliot Lake it was inferred that the trees were stunted. Trees on non-tailings sites had attained the same height as the trees on the tailings, but in less time. The tree form (the relationship between height, trunk and crown diameter and number of branches), however, did not deviate from that expected in regenerating forests.

The establishment of tree populations on the tailings reflected ecological characteristics of the species. Trembling aspen root systems sometimes suckered, while white birches gave no such indication, suggesting that this tree population originated from seeds only. The height class composition of the tree stands differed between the two species because of this. White birch appeared to exhibit more stable, consistent growth than trembling aspen on the tailings, though both species were shallow rooted.

Investigations of the root region of trees indicated large pH differences within several centimetres of depth. In locations where alkaline and acidic layers were not clearly separated, establishment of both aspen and birch was low, compared to locations which had clearly separated pH strata.

Given the slow development of trees, the different establishment methods of new trees in stands, and the chemical characteristics of the root region on the tailings, development of these trees in the long-term cannot be determined.

The long-term development of semi-aquatic environments appeared considerably more stable as cattail growth was found to be extremely tolerant of the tailings conditions. The trees in the terrestrial environments, on the other hand, appeared to be growing at their limits of ecological tolerance. Thus, before the pathways of long-lived radionuclides in the terrestrial environment from the tailings can be delineated, further work is required.

INTRODUCTION

The movement of long-lived radionuclides from uranium mill tailings to surface waters and vegetation is governed largely by the ecological, chemical and physical characteristics of the tailings environment. During the operation of a mine, the tailings environment is maintained so that dispersal of radionuclides by air and/or through water is minimized. Any mining operation, however, has a finite life time which eventually renders the tailings sites unattended. The characteristics of the tailings environment gradually changes as colonization of indigenous vegetation progresses. Whicker and Shultz (1982) suggested that environments which support lush communities of high biomass generally contain a large fraction of radionuclides. The movement and accumulation of long-lived radionuclides and their partitioning between biotic and abiotic compartments of the ecosystem is affected by species diversity and community biomass. The pathways of radionuclides within the tailings environment and, in the long-term, the environment at large, is a reflection of the basic character of the colonizing communities.

In order to undertake pathways analysis for radionuclides migrating from uranium mill tailings to the environment, plant communities which are likely to colonize inactive tailings sites must be identified. Abandoned and inactive uranium mill tailings have already been investigated , where it was found that pioneering species are colonizing all of the waste sites to various degrees (Kalin, 1983). The establishment of some plant groups was shown to be particularly successful in dry areas of tailings sites and on tailings beaches (Kalin and Caza, 1982).

The objective of the present research was to determine whether these plant groups are forming stable habitats capable of long-term survival. More specifically, from May to August, 1981 and 1982 a study was made of the growth and development of indigenous primary colonizers in the semi-aquatic and the terrestrial environments of uranium mill tailings in Ontario.

1 SEMI-AQUATIC AREAS ON INACTIVE OR ABANDONED URANIUM MILL TAILINGS

1.1 Specific Objectives

The objective of the study of wet areas on tailings was to determine the growth dynamics of cattails and the species composition of the cattail stands on tailings sites in the areas of Elliot Lake and Bancroft. Above-ground biomass produced per year, the decomposition rate, and the litter accumulation were measured to indicate growth of the cattail population. These characteristics of the cattail stands on tailings were compared to characteristics of stands growing in undisturbed environments in both areas.

1.2 Methods and Materials

1.2.1 Description of Study Sites. In the past, uranium mill tailings were frequently deposited in natural depressions such as lakes or ponds, which were contained by dams at one or more of their boundaries. This process has often resulted in the retention of shallow water covering the surface of the tailings site. Similar shallow water bodies can be formed by surface water run-off collecting at low points. Tailings beaches are quite common on abandoned or inactive sites, often forming extensive stands (Plates 1a and 1b), or developing islands (Plate 2). In Table 1, information on the tailings sites and descriptions of the location of the cattail stands are summarized. The locations where cattails have established colonies have different characteristics. Some surface water input to the tailings appears to be present at all stands and water drains often result from surrounding slopes. The type of water input for each stand studied is described in Table 1.

Control stands were studied in order to compare the growth characteristics of cattails on the uranium mill tailings to cattail stands not associated with tailings. The control sites were located at least 200 m away from roadsides in order to prevent contamination by dust, although disturbance of the control stands by beavers and/or hunters could not be prevented. The locations of all study sites are shown in Map 1 for the Elliot Lake area and in Map 2 for the Bancroft area.

1.2.2 The Plants: Cattail Biology. Cattails, also referred to as reed mace, water torch, candlewick or flag tulex, are aquatic emergent macrophytes with erect annual herbage and a perennial creeping, stoloniferous rootstock. The cattail family, Typhaceae, consists of a single genus *Typha*, with an undetermined number of species in the world (Morton, 1975). In North America, about 15 morphologically similar species have been documented, and two major species, *Typha latifolia* and *Typha angustifolia*, are sympatric

PLATE 1a
OVERVIEW OF T-4 CATTAIL STAND (OLIVE). The shallow tailings beach was submerged by the end of August, 1982. The dried plants are growth from 1981 at the border of the dry portion of the tailings. Arrows indicate six permanent quadrats distributed throughout the stand.

PLATE 1b
VIEW OF CATTAILS (T-4) FROM THE TAILINGS BEACH ON OLIVE. In 1981 the tailings beach was exposed.

PLATE 2
OVERVIEW OF CATTAIL STAND D-5 (BICROFT PROPER). A narrow band of cattails and sedges are found on the beaches of the pond.

in central and eastern Canada (Smith, 1967). Hybridization and introgression are common, and cattail hybrids (*T. glauca*) are believed to be particularly tolerant of fluctuating environmental conditions. Cattails are dominant over large areas of marshland and are frequently a pioneer species colonizing disturbed semi-aquatic lands. They form an important source of food, cover, and building material for many kinds of wildlife (Martin et al., 1951).

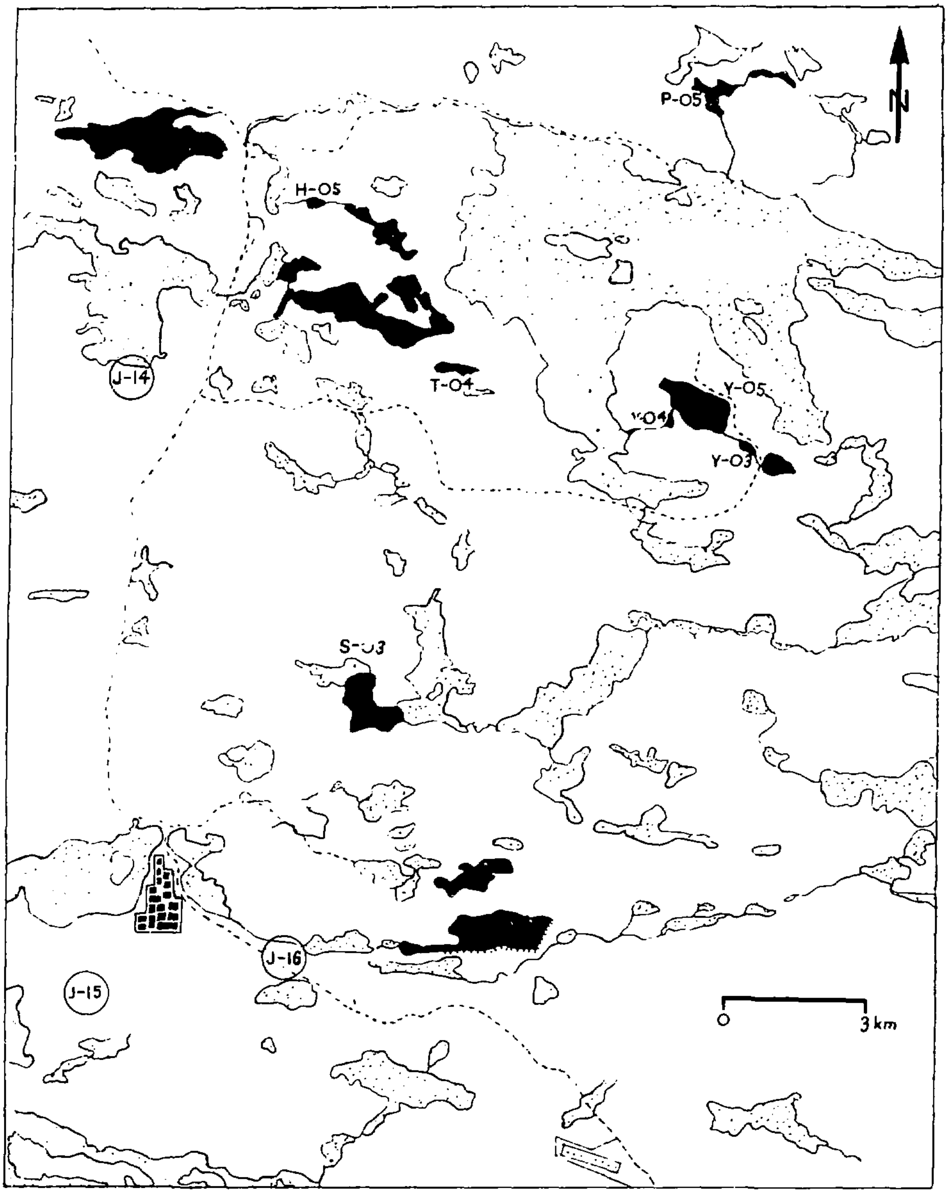
Cattails are wind pollinated and the fruits are wind dispersed. Seed germination and seedling establishment within an existing cattail stand are rare, but establishment from seed on bare soil in irrigation ditches and in rice fields has been reported (Smith, 1967). Vegetative reproduction in *Typha* is extremely effective and provides conditions which allow long-term survival of the plants, as well as the spread of clones which can be partially or completely sterile. McDonald (1951) reported a hybrid cattail stand on the shores of Lake Erie that was spreading about 5.5 m/yr vegetatively. The ability of *Typha* to hybridize and backcross so readily is believed to provide this genus with an increased ecological amplitude to pioneer in extremely harsh and barren environments. *Typha* is reported to be tolerant of salt (Smith, 1967); tolerant of elevated

TABLE I CHARACTERISTICS OF SEMI-AQUATIC AREAS ON URANIUM MILL TAILINGS IN BANCROFT AND ELLIOT LAKE

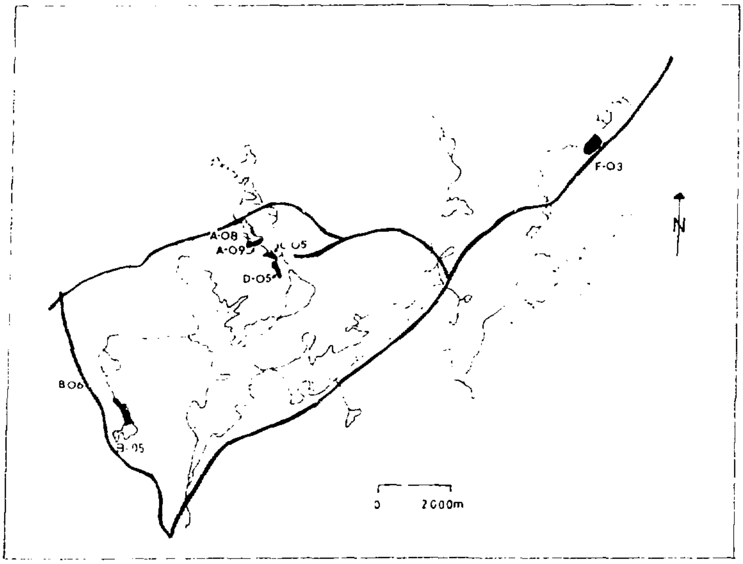
Site Code	Former Land-form of Tailings	Tailings/Water Contact (length of beach)	Est. Area of Cattail Stand in 1982 (m^2)	Surface Water Input to Stand	Age of Site in 1982	Amendment of Site
A8	lake	tailings beach (500 m)	1000	none	19	none
A9	lake	tailings beach (500 m)	600	drainage from swamp	19	none
C5	swamp	seepage from tailings and tailings spill	13 000	drainage from tailings and surroundings	19	flooded in 1982
D5	bog with small pond	tailings beach (700 m)	700	intermittent creek	25	none
F3	lake	tailings beach (100 m)	300	none	18	stand covered with overburden in 1982
H5	swamp with pond	tailings beach (160 m)	3300	treated water seepage	23	treatment pond
P5	swamp with pond	shallow water over tailings	36 400	surface drainage	21	some liming on west end
S4	lake	tailings beach (1.5 km)	700	surface drainage	22	some liming on dry areas
T4	lake	tailings beach (610 m)	4700	surface drainage	23	revegetated dry areas
Y3	creek	tailings spill with creek	5000	surface drainage	18	diversion of seepage
Y4	creek	tailings spill with creek	1600	creek and road ditch drainage	18	treatment of seepage
Y5	valley	creek on tailings	500	surface drainage	18	liming on dry areas

A = AUGER
D = BICROFT PROPER
H = WILLIAMS
S = CROTCH
Y = STANROCK

C = BICROFT SWAMP
F = MADAWASKA
P = PANEL
T = OLIVE



MAP 1 CATTAIL STAND LOCATIONS IN THE ELLIOT LAKE AREA. Circled site codes are the locations for the control stands.



MAP 2 CATTAIL STAND LOCATIONS IN THE BANCROFT AREA. Circled site codes are the locations for the control stands.

heavy metal concentrations in soils (McNaughton et al., 1974 b); and also tolerant of high acidity in water (Hargreaves et al., 1970).

The occurrence of cattails in the wet areas of the tailings was expected, because of their ability to adapt to harsh environmental conditions. Reproductive vigor and tolerance, however, do not necessarily guarantee successful growth and long-term survival in harsh environments. The tailings may exert toxic effects on the plants which could impair growth and reproduction.

1.2.3 The Cattail Stands: Plant Growth.

Species richness and ground cover. The stands were surveyed extensively several times throughout the growing seasons of 1981 and 1982 for vascular and non-vascular plants. Specimens were collected, dried, pressed and identified, and voucher specimens were forwarded to the Herbarium of the Royal Ontario Museum, Toronto.

Permanent quadrats (1 m^2) were established within each cattail stand. Depending on the size of the stands, twelve (12) or six (6) quadrats were evaluated. Percentage ground cover was estimated for each species within these quadrats. In some cases, line transects were used in addition to the quadrats.

Growth of cattails. Within each stand, six of the permanent quadrats were marked with posts. The quadrats were randomly distributed in the stands. Within each quadrat the depth and temperature of the water as well as the temperature of the air and relative humidity were measured. These measurements were made at least three times in each quadrant over the season. In addition, the pH of the surface water and the electrical conductivity and the pH of the root region (tailings or soil) were also measured in each quadrat. Root region measurements were obtained by immersing the instrument probes alongside a hand trowel to the desired depth. The immersion of the probes had to be carried out quickly to avoid mixing of the surface water. Surface water was used, where present, to wash the probes free of tailings slurry, after which, the probes were rinsed with distilled water.

From May to August of 1981 and 1982, the number of shoots and fruits were counted in each quadrat. In May of 1981, a maximum of 15 plants were marked. On these plants the number of leaves were counted and the height of the tallest leaves was measured (Plates 3a and 3b). This was accomplished by submerging a metre stick on an elastic band to the depth at which the stick met resistance alongside the plant. These measurements on individual plants were used to evaluate growth rates in the stands. During June and August of 1982, only the number of shoots and the number of fruit bearing plants were counted.

Aerial biomass, litter accumulation and decomposition. Prior to the initiation of the 1981 study, all of the previously accumulated litter was removed from four of the six quadrats within each stand in order to obtain 'total litter accumulation' for each cattail stand. At the end of the growing season, aerial growth was harvested in two quadrats; from one quadrat litter was removed and in the other it was left undisturbed. From this harvest, the annual above-ground biomass production was derived and possible effects of litter removal on growth were evaluated. To assess decomposition, litter was collected in August, 1982 in a quadrat where all previously accumulated litter had been removed, but the growth of the 1981 season remained.

Preparation of biomass collection. The fresh aerial growth was sorted into thick leaves (vegetative shoots), brown leaves (senescent leaves), green leaves, stems and fruits, then air dried for three days before weighing (fresh weight). The material was washed under tap water with some detergent added to act as a surfactant, then rinsed several times in tap water and finally rinsed in distilled water. The dry weight was taken after drying the biomass at 75°C for seven days. The dried material was then pulverized with a Wiley Mill to 20 mesh and the resulting powder stored in snap-top vials.

PLATE 3a
A QUADRAT ON SITE F-3 (MADAWASKA). At the beginning of the growing season, the shoots were marked loosely with tags.

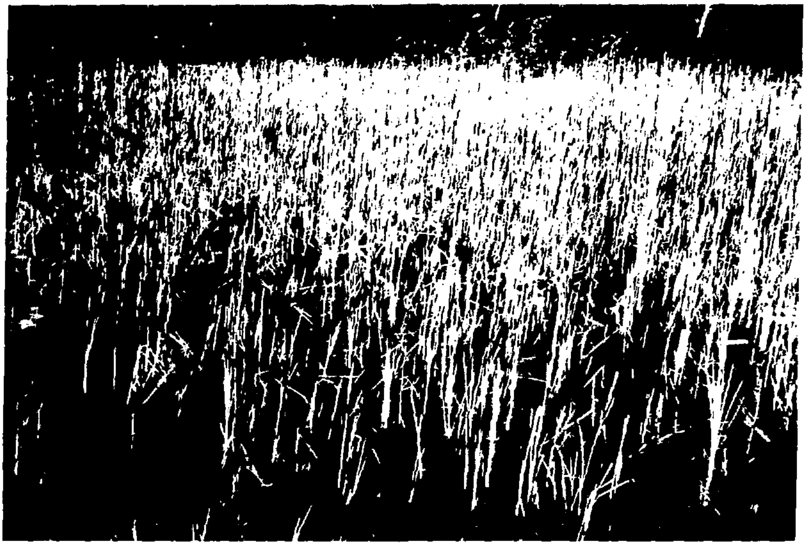


PLATE 3b
QUADRATS ON D-5 (BICROFT PROPER). The loose tags around the shoots moved higher as growth occurred. Fruit bearing shoots from the previous year still carry some seeds.

The original collections of accumulated litter and the litter collected after one year of decomposition were also sorted into stems, leaves and fruits, dried at 75°C for three days, weighed, and ground. In this case the litter was not washed because washing of the material could leach some elements. The analysis of the litter represents the elemental concentrations which have accumulated in the decomposing matter.

1.3 Results and Discussion

1.3.1 Physical and Chemical Characteristics of the Cattail Stands. Growth of plants is generally affected by weather conditions. The initiation of growth, the formation of inflorescences and the ripening of seeds all influence the ability of a species to propagate, while variations in temperature can severely affect any of these stages of plant development. Climatic ecotypes have been reported by McNaughton (1966) for *Typha latifolia*, the common cattail. Growth of cattails is also affected by water depth (Bedish, 1967; Weller, 1981). Since these factors could affect growth of the cattails, their measurement was necessary.

Air temperature, relative humidity, water temperature and depth in the cattail stands are summarized in Table 2. All values represent averages of the four or five observations made between May and August of 1981.

The air temperatures measured for the stands on tailings and in control areas at both Bancroft and Elliot Lake were essentially within the same range. At Elliot Lake, the water temperature was generally 2° to 4°C lower than the air temperature. The seasonal average water levels fluctuate drastically at both Elliot Lake and Bancroft. On shallow sites, the coefficients of variation are almost equal to one. In cattail stands where water depths are greater than 10 cm, seasonal fluctuations are about 30 to 40 percent of the average depth. Substantial changes in water temperature were expected, because of the fluctuation in water depth. At Elliot Lake the fluctuations were not realized until June and July when variations of up to 18°C were noted between stands (Figure 1). In May, at the beginning of the season, the temperatures differed by only 6°C and in August they varied by 11°C.

All cattail stands are surrounded with humid air, and Elliot Lake's relative humidity was slightly lower than at Bancroft. However, differences in relative humidity may be more of a sampling artifact than real, because it rained during every field trip to Bancroft whereas at Elliot Lake rainy days could be avoided. Furthermore, the Bancroft field trips were plagued by bad luck with the thermometer. It was forgotten, lost and broken in sequence for every trip, thus resulting in the absence of water temperature measurements for Bancroft.

TABLE 2 SELECTED PHYSICAL CHARACTERISTICS OF CATTAIL STANDS FROM MAY TO AUGUST, 1981

SITE CODE	AIR TEMPERATURE (°C)	RELATIVE HUMIDITY (%)	WATER TEMPERATURE (°C)	*WATER DEPTH (cm)
		BANCROFT		
A-8	23± 3	86± 15	-	1.7 ± 2
A-9	24± 4	89± 13	-	0.7 ± 1
C-5	30± 3	86± 18	-	46 ± 9
D-5	24± 3	81± 15	-	12 ± 4
F-3	26± 6	80± 11	-	7 ± 6
		BANCROFT CONTROLS		
B-5	25± 5	87± 13	-	0.3 ± 1
B-6	24± 4	81± 10	-	2.5 ± 3
		ELLIOT LAKE		
H-5	23± 4	69± 18	20± 5	4.5 ± 5.7
P-5	19± 4	83± 13	15± 1	7 ± 6
S-4	24± 4	80± 17	19± 4	4 ± 4.5
T-4	20± 2	76± 15	20± 3	0.07 ± 0.2
Y-3	18± 4	76± 14	16± 2	2.1 ± 2.7
Y-4	18± 4	77± 17	17± 3	0.3 ± 0.7
Y-5	19± 4	71± 19	19± 2	0.7 ± 1.3
		ELLIOT LAKE CONTROLS		
J-14	21± 2	66± 15	19± 4	3 ± 4
J-15	21± 3	67± 22	18± 2	13 ± 4
J-16	24± 5	78± 17	20± 4	3 ± 3
		BANCROFT AREA AVERAGE		
	25± 5	84± 15	-	12 ± 17
		ELLIOT LAKE AREA AVERAGE		
	20± 14	76± 17	18± 4	2.7 ± 4.5

* Standard error is very large compared to the mean because there were many small values and a few large ones.

Since the average daily air temperatures observed during this study are comparable to the daily maximum reported by Environment Canada for Bancroft and Elliot Lake from 1941 to 1970 [Atmospheric Environment Service (1971)], the year 1981 is considered an average year. The variations in water temperature within one cattail stand

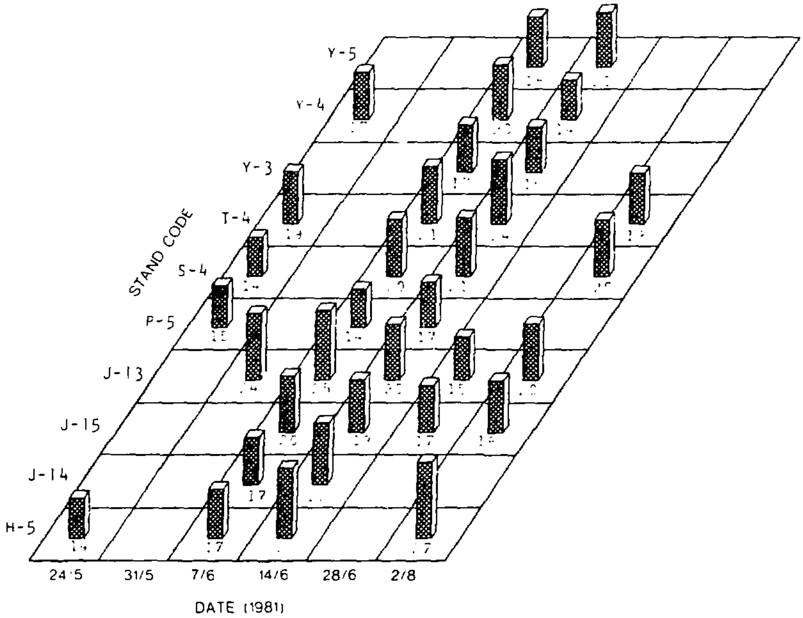


FIGURE 1 WATER TEMPERATURE IN CATTAIL STANDS IN ELLIOT LAKE. Seasonal trends for each stand are presented along the horizontal plane, and differences in water temperatures between the stands are plotted along the vertical plane. The blocks represent the mean temperature of the six quadrats in the stand.

are as large as those between stands. The temperature differences are not consistent enough over the season to affect the growth. A linear correlation analysis revealed no significant relationship between most characteristics discussed, with the exception of air and water temperatures. Those were somewhat related to each other by $r = 0.539$ and $p < 0.0001$. This correlation was expected since shallow water is warmer.

The soil or tailings in which the cattails grow show drastic differences. In Figure 2, ranges of electrical conductivity are depicted for the Elliot Lake tailings, the Bancroft tailings and all control sites combined. The variations of all parameters observed between control stands of Elliot Lake and Bancroft and within the stands were not significantly different from each other. Thus, all control stands were combined to compare the tailings stand characteristics with those of the control stands. The vertical lines in Figure 2 represent the ranges of values (minimum and maximum) for each group of cattail stands from May to August, 1981. The average seasonal electrical conductivity for Elliot Lake was 1106±935 µmhos/cm, 1161±785 µmhos/cm for Bancroft, and

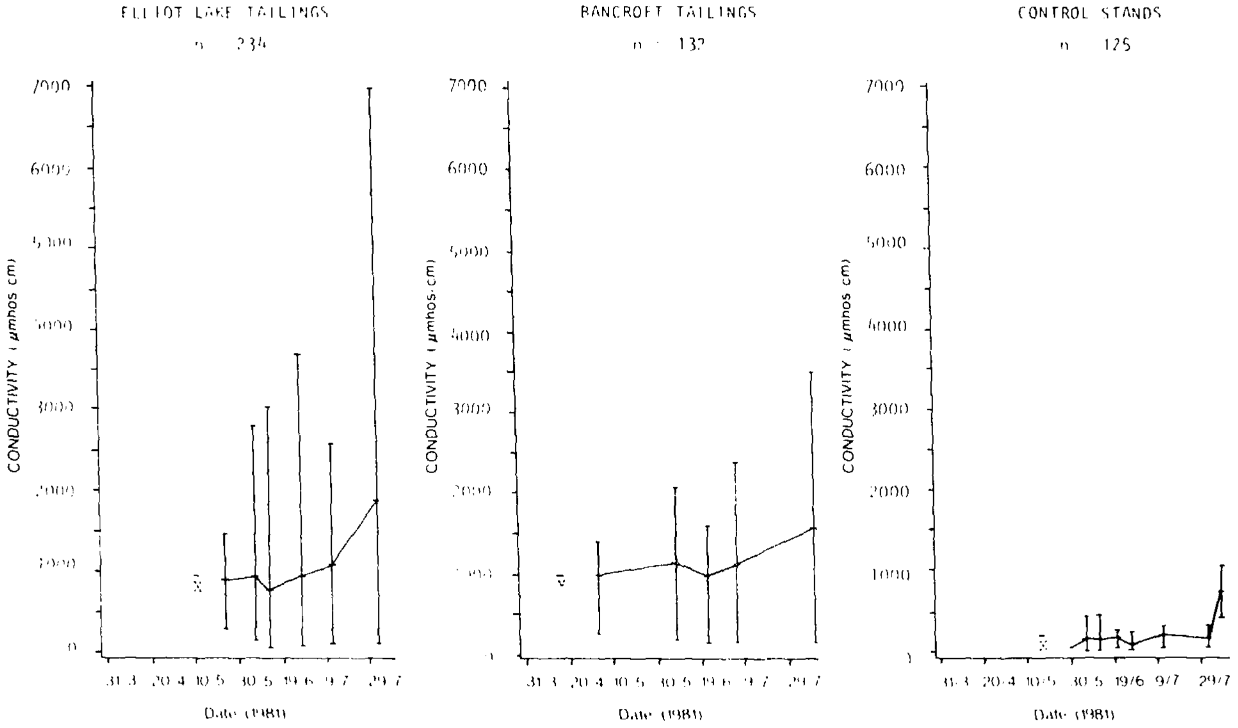


FIGURE 2 ELECTRICAL CONDUCTIVITY IN THE ROOT REGION OF CATTAILS. Vertical lines indicate minimum and maximum values measured for the given time intervals of 20 days.

222±187 µmhos/cm for the controls. The seasonal average electrical conductivity on the tailings in Elliot Lake and Bancroft are approximately equal and five times higher than that of the control sites. A slight seasonal trend is noticeable in August as maximum values are generally higher, possibly a reflection of less precipitation during this month. The magnitude of the ranges encountered throughout the season clearly differentiates the tailings sites from the control sites. The electrical conductivity measurements were obtained in the root region. It might be expected that these extremely large ranges would have some effect on cattail growth.

As electrical conductivity indicates the presence of dissolved material, and hydrogen ion concentrations influence the solubility of minerals, differences in pH values for the cattail stands were expected. The pH values of the water on the surface of the tailings and the water at root depth are presented in Figures 3a, 3b. Minimum and maximum values are reported for each 20-day period. Seasonal trends of the pH values are neither pronounced on the surface nor in the root region. The ranges of pH values encountered on the surface of Elliot Lake tailings, however, are clearly larger than on the Bancroft tailings and extremely large compared to those on the control sites (Figure 3a). In general, the pH values in the root region of the tailings stands differ from those on surface, whereas the control stands have pH values which are more or less identical in the root region and on the surface (Figure 3b). The ranges of pH values in the root region of the cattails on the Bancroft tailings are only slightly different from those in the control stands.

In Elliot Lake some of the high values recorded in the root region for July and August may be misleading. They represent only five observations from a total of 165 measurements. These values are likely the result of the mixing of limed surface water with the root region, and thus do not reflect the prevailing conditions around the roots. An upper limit of pH values for the root region in tailings is realistically around pH 7 and the lower limit at pH 3.5. For the surface, in contrast, the upper limit is at pH 8.5 and the lower limit around pH 2.5 to 3.0. These limits are based on the maximum and minimum pH values found in a cattail stand. Clearly the Bancroft sites and the control sites do not display such large ranges as the tailings in Elliot Lake (Figures 3a and 3b).

The physiological effects caused by pH and electrical conductivity are important in relation to plant growth. High concentrations of electrolytes in soil solutions, expressed by the electrical conductivity (Figure 2), affect the osmotic retention of water and have a specific ionic effect on the protoplasm of plants. At pH values below three and above nine, the protoplasm of the root cells of most vascular plants are severely

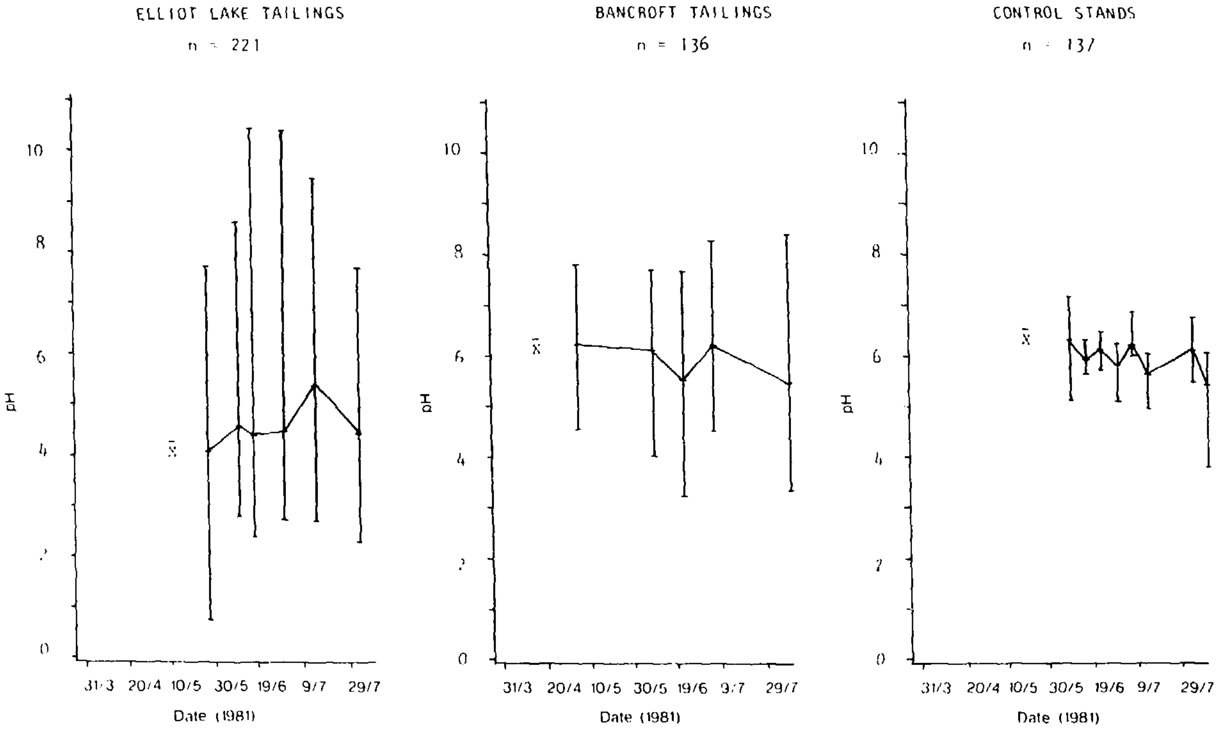


FIGURE 3a FIELD MEASUREMENTS OF pH ON THE SURFACE IN CATTAILS STANDS. Vertical lines are the minimum and maximum pH values observed in 20-day intervals.

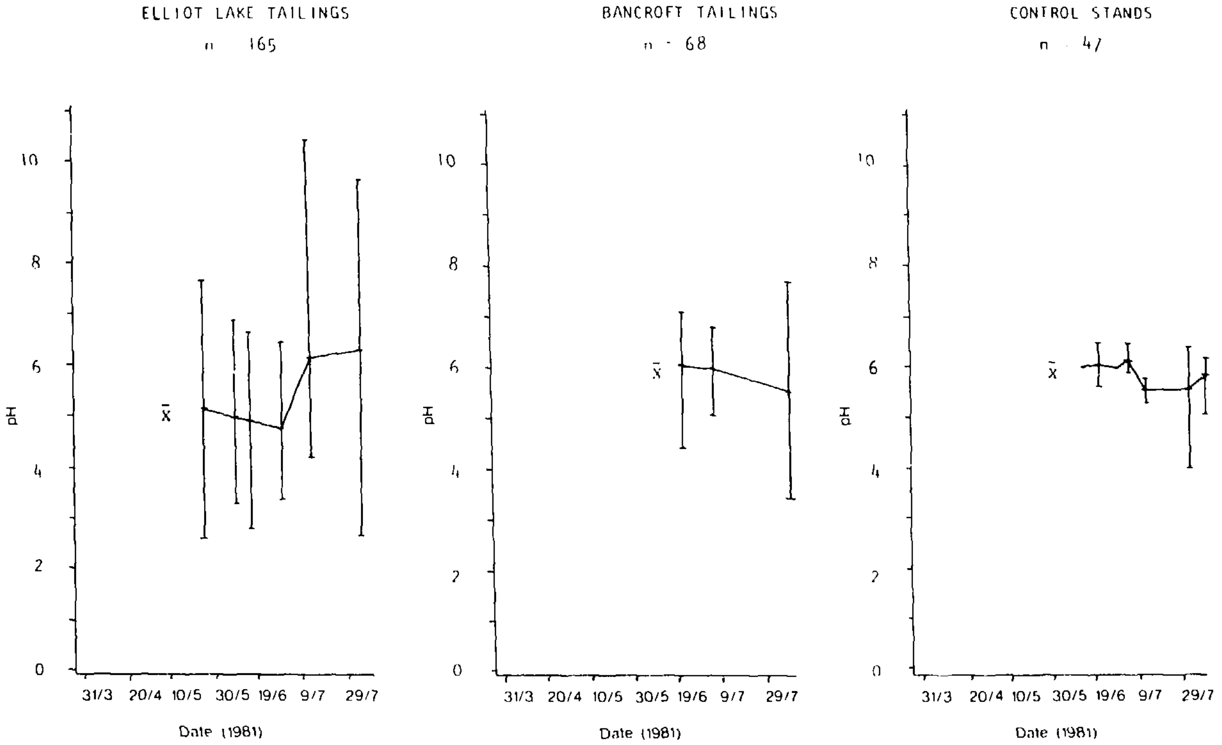


FIGURE 3b FIELD MEASUREMENTS OF pH IN THE ROOT REGION IN CATTAIL STANDS. Vertical lines are the minimum and maximum pH values observed in 20-day intervals.

damaged. The tolerance limits for most vascular plants are generally believed to be between pH 3.5 and pH 8.5 (Larcher, 1980). As well, very acidic soil solutions often increase concentrations of toxic metals and may, therefore, accentuate adverse conditions for plant growth.

The extreme ranges of pH values on the surface and in the root region of the tailings stands, and particularly in Elliot Lake, may result in growth differences in some locations within the stands (Figures 3a and 3b). A detailed evaluation of the pH in the cattail stands is given in Tables 3a, 3b and 3c. All pH values observed from May to August are reported as mean pH along with minimum and maximum pH values measured on each site. As shown in Figure 3, the differences on the control sites for pH values between the surface and the root region were small. Similarly, the mean pH differs little on these sites (Table 3a). The differences are expressed in hydrogen ion activity and range from 9.0×10^{-8} to 1.15×10^{-5}.

For the Bancroft sites, the differences between the surface hydrogen ion activity and those of the root region also cover three orders of magnitude (1.5×10^{-7} to 1×10^{-4}), but a shift towards a higher hydrogen ion activity of one order of magnitude has occurred (Table 3b). Indeed, it can be noted that in the root regions at Bancroft, pH values tend to be around 5.4 to 6.7, close to those values observed on the control sites. The mean pH values in the root region on Bancroft sites are very similar to those on the control sites, regardless of whether the surface is acidic or alkaline (as exemplified for sites F-3 and D-5 or A-9).

For the cattail stands in Elliot Lake, the differences between the surface and the root regions range from 3.8×10^{-6} to 2.3×10^{-3} hydrogen ion activity (Table 3c). The mean pH in the root region for S-4, Y-3, Y-4 and Y-5 is considerably lower than in Bancroft and on the control sites. The values indicate, though, that the pH in the root region is never outside of the tolerance limits already quoted, at which protoplasm damage of the root cells occurs. On the surface, however, where microbial acid generation contributes to the hydrogen ion concentration, the tolerance limits of the plants would frequently be exceeded at the lower pH limit and liming of the tailings surfaces results in the extreme ranges observed in Figure 3, possibly exceeding the upper limits of tolerance.

From these considerations of pH and hydrogen ion activity in cattail stands, it is evident that the plants in Elliot Lake generally grow under more acidic conditions than on the other sites. When the root region is observed, however, it can be seen that the pH values lie within the tolerance limits at which plants are expected to function

TABLE 3a: pH AND HYDROGEN ION ACTIVITY IN CATTAIL STANDS FOR CONTROL SITES

Site Code	Minimum pH Value	Maximum pH Value	Mean pH	Mean H^+ Activity	ΔH^+ Roots-Surface
B-5 surface	3.8	6.9	5.05	8.74×10^{-6}	(7.28×10^{-6})
B-5 roots	5.1	6.3	5.83	1.46×10^{-6}	
B-6 surface	5.1	6.4	5.89	1.29×10^{-6}	(3.4×10^{-7})
B-6 roots	5.6	6.5	6.02	9.50×10^{-7}	
J-14 surface	5.0	7.2	5.49	3.23×10^{-6}	(1.097×10^{-5})
J-14 roots	4.0	6.4	4.84	1.42×10^{-5}	
J-15* surface	5.8	6.8	6.19	6.37×10^{-7}	
J-16 surface	5.6	6.8	5.95	1.09×10^{-6}	(9.0×10^{-8})
J-16 roots	6.0	6.0	6.00	1.00×10^{-6}	

*J-15 - the water was too deep to obtain root measurements

TABLE 3b pH AND HYDROGEN ION ACTIVITY IN CATTAIL STANDS FOR BANCROFT

Site Code	Minimum pH Value	Maximum pH Value	Mean pH	Mean H^+ Activity	ΔH^+ Roots-Surface
A-8 surface	5.1	6.5	5.64	2.24×10^{-6}	(1.85×10^{-6})
A-8 roots	5.0	6.1	5.38	4.09×10^{-6}	
A-9 surface	3.2	7.8	4.06	1×10^{-4}	(6.6×10^{-5})
A-9 roots	3.4	6.5	4.46	3.44×10^{-5}	
C-5* surface	5.9	7.3	6.19	6.34×10^{-7}	
D-5 surface	3.6	6.5	4.39	4.00×10^{-5}	(1.87×10^{-5})
D-5 roots	3.7	6.2	4.67	2.13×10^{-5}	
F-3 surface	7.0	8.4	7.42	3.76×10^{-8}	(1.50×10^{-7})
F-3 roots	6.1	7.7	6.72	1.88×10^{-7}	

*C-5 - the water was too deep to obtain root measurements

TABLE 3c pH AND HYDROGEN ION ACTIVITY IN CATTAIL STANDS FOR ELLIOT LAKE

Site Code	Minimum pH Value	Maximum pH Value	Mean pH	Mean H^+ Activity	ΔH^+ Roots-Surface
H-5 surface	3.3	10.5	4.63	2.29×10^{-5}	(3.8×10^{-6})
H-5 roots	3.7	9.7	4.57	2.67×10^{-5}	
P-5 surface	3.0	7.1	3.80	2×10^{-4}	(2×10^{-4})
P-5 roots	5.4	10.5	6.14	7.24×10^{-7}	
S-4 surface	0.7	6.5	2.13	7.3×10^{-3}	(7.1×10^{-3})
S-4 roots	2.6	6.0	3.70	2×10^{-4}	
T-4 surface	2.5	6.6	3.08	8×10^{-4}	(8×10^{-4})
T-4 roots	4.0	7.6	5.04	8.98×10^{-6}	
Y-3 surface	2.9	6.6	3.81	2×10^{-4}	(1×10^{-4})
Y-3 roots	3.5	6.6	4.29	1×10^{-4}	
Y-4 surface	1.3	6.5	2.59	2.5×10^{-3}	(2.3×10^{-3})
Y-4 roots	2.7	6.7	3.63	2×10^{-4}	
Y-5 surface	2.4	6.1	3.26	5×10^{-4}	(4×10^{-4})
Y-5 roots	2.8	6.6	3.90	1×10^{-4}	

physiologically without severe effects. Nevertheless, the surface conditions of the tailings sites in Elliot Lake subject the plants in isolated quadrats to possibly damaging conditions (Figures 3a and 3b).

In addition to pH and electrical conductivity, metal toxicity and nutrient availability should be considered if growth is evaluated on waste sites. Kalin and Sharma (1981) reported concentrations of Ra-226 and Pb-210 in cattails from the same tailings sites discussed in this report. Pb-210 and all of the lead isotopes (referred to as Pb total) remained in the roots of the plants and were not transported in significant fractions to the aerial parts of the plants. McNaughton et al. (1974b) in their investigation of the metal tolerance of *Typha latifolia* concluded that no evidence could be found for genotypes resistant to elevated metal concentrations; in fact, a slight inhibition of cattail (*Typha latifolia*) growth was reported on soils with high metal concentrations. This was explained as a peculiarity of *Typha* physiology compared to other plants.

In cattails, the chemoecotypic response as defined by Larcher (1980) can be expected, which may explain some metal tolerance of the genus. It is unlikely that the growth of cattails on the tailings would be impaired due to metal concentrations; however, these specific aspects of cattail growth were not addressed in detail in this study.

The availability of nutrients to plants will also affect growth. Boyd and Hess (1970) correlated an increase in the standing crop of shoots for *Typha latifolia* with increasing concentrations of dilute, acid soluble phosphorus in the soil and dissolved phosphorus in the water. From his work it would follow that the control stands of this study should have a larger standing crop than the tailings sites where the available phosphorus is extremely low (Caza, 1983; Murray, 1977). McNaughton et al. (1974) reported that differences in root temperature can result in differences in leaf water content which, in turn, can affect phosphorus uptake. Water content of leaves may also be considered as an indication of growth conditions (Table 8).

In summary, the values of pH and electrical conductivity of the tailings sites along with theoretical considerations and a review of the literature, suggest that cattail growth could be impaired on uranium mill tailings sites. The question as to whether or not these cattail colonies on tailings exhibit growth characteristics which indicate that existence of the stands will continue in the future, is of primary importance.

1.3.2 The Species Composition of the Cattail Stand. Harsh environments are generally invaded by aggressive pioneering species and usually exhibit a low species richness. Brinson, Lugo and Brown (1981) referred to wetlands as freshwater ecosystems or as monocultures meaning that the community was dominated by a single species. Wetlands dominated by *Typha* species are common. Mason and Bryant (1975) reported that communities dominated by *Typha angustifolia* and *Scripus lacustris* have a lower species richness than those dominated by *Phragmites communis* reeds. Environmental conditions are, however, seldom so severe that only one organism occupies the habitat, rather than a range of organisms characterized by different sizes, habits and abundances comprising an ecological community. In order to predict the long-term development of a particular environment or a community, therefore, all of the species within the community must be evaluated.

In Figure 4, the number of species found in cattail stands on tailings in Bancroft and Elliot Lake, can be compared to three control stands. In stands on the tailings, usually only one or two species were identifiable. On two tailings shores in Bancroft (A-8 and A-9) the species richness is higher than on the other tailings sites in Bancroft (D-5, C-5 and F-3), and is close to that of the control stands. Drastic changes in submergence of these two tailings beaches have been observed since the beginning of ecological studies in 1979. These may be partly contributing to the noted species richness. For all other stands investigated, the species richness within the stands was low, i.e., mainly monocultures of cattails. The data concerning species richness of the control stands and those on the tailings are in general agreement with data found in the literature.

Some interesting observations can be made from estimates of the percentage ground cover of each of the major species (Figure 5). On sites A-8 and A-9 in Bancroft, *Juncus pelocarpus* (brown-fruited rush) occupied a large percentage of the area in nearly all quadrats and grasses (Gramineae) and some *Potamogeton* spp. (pond weed) occupy a significant fraction (Plate 4). On the control sites, only grasses were found to occupy significant areas within the cattail stand along with some *Lycopus* spp. (water hoarhound). *Juncus brevicaudatus* (narrow-panicled rush) occurred mostly on the acidic sites in Elliot Lake along with some *Carex canescens* (silvery sedge).

Generally, *Typha latifolia* is the dominant cover, providing an average of 40 to 60 percent of the vegetation cover in the wetlands (Figure 5). These cover estimates do not consider mosses, and it was found that areas where vascular plants provided a sparse cover were carpeted with mosses. *Leptobryum pyriforme* and *Pohlia nutans* were the most frequently encountered moss species in the cattail stands.

At the edges of the stands and in transition zones from wet to dry areas, changes in species dominance were observed on site T-4. Here, a belt of *Phragmites communis* (common reed-grass) invades the drier base areas. *Scripus cyperinus* (wool-grass) hummocks are also frequently found in these transition zones along with *Carex*

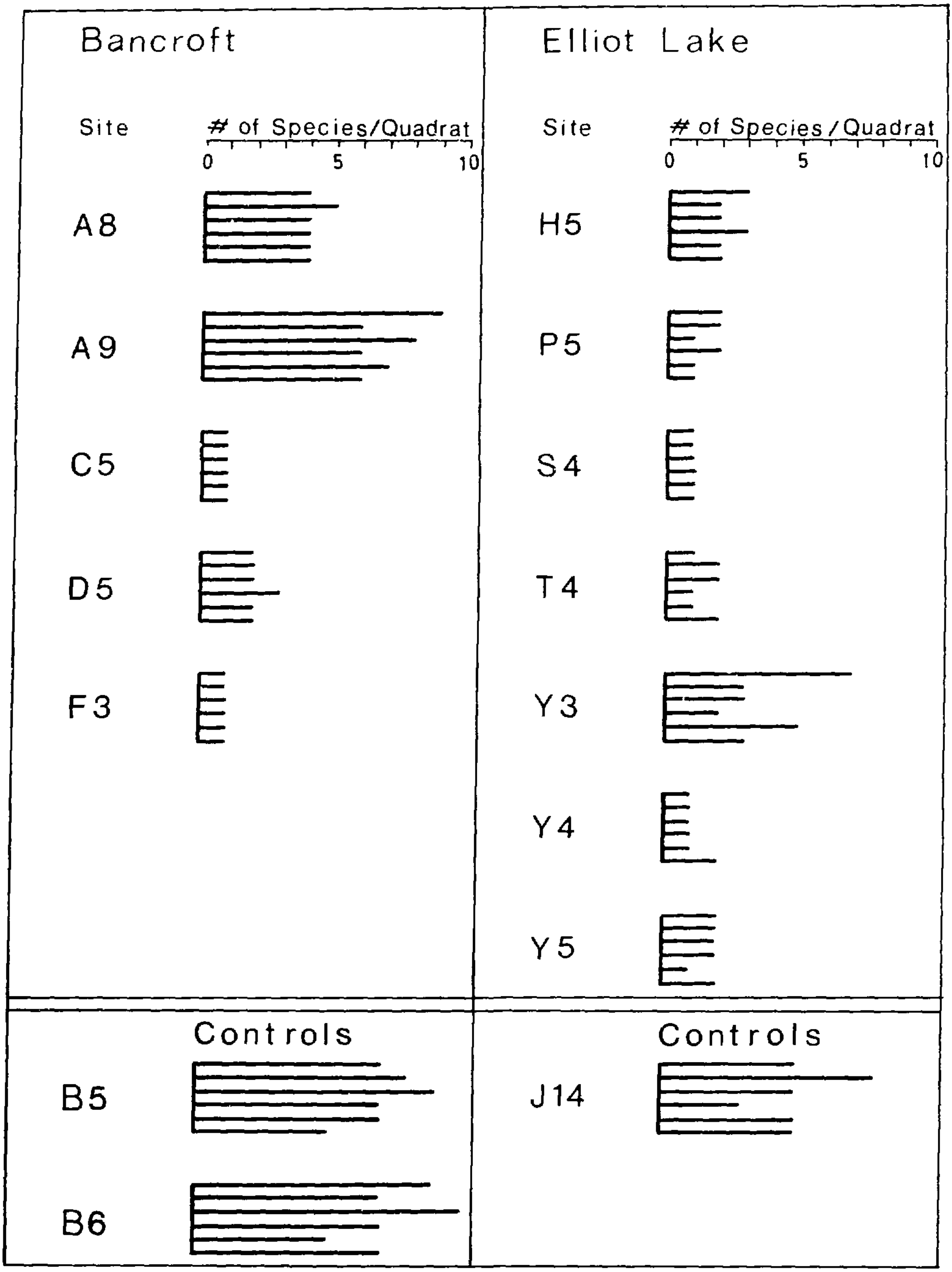


FIGURE 4 SPECIES RICHNESS IN CATTAIL STANDS. The number of species in each of the six quadrats for each stand are given for Bancroft, Elliot Lake and the control locations.

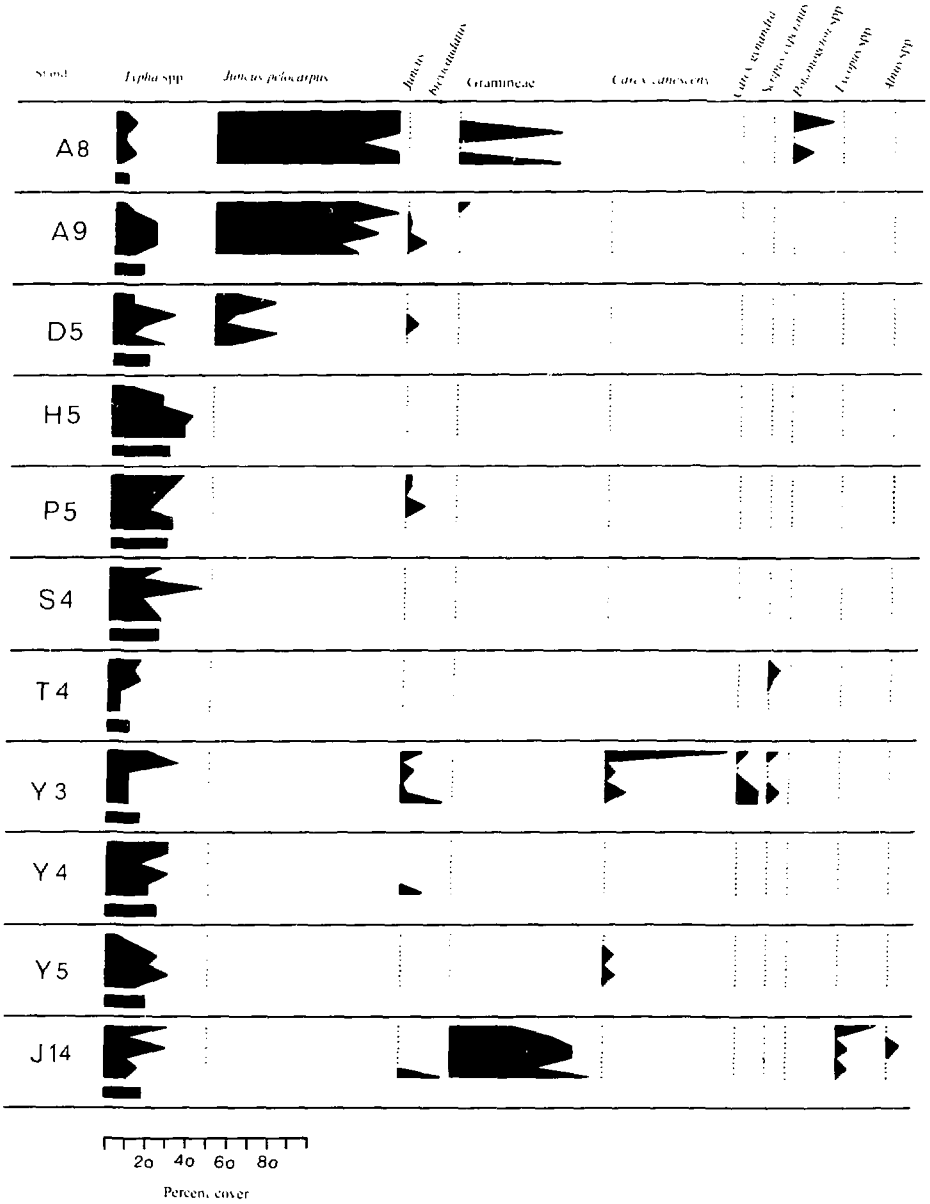


FIGURE 5 COVER ESTIMATES OF SPECIES IN CATTAIL STANDS. The percentage cover is given to scale, evaluated for each species within 6 m^2 for the stands. For *Typha* spp. the bars at the bottom of the stand represent the average *Typha* cover for the stand.

PLATE 4
VEGETATION COVER ON A-8 (AUGER). G. Brumelis holds the bags containing the accumulated cattail litter.

gynandra (nodding sedge) (Plate 5). The occurrence of wool-grass is not restricted to wetland areas on tailings alone; frequently, large numbers of individuals of this species occupy water-logged areas within revegetated sites.

The transition zones of the cattail stands were investigated in some detail to determine the expansion rate of the cattail stands. It was found that topographical factors and water saturation influence the expansion of the limits of aerial extent of the cattail stands. For the stands where the boundary between dry and moist areas was very distinct (H-5 and D-5), no expansion of cattail growth was noted. For stands where the hydrological conditions appear to have changed in 1982 (Y-3 and Y-4, S-4), drastic expansions of the aerial cover of the stand was observed. Two stands (Y-3 and Y-4) actually doubled in aerial extent. For the other sites, the edges expanded about 1 to 3 metres into the bare tailings areas. Change in the density of cattails and other dominant vasculars within the stand boundaries were pronounced, particularly in stand T-4.

Observations on the expansion of the cattail stands, i.e., the ability of the plants to cover more extensive areas on the tailings, lead to the conclusion that the overriding factor controlling the aerial extent of the stands are physical and hydrological conditions, but not the chemical characteristics of the tailings.

PLATE 5
Scripus cyperinus ON THE EDGE OF THE CATTAILS ON T-4. At the edge of the cattail colonies, large hummocks of *Scirpus cypernus* are frequently found.

1.3.3 Growth Characteristics of Cattails. The number of leaves and height of the plants were chosen as a measure of plant growth. A maximum of 15 plants were labelled in six quadrats in all stands. The growth characteristics of these plants were measured three or four times between May and August 1981. For the description of the cattail stands, the density of shoots per m^2 and the number of fruit bearing shoots (inflorescences) were counted. In Table 4, the average values are given for the cattails on the Elliot Lake and Bancroft tailings and also for the control locations. Averages are given for the entire 1981 growing season and for the number of inflorescences, the 1982 counts are also included. The differences in the number of fruits between the stands in Bancroft and Elliot Lake were very pronounced in 1981. The higher number of fruit bearing shoots on the Elliot Lake sites persisted in 1982. In general, the standard

TABLE 4 CATTAIL CHARACTERISTICS

Location and Quality	No. of Leaves/Plant	Height of Plant (cm)	No. of Shoots/m^2	*No. of Fruit Bearing Shoots/m^2 (1981)	*No. of Fruit Bearing Shoots/m^2 (1982)
CONTROLS					
n	138	138	134	137	24
$\bar{X}$ + sd	7± 2	106± 40	20± 9	1.0± 2.2	1.2± 1.3
BANCROFT					
n	120	120	144	138	18
$\bar{X}$ + sd	6± 1	107± 42	18± 10	0.8± 1.5	0.4± 0.6
ELLIOT LAKE					
n	209	208	238	239	60
$\bar{X}$ + sd	7± 2	111± 34	26± 9	2.8± 4.1	4.1± 0.9

* Standard error is very large compared to the mean because there were many small values and a few large ones.

deviations for fruits in 1981 and number of shoots/m^2 are rather large. This can be expected, because at the beginning of the season, when counting was initiated, the density was low in some quadrats and initially no fruits were found.

The number of leaves per plant for all locations investigated is quite consistent (Table 4). The average number of leaves per plant was six or seven, however, the rate at which the leaves grow over the season along with the time at which the number of leaves is reduced, may reflect some stress exerted on the plants by the tailings conditions. Determination as to whether cattails started senescing earlier in the season on the tailings than on the control sites was important, since early senescence would reduce productivity, vigor, and overall biomass production. In Figure 6, the mean number of green leaves for each quadrat is plotted against time. A slight decrease in leaves can be noted in July for all stands. The mean average (connected lines - Figure 6), however, can hardly be considered to express a difference in the onset of senescence. In the control stands the ranges of the number of leaves per plant increased slightly at the end of the season, but not on the tailings sites. It may be concluded that the stands on the tailings do not experience senescence earlier than the cattails growing on undisturbed habitats. It is interesting to note, that only on the tailings sites are plants with one leaf observed (minimum values in Figure 6). The average number of leaves are similar for all

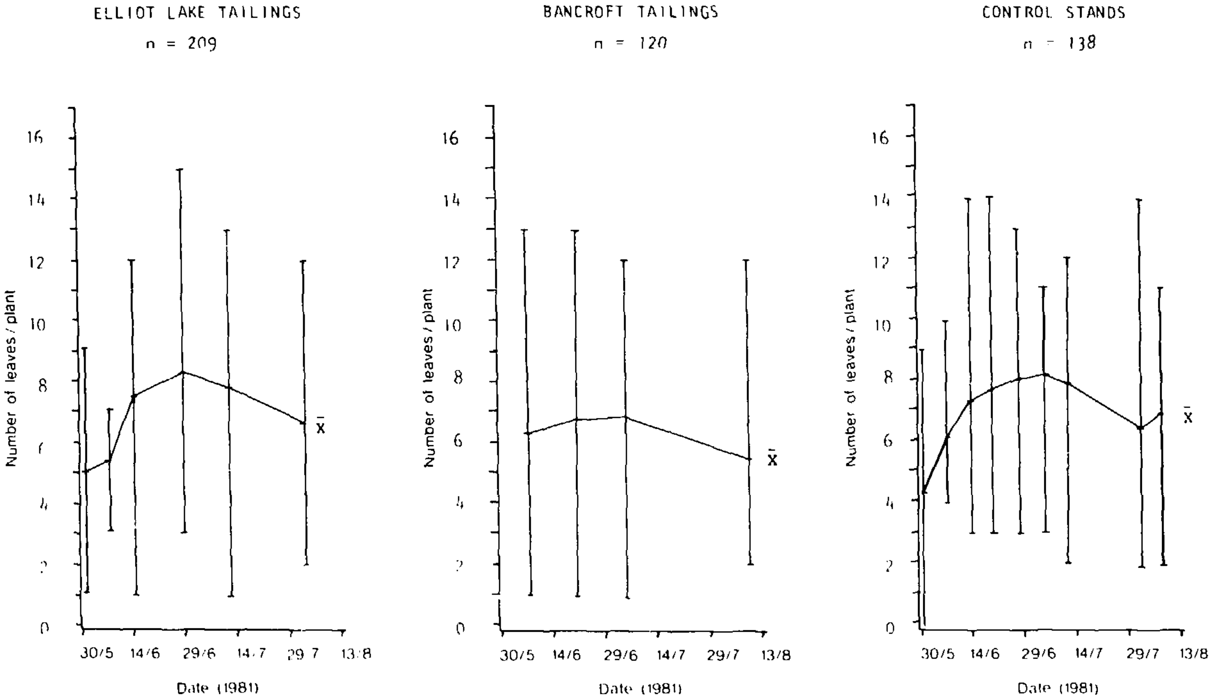


FIGURE 6 MEAN NUMBER OF LEAVES PER CATTAIL PLANT OVER THE GROWING SEASON FOR BANCROFT, ELLIOT LAKE AND CONTROL STANDS. The number of green leaf plants are plotted over the growing season. The bars indicate minimum and maximum encountered at each time interval.

stands throughout the season, and plants with one leaf only form a small fraction of the cattail population.

The cattails in all three locations achieved an average height of about 100 cm (Table 4). Bayly (1972) reported plant heights for *T. glauca* in Ontario on the average of 250 cm which is considerably taller than the plants observed in this study. Unfortunately, the method used by Bayly to measure the height is unclear. This is important because the degree of submergence of the plants in water and the amount of litter accumulation may affect the measurement of plant height. The shorter cattails of this study could either be a result of different hybridization, or a consequence of the measurement technique. Haslam (1970) found that reed grass plants growing on sand and silty soils were very short compared to reed grass plants growing on river deltas. If such a response to substrate conditions applies to cattails, then clearly shorter plants on the tailings could be expected as tailings are a sandy salt-rich substrate. Nothing, however, can be said about the short plants in the control stands, as the underlying soil texture is not known.

Though the average plant height was similar for the tailings stands and the control stands the rate at which this height is reached might differ between the locations. The height ranges measured over the season were examined in Figure 7. The height and growth are given for both tailings areas and for the control stands with the minimum and maximum heights observed. At the end of June, plants had reached average height on all locations. The height ranges are similar in all three areas, however, for any time period plant height is extremely variable. The mean height of plants within a m^2 area can differ by about 100 cm for any time period. In Bancroft, plants in stands A-8 and A-9 are particularly small, as shoots do not exceed 90 cm. Individual height curves exhibited extremely large differences, both within and between the quadrats, as well as between stands. The height growth for the cattail stands grouped by area for each time period represents 600 tagged plants for the Elliot Lake stands and 400 for the Bancroft and control stands respectively (Figure 7). The ranges of plant heights observed in all three areas over the growing season reflect the individualistic growth behaviour of the plants. It follows that the rate at which average height of plants is achieved during the growing season does not differ between tailings and control stands (Figure 7).

An assessment of shoot mortality was obtained by counting the number of dead plants which were tagged. The number of dead and/or broken plants in any one quadrat never exceeded two, unless beavers or hunters had damaged the quadrat. Mechanically damaged plants cannot be considered as mortality due to growth conditions. It was found in all stands throughout the season, that shoots marked at the beginning of the growth

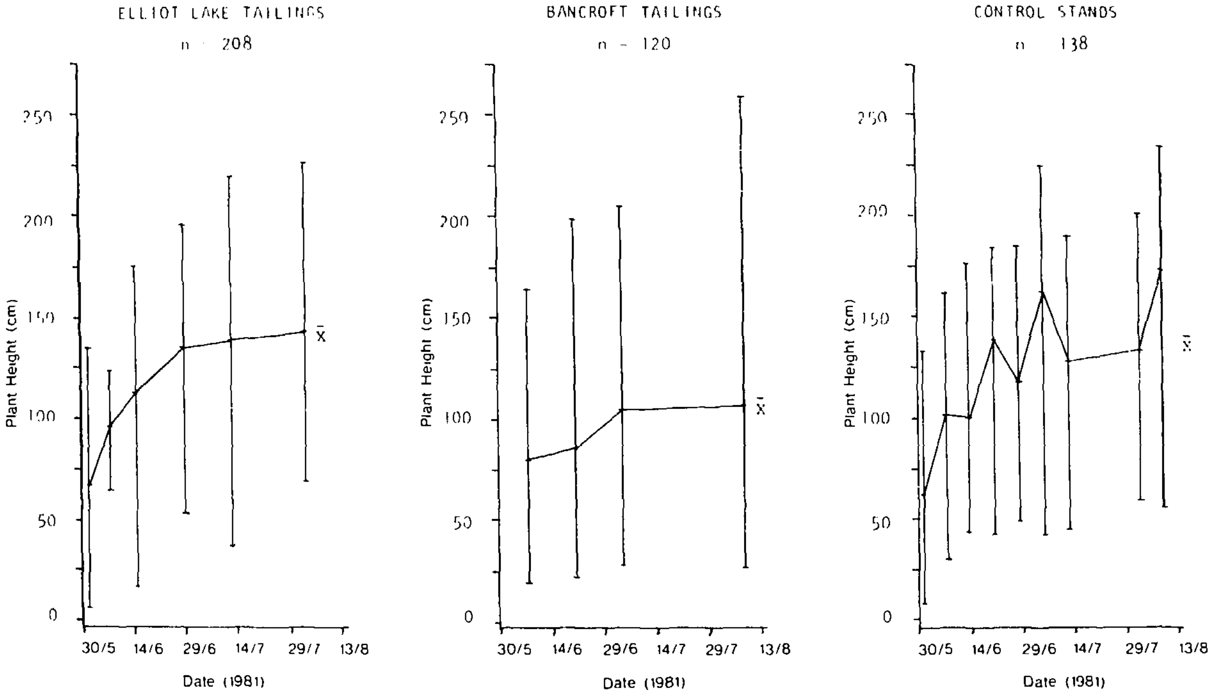


FIGURE 7 MEAN HEIGHT OF CATTAILS OVER THE GROWING SEASON FOR BANCROFT, ELLIOT LAKE AND CONTROL STANDS. The height of the plants are plotted over the growing season. The bars indicate minimum and maximum heights observed for each time interval.

season at a height of 25 cm did not die. This height corresponds to the time at which the shoots were tall enough to be tagged, either on tailings or control sites. Therefore, mortality was nil or minimal in the stands, after an initial height of 25 cm was obtained by the plants.

The average density of shoots appeared to differ between the Elliot Lake stands and those in Bancroft or the control sites (Table 4). Seasonal trends of shoot density in the stands are given in Figure 8. It is immediately obvious that in all three locations, stands can be dense or sparse. The densities of stands on the tailings, however, vary more than in the control stands. The number of shoots per m^2 of a cattail stand could reflect not only changes in density because of changes in growth conditions, but also because of changes in hydrologic and climatic conditions from year to year.

Density of shoots within a unit area is given in Table 5 for 1981 and 1982. All of the accumulated litter was removed from quadrats 1-4 (Q1-Q4), but it was allowed to remain in quadrats 5 and 6 (Q5 and Q6). The litter collection was made to determine the total amount of accumulated litter in the stands since its establishment. The amount of litter could affect growth as decomposition is likely to alter the chemical environment on the tailings. Shoot density within a cattail stand, however, is not affected by the removal of the accumulated litter over one year, as the densities in Q5 and Q6 do not differ significantly from the densities observed in Q1 through Q4. The average number of shoots in the same quadrat for the control stands and those in the Bancroft and Elliot Lake tailings varies between 1981 and 1982. In general, the same quadrat has less shoots in 1982; however, by comparing the variation of the quadrats with one group of stands (Q1-Q6) it is evident that shoot density varies as much within the stands as it does from year to year.

Boyd and Hess (1970) determined that nutrient availability in cattail stands is one of the major factors controlling shoot density. Tailings are nutrient deficient (Murray, 1977; Vivyurka, p.c. 1982; Kalin, 1982), but nevertheless the densities of the stands are the same and even slightly higher than the control stands (Table 5). Shoot density in a cattail stand, therefore must be controlled by a factor or factors other than nutrient availability. Species composition of the stands, environmental tolerances of species and species competition, may well play a significant role in controlling shoot density of a cattail stand, in addition to the availability of nutrients. Site specific characteristics such as water regime and exposure of the stand, can influence the litter accumulation in the stand, which in turn, can have an effect on the stand density (Figure 9). For all stands in the study, a significant correlation between shoot density and

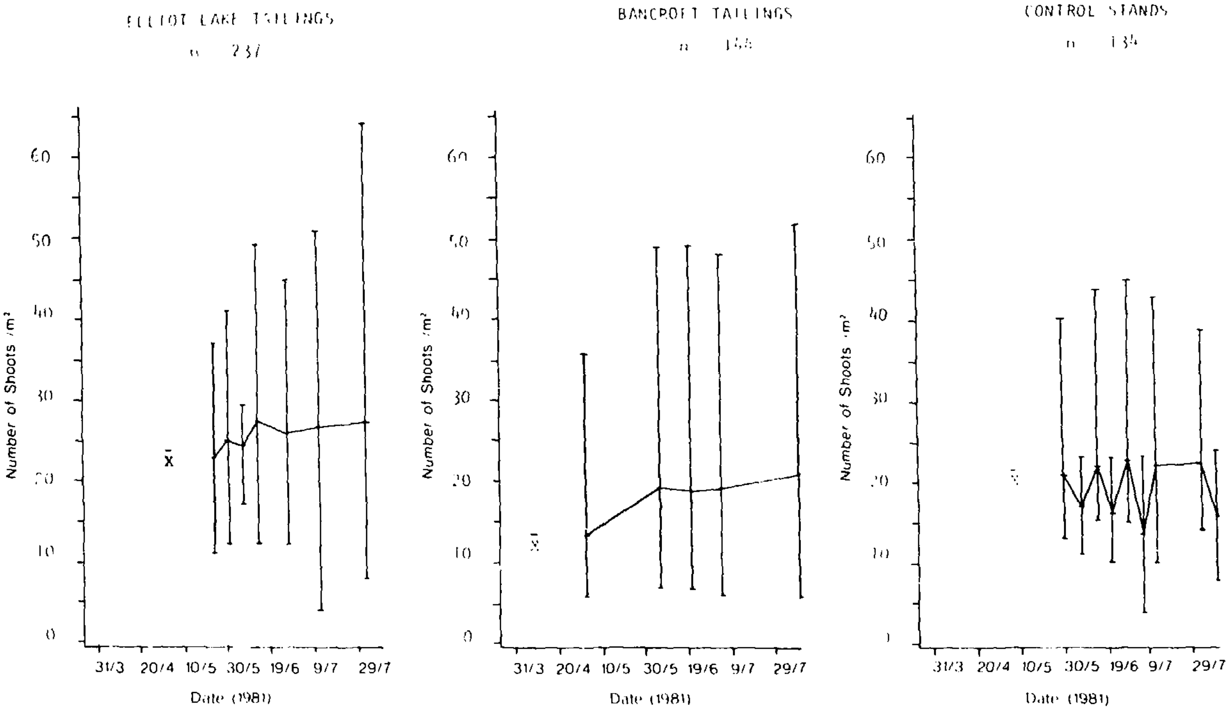


FIGURE 8 SHOOT DENSITY OVER THE GROWING SEASON IN BANCROFT, ELLIOT LAKE AND CONTROL STANDS. The density of shoots/m^2 is plotted over the growing season. The bars indicate minimum and maximum densities encountered in each time interval.

TABLE 5 SEASONAL AVERAGE SHOOT DENSITY IN QUADRATS (1981 and 1982)

Litter Removed From Quadrats:	CONTROLS		BANCROFT		ELLIOT LAKE	
	1981	1982	1981	1982	1981	1982
	No./m^2		No./m^2		No./m^2	
Q.1-R	18± 6	16± 6	24± 6	9± 6	23± 5	19± 8
Q.2-R	24± 11	17± 7	21± 15	12± 6	27± 10	22± 6
Q.3-R	18± 5	17± 5	20± 3	18± 6	28± 6	23± 7
Q.4-R	19± 6	16± 7	20± 11	15± 11	25± 10	24± 12
Litter Remained In Quadrats:						
Q.5-N	19± 5	14± 7	19± 13	12± 6	24± 5	24± 5
Q.6-N	19± 7	15± 5	15± 2	14± 3	25± 8	23± 5

R = litter removed in quadrat
N = litter not removed in quadrat
Q = quadrat number

total accumulated litter per m^2 was observed with a correlation coefficient of $r=0.43$ at a probability of $p=0.00016$. The explanatory power $r^2=0.1899$ of this relationship was, however, relatively low indicating that many interrelated factors exert influence on shoot density in a cattail stand. As the objective of this study is the determination of growth conditions of cattails in the absence of growth supporting measures, the specific factors affecting density are somewhat irrelevant in this context. The important conclusions from these results were that shoot density is extremely varied, but not reduced on the tailings sites.

The number of fruit bearing shoots in Table 4 appeared high in Elliot Lake, even though they were associated with a large standard deviation. In Table 6, the number of fruit bearing shoots/m^2 are given for the entire season and for the months of July and August, for in these months the final set of inflorescences is expected. In 1981, most fruit bearing shoots/m^2 in Bancroft and on the control sites had been formed before July and August. The increase during these months was relatively small on these sites compared to the continued production of fruits in the same period for Elliot Lake. On the average, the number of fruit bearing shoots increased in Elliot Lake by two to four fruits/m^2 for the last two months of the season. Comparing the same months for the

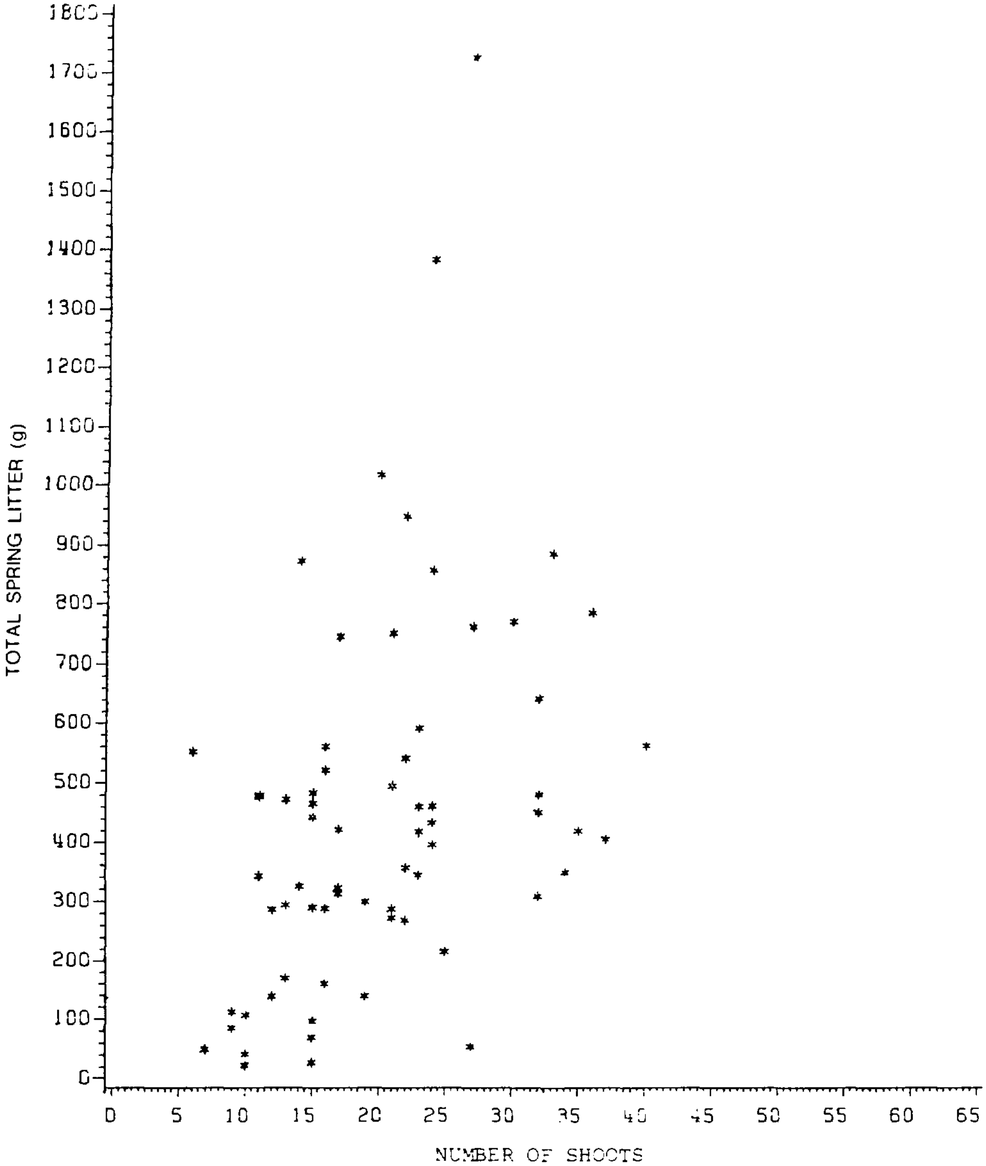


FIGURE 9 NUMBER OF SHOOTS AND TOTAL LITTER ACCUMULATION. The shoot density in the stand is related to the accumulated litter weight collected in the stand. The relationship is relatively weak with a correlation coefficient of $r=0.43$ (significant at $p=<0.01$) which explains only 19 percent of the observed variation. Sixty-four observation pairs were available for the correlation.

TABLE 6 MEAN NUMBER OF FRUITS PER m^2 IN 1981 AND 1982

Site Code	Over 1981 Season	Before July 1981	July-August 1981	July-August 1982
	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$
		CONTROLS		
	(n=23 to 30)	(n=12)	(n=12)	(n=6)
B-5	0.3	0.3	0.6	0.0
B-6	0.0	0.0	0.0	N/A
J-14	0.7	0.0	0.6	0.2
J-15	1.7	1.8	3.5	2.8
J-16	1.8	3.2	5.0	2.0
		BANCROFT		
	(n=24 to 30)	(n=12)	(n=12)	(n=6)
A-8	0.1	0.1	0.2	0.0
A-9	0.1	0.1	0.2	0.0
C-5	2.0	1.0	3.0	flooded
D-5	1.3	0.4	1.7	1.2
F-3	0.7	0.0	0.7	buried
		ELLIOT LAKE		
	(n=29 to 37)	(n=12)	(n=12)	(n=6 to 10)
H-5	1.3	2.1	3.4	5.6
P-5	3.6	2.8	6.4	4.1
S-4	3.4	6.2	9.6	3.3
T-4	1.8	3.1	4.9	5.3
Y-3	3.1	4.2	7.3	3.4
Y-4	2.2	4.3	6.5	3.2
Y-5	4.6	4.9	9.5	3.8

X = mean number of fruits counted/m^2 for time period indicated
n = number of observations within the stand

second year of observation, it is noted that fruit density in 1982 was again highest on the Elliot Lake tailings compared to Bancroft and controls. In 1982, however, with the exception of two sites (H-5 and T-4), generally fewer fruit bearing shoots were produced in each stand. All stands had a lower density of fruit bearing shoots at the end of the 1982 season compared with the 1981 season.

In plants which have the ability to grow vegetatively, the production of inflorescences can be induced by environmental stress. From earlier considerations, two characteristics of the tailings environment measured in this investigation could possibly exert some stress on the cattails. These are the high electrical conductivities in the root zone and the large differences in pH values between the surface and the root zone on the Elliot Lake tailings. The differences in number of fruits between 1981 and 1982 furthermore suggests that seasonal characteristics may influence production.

On the edge of cattail stands, or in areas with low shoot density, mats of germinating seedlings are frequently found. This suggests that the tailings provide conditions which allow cattail seed to germinate and possibly establish. It is also noteworthy that the seeds produced in the cattail stands on tailings appear to be fertile. In summary, it may well be that the cattails, known as aggressive pioneers, respond to the harshness of the Elliot Lake tailings by utilizing vegetative growth in addition to increased sexual reproduction expressed in the higher number of fruit/m^2.

It can be speculated that as the conditions in the cattail stand improve with time, as a result of litter accumulation and decomposition, the number of fruits produced in the stands in Elliot Lake might decrease. Litter decomposition and accumulation of biomass is believed to increase nutrients. Presently, the cattail stands on the Elliot Lake tailings are generally denser and have a higher number of fruit-bearing shoots than the stands in Bancroft and on the control areas. As the denser stands are likely to produce a higher aerial biomass, a relationship between the number of fruit-bearing shoots and standing crop or aerial biomass/m^2 can be expected (Figure 10). Indeed, stand density, productivity and fruit production may all be an expression of growth characteristics of cattails during initial establishment of colonies on harsh sites.

1.3.4 Aerial Biomass Production and Litter Accumulation. In the previous sections, the growth of the plants and the differences between the stands were discussed. The result of a plant's growth is the production of net biomass which decomposes and thereby changes the system. Biomass productivity, litter accumulation and its decomposition are thus important components of any wetland ecosystem. As the pathway of long-lived radionuclides and persistent substances are one of the major environmental concerns on tailings, the biomass productivity and its fate on the tailings is of utmost importance in the long-term. It is apparent from the results previously discussed that cattails grow well on uranium mill tailings. The results presented in this section address the quantity of growth and the decomposition coefficients.

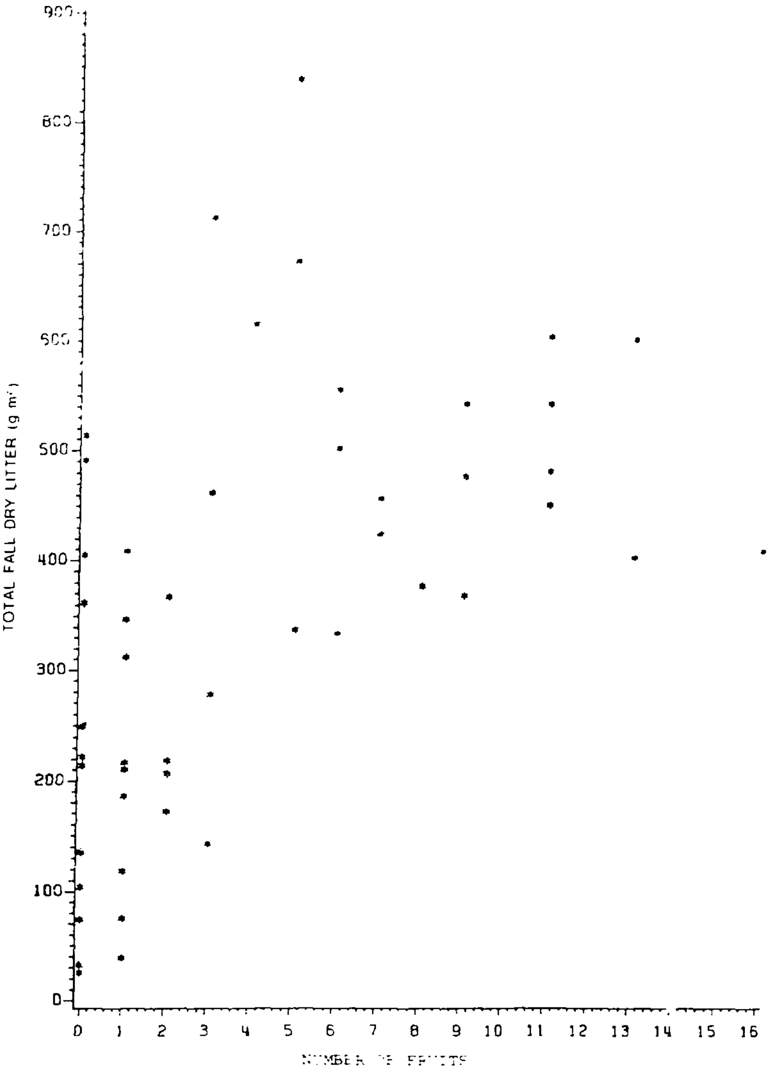


FIGURE 10 NUMBER OF FRUITS/m^2 RELATED TO BIOMASS WEIGHTS/m^2 FOR 1981. The relationship of above-ground biomass in g/m^2 and the number of fruit bearing shoots is presented for 37 quadrats with a correlation coefficient of 0.49 (significant at $p<0.01$) which explains 25 percent of the variation between the two variables.

As the cattail stands were found to differ in the extent to which they reproduce sexually, the composition of the litter in the stands is likely to be affected. The components of accumulated litter in the stands was evaluated by determining the dry weights of leaves, stems and fruits separately (Table 7). More than 60 percent of the litter consisted of leaf material. Stems which bear fruit comprised about 20 percent of the accumulated litter in Elliot Lake, but comprised a lesser amount both on the control sites and on the Bancroft sites. Fruits contributed less than 8 percent to the overall litter mass, with the exception of site P-5, which had 31 percent fruits in the litter.

In summary, the composition of the litter which accumulates in a cattail stand is a direct reflection of type of reproduction prevailing in the stand. The stands in Elliot Lake have about 20 percent less leaves in the litter than stands in Bancroft and the control stands. This suggests that the stand characteristics identified during this study prevailed previously as the litter composition is consistent with the characteristics of the above-ground biomass.

In addition to the accumulated litter composition in the stand, the above-ground biomass produced during a growing season also reflects stand characteristics. In Table 8, the fractions of the biomass harvest are given as the percentage of thick leaves, which are the vegetative aerial shoots and thin leaves which are green or brown and are associated with fruit-bearing shoots. The percentage of thick leaves is higher in Bancroft and control stands than in the Elliot Lake stands. Furthermore, at the end of the growing season (the time of the harvest), a difference in quality of the thin leaves (brown or green) can be noted. Early senescence was not apparent on the Elliot Lake sites, but a subtle difference was noted during the harvest in the ability of the leaves to remain green. After transport of the biomass, approximately half of the leaves from fruit-bearing shoots in Elliot Lake turned brown, whereas, this fraction was slightly smaller from the Bancroft and the control sites. The conditions during the transport were the same for the material from the tailings and the control sites in the respective areas. Thus this phenomenon may be interpreted as a more rapid loss of vigor of the leaves from the Elliot Lake tailings than of the leaves from either the Bancroft tailings or the control sites. The high electrical conductivity in the root region on the tailings compared to that on the control sites (Figure 2) could result in a difference in the moisture balance, loss of vigor, and reduced above-ground dry weight on the tailings.

TABLE 7 COMPOSITION OF ACCUMULATED LITTER (%)

Location and Site Code	Stems	Leaves	Fruit
Bancroft			
A-8	0	100	0
A-9	2	97	1
C-5	17	78	4
D-5	9	89	2
F-3	0	100	0
Elliot Lake			
H-5	19	77	3
P-5	21	48	31
S-4	22	72	5
T-4	27	66	6
Y-3	28	63	0
Y-4	27	66	6
Y-5	14	83	2
Controls			
B-5	19	76	5
B-6	0	100	0
J-14	12	87	2
J-15	10	83	7
J-16	12	85	3

TABLE 8 ANNUAL AERIAL BIOMASS COMPOSITION, AMOUNT, AND MOISTURE CONTENT

Biomass Type	Controls	Bancroft	Elliot Lake
(%)			
Green Leaves	42	45	25
Brown Leaves	19	19	27
Thick Leaves	29.5	24	17
Stems	5.5	6	19
Fruits	3	6	12
(g)			
Total Dry Weight/m^2	383± 143	155± 143	462± 145
Total Wet Weight/m^2	1317± 614	406± 519	1489± 827
Water Content/m^2	898± 495	250± 380	1036± 690
(%)			
Moisture Content	68	62	69

The above-ground dry weight/m^2 generally reflects the shoot density of the stand and of the area (Tables 4 and 9). In Table 8, the percentage composition of different above-ground biomass components is given. In Elliot Lake, a higher percentage of stems and fruits result in a shift of the fractions of vegetative and reproductive leaves, which in turn could affect the water content. The standing crop fresh weight contains about 60-70 percent of water in all stands (Table 8). The water content of the above-ground crop, however, does not differ based on the mean dry and wet weight/m^2.

Bayly and O'Neil (1972) investigated moisture content in *T. glauca* in Ontario. They reported for the later growing season months a moisture content of flower stalks and leaves of 60 to 70 percent. This is in agreement with the moisture content found in the present study. In the Bayly/O'Neil study, leaf length had reached the maximum height of 280 cm by the end of July and was followed by a steady decrease thereafter, due to shrinkage, dessication and fragmentation of terminal portions of the leaves. Generally, the maximum height of the shoots was also attained by the end of July in this study in all cattail stands, though the shoots were considerably shorter (Figure 7). A decrease in plant or leaf height was not apparent by the end of August in either tailings or control sites. The agreement of this study and the Bayly and O'Neil (1972) investigation of the months in which peak heights are reached, in addition to the moisture content of the above-ground biomass suggests that the cattails display a similar physiological behaviour in both studies. The available observations and inferences from studies of cattails indicate that growth and physiological activities of these plants are not impaired on the tailings.

Though height growth rates of cattails appear similar to those reported from other studies, densities of shoots in the stands are varied and generally low, when compared to other studies. Above-ground biomass depends upon the shoot density, the quantity of litter is in turn a result of the amount of yearly biomass produced within a stand. The reproductive mechanism prevailing in the stand further affects the litter composition (Figure 9 and Table 7). The seasonal average density for each stand investigated along with the average above-ground biomass weight for 1981 and the biomass of one quadrat harvested in 1982 are given in Table 9. Some stands on the Elliot Lake tailings sites have net productivities similar to the lower range of the quoted average for freshwater wetlands with weights of 465 to 568 g/m ^{2}/yr. Other stands have lower productivities, but in 1981 the variations encountered within one stand, as well as from year to year, are large (Table 9). These weights were based on one-time clipping in three quadrats at the end of the growing season. Based on the biomass from a single quadrat clipped in each stand in 1982, it appears that the net productivity of biomass is maintained in the same ranges in 1982 as in 1981. It is reasonable to conclude that once a

TABLE 9 DENSITY OF SHOOTS AND ANNUAL AERIAL BIOMASS

Site Code	No. of Shoots/m^2 Seasonal Average 1981	g of Dry Aerial Biomass/m^2 1981	g of Dry Aerial Biomass/m^2 1982	g of Dry Litter/m^2 After 1 yr 1982
BANCROFT	(n=30)	(n=3)	(n=1)	(n=1)
A-8	12± 5	32± 6	21	46
A-9	32± 13	115± 35	33	132
C-5	15± 6	339± 238	stand destroyed	stand destroyed
D-5	14± 4	112± 34	97	74
F-3	20± 6	178± 64	stand destroyed	stand destroyed
ELLIOT LAKE	(n=32)	(n=3)	(n=1)	(n=1)
H-5	23± 8	431± 84	608	141
P-5	20± 5	568± 97	271	266
S-4	31± 8	395± 16	260	370
T-4	17± 3	299± 158	81	228
Y-3	25± 4	465± 105	238	258
Y-4	32± 9	543± 257	95	588
Y-5	32± 8	550± 87	232	290
CONTROLS	(n=30)	(n=3)	(n=1)	(n=1)
B-5	12± 3	362± 42	stand not found	stand not found
B-6	19± 4	448± 61	125	170
J-14	22± 6	482± 246	521	183
J-15	24± 9	275± 115	258	73
J-16	19± 4	407± 120	152	353

cattail stand on the tailings has reached an average shoot density of 25 to 30 shoots/m^2, the aerial biomass production on the tailings and control sites is maintained. Mason and Bryant (1975) observed May peak shoot densities of 100±5.0 shoots/m^2 in a reed swamp in England for *T. angustifolia*. This was followed by a relatively rapid density decline in the remaining months of the growing season to an average of 50 shoots/m^2. These densities are higher than those reported in this study, for control stands and tailings stands alike.

Brinson et al. (1981) discussed net biomass production in freshwater wetlands. Three types of wetlands are differentiated by the authors, based on the degree of water fluctuation. The cattail stands in this study are considered as wetlands with low water fluctuations. Net biomass production is reported for wetlands in South Carolina, Alabama and Oregon for marshes with low water fluctuations (a mean of 822±283 g/m^2/yr).

Though these climatic regions are not necessarily comparable to Ontario, the values serve as a reference point.

Net biomass production of an ecosystem is an important characteristic with respect to radionuclide transport (Whicker and Schultz, 1982). For the evaluation of long-term development of communities on the tailings sites, it is necessary to determine whether the tailings communities have the same or different characteristics than functioning communities in non-tailings environments. In the following discussion, densities, net biomass production and decomposition coefficients of cattail stands on uranium mill tailings are compared to freshwater wetlands in North America. The cattail stands on the tailings are considerably smaller in size than wetlands generally studied. Edge effects or transition zones from wet to dry areas of the stands could affect densities and biomass production. These parameters were not quantified in this study.

Some caution must be exercised in making comparisons of productivities between wetlands with respect to the species composition. The stands on tailings investigated during this study are essentially monocultures of cattails, so the control sites were chosen to resemble monocultures. The wetlands studied by Brinson et al. (1981) encompass a broader range of species. Should the species composition change in the stands on the tailings, different productivities may be expected.

Annual biomass production has to be balanced by appropriate decomposition rate if the ecosystem is to maintain an equilibrium. Decomposition rates of the aerial biomass were also assessed for the stands. This was achieved by collecting the litter which had remained in the quadrat in 1982, where the accumulated litter had been removed in the previous year and the aerial biomass was not harvested, i.e. left to decompose. The method used in this study to determine litter decomposition attempts to capture site specific differences. The conventional method of obtaining litter weights and decomposition coefficients (by suspending litter bags) was not used purposely, since mesh sizes of bags, differences in location of suspension of the bags and compaction of the biomass all affect the results. The litter weights of this study represent the amount of litter which remains after one year on the site and takes into account the physical removal of biomass as well as actual decomposition of the biomass.

The last column in Table 9 reports the absolute weights of this litter collection. Given the variation of aerial biomass within the stands, it is not surprising to find that some quadrats had a greater litter weight in 1982 than the average weight of aerial biomass harvested in 1981. This holds true particularly for the shore stands of A-8 and A-9 in Bancroft and on site Y-4 in Elliot Lake. Indeed, the cattail stand on this spill area (Y-4) is dense and productive. This stand had doubled in aerial extent in 1982.

Brinson et al. (1981) discussed in detail factors affecting decomposition coefficients. Temperature is identified to be probably the most important physical variable affecting organic matter loss in situations where moisture and oxygen availability do not limit decomposition. The water temperature in the cattail stands on tailings for Elliot Lake did not differ from those of the control stands, but the degree of submergence of the litter which would affect moisture and oxygen did vary between the sites (Table 2). In Table 10, decomposition coefficients are calculated for each stand. The water temperatures and moisture regimes might have contributed to some of the higher decomposition coefficients of 1.10 to 1.33 on sites H-5 to J-16 respectively. Both are stands in the Elliot Lake area, one stand on the tailings and one control stand. Those two sites had a varied water depth but similar water temperature compared to other stands (Table 2).

The pH of the surface water and other chemical characteristics of the water in the stand were not considered by Brinson et al. (1981) though they may also affect decomposition. If the acidic surface water on the tailings in Elliot Lake affects decomposition, then the decomposition on the Elliot Lake stands should be comparable to that reported for acidic peatlands. Such a comparison does not take into account any difference in plant material present in peatlands. A cumulative frequency distribution for all decomposition coefficients is reported in the review by Brinson et al. (1981). In Figure 11, the first year decomposition coefficients of northern peatlands (44°N - 75°N), derived from this study and other wetlands were compared. The other wetlands considered include all those in the region of 26°N - 51°N, excluding the northern peatlands. The type of ecosystems which are included are cypress stands, monocot marshes and beaver ponds. Indeed, the tailings stands curves (dotted lines) are very close to curves obtained for other wetlands (Figure 11). The higher number of low decomposition coefficients could possibly be a result of the location, in combination with the chemistry of the surface water. In summary, some conclusions are of significance with respect to the decomposition discussed. The coefficients are site-specific and do not appear to be impaired by the pH or chemistry of the surface water. Given that the net biomass production and decomposition coefficients are within ranges found in other studies, it is strongly suggested that cattail growth on tailings will continue as long as the conditions on the sites are not drastically changed.

TABLE 10 LITTER ACCUMULATION IN CATTAIL STANDS, MEASURED AND CALCULATED WEIGHTS

Site Code	Total Litter Weight Collected in Stand ($\bar{X}$) (kg)	A_L: Accumulation Calculated for Stand (kg)	Decomposition Coefficients (kg/yr)
CONTROLS			
B-5	0.5± 0.2	n.d.	n.d.
B-6	0.3± 0.06	0.27	- 0.97
J-14	0.6± 0.2	0.29	- 0.97
J-15	0.5± 0.2	0.10	- 1.33
J-16	0.4± 0.6	2.66	- 0.14
BANCROFT			
A-8	0.1± 0.1	-	acc.
A-9	0.2± 0.1	-	acc.
D-5	0.1± 0.03	0.22	0.41
C-5	0.3± 0.2	n.d.	n.d.
F-3	0.04± 0.02	n.d.	n.d.
ELLIOT LAKE			
H-5	0.2± 0.04	0.21	1.10
P-5	0.5± 0.2	5.85	- 0.06
S-4	0.5± 0.3	0.50	- 0.75
T-4	0.5± 0.2	0.96	- 0.27
Y-3	0.7± 0.3	0.58	- 0.57
Y-4	0.8± 0.6	-	acc.
Y-5	0.6± 0.2	0.61	- 0.64

A_L - litter accumulation in long-term, calculated as $A_L = X_0 e^{-k} / (1-e^{-k})$ and $k = \ln (X_i/X_0)/t$ in years, where X_i - dry weight remaining after 1 year, X_0 - dry weight added each year.
n.d. = no data
acc. = accumulation

The study of the growth of wetlands or cattail stands on uranium mill tailings is of importance mainly with respect to an evaluation of the long-term development of these waste sites and the biogeochemical cycling of long-lived radionuclides. Before the pathways of these undesirable substances from the tailings to the surrounding environment can be assessed, the character of the tailings environment must be known. The question of anticipated changes in total litter mass in the stands will be relevant when radionuclide concentrations in litter are determined and those in turn are used to estimate long-term implications. Thus, it would be of interest to assess whether the presently observed characteristics of the cattail stands reflect a 'steady state' of the cattail environment.

For the cattail stands, a simple model can utilize the type of data previously discussed to obtain an understanding of long-term developments. The results of

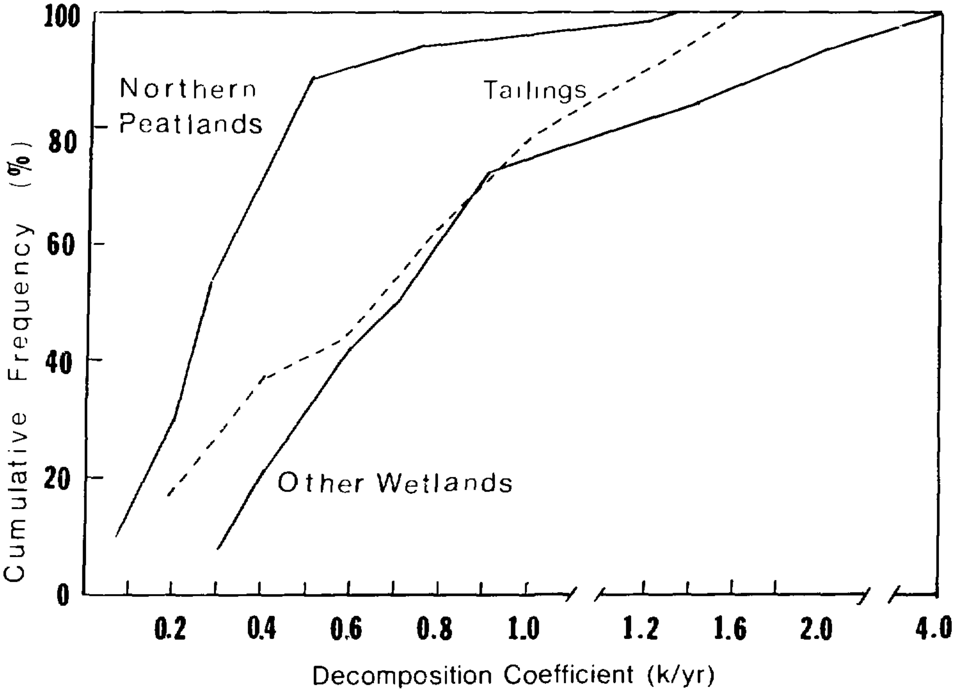


FIGURE 11 CUMULATIVE PERCENTAGE FREQUENCY CURVES FOR DECOMPOSITION COEFFICIENTS: The cummulative frequency curves for decomposition coefficients (k/yr) from Brinson et al. (1981) are compared to the curve obtained in this study (dotted lines) from the different cattail stands.

calculations given for each stand are found in Table 10. The litter accumulation in the long-term is given by the equation:

$$A_L = X_o e^{-k} / (1-e^{-k})$$

where: A_L - is the expected maximum litter accumulation in the long-term for the stand,

X_o - is the dry weight added each year per m^2, and

k - is the decomposition for the stand.

The decomposition is assumed to be an exponential decay process. For low decomposition coefficients, the difference in weight loss is minimal after one year regardless if a linear or an exponential decay is assumed. The weights calculated for this model which are the maximum litter weight/m^2 expected in each cattail stand in the long-term, are found in the centre column of Table 10.

These calculated "A_L" weights can be compared to the weights actually collected in the stands reported as total litter accumulated in the stand by 1981. Clearly, the calculations can only be made for those stands in which decomposition coefficients could be calculated, as it is a model assuming decay and not accumulation. From the available data set, it can be concluded that in half of the stands the amount of litter present to date is all that might ever be expected. The model thus predicts that at least half of the stands are in a 'steady state'. If the presently existing conditions on the tailings remain and are similar to those in the past, the yearly biomass input and output of the stands can be evaluated. These considerations, in conjunction with determination of radionuclides contained in the litter on the tailings and in the aerial biomass, will lead to a realistic assessment of radionuclide pathways from the tailings to the environment.

1.4 Conclusions

From the investigation of the wetland areas on uranium mill tailings in Ontario, several conclusions can be drawn. Despite extremely varied and environmentally harsh conditions, wetlands on tailings beaches will remain permanent environments on inactive sites. The continued growth of the wetlands on tailings beaches and in wet areas of the tailings, however, will be endangered when tailings surfaces experience drastic changes in hydrological or chemical conditions due to interference by man. From the observations on cattail stands on accidental tailings spill areas, and on tailings beaches, changes in hydrological conditions do not appear to impair cattail growth as long as they are not accompanied by drastic changes in the chemistry of the environment, such as run-off from liming. The study of the characteristics of cattail stands, their composition and growth dynamics in comparison with studies on non-tailings populations gave no indication that these wetlands are under any serious environmental stress. The root region of the cattail stands on tailings is less harsh than the surface areas in the stands. The stand provides surface stabilization and potentially reduces acid generation in the root zone.

From the evaluation of net biomass productivity in the wetland stands on the tailings, it is apparent that litter accumulation and decomposition take place in a manner similar to stands in non-tailings environments. Potential pathways of long-lived radionuclides from the tailings to wetlands and to the environment at large can now be based on quantitative data. The ecological characteristics of wetlands on uranium mill tailings have been quantified. Consequently, an evaluation of a scenario for their long-term development on tailings beaches and in wet areas of tailings sites is now feasible.

2 DRY AREAS ON INACTIVE OR ABANDONED URANIUM MILL TAILINGS

2.1 Specific Objectives

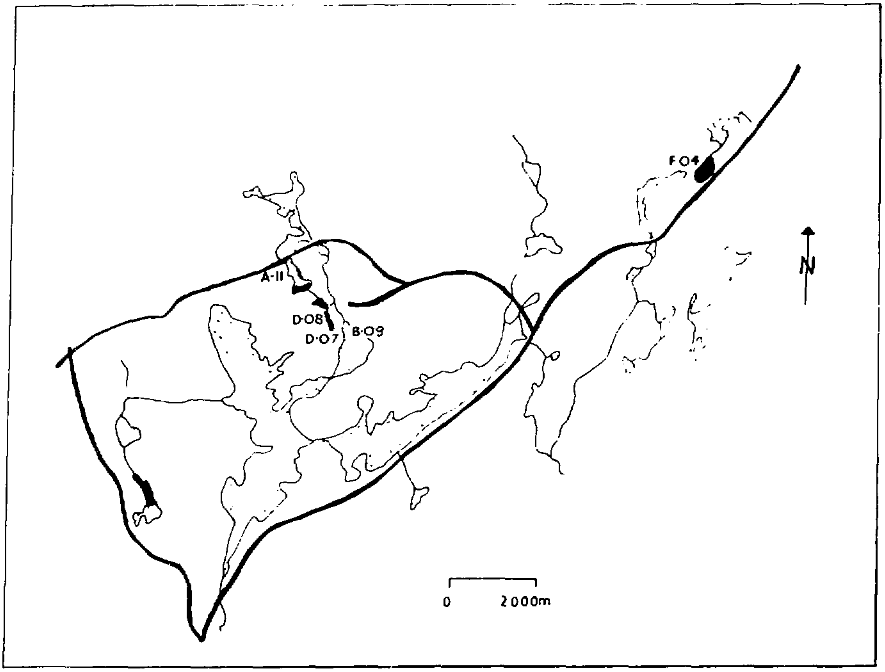
Trembling aspen and white birch are two tree species frequently colonizing dry areas on the tailings. These trees may form a major component of the future tailings environment, if their growth and development continues. The spatial distribution of tree stands on the tailings, the growth forms of the stands and the time since abandonment suggested, however, that growth may be impaired and expansion of tree stands inhibited (Kalin, 1983). The objective of the study was, therefore, to arrive at a preliminary assessment of tree growth and population development on the tailings sites.

Both species grow on sites which had been amended and received fertilization every year, but also on sites which had received single treatments or those with no surface treatment at all. Tree populations on tailings and non-tailings sites were described by height, trunk and crown diameter and the number of branches were counted. These characteristics indicate the growth form of the trees. Basic growth dynamics of the populations were delineated from changes in these characteristics observed between 1981 and 1982. The study of trembling aspen and white birch populations may provide a basis from which the long-term ecological implications of terrestrial plant populations on uranium mill tailings can be evaluated.

2.2 Methods and Materials

2.2.1 Description of Study Sites. Tree colonies of two pioneering species, trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*), were selected on the tailings sites. In the Bancroft area (Map 3) the sites differed in their surface characteristics and topographies. On Auger (Site A) tailings beaches are bordered by a belt of shrubs, dominantly willows, cattails and sedges, with bare areas of tailings reaching close to the forest edge (Plate 6). The elevated parts of the tailings are either extremely dry and vegetation-free or relatively moist and vegetated with trees, mosses or sedges. Unfortunately, across the elevated areas on Auger a winter snowmobile trail inflicts damage on the young trees every year and this site has never received any surface amendment since abandonment in 1963.

On Bicroft Proper (Site D), the second site in the Bancroft area, a bog was filled with tailings, creating a sharp boundary between the tailings and the forest edge. A small pond remained in the centre of the site. Trees have established themselves



MAP 3 TREE STAND LOCATIONS IN THE BANCROFT AREA. Circled site codes are the locations for the control stands.

extensively on the north and south sections of the site (Plate 7). Similar to Auger, Bicroft Proper tailings never received any type of surface amendment since abandonment in 1957.

On Madawaska No. 2 (Site F) several surface cover types exist. Gravel and waste rock were used to cover some sections of the tailings pond, whereas other areas remained bare. Some efforts to revegetate the surface were made in 1979, but in most of the sections of Madawaska No. 2 the introduced grass and legumes species did not continue to grow and indigenous vegetation forms an extensive plant cover. The vegetation composition on Madawaska No. 2 has been described by Stokes and Kalin (1978).

The Nordic, Crotch and Stanrock tailings in the Elliot Lake area have all received surface amendments (Map 4). The Nordic Main tailings (Site V) have been revegetated since 1970. Different surface amendments, seed combinations and application techniques have resulted in a complete vegetation cover on the site. Plate 8 shows a trembling aspen grove (stand V-4) amidst a Bird's-foot trefoil cover, typical for some sections of the Nordic site. The site is fertilized frequently to support the continued growth of the introduced cover.

PLATE 6
THE VEGETATION BELT ON AUGER. On the tailings beach some shrubs have established themselves but dry raised sections of the site are free of vegetation.

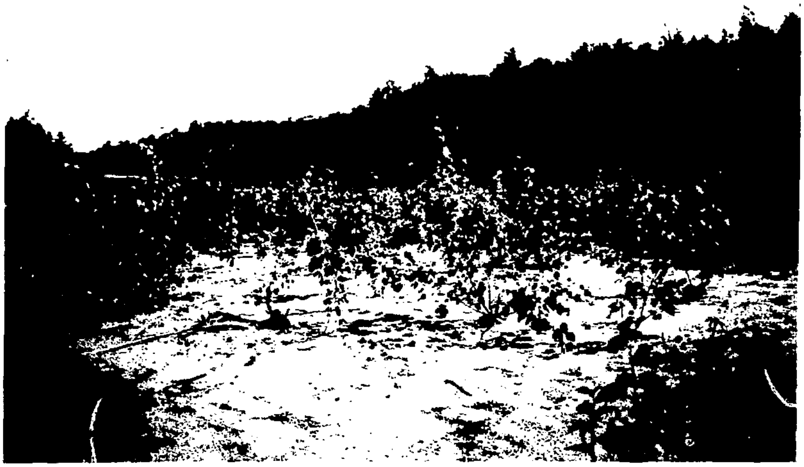
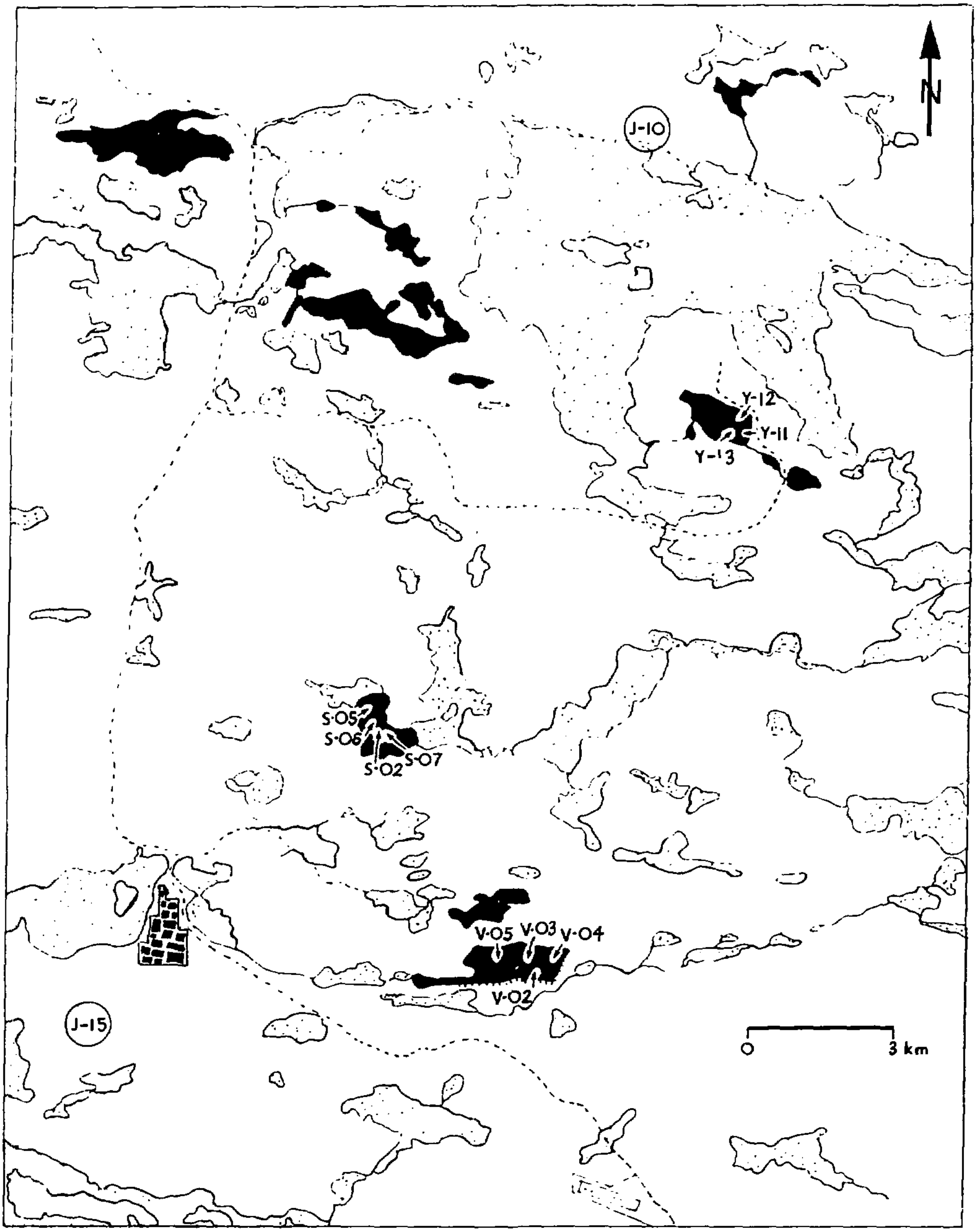


PLATE 7
TREMBLING ASPENS ON BICROFT PROPER. Mainly aspens have colonized dry sections at the north-end of the tailings. Closer to the pond, in the centre of the site, the vegetation cover is more diverse.



MAP 4 TREE STAND LOCATIONS IN THE ELLIOT LAKE AREA. Circled site codes are the locations for the control stands. On Nordic (V) and Crotch four tree stands are studied. On Stanrock (Y) three transects are evaluated for tree densities.

The revegetation program on Nordic Main was partly based on results of revegetation trials which were carried out on the Crotch tailings (Site S). Trees have established here on a belt of introduced and indigenous vegetation in the middle of the eastern tailings area. Trees cover the area extensively and have established after initial amendment of the surface in 1970 without further fertilization and maintenance (Plate 9). Herbaceous species, grasses and mosses are the major components of the vegetation cover which varies in density throughout the tree area.

On Stanrock Main (Site Y) trees have established after the surface was only treated with limestone in 1979 (Plate 10). No experimental seedings or fertilization was carried out here in contrast to the Crotch or Nordic site. Tree seedlings were observed in 1981 forming densely populated islands on the south end of the site (Figure 12). The vegetation cover is dominated by a calciphile terrestrial moss *Funaria hygrometica*. On other tailings sites the dominant moss species are *Pohlia nutans* and *Ceratodon purpureus*, species with broad environmental tolerances.

The trees on tailings sites are compared to trees which establish on non-tailings sites, such as gravel pits, road sides (J-10) and open fields. On these locations colonization occurred after a disturbance, for example, earth movement due to construction (control site B-9 in Bancroft), or from quarry activities, like control site J-15 (Plate 11). All control sites selected did not receive amendments, and thus represent a natural colonization process of disturbed non-tailings environments.

2.2.2 Tree Stand Selection on Tailings Sites. Tree stands within the tailings area were selected to represent the general height of trees on the entire site. Their location was dependent on the existing stand. Nevertheless, the stands only represent certain areas of sites, as in many sections of the tailings no trees have established themselves yet. An overall description of the vegetation cover of abandoned uranium mill tailings sites in Ontario, referring to locations of tree growth is given in Kalin (1983). The locations of the stands on Nordic are discussed in section 2.3; Nordic is the only tree site with a complex amendment history.

2.2.3 Measurements and Mapping. In June, July and August of 1981 at least 50 trees in each stand were labelled with plastic tags. Each tree was numbered and its height, trunk and crown diameter were recorded by using a metre stick. Measurements were made for height and crown diameter to the nearest 2 cm by aligning the tree with the metre stick. The number of branches were counted on all trees. In 1982, the stands were remeasured after 12 months for the same characteristics. Stem diameter was recorded

PLATE 8
TREMBLING ASPENS ON NORDIC. The stand V-2 is the tallest of all stands investigated and has established itself in close proximity to a road consisting of waste rock. The herbaceous cover is dominated in this section by birdsfoot trefoil.

PLATE 9
TREE POPULATIONS ON CROTCH. The stand S-5 at the northern tip of the vegetated belt on Crotch was harvested in 1982. Trees marked with flagging tape are inside the S-5 stand.

PLATE 10
WHITE BIRCH ON STANROCK MAIN. A dense population of seedlings, mainly white birch, are found in this area of transect 13 on Stanrock.

PLATE 11
OVERVIEW OF CONTROL SITE J-15. This quarry pit represents a fairly typical colonization pattern of a disturbed site for trembling aspen and white birch.

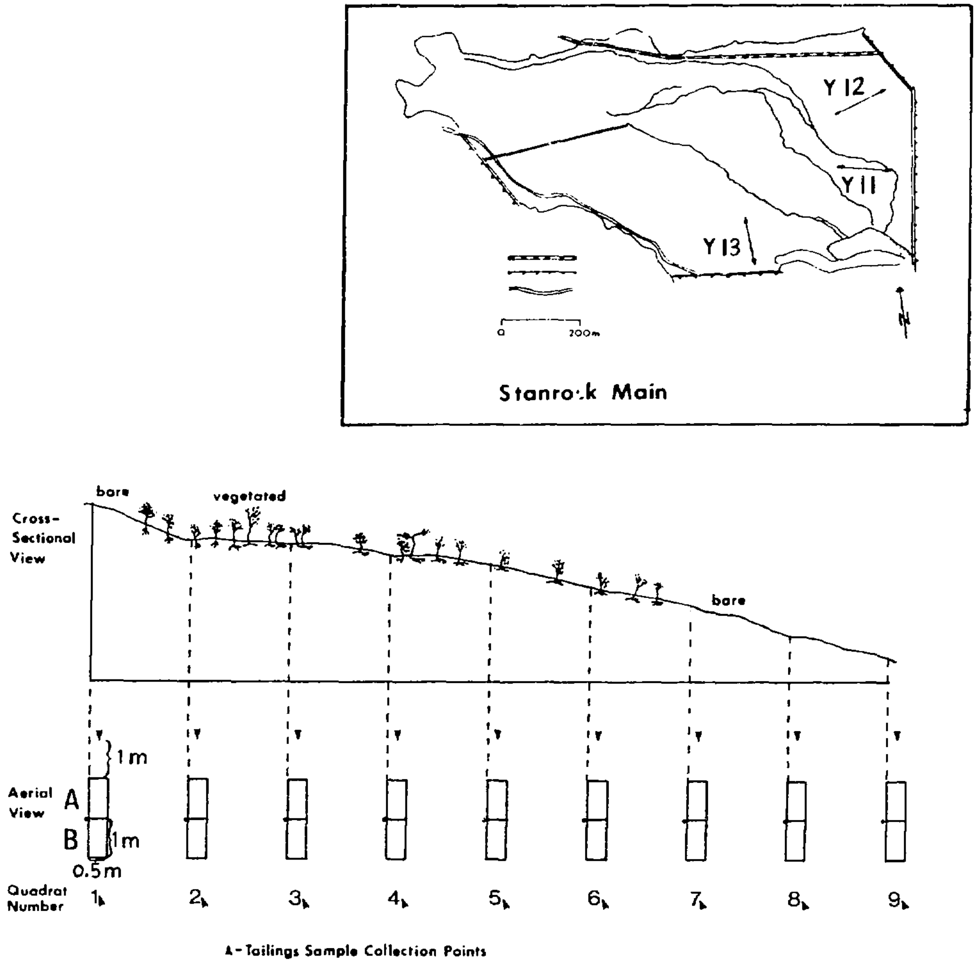


FIGURE 12 SCHEMATIC REPRESENTATION OF THE TREE TRANSECTS ON STANROCK. The transects 11, 12 and 13 varied in total length. Sampling quadrats were evenly spaced. The aerial view shows both sides (A and B) of the quadrats. The tailings sampled points, indicated by arrows, were one metre from the vegetation plots.

5 cm above ground level with a caliper and measured to the nearest 0.5 mm. For trees smaller than 5 cm, the stem diameter was measured at ground level. The trunk diameters were measured at 5 cm above the ground, contrary to the usual measurement in Forestry at breast height, because most trees did not reach breast height. Comparison of measurements at both positions for tall trees, however, yielded differences only as small as those differences in measurements from a different angle of the trunk at the same height. This can be explained easily, as on these thin trunks the taper is small and trunks are not perfectly round. Therefore, it was concluded that trunk diameters recorded at 5 cm are comparable to d.b.h. (diameter at breast height) measurements available in the literature.

In 1982, the position of all measured and labelled trees in 1981 for the area in which they were found was mapped with a precision of approximately 10 cm. In addition, all trees present in this area were measured and tagged. Tree density (no. of trees/m^2) was determined based on the maps. For statistical analyses of the tree characteristics, the data were manipulated with the SAS statistics package (SAS Institute, 1982).

2.2.4 Experimental Methods Addressing Physical Characteristics of the Surface and the Root Region, Tree Density and Clonal Growth. Experimental work was carried out to determine basic physical and chemical characteristics of the root region of the trees. Transects were set up on Stanrock to intercept tree cover from bare tailings areas through dense tree areas into bare or moss covered surfaces (Plate 12). A general transect schematic is given in Figure 12. In each transect, nine quadrats were spaced evenly over the entire length of the transect. Tailings material was collected from the surface and at the depth of the tree roots at one metre distances from the quadrats (arrows in Figure 12). The quadrat was divided into a left- and right-hand side portions covering 2 m in length (Figure 12 - Sides A & B).

Electrical conductivity and pH were determined in the laboratory by preparing 1:1 (w:v) tailings slurries. Tree density was recorded along the transects differentiating trembling aspen, white birch and willow in 1981 and 1982, and the percentage of moss cover was assessed. Transects were established in three areas on Stanrock (Transects 11, 12 and 13) where tree colonization was particularly prominent (insert in Figure 12). Transect 13 is depicted in Plate 12. Sampling location nine is in the foreground and stakes were used to identify the sampling intervals. The slope of the transects were determined with a survey level.

A dye-injection method to trace root connection of trees was adapted for small trees, which if successful, would yield information on the size of the clone. DeByle

PLATE 12
TREE TRANSECT 13 ON STANROCK MAIN. Dense growth of white birch seedlings in the upper portion of the transect changes to bare surface of sampling location No. 9 in the foreground. Paper was placed on the stakes to make the sampling intervals visible.

(1961) experimented with several methods of dye and radiotracer injections to determine the number of trees in a clone and the aerial extent of the clone. The leaves of those trees which are connected by their roots are stained as the dye moves through the roots. DeByle found that the Boremann and Graham (1959) method using tar paper funnels constructed around the cut-off tree stump sealed with melted paraffin was most effective. The tree was severed under water to prevent air penetration into the xylem, for this would prevent the movement of the dye.

The basic concept of Boremann and Graham (1959) was adapted for trees with small trunk diameters. PCV tubing with the appropriate inner diameter was fixed around the cut tree. The tubing was fitted with plastic funnels of various sizes and fastened with a hose-clamp to the tree stump. The funnels were supported by stakes and filled with 0.1 or 0.5 percent aqueous eosin solution, and then covered with aluminum foil. Additional solution was added after 24 h, as initially the dye moved rapidly. Sufficient solution was maintained in the funnels to allow further transport for a period of one week. After that time no further movement could be expected as the cut tree would be physiologically isolated from the remaining clone. The leaves of receptor trees were stained red, if the dye had moved. In addition, roots were also excavated by hand, tracing root connections.

2.2.5 The Trees: Trembling Aspen and White Birch Biology. Poplars and birches are studied extensively by foresters and botanists alike and the following section is only a brief review of selected ecological characteristics of trembling aspen and white birch relevant to this study. These are the general characteristics of growth, seedlings characteristics, reproductive modes and environmental tolerances. *Populus tremuloides* Michx. (family Salicaceae), commonly referred to as trembling or quaking aspen, is a tree native to North America. It is an aggressive, medium-sized, fast-growing and relatively short-lived pioneering species. Although it can attain heights of over 32 m, average mature height is approximately 18 m, and the average maximum age is 50 to 60 years. Growth is extremely variable within the species' geographic range. Trembling aspen is considered to be the most widely distributed tree species in North America, being found from Newfoundland, across the northern tree limit, up to northwestern Alaska and as far south as northern Mexico (USDA, 1965).

White birch *Betula papyrifera* Marsh. of the family Betulaceae is also native to North America. Common names for this species are paper, white or silver birch. Like trembling aspen, it is an aggressive colonizing tree species, rather short-lived (average maximum age of 60-75 years) and particularly fast growing when young (USDA, 1965). Average-sized, mature trees have an height of approximately 21 m, but they can exceed 30 m in height under optimal growth conditions. The species' geographic range is almost that of aspen, being slightly more restricted in its northwestern and southeastern distribution. It also occurs somewhat farther north in eastern Canada and along the southwestern coast of British Columbia. Being a cool-climate species, white birch does not generally grow where average July temperatures exceed 21°C (USDA, 1965).

Within the large geographic range, trembling aspen and white birch occur on many substrate types, from shallow rocky soils to heavy clays and in sphagnum bogs. Optimal growth conditions for aspens are well-drained, moist, sandy or gravelly loams. For white birch, best growth is reported to occur on well-drained sandy or silty loams (Hosie, 1979). White birch grows on both acidic and calcareous soils and is rarely found on very wet, poorly-drained soils. It does occur, however, in dry bogs, on river banks and on beaches. White birch and trembling aspen are relatively tolerant of low moisture and nutrient conditions and are early colonizers of perturbed environments (Watson et al., 1980), though growth is generally restricted under these conditions (Schlatzer, 1973).

The ectomycorrhizal root systems of aspen and birch may play an important part in their success as early pioneer species in many types of environments. The symbiosis between fungus and the plant root enables increased absorption of nutrients (and possibly water) from the substrate beyond the root's normal capability (Hacskaylo, 1971). Studies on coal spoils in Britain and the United States have suggested a strong role of mycorrhizae in the successful establishment and early growth of many plant species in such severely perturbed environments (Daft et al., 1975; Schramm, 1966). Well-developed ectomycorrhizae characterize birches growing in low-nutrient, acidic smelter wastes in the area of Sudbury, Canada (Rood, 1983).

Trembling aspen and white birch regenerate from both seedlings and root suckers (USDA, 1965). The dioecious aspen produces abundant seed in catkins of female individuals annually. Seed release in trembling aspen occurs generally in May and June, but for the monoecious white birch seed release does not begin until autumn and may continue into winter. The quality of the seeds is known to vary from year to year for both species. Good seed years occur on average, every four or five years for trembling aspen. Though viability is high when seed is fresh, seeds become inviable within two or three weeks under natural conditions (Graham, 1963). In some years, birches are extremely prolific seeders and seed viability is high. Other years, seed production is low, and though seedfall is observed, seed viability may also be extremely low (Marquis, 1969). Though seeds of birch are small, they retain viability under natural conditions for approximately one year.

The seed characteristics of trembling aspens are such that establishment by seeds is rare, due to the short period of seed viability, enhanced by the specific microclimatic requirements for seedling survival. Following germination of the aspen seed, primary root growth is initially extremely slow. Moisture absorption of the very young seedling depends on a ring of long delicate hairs that arise at the junction of the hypocotyl and the root (Graham, 1963). For adequate moisture absorption, the substrate surface be continually moist for at least the first week after germination. These conditions occur infrequently in the geographic range of aspens.

Seed germination in white birch requires high light intensity and high soil temperature. Early seedling survival after germination is also dependent on adequate surface moisture (Schlatzer, 1973; USDA, 1965). The ideal conditions for seed germination and early seedling establishment, however, are different than those required for optimum growth of the seedling (Winget and Kozlowski, 1965). For example, while a sandy substrate provides a stable water supply for germinating seeds, it is low in nutrients for subsequent seedling growth. Despite this, the majority of birch establishments under natural conditions is believed to take place from seeds. This is in contrast to the establishment of trembling aspen, where seeds rarely lead to tree stands.

Most aspen stands are believed to be a result of regeneration by sucker production because of the extreme sensitivity of the seedling during establishment. Suckers arise from buds on the shallow lateral root system of an established aspen (Schier and Campbell, 1976). Studies have suggested that both high soil temperatures and damage to the parent aspen stimulates root suckering, through changing auxin concentrations within the parent tree (Schier, 1973; Stoeckeler, 1948). Fires which destroy above-ground vegetation, but leave root systems relatively undamaged often result in regenerated stands which are even aged. Seedling establishment and sucker production is rare under closed canopies, but aspen establish quickly in the absence of competition from other species in post-fire gaps in northern forests (USDA, 1965). Vegetative regeneration takes place in white birch through the production of sprouts on stumps and suckers along the shallow, laterally spreading roots. Above-ground destruction of trees usually results in the sprouting of burned stumps (USDA, 1965).

Young aspen and birch trees are shade intolerant and poor competitors in established vegetation. Subsequently, growth is difficult in areas of dense ground cover. White birch, once established, however, is considered more tolerant to harsh environmental conditions than aspen, and competes better with other species.

Birch and aspen trees are susceptable to a range of predators. Seedlings and saplings are killed by bark-eating animals such as beaver, deer and hares. Aspen trees of all ages are attacked by a variety of insects and wood-rotting fungi, the latter being responsible for considerable economic losses in areas where the species have commercial value. One of the few diseases attacking vigorous stands of white birch is known as birch dieback. The symptoms are reduced growth and dying back of twigs and branches (Hyvarinen, 1968). This disease has been responsible for the destruction of most of the production grade birch forests in the Canadian Maritimes (USDA, 1965).

Aspen can occur in relatively pure (single species) stands, but because of their extensive range they are also an important component of many different types of vegetation communities (Graham, 1963; USDA, 1965). Aspen suckers are reported to compete less successfully with grasses as compared to other woody plants (Watson et al., 1980). In addition, aspen act as 'nurse trees', or ameliorators of the micro-environment allowing colonization by other species (Watson et al., 1980). Birches also grow in pure stands, but more frequently they are associated with mixed vegetation communities. Birches are often replaced in time by other tree species over a large part of their geographical range because of their inability to compete successfully (USDA, 1965).

In summary, trembling aspen and white birch are similar in their pioneering character and growth form but they differ in their reproductive mode, their environmental tolerances and their seedling characteristics. Both species are expected to establish on uranium mill tailings, but their growth and expansion on these nutrient poor sites with low moisture holding capacity may differ. Furthermore, the different degrees of vegetation cover of the tailings sites may challenge the respective competitive ability of the species.

2.3 Results and Discussion

2.3.1 The Characteristics of the Trees. Height of trees is generally accepted as one of the indicators of growth (Kramer and Kozlowski, 1979). The mean heights of white birch and trembling aspen stands for the areas of Elliot Lake, Bancroft and the stands on non-tailings sites for each area are presented in Figure 13. The heights are given for the populations in 1981 and 1982. The trees on Nordic for both species are generally 50 to 100 cm taller than on other sites. In each stand, large variations in tree heights are indicated by the standard error bars (Figure 13).

An analysis of variance procedure was used to test differences in mean tree heights of the individual stands and those of the entire site (Figure 13 - bars labelled 'all'). A Scheffe's grouping produced a detailed analysis of the mean heights, differentiating the means of the stands or sites. Trees on the Auger site (stand A-11) were damaged extensively by snowmobiles during the winter of 1981, therefore, the trees were excluded from the analysis. The results for white birch are given in Table 11a. Significant differences at p = 0.0001 were found for three groups, Nordic (V-2 and V-5), Crotch (S) and Bicroft (D) stands. For both years, means of stands and means of sites were compared; the same grouping was determined for 1981 and 1982. The Nordic trees were significantly taller than the control trees in both areas. The control stands, however, were not significantly different from other stands or sites.

For trembling aspen, the mean heights of the stands differed significantly from each other, forming three groups of heights in 1981 and four in 1982 (Table 11b). The Crotch stands (S-2, 6 and 7) were similar to all other stands, with the exception of two stands on Nordic (V-3 and 5). The addition in 1982 of the stand on Madawaska No. 2

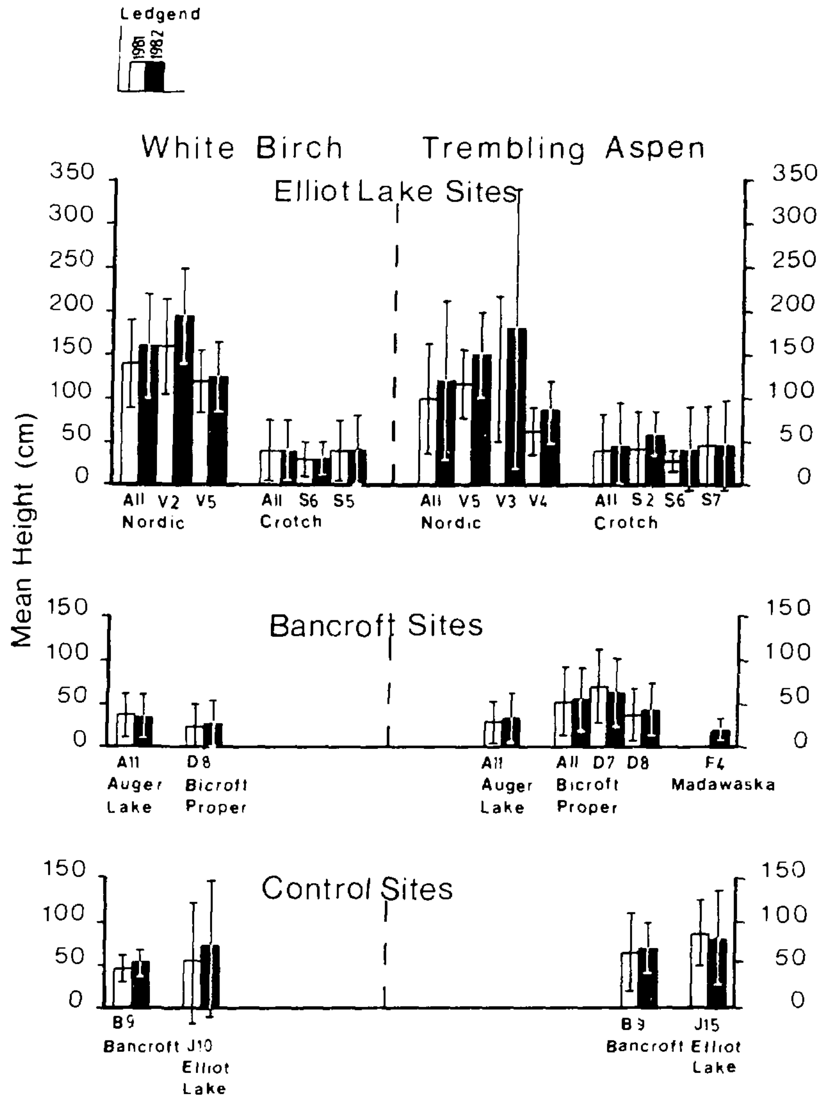


FIGURE 13 THE AVERAGE HEIGHT OF TREE STANDS ON TAILINGS AND CONTROL SITES FOR WHITE BIRCH AND TREMBLING ASPEN. The dark bars are heights for the 1982 populations and the light bars are those for 1981. The mean heights of the stands are given with the standard errors, and the bars labelled all represent the average height of the tailings sites, where more than one stand was studied.

TABLE 11a SCHEFFE'S TEST FOR WHITE BIRCH VARIABLE TREE HEIGHT

1981 Height				1982 Height		
Scheffe Grouping*	Mean (cm)	n	Stand and Site	Scheffe Grouping	Mean (cm)	n
A	116.1	65	V-2	A	194.4	52
B	119.2	54	V-5	B	124.6	56
C	41.5	111	S-5	C	41.9	138
C	29.2	29	S-6	C	31.4	123
C	24.5	49	D-7	C	27.8	47
A	141.5	119	Nordic	A	158.2	108
B	56.3	100	E.L. Controls	B	68.6	175
B C	45.2	30	B. Controls	B C	52.8	19
B C	38.9	140	Crotch	B C	37.3	281
C	24.5	49	B. Proper	C	27.8	47

* Means with the same letter are not significantly different at p<0.01

TABLE 11b SCHEFFE'S TEST FOR TREMBLING ASPEN VARIABLE TREE HEIGHT

1981 Height				1982 Height		
Scheffe Grouping*	Mean (cm)	n	Stand and Site	Scheffe Grouping*	Mean (cm)	n
A	134.6	50	V-3	A	179.8	50
A	117.0	45	V-5	A	151.0	46
B	68.9	50	D-7	B	65.4	42
B C	63.4	63	V-4	B	87.0	126
B C	46.0	60	S-7	C D	45.0	145
B C	42.4	63	S-2	B C D	57.0	63
B C	37.4	49	D-8	C D	42.6	42
C	27.6	25	S-6	C D	41.7	82
			F-4	D	20.3	109
A	101.2	158	Nordic	A	121.1	222
A B	87.0	100	E.L. Controls	B	80.2	155
B C	65.5	30	B. Controls	B C	71.2	21
C		99	B. Proper	B C	54.0	84
C	41.4	148	Crotch	C D	46.7	290
			Madawaska	D	20.3	109

* Means with the same letter are not significantly different at p<0.01

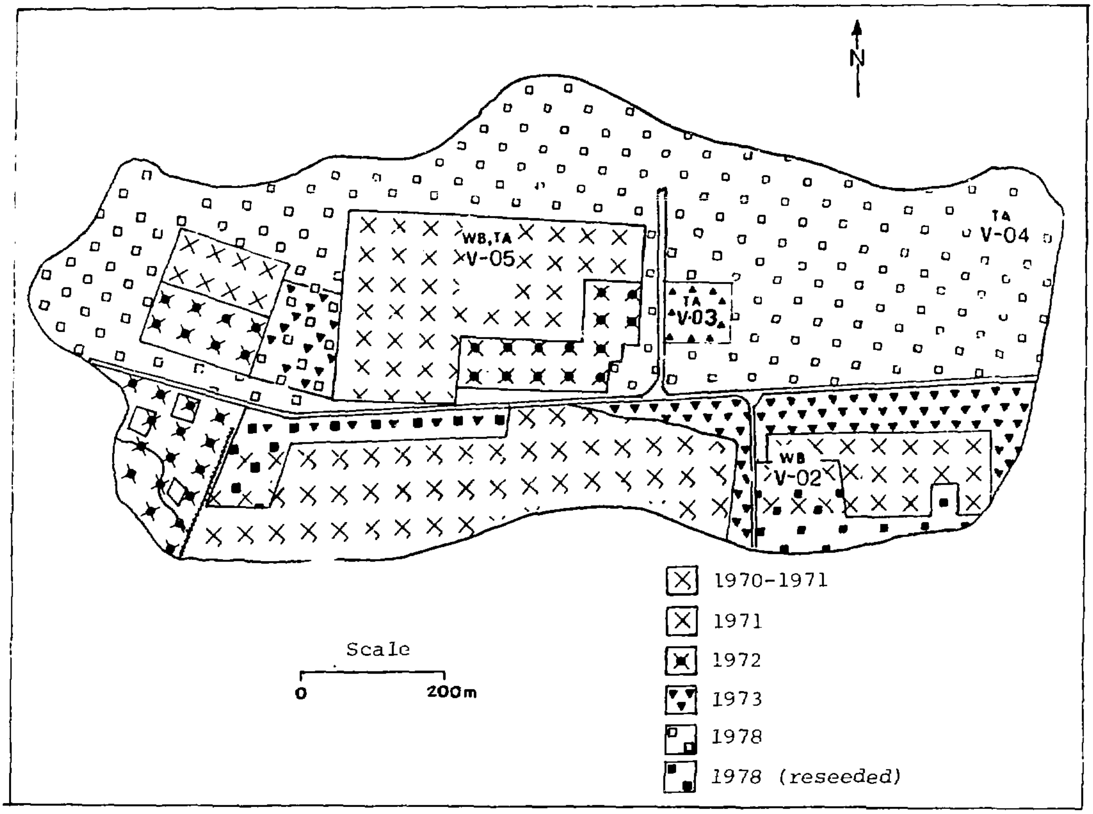
(F-4), the smallest aspen stand of the study, produced the fourth group of populations, ranging from 20 to 45 cm in height. Nevertheless, the Nordic stands were the tallest, with the exception of stand V-4 which had a mean height similar to that of Crotch and Bicroft Proper.

Taller trees on Nordic may be a result of the site amelioration history or simply an indication of better growth of trees on this site. The location of the tree stands and the time of amendment is given in Map 5. The symbols represent the summers during which certain sections of the surface were amended and seeded. The two white birch stands are located in areas with slightly different amendment history. The V-2 stand is located in an area which had received extensive attention since 1971, whereas V-5 is in a section which received one general treatment with subsequent fertilization. The reseeding of the area around V-2 may have contributed to growth (Table 11a).

The trembling aspen stands (V-3, 4 and 5) also grow in sections with different amendment history. Their heights differ drastically since V-3 is twice as tall as V-4 (Table 11b). Trees in stand V-5 could have potentially established themselves in 1971, six to seven years earlier than V-4 and two years later than V-3, therefore the trees in V-5 should be the tallest. The mean height of 90 cm for V-4 compared to 150 to 180 cm for V-3 and V-5, most certainly does not reflect any relationship to the time of amendment of the area. Indeed, time of the site amendment reveals little relationship to the aspen tree heights.

Crotch was amended in 1971, while the Bancroft sites became inactive during 1957 (Bicroft Proper), Auger in 1963, and Madawaska No. 2 in 1964. The heights of the trees for both species on these sites also exhibit no relationship between height and age of site. One-hundred and fifty white birch trees have been aged by ring counts for the stand S-5 on Crotch (Kalin, unpublished data). Birch trees on Crotch had an average age of 5.2 years, with only three trees 10 years old and two trees 11 years old. The ages of trembling aspen trees on Bicroft Proper have also been determined (Caza, 1983). The aspen population on Bicroft Proper, which was abandoned in 1957, ranged from two to eight years in age. The ages of the trees suggest strongly that tree age does not reflect site age.

Murray and Turcotte (1982) investigated tree stands of volunteer and planted trees for Nordic and found a difference in the height of the populations (birch, poplar and willows mixed) with respect to the age of 8 to 11 years. Murray and Turcotte (1982) defined age of the stand by the time since amendment of the surface. Generally height classes of 100 to 150 cm constituted about 20 percent of their tree population. They



Map 5 THE RECLAMATION HISTORY OF NORDIC (ELLIOT LAKE). The year at which a given section of the site was amended is indicated by different symbols, and the location of *the tree stands are given by their codes.* The amendment history of the site was derived from personal communication with A. Vivyurka, Rio Algom Ltd. (1982).

suggested that the large fractions of the smaller size classes are found in younger stands; the observations, however, had not been statistically tested. The size class composition of stands in this study is not related to the age of the tailings.

Some perspective on the expected height growth of aspens can be gained from Bate and Canvin (1971). They reported that aspen seedlings grown under controlled environmental conditions attained an average height of 65 cm with 25 to 30 leaves in their first five months of growth. Zavitkovski (1974) reported from the Enterprise Radiation Forest in northern Wisconsin, a forest area typical for much of the upper Great Lake Forest Region, tree heights for trembling aspen reaching 5, 10 and 15 m at 7, 16 and 24 years of age, respectively. The corresponding ages for white birch in the same forest, for the same heights, are reported as 10, 22 and 36 years. White birch can thus be expected to grow somewhat slower. These heights of the Enterprise Radiation Forests and the height growth achieved under controlled conditions are clearly not attained on the tailings.

Tree height growth reflects the environmental conditions of the site and tailings are likely a poor growth substrate. Basic physiological components which control growth are rate of photosynthesis and respiration, development of photosynthesizing leaf area, partitioning of matter within the tree and finally the efficiency of nutrient and water use (Dickman, 1979). These components are all influenced by environmental conditions of the growth substrate and the geographic location of the trees. Of primary importance is an initial evaluation of the tree growth on the sites.

Rather than depending upon environmental conditions, increases in radial growth of the trunk always occurs to greater or lesser amounts over each growing season. Therefore, it can be expected that though the height of the tree populations varied, that radial growth or trunk diameter could differ with time more than shoot elongation. The mean trunk diameters of all stands, and the site means for the Nordic and Crotch stands are presented in Table 12a for white birch. The Scheffe groupings, derived from an ANOVA in the same way as for tree heights relfects the same order as that observed for height. The trunk diameters have large standard errors in both years and consequently the means are not significantly different from each other with the exception in the tree stands on Nordic. These results suggest that, though the trunks increase annually, they do not reflect the age of the stands. As the trunk diameters and heights fall in similar statistically significant groupings, it may be concluded that radial growth does not differ from shoot elongation for white birch.

The mean trunk diameters of trembling aspen of the stands are given in Table 12b. Significant differences in mean trunk diameter exist between the stands in 1981 and 1982. Such changes were not observed for white birch stands (Table 12a). The groupings of the sites for the trunk diameters of aspens on Nordic did not significantly differ from that on the Elliot Lake control sites; however, the heights of the stands differed in 1982 statistically. Aspen trunk diameters and the heights have the same grouping of means in 1982 (Table 11b and 12a). In summary, the Nordic stands for both species have the tallest trees with the largest trunk diameters.

From the characteristics of the trees on tailings it can be inferred that tree growth is stunted. Zavitkovski (1974) reported that birches with a diameter at breast height (d.b.h.) of 5 cm were about 15 to 20 years old, but a corresponding d.b.h. in aspens

TABLE 12a TRUNK DIAMETER FOR WHITE BIRCH

1981 Diameter				1982 Diameter		
Scheffe* Grouping	Mean and sd (cm)	n	Stand and Site	Scheffe* Grouping	Mean and sd (cm)	n
A	3.0± 1.8	65	V-2	A	3.6± 1.7	52
B	2.0± 0.9	54	V-5	B	2.2± 0.9	56
C	0.7± 0.7	111	S-5	C	0.7± 0.7	158
C	0.5± 0.3	29	S-6	C	0.4± 0.3	123
C	0.4± 0.3	49	D-7	C	0.4± 0.4	47
	0.5± 0.3	49	A-11		0.6± 0.3	38
A	2.6± 1.5	119	Nordic	A	2.9± 1.5	108
B	0.9± 1.0	100	E.L. Controls	B	1.3± 1.6	174
B	0.6± 0.6	140	Crotch	B C	0.6± 0.6	281
B	0.4± 0.2	30	B. Controls	C	0.4± 0.2	19
B	0.4± 0.3	49	B. Proper	C	0.4± 0.4	47

* Means with the same letter are not significantly different at p<0.01

TABLE 12b TRUNK DIAMETER FOR TREMBLING ASPEN

1981 Diameter				1982 Diameter		
Scheffe* Grouping	Mean and sd (cm)	n	Stand and Site	Scheffe* Grouping	Mean and sd (cm)	n
A	1.8± 1.5	50	V-3	A	2.1± 2.0	50
B	1.2± 0.5	45	V-5	A	1.8± 0.6	45
B C	0.5± 0.4	49	D-7	B C	0.5± 0.4	42
C	0.6± 0.3	63	V-4	B	1.0± 0.8	126
C	0.6± 0.7	60	S-7	B C D	0.5± 0.7	145
C	0.5± 0.4	49	D-8	B C D	0.5± 0.4	42
C	0.4± 0.4	63	S-2	B C D	0.6± 0.3	63
C	0.4± 0.2	25	S-6	C D	0.4± 0.5	82
			F-4	D	0.3± 0.2	109
	0.3± 0.2	44	A-11		0.5± 0.3	37
A	1.2± 1.0	103	Nordic	A	1.4± 1.2	221
A B	0.9± 0.4	100	E.L. Controls	A B	1.0± 0.9	154
B C	0.7± 0.5	99	B. Proper	B C	0.7± 0.5	84
C	0.5± 0.6	148	Crotch	C	0.5± 0.6	290
C	0.5± 0.3	30	B. Controls	B C	0.6± 0.3	21
			Madawaska	C	0.3± 0.2	109

* Means with the same letter are not significantly different at p<0.01

was reached by 11 years. White birch grows slower than trembling aspen in forests, however, both species are fast growing compared to other forest trees. The average age of aspens on the control site (J-15) was four to five years (Kalin, unpublished data). The control stands are of younger age, but of similar height than trees on tailings. Murphy and Sharitz (1974) classified seedlings, saplings and canopy trees with respect to d.b.h. in a forest environment. Saplings are considered trees of at least 30 cm in height or more with a d.b.h. of 2.5 cm or less, while seedlings are considered as those whose height is less than 30 cm. The trunk diameter means of the Nordic aspen stands ranged from 1.2 to 1.8 cm, and mean height ranged from 117 to 134 cm. White birch trunk diameter means ranged from 2.0 to 3.0 cm, and height means ranged from 119 to 160 cm. These values of height and trunk diameters qualify the Nordic stands as sapling populations. Most of the remaining tree stands would fall in the seedling category. Canopy trees were classified by Murphy and Sharitz (1974) for both species as trees with d.b.h. larger than 2.5 cm and generally less than 20 years of age. Trees of this category, according to their d.b.h., are not found on the tailings.

Given the average heights of trees, their trunk diameters and the time since trees could have potentially established themselves, the poor site conditions can be deduced. Schier and Campbell (1976) reported heights of aspen suckers of about 50 cm in their first year and 50 to 90 cm in their second year. Bailey and Wroe (1974) studied aspen invasion in Alberta Parklands where young stands, 3 to 10 years of age, had trunk diameters (d.b.h.) of 1.3 to 7.1 cm and heights of 1.4 to 8.7 m. The average age of the aspens on Elliot Lake control site (J-15) was determined to be four to five years. The height and trunk diameter of the control sites are in the lower ranges reported for Alberta Parkland, therefore, the gravel pit, as expected also represents poor growth substrate. The trees on the control sites are appropriate populations to compare tree growth on tailings.

The shape of the crowns and number of branches on the trees also reflect aspects of tree growth. The trees on tailings grow on open fields, where wind stress may induce crown shape modification. King and Loucks (1978) suggested by modelling of tree forms, that the younger age classes reduce crown drag by low cost design of branches in return for rapid height growth. It is thus reasonable to suggest that perhaps trees with less branches will be found on exposed tailings sites, compared to more sheltered control sites.

The means of crown width and branch number for each stand are given for white birch in Tables 13 and 14 for the years of 1981 and 1982, respectively. The stands

TABLE 13 CROWN DIAMETER FOR WHITE BIRCH (cm)

Site Code and Location	1981		1982	
	*$\bar{X}$±sd	(n)	*$\bar{X}$±sd	(n)
NORDIC - all	73.9± 37.2	(119)	94.0± 48.0	(108)
V-2	59.3± 21.5	(54)	72.0± 29.6	(56)
V-5	86.0± 42.9	(65)	117.6± 52.8	(52)
CROTCH - all	22.1± 18.7	(140)	23.4± 21.8	(281)
S-5	23.7± 20.0	(111)	27.8± 27.0	(158)
S-6	15.8± 10.8	(29)	17.8± 9.8	(123)
AUGER LAKE	19.4± 13.9	(49)	20.7± 15.2	(38)
B. PROPER	11.2± 10.7	(49)	13.9± 12.3	(47)
B. CONTROLS	19.5± 9.6	(30)	21.1± 6.4	(19)
E.L. CONTROLS	32.4± 38.1	(100)	44.7± 49.7	(174)

*Standard deviation is very large compared to the mean because there were many small values and a few large ones.

TABLE 14 NUMBER OF BRANCHES FOR WHITE BIRCH

Site Code and Location	1981		1982	
	*$\bar{X}$±sd	(n)	*$\bar{X}$±sd	(n)
NORDIC - all	14.4± 8.3	(119)	15.9± 9.0	(108)
V-2	17.1± 9.6	(65)	20.1± 10.1	(52)
V-5	11.1± 4.7	(54)	12.0± 5.7	(56)
CROTCH - all	4.3± 5.0	(140)	5.8± 6.3	(281)
S-5	5.1± 5.3	(111)	7.0± 7.4	(158)
S-6	1.7± 2.5	(29)	4.2± 4.0	(123)
AUGER LAKE	2.2± 1.9	(39)	2.5± 2.0	(40)
B. PROPER	1.6± 2.4	(47)	1.8± 2.2	(47)
B. CONTROLS	2.5± 1.4	(19)	2.7± 2.0	(18)
E.L. CONTROLS	5.4± 6.3	(100)	7.0± 7.6	(175)

*Standard deviation is large compared to the mean because there were many small values and a few large ones.

on the Nordic site which differed in height and trunk diameter from other stands, also have the widest crowns and the largest number of branches. The relationship of crown diameter and tree heights, however, is relatively consistent for the site and the stands. The trees are generally 1.5 to 2.5 times taller than the crown is wide.

The ratio of crown diameter to number of branches for white birch can be assessed from the mean values in Tables 13 and 14. The Crotch site and stand V-2 on Nordic range from 3.5 to 4.2, while ratios of the control sites and all other stands, range from 7 to 10. This may indicate some effects from the wind exposure given the Crotch and Nordic stands growing on large open areas. For trembling aspen, crown diameter and number of branches are summarized in Tables 15 and 16. The proportion of the mean height and crown diameter is related generally with a ratio of 1.5 to 2, with the exception

TABLE 15 CROWN DIAMETER FOR TREMBLING ASPEN (cm)

Site Code and Location	1981 *$\bar{X}$±sd	1981 (n)	1982 *$\bar{X}$±sd	1982 (n)
NORDIC - all	49.0± 40.0	(158)	61.8± 46.9	(222)
V-3	63.5± 55.6	(50)	75.9± 68.1	(50)
V-4	27.2± 19.1	(63)	42.6± 23.6	(126)
V-5	63.2± 25.3	(45)	98.9± 39.6	(46)
CROTCH - all	19.8± 26.5	(148)	22.1± 31.1	(290)
S-2	17.7± 23.7	(63)	25.7± 18.2	(63)
S-6	13.2± 14.4	(25)	19.2± 27.2	(82)
S-7	24.9± 32.0	(60)	22.2± 37.1	(145)
AUGER LAKE	10.7± 16.2	(44)	13.3± 20.4	(37)
B. PROPER	25.1± 25.5	(99)	29.1± 28.0	(84)
D-7	34.7± 29.6	(50)	40.7± 33.8	(42)
D-8	15.3± 15.6	(49)	18.6± 16.4	(42)
MADAWASKA	-	-	6.7± 4.2	(109)
B. CONTROLS	18.8± 16.1	(30)	27.6± 25.1	(21)
E.L. CONTROLS	44.3± 27.4	(100)	47.3± 39.7	(155)

*Standard deviation is large compared to the mean because there were many small values and a few large ones.

TABLE 16 NUMBER OF BRANCHES FOR TREMBLING ASPEN

Site Code and Location	1981		1982	
	*$\bar{X}$±sd	(n)	*$\bar{X}$±sd	(n)
NORDIC - all	15.1± 10.7	(158)	14.7± 10.1	(222)
V-3	18.5± 13.5	(50)	16.2± 13.1	(50)
V-4	10.6± 7.9	(63)	11.0± 6.4	(126)
V-5	17.7± 8.5	(45)	23.1± 9.6	(46)
CROTCH - all	6.6± 9.5	(148)	8.2± 10.0	(290)
S-2	6.0± 8.8	(63)	10.9± 8.5	(63)
S-6	4.9± 3.6	(25)	6.2± 9.5	(82)
S-7	7.8± 11.7	(60)	8.1± 10.7	(145)
AUGER LAKE	1.2± 2.7	(37)	1.7± 4.1	(35)
B. PROPER - all	2.5± 3.0	(87)	3.5± 3.8	(83)
D-7	3.1± 3.4	(41)	3.9± 3.5	(41)
D-8	1.9± 2.5	(46)	3.1± 4.0	(42)
MADAWASKA	-	-	1.2± 1.8	(109)
B. CONTROLS	0.8± 1.1	(24)	2.0± 2.7	(21)
E.L. CONTROLS	15.4± 8.1	(100)	13.7± 10.8	(155)

*Standard deviation is very large compared to the mean because there were many small values and a few large ones.

of the V-4 stand on Nordic, which is 3.7 times wider than tall. The ratio of the number of branches to crown diameter for aspens on the Nordic tailings and the Elliott Lake controls ranges from 3.4 to 4.6. The stands on the Bancroft tailings, however, generally have fewer branches in relation to crown diameter; the ratios on these sites range from 1.3 to 5.5. The aspens on Crotch have a relatively narrow crown with many branches (ratio 2.3 to 3). This suggests indirectly that the growth form of white birch and trembling aspen on Crotch might differ slightly with respect to the number of branches in the crown, or that the response to wind exposure differs between the species. As birches are reported to be more tolerant to environmental stress than aspens these branch/crown ratios may be a result of their exposure to open areas.

The characteristics of height, trunk and crown diameter, and the number of branches all indicate growth and are expected to be related to each other. Relations between tree age, d.b.h., crown width and crown volume are generally expressed as growth functions (Zavitkovski, 1974). Zavitkovski analysed data of these tree characteristics for the Enterprise Radiation Forest. At a height of less than 5 m, d.b.h. of < 2.5 cm and crown width of < 2.5 m, the relationships are essentially linear for trembling aspen and white birch. Significant deviations would indicate greater complexities in the early stages of the development of tree stands on tailings compared to growth in forests.

Linear regressions of height versus trunk, crown diameter and number of branches were compared between stands and sites, then combined for all trees on tailings and all control tree populations for each species. The correlation coefficients were in all cases significant and close to ±1.0 indicating a strong relationship between the tree characteristics and height. The individual correlation coefficients are not reported, but a summary of all correlation coefficients, for the entire tree population investigated in this study, represent the relations observed (Table 17). Zavitkovski's correlation coefficients (height versus d.b.h.) based on growth function were 0.888 for white birch and 0.916 for trembling aspen, indeed very similar to the correlation coefficients of these small populations. Alder (1970) also reported linear correlation coefficients between tree heights and d.b.h. with r^2 values of 0.825 for mature aspen forest stands. Given the linear relationship of height versus other tree characteristics, it is suggested that trees on tailings and on naturally poor sites, such as the control sites, do not differ in their form significantly from those expected to be found in natural forest and with taller trees.

The previously discussed tree characteristics were based on individual stands or sites. The tailings sites exhibit drastic differences in cover type and thus growth conditions. To ascertain differences in tree development with respect to amended, partially amended, and unattended tailings, the tree populations are grouped by area. In Figure 14, the cumulative frequency of the white birch stands are given for the tree populations for each year (1981 and 1982) separately. The composition of tree heights on Elliot Lake tailings clearly differs from the other two populations. The Bancroft tailings where seventy percent of the trees have heights of 25 cm or less have a larger fraction of smaller trees in both years. The mean heights of this 70 percentile is 13.5±5.7 cm tall. For the control sites the same percentile has trees with mean heights of 21±12 cm, but for Elliot Lake the 70 percentile has a mean height of 50±36 cm. The respective mean height at the 70 percentile for Bancroft is 25 cm or less, for the control sites 45 cm or less and the Elliot Lake sites 125 cm or less.

For trembling aspens, the Elliot Lake sites have a more comparable composition of height classes to those of the control sites (Figure 15). Furthermore, the

TABLE 17 *CORRELATIONS OF HEIGHTS WITH OTHER CHARACTERISTICS OF TREES*

	Trembling Aspen			White Birch		
Height For	Correlation Coefficients	Probability	No. of Observations	Correlation Coefficients	Probability	No. of Observations
1981						
Branches	0.860	0.0001	554	0.889	0.0001	463
Crown	0.888	0.0001	579	0.925	0.0001	487
Trunk	0.879	0.0001	579	0.895	0.0001	487
1982						
Branches	0.823	0.0001	915	0.874	0.0001	665
Crown	0.869	0.0001	918	0.925	0.0001	665
Trunk	0.848	0.0001	916	0.878	0.0001	666

aspen height class composition of the populations is less distinctive between the areas than for white birches. Seventy percent of the trees on Elliot Lake tailings were 95 cm tall or less, with a mean height of 60±25. Aspens on both control sites have a mean height of 47±29 cm for the same fraction of the population. A 10-cm difference in the height of the aspen population can be noted which is smaller than that of the birch population. On the Bancroft tailings, trees of 95 cm height or less comprise 90 percent of the population with an average height of 38±24 cm. Only one or two trees were taller than one metre. Aspens are more likely to sucker than birches, while birch seedlings establish more successfully on mineral soils than aspen seedlings. These height class compositions of the species possibly reflect the establishment process on the tailings and the recruitment of trees in the stands.

The height class composition of the white birch differed clearly for the three populations. As height, growth, or shoot elongation should reflect the radial growth, the cumulative frequency of trunk diameters can be expected to produce the same separation of the curves as did height. For white birch, the differentiation between composition of trunk diameter reflected that of the heights (Figure 16). The 55 percentile trunk diameter on the Elliot Lake tailings consists of trees with a 1.25 cm diameter or less. On the control site the same diameter is found in up to 80 percent of the trees and in Bancroft nearly the entire population has trunks with smaller diameters.

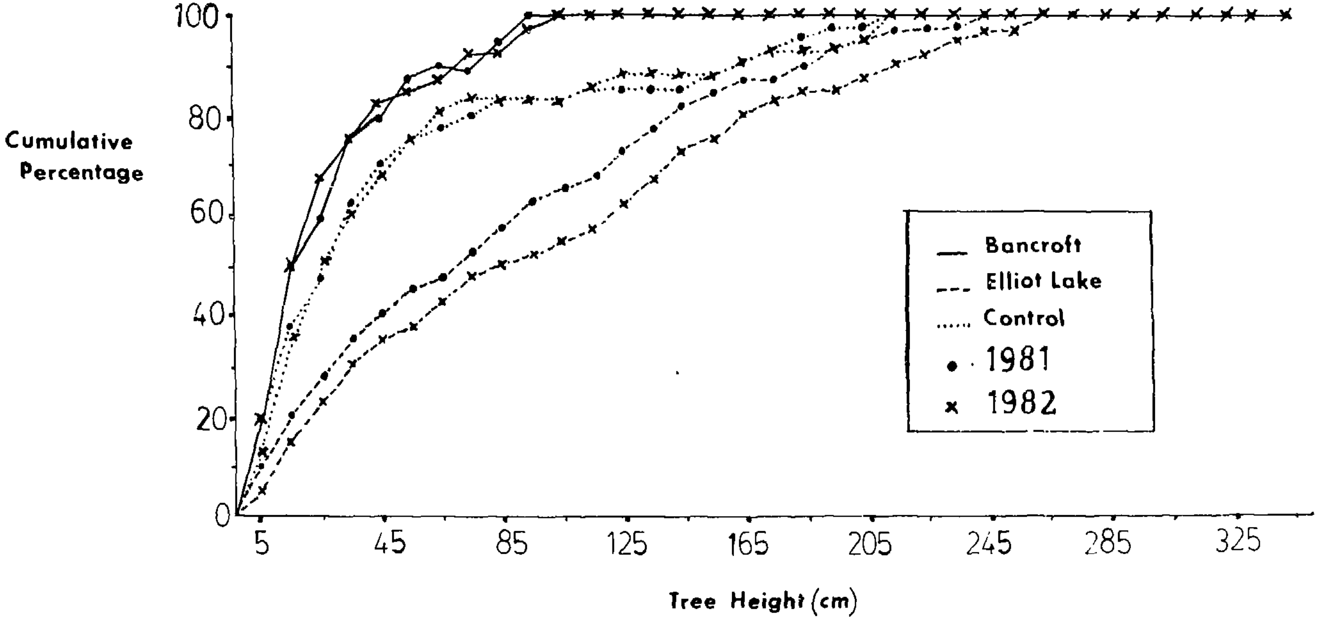


FIGURE 14 CUMULATIVE PERCENTAGE OF HEIGHTS FOR WHITE BIRCH

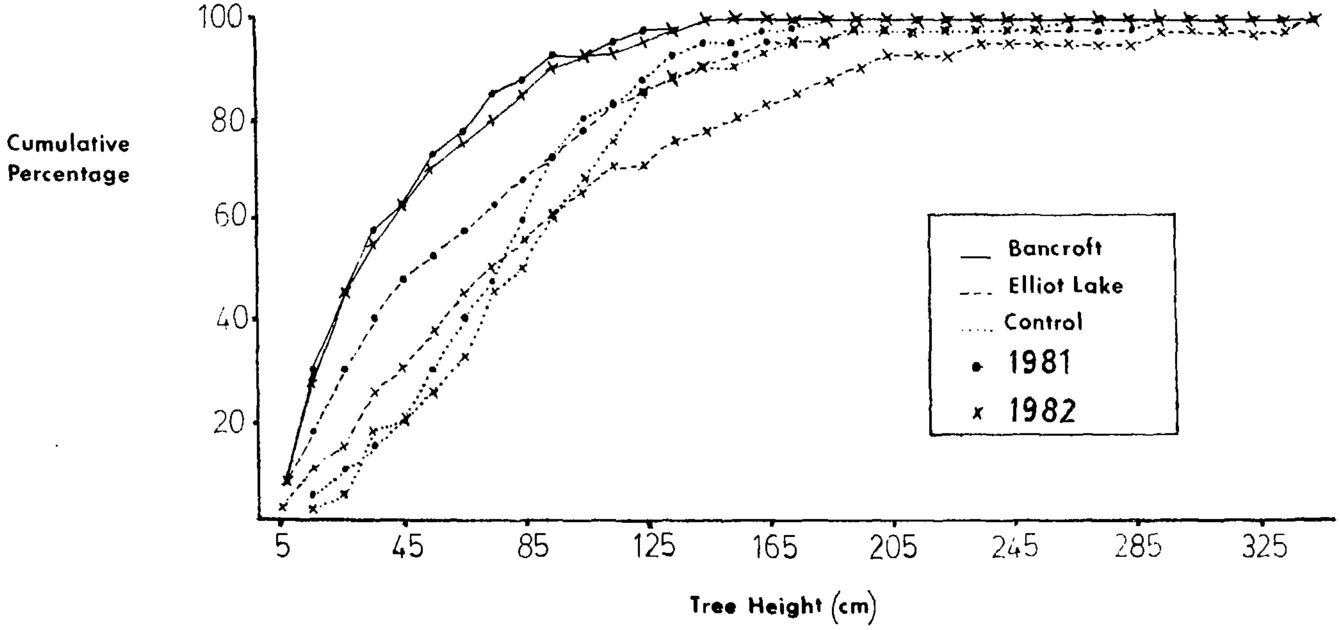


FIGURE 15 CUMULATIVE PERCENTAGE OF HEIGHTS FOR TREMBLING ASPEN

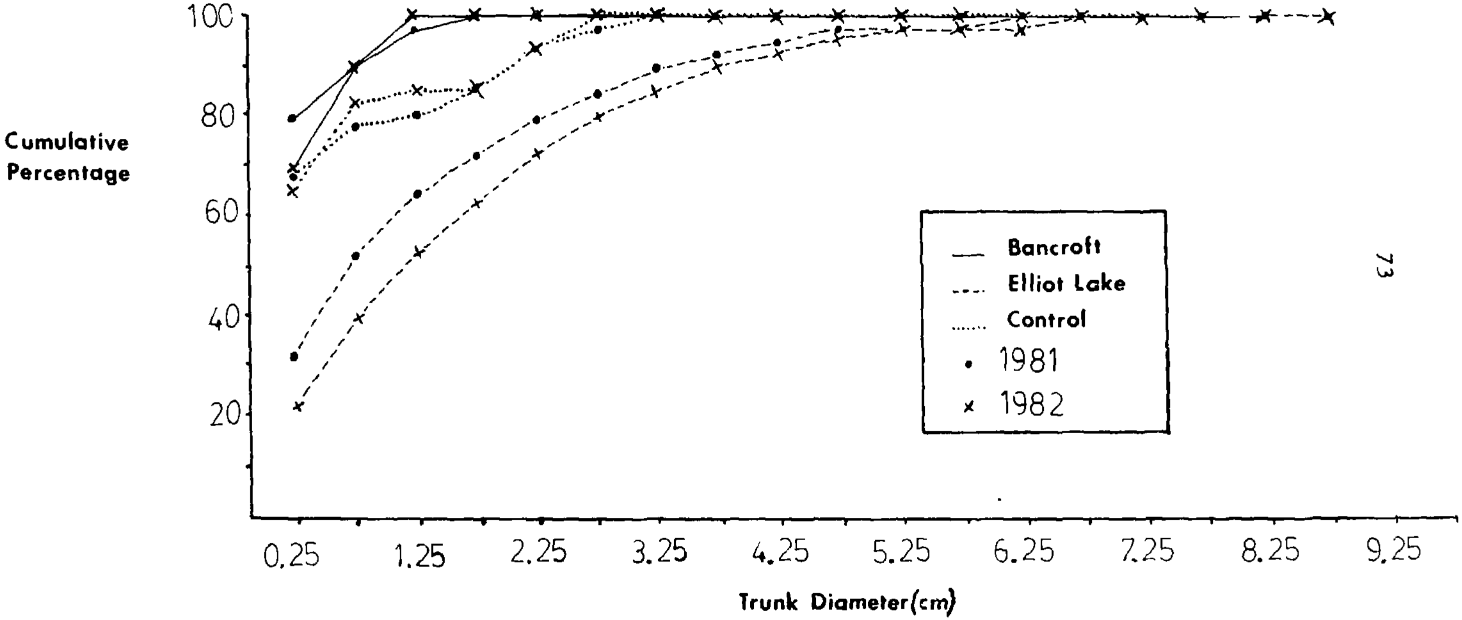


FIGURE 16 CUMULATIVE FREQUENCY DISTRIBUTION OF TRUNK DIAMETERS FOR WHITE BIRCH

For the trembling aspens, the trunk diameter frequencies do not differentiate between areas as clearly as the white birch (Figure 17). The curves for the control sites rise steeply between the 20 and 70 percentile, with trunk diameters of 0.25 cm or less, and 0.75 cm or less, respectively. The Elliot Lake populations have 60 percent with trunk diameters of 0.75 cm or less, and the Bancroft populations have extremely thin trunks, where 80 percent of the trees have trunk diameters of 0.75 cm or less.

These compositions of the height classes and trunk diameters differ for the three areas and also between the species. This might suggest that small trees grow differently on the control sites than on the two tailings areas. On the average the trunk diameters are 65 times smaller than the height of birches and 100 times smaller than the height of aspens.

In summary, from these limited observations on trees, it is reasonable to suggest that small and large trees have the same tree form, despite the large differences between the stand, site and area characteristics. The main differences determined were those of the composition population with respect to height and trunk diameters between the tailings areas and the control sites.

2.3.2 Dynamic Aspects of the Tree Population. The regeneration of disturbed lands by aspen and white birch is often a result of vegetative reproduction through suckers from parent root systems (Schier and Campbell, 1976; Bailey and Wroe, 1974; Horton, 1981). Most aspen stands are clonal, and are capable of producing suckers in their second year of growth (Barnes, 1966). Clone size of aspen can range in area from 0.05 to several hectares. Vegetative stands of white birch are less frequent, though root suckers are produced after fires (Ovington and Madgwick, 1959; Bjorkbum, 1967). White birch seeds germinate and establish more successfully on disturbed sites than aspen seeds. In good seed years, Bjorkbom (1967) reported 16 800 000 birch seeds per acre in Maine (USA) and a germination success of 73 percent. He found that seed beds most favourable to germination and establishment were exposed mineral soils with an uneven surface. It can be expected that initial tree establishment is primarily from seeds because a parent root system is absent on tailings. From seedling stage to tree maturation, water stress and nitrogen dificiencies are accepted as the most common limitations to tree growth and stand expansion (Kozlowski, 1979). Tree stands have established themselves on the sites despite these inherent stresses.

The extent of clonal growth in both species was determined. Suckering of aspens was investigated on Bicroft Proper by using the dye injection method. Ten

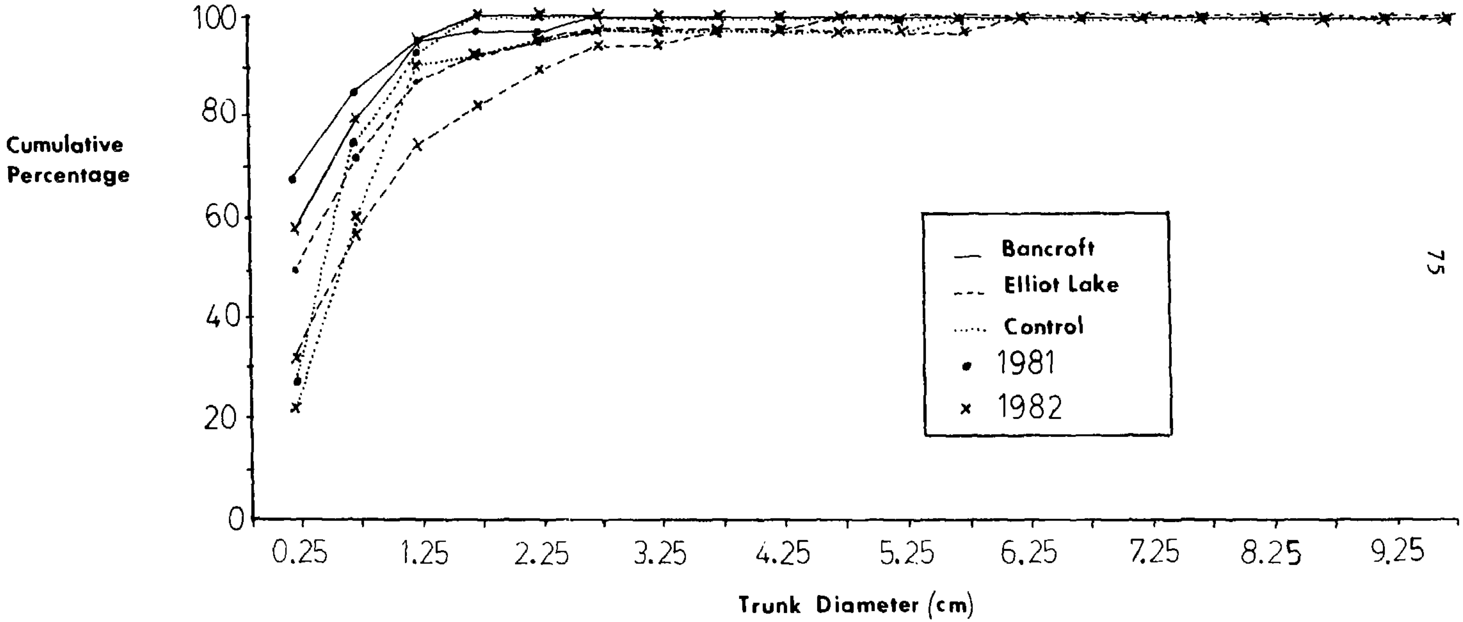


FIGURE 17 CUMULATIVE FREQUENCY DISTRIBUTION OF TRUNK DIAMETERS FOR TREMBLING ASPEN

different clones were identified which had, on average, four receptor trees. On the Crotch tailings, dye injections of three trees did not reveal any root connections. The excavations of eight aspen root systems in the vicinity of the S-5 stands revealed only one single aspen sucker. On Stanrock, dye moved over several metres from each of the three donor trees but no connections between trees were found. On Nordic, three out of six donor trees were connected with other trees. The ramets ranged from 66 to 100 cm in height. Stands in different sections of the tailings appear to have developed independently from each other. These limited excavations and dye experiments indicate that aspens produced suckers on at least two sites, Nordic and Bicroft Proper.

Approximately 100 white birch root systems were excavated both on Crotch and Stanrock. All trees had independent root systems, which indicates that root suckers of white birch are absent or extremely rare. The expansion of white birch stands on tailings, given the absence of vegetative reproduction, is likely dependent on suitable seed bed conditions. For aspens, the stands may expand by vegetative reproduction.

Densities of tree populations are also indicative of ongoing growth patterns in tree stands. In Figure 18, the mean number of trees per μ^2 for each stand is presented beside the mean heights of 1982. White birch trees in low density stands are taller on the average than those in high density stands. For trembling aspen, low density-tall tree stands are found on Nordic. Most of the remaining aspen stands lack such a trend. These observations tentatively suggest that the tall stands on Nordic have completed a first cycle of natural thinning and possibly an upsurge of growth might be expected in the near future. In the remaining high density stands thinning has not yet occurred. Graham (1963) described cyclical growth and thinning periods in young aspen stands in relation to their densities. He expected stands with densities comparable to those observed in this investigation (Figure 18) to experience vigorous growth in the first seven years, followed by stagnation and rapid natural thinning, then an upsurge of survivors. Pollard (1972) reported a density of 3.13 trees per μ^2 for a five-year old aspen stand. Murphy and Scharitz (1974) reported seedling densities of 0.5 to 1 per μ^2 and sapling densities of 2 per 10 μ^2 in forest ecosystems. The canopy tree density ranges from 4 to 8 trees per 10 μ^2. Considering the expected sapling density of forests, the stands examined in this study are on average about 10 times denser.

Measurements could be secured in 1982 for trees on which the labels remained intact during the winter. Based on these tree populations annual growth characteristics

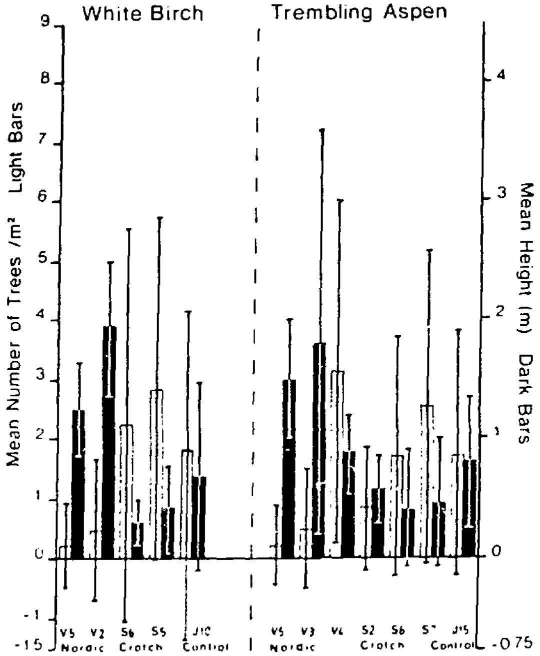


FIGURE 18 THE MEAN HEIGHT OF TREE STANDS AND THEIR MEAN DENSITY. White Birch stands with tall trees have low densities and as the density increases the trees are smaller. For the aspens this relationship only holds for stands V-3 and V-5, but appears to be the reverse for the other sites.

can be evaluated. Height changes of white birch populations are given in Figure 19. As the chance of survival of smaller trees is expected to be lower than that of larger trees, increases and decreases are evaluated by size class. The net height change in tall birches (125 to 200 cm), taking dieback into account, is about 20 cm, while the smaller trees have a net increase of about 4 cm. Generally the net change of the white birch population is constant and related to the height of the tree in the previous year. For trembling aspens 25 cm in height or less, a net average increase of 20 cm can be noted (Figure 20). Trees 150 cm in height showed a net average increase of 40 cm. Some of the taller aspens showed a large increase per year, but the number of tall trees is small. The actual height change for one year can be large in aspens if they are root suckers. Suckers receive growth support from the parent trees, thus resulting in more rapid growth.

Insects inflicted severe defoliation on aspens, particularly on Nordic, while gall formation was prevalent in both species on all sites. It can be concluded that despite

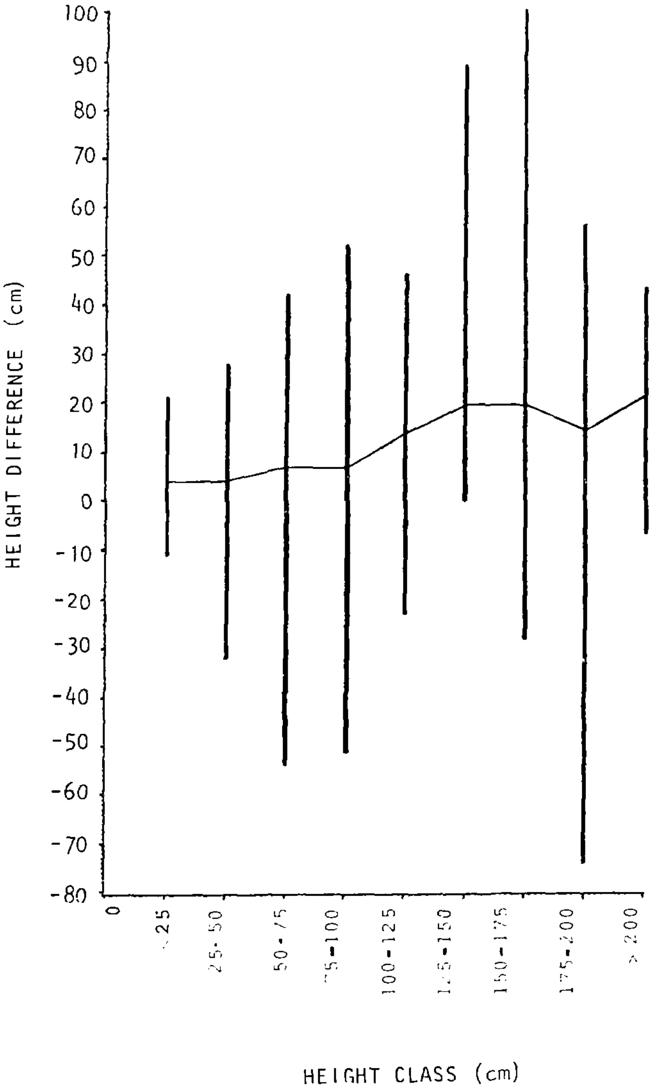


FIGURE 19 NET HEIGHT CHANGES OF WHITE BIRCH BY TREE SIZE CLASS. The net height increase of the entire population of young trees is small. The height increase or decrease (cm) of all trees is measured over one growing season (1981-1982). Mean height changes are plotted for each size class.

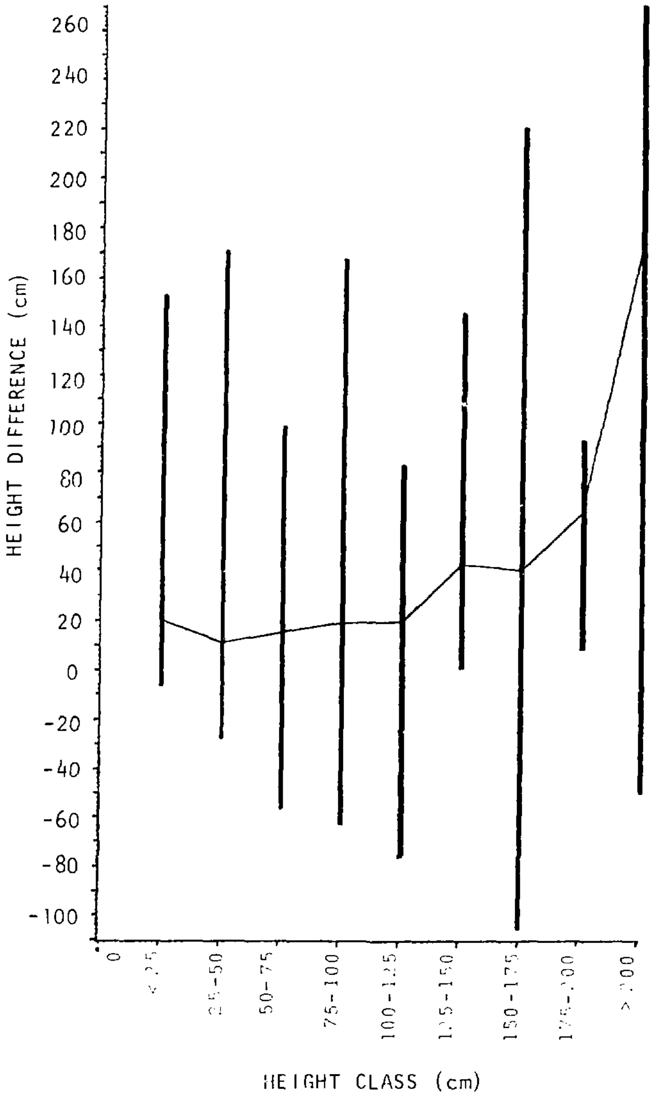


FIGURE 20 NET HEIGHT CHANGES OF TREMBLING ASPEN BY TREE SIZE CLASS. Trees above a height of 150 cm appear to exhibit a greater net height change than trees in the lower size classes.

dieback of some trees, a net height increase which is not related to the size of the trees, occurs in the tree population. If the net height changes of the population were negligible, increases in height of individual trees would have been negated by death or dieback by others. As net height increases occurred in populations of both species, the annual growth increments for each size class truly represent changes in the stands. To quantify these changes, only those trees are selected which exhibited height increases between 1981 and 1982. In Figure 21 the annual height increase of white birch is presented again for each height class. A total of 175 trees were smaller than 50 cm and comprised the largest fraction of the growing trees. Trees less than 100 cm tall generally increased over one growing season by one-fifth of their original height, while taller trees increase only one-eighth based on the average height of each size class. Maximum height increases observed in some individuals approached 50 percent of the previous year's height. White birches, regardless of their size class show a slow but steady height increase.

The average height increases of the aspen population are presented in Figure 22. Trembling aspens increased in height more irregularly than white birches. Trees up to 100 cm in height differ minimally from the net change in this size class. Maximum height increase reached 200 cm in aspens, whereas in birches, the maximum increase of any individual tree was approximately 100 cm. Most trees growing are in the smaller size classes, only a relatively small number of tall trees show annual height increases. The average height increase in aspen does remain more or less constant between 20 to 30 cm for trees up to 125 cm tall. The few trees in taller size classes exhibit, in proportion to their height, smaller height increases.

In summary, the evaluation of annual height changes indicates that the tree populations of both species grow, regardless of the size class. For white birch, shoot elongation is more consistent over tree size classes than for trembling aspens; however, small trees persist in spite of the high densities (Figure 18). It may be inferred that development of stunted trees on poor sites are not necessarily followed by thinning and stagnation as observed by Graham (1963). A longer period of observation, however, is required before tree development cycles on these sites can be delineated.

Absolute height changes were discussed earlier for the entire tree populations (Figures 19-22). Percentage height increase or decrease is now considered for the individual stands (Figures 23 and 24). The number of trees in the same percentage category (increase or decrease) are represented by the relative heights of blocks. For white birches (Figure 23), the Nordic stands (V-2 and 5) had the largest number of trees in the 0 to 25 percent category, representing 72 and 74 percent, respectively, of all trees in those stands. On the Crotch site (stands S-5 and 6), only 20 to 30 percent were in the

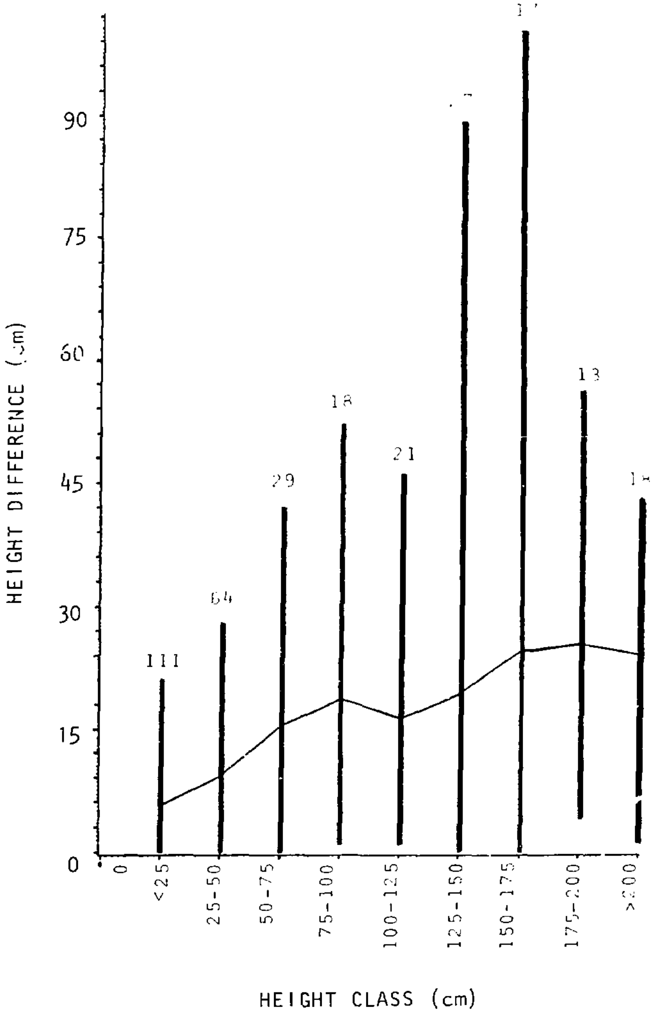


FIGURE 21 HEIGHT INCREASE IN THE WHITE BIRCH POPULATION. Trees up to one metre in height exhibit an average height increase equivalent to one-fifth of their height, which is reduced to one-eighth for the taller trees. The number of trees in each category are indicated above the maximum value of the size classes.

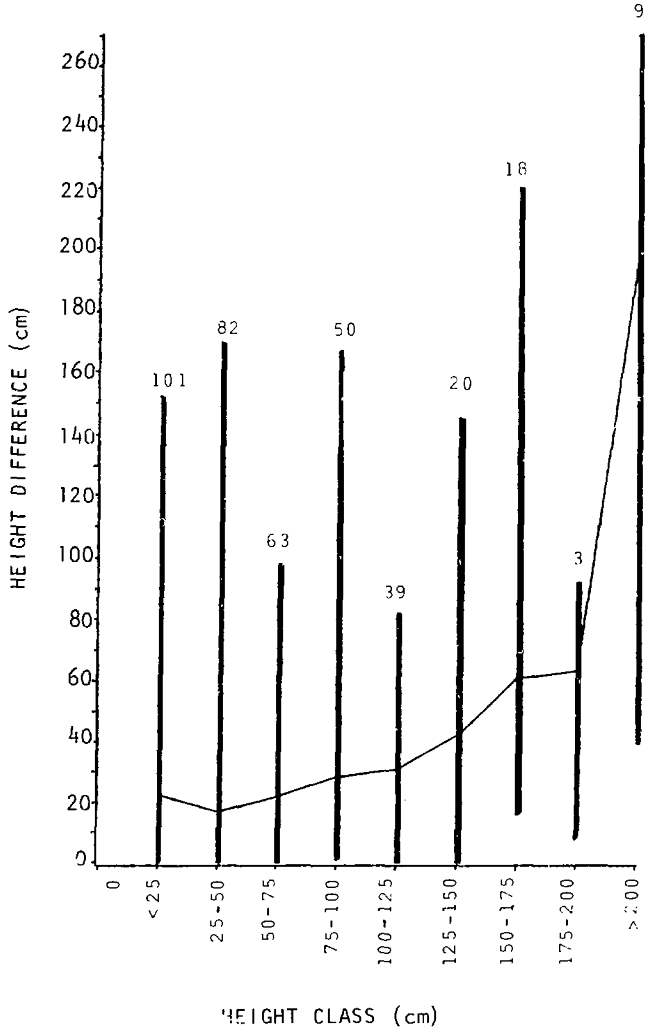


FIGURE 22 HEIGHT INCREASE IN THE TREMBLING ASPEN POPULATION. Trees in the smallest size class double their height, but as they grow over 25 cm tall the height increase is reduced to one-third of their original height obtained in the previous year. The number of trees in each category are indicated above the maximum value of the size class.

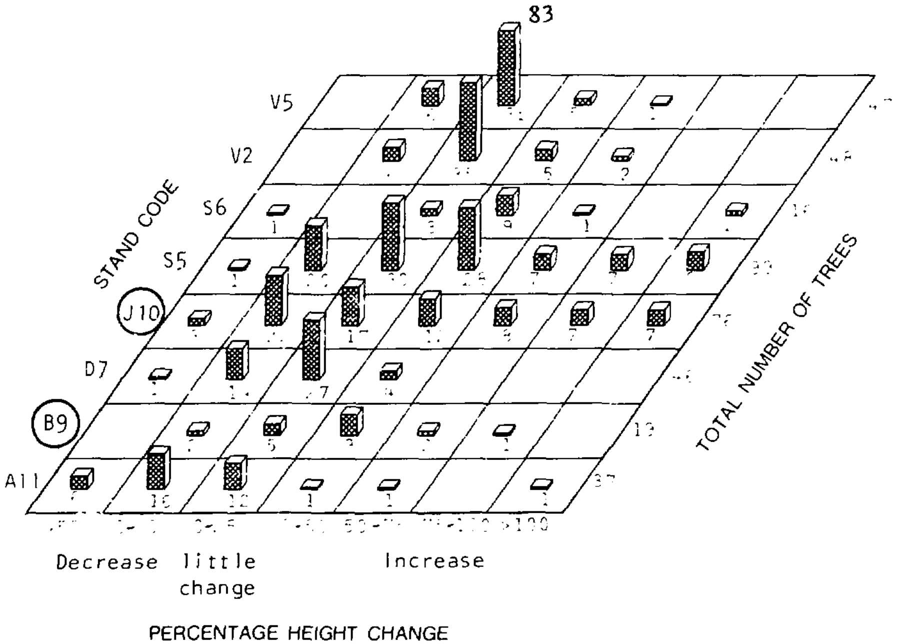


FIGURE 23 PERCENTAGE HEIGHT CHANGE IN ALL WHITE BIRCH STANDS. Control stands are indicated by circles. The total number of trees which were measured in both years is shown on the right side, percentage change (increase or decrease) is given in each square. The percent change intervals are given along the horizontal axis. The percentage height change in the Bancroft tailings stands is small, compared to the increases in the control sites and the Crotch site.

0 to 25 percent category, a similar fraction to that of the control stands. Therefore, the tall Nordic stands exhibit less percentage height change than S-5 and S-6 on Crotch. Crotch stands resemble the control stand J-10. The birches on Bancroft tailings (A-11 and D-7) exhibit an actual decrease in height of 30 to 40 percent of the trees while none of the birches on Auger increased in height at all.

The percentage change in height of trembling aspen stands are presented in Figure 24. This species clearly shows larger height increases in the Elliot Lake stands (sites V and S) than in the control site. Fifty-eight percent of all trees are in the category of 0 to 25 percent increase. On the control site (J-15), only 8 to 29 percent of the total number of trees are in this category. On stands D-7 and D-8 of Bicroft Proper, 65 to 69 percent of all trees exhibit this. The trees on Auger generally decreased in height. On the Bancroft tailings, aspen stands increase minimally compared to the controls and the Elliot Lake stands. From this analysis it can be seen that height increases of aspen occurred mostly on the Elliot Lake tailings sites.

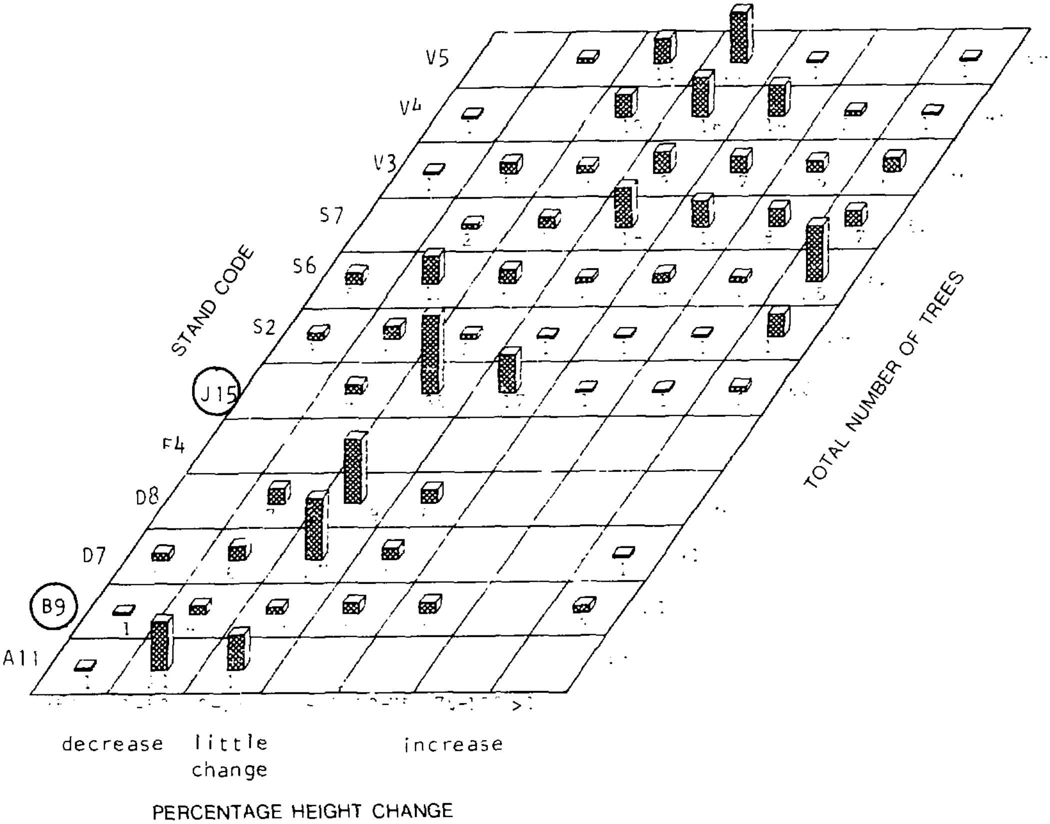


FIGURE 24 PERCENTAGE HEIGHT CHANGE IN ALL TREMBLING ASPEN STANDS. Trembling aspens on the Crotch site (Code S) exhibit definite height increases which are comparable to the control sites (J and B). The percentage change on the Bancroft sites is moderate.

The trunk diameter changes were also evaluated because the response of height changes differed for the species and the tailings areas. Some observations are of interest in Figure 25 where the percentage trunk changes for the white birch stands are presented. On the stands V-2 and V-5 on Nordic, 72 percent were in the 0 to 25 percent increase category. Only a small number of trees showed larger changes, while a great number of trees decreased in diameter. The stand S-5 on Crotch, on the other hand, reflects the height increases, as do trunk diameters of the control stands J-10. In Bancroft, the Auger stand (A-11) shows a consistent increase in trunk diameter by more

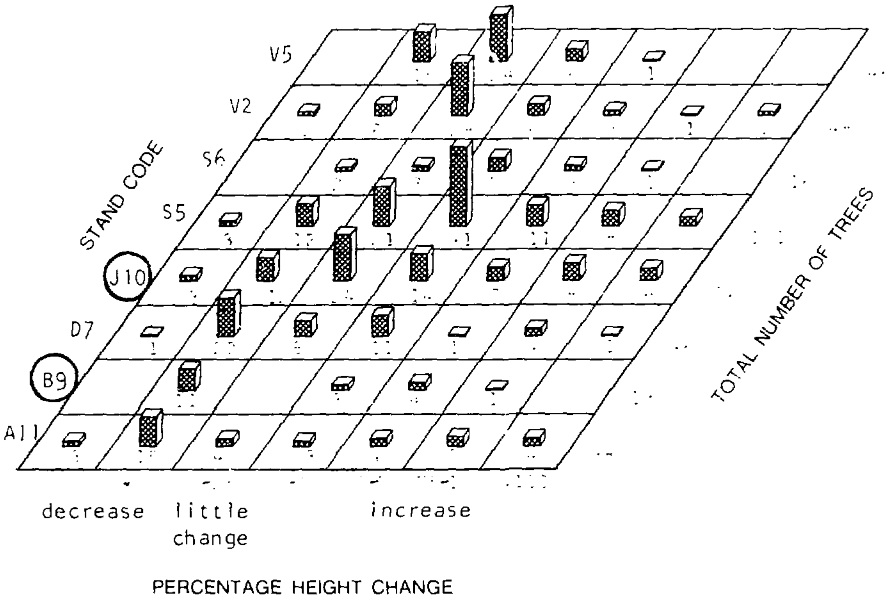


FIGURE 25 PERCENTAGE TRUNK CHANGES IN WHITE BIRCH STANDS. The percentage trunk increase on the Bancroft trees appears particularly pronounced on the Auger stand (A11) where mechanical damage was inflicted to the trees. In most other stands, the distribution of percentage (increase or decrease) reflects that of the heights.

than 25 percent, whereas the height increases were proportionally smaller. These results indicate that in stands where the proportion of height increases are small a larger proportion of trunks tend to become thicker. A similar trend is observed in the trembling aspen stands (Figure 26). The proportion of trunk diameter increases are larger in the Bancroft stands (D and A), where the proportion of height increase was found to be moderate (Figure 24). On Nordic stands V-4 and V-5, about half of the tree trunks increased in diameter by 25 to 75 percent, whereas a smaller fraction of the population increased by the same percentage in height.

Zavitkovski (1974) reports yearly diameter increases of canopy trees of 5.8 percent for trembling aspen and 3.3 percent for white birch. Clearly, in this study the trunk diameter increases in both white birch and the aspen stands are larger and extremely varied. This could be a reflection of the thin trunks in the tailings stands compared to those of the forest trees. The differences may be more prone to be the result of measurement error of thin trunks than of larger trunks. Other factors could also

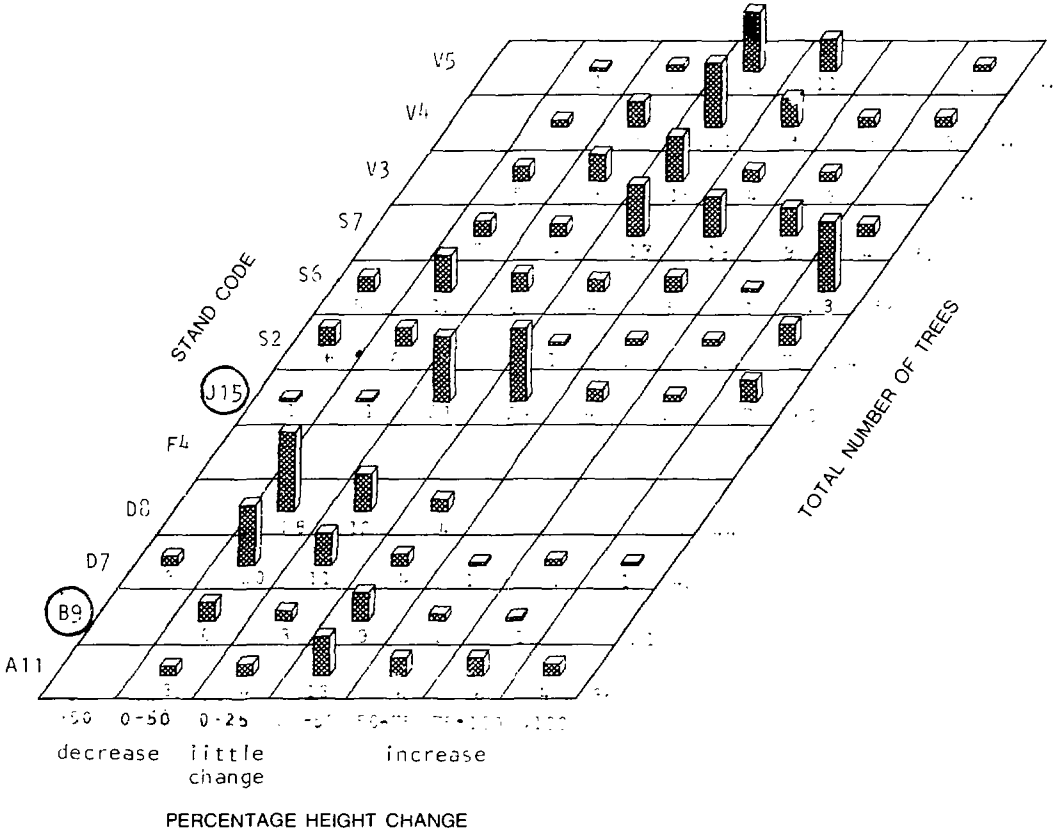


FIGURE 26 PERCENTAGE TRUNK CHANGES IN TREMBLING ASPEN STANDS. The percentage changes observed in trunk diameters on the Bancroft sites is larger than the percent height changes. For the control and the Elliot Lake stands shoot elongation reflects radial growth more closely.

contribute to the observed changes. Swelling and shrinking of trunks in some tree species is a response to water stress. This response is species specific, which may possibly explain the differences between birch and aspen (Kozlowski, 1979).

Water stress is but one of the many challenges trees face when growing on the tailings sites. The observations of tree density and vegetation cover on Stanrock may be used to describe some of physical and chemical conditions encountered by tree roots. The pH and electrical conductivity of the root zone and the surface were determined. A schematic of sampling plots in the transects is presented in Figure 12. Tree seedlings were noted in 1980, the first year after the limestone was applied. The observations of tree densities and vegetation cover were initiated in 1981, two years after liming (see Figures 27, 28 and 29).

There are several striking observations which can be derived by comparing the three transects. The surface samples have, as expected, much higher pH values than the root zone samples. The depth difference, however, is not more than 5 to 10 cm in all sampling locations. Roots do not penetrate deeply, but run shallowly below the surface, often encased by a zone oxidized tailings. Both sides of the plots (A and B) in all transects exhibited the same surface and the root zone patterns; therefore, the characteristics are not specific to one sampling location but apply to the whole area. At the low points of Transect 13, sampling plots 8 and 9 (Figure 27), the neutralizing effects of the lime have been reduced, likely due to run-off along the slope. Here, a vegetation cover of any type was virtually absent and the moss cover was further reduced in 1982. On the top of the slope (sampling location No. 1), a large number of white birch trees were counted. Eighty to one-hundred white birch seedlings were present in a m^2 area. This high density of birch is maintained in the upper part of the transect for 15 metres. As the decline begins, the electrical conductivity rises slightly, the pH drops and the number of birches decrease. Aspens and willows are a small component of the vegetation cover in this transect.

For Transect 11 (Figure 28), a partially flat area, the tree density was low in 1981 and the vegetation is predominantly moss. Other species, such as horsetails and willows (Plate 13) are frequently present in some plots, whose densities can be as high as 20 to 50 plants per μ^2. In 1982, a large number of willows and aspen seedlings were recorded, though they were considerably smaller than the specimens depicted in Plate 13.

Willows and moss are a persistent, but sparse component of the vegetation cover found on the flat portion of Transect 11. The moss cover remained stable during the two years of observations and may have facilitated seedling survival. In the depression around sampling points 1 and 2, the moss cover is sparse and trees are absent. The physical characteristics created by a very slight slope appear, however, to affect vegetation establishment drastically.

For Transect 12 (Figure 29), distinct stratification of pH between root zones and surface is absent. This heterogeneous surface with respect to pH, results in a plant cover with less moss, fewer seedlings in 1982 and generally a low density. As the slope of the transect increases at sampling points 6 to 9, however, the surface supports decreasing

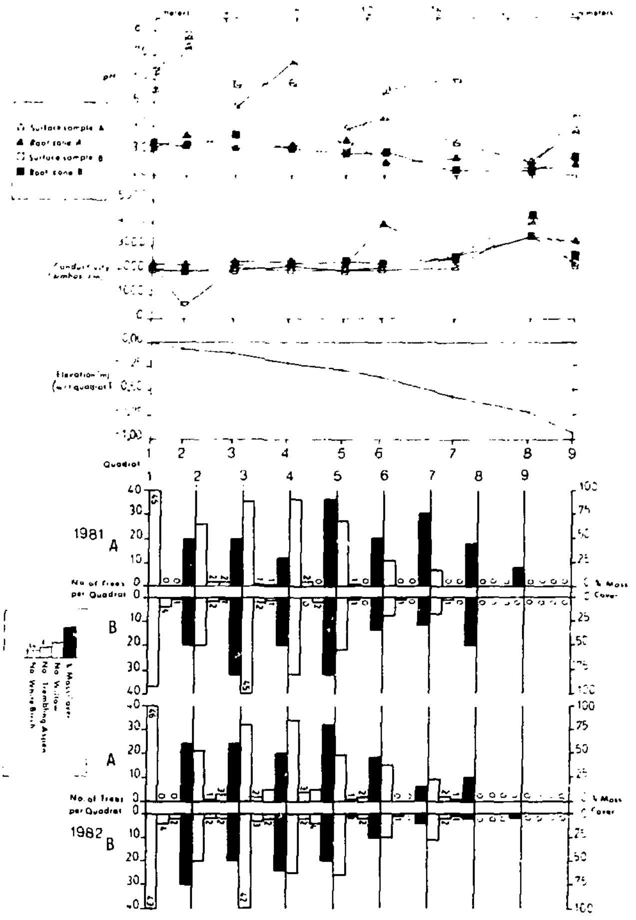


FIGURE 27 TREE TRANSECT (13) ON STANROCK. The pH of 1:1 (w/v) slurry after 24 h is reported for the surface and the root samples in the uppermost graph along the transect. Symbols differentiate between sides A and B (Figure 12). The second graph represents the electrical conductivity in the same format as the tailings slurries. The slope is depicted in the third graph along the transect with reference to sampling point 1. Main vegetation components are graphed for each side year in the two lower graphs. The scale on the right-hand side indicates the number of trees in 0.5 m^2. The sequence of the open bars indicates the numbers of white birch, trembling aspens and willows, followed by the dark bars, which is percent moss cover. This transect has the steepest slope, extensive moss cover and is dominated by white birch and willows.

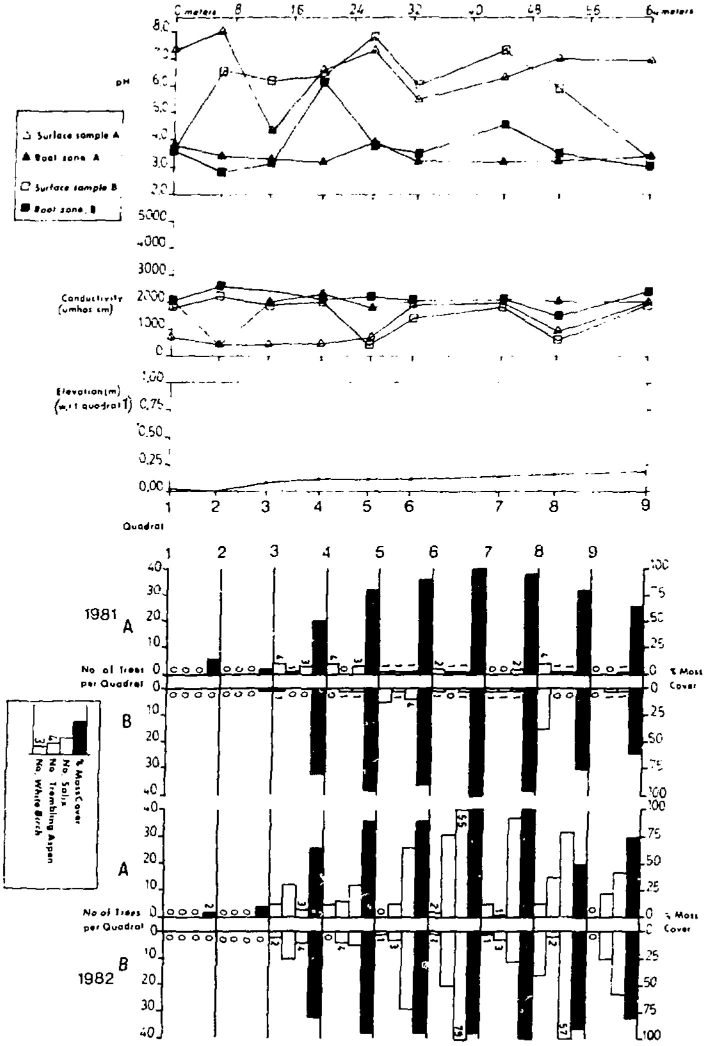


FIGURE 28 TREE TRANSECT (II) ON STANROCK. Trees have established on a relatively flat surface, but their numbers are low. In 1982 a large number of small (1 mm in height) willow and aspen seedlings were counted.

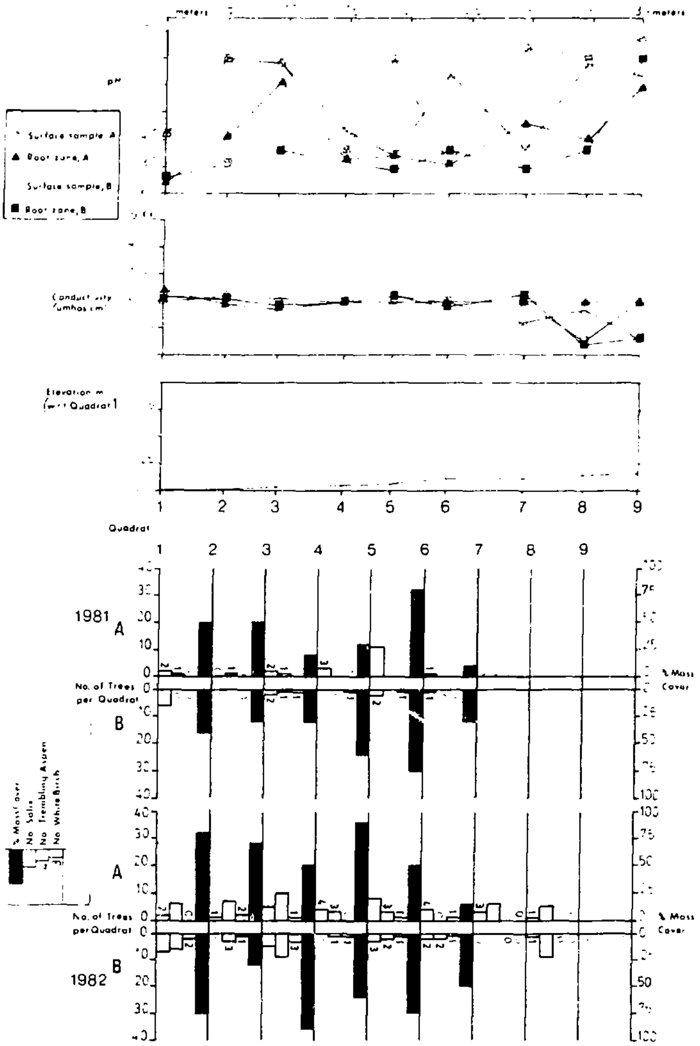


FIGURE 29 TREE TRANSECT (12) ON STANROCK. A very gradual slope can be observed in this transect, where the slope remained free of vegetation in 1981, but some aspens were found in 1982. White birch and trembling aspen are slightly more frequent than willows.

PLATE 13
GROUND COVER IN TREE TRANSECT 11. In the foreground a willow can be seen among patches of horsetails, small fireweed, limestone and moss.

amounts of vegetation. This opposes the observations in the previous transects, and suggests that additional factors to run-off from slopes affect the micro-environment.

These results are purely descriptive. The two years of observation cannot be quantified further, as methodological errors are considered large in these counts, and cover estimates. The physical characteristics of the limed surface and the difference in the three transects, however, suggests some trends. Flat neutral surfaces (Transect 11) support an extensive moss cover in which seedlings of willows and aspens germinate, but birch density is low. On this type of surface, fireweed, sedges, liverworts and horsetails grow sparsely, but they are less frequently found in the other two transects. Surfaces which exhibit varying pH values (Transect 12) are least favourable for tree establishment. Sloped transects with a neutral surface support dense stands of white birch and moss covers of 50 to 75 percent, but aspen and willow densities are similar to the other two surfaces. The electrical conductivity in all three areas is high. In two transects both root and surface conductivities are the same, but for transect 11 a difference can be noted. The surface samples have a lower conductivity between the root zone and the surface only on Transect 11. The higher concentrations of solutes in the soil solution on the tailings exert less effect on the vegetation development than pH does. These observations on the limed surface of Stanrock indirectly support the tree stand composition. Most frequently, the stands consist of single species, which appears to be a response to the initial seed bed conditions and differ for birch and aspens. Populations of willows, though prominent on Stanrock, are less dense than on all other tailings sites. Only on the tailings beaches of Bicroft Proper and on Auger are these shrubs a major component of the vegetation.

The micro-environmental conditions, pertinent to seedling establishment and survival success, differ sufficiently within a single amendment area, so that either aspens or birches dominate. The pH of the root region and that of the surface reflect two completely different environments and the roots of the trees are unlikely to survive in both extremes. The majority of the root development will take place at a shallow depth, likely at the interface of these two conditions. During the harvest of the white birch tree stand (S-5) on Crotch, roots formed a solid mat that was not thicker than 7 cm. Below the root mat, the pH and the electrical conductivity were similar to that observed on Stanrock transects. From root excavations on Nordic, there were indications that some roots penetrated deeper, but generally the conditions were found to be similar. When the neutralization effect of lime is uneven (Transect 12), plant diversity increases, but moss cover is reduced. As long as a neutral, even surface is maintained, tree growth continues and recruitment from seeds occurs.

2.4 Conclusions

Since growth characteristics of white birch and trembling aspen were found to differ on the tailings areas it can be concluded tentatively that the stands will develop differently in the future. Tree stand development reflected the biological characteristics of the species, the seedlings and vegetative growth. Indeed, the trees on Bancroft, Elliot Lake tailings and the control sites in both areas exhibited a remarkable degree of similarity, despite the large density and annual growth differences, the surface characteristics of the sites and ages of the tailings sites. The tree characteristics of trunk diameter, crown width and number of branches, however, increased linearly with the height of the trees. The tree form was not affected by the site conditions. It can be concluded from the net annual height increase evident for both species, that the trees continue to grow.

To outline the long-term ecological development of terrestrial areas of the tailings, the existing descriptive data are insufficient. Tree ages of all stands, biomass data, seasonal growth patterns of different size classes, effects of different suface characteristics on mortality and recruitment of trees are some of the essential components necessary to understand the stand development on these wastes.

This study could only address selected aspects of the pioneering tree communities colonizing uranium mill tailings. The trees generally reflect the poor site conditions which prevail on the waste sites. More importantly the tree stand comparisons and growth characteristics show the complexity of growth processes under such conditions. Tree stand development has been well documented for disturbed forests. Patterns and processes of such developments are fairly well understood (Bormann and Likens, 1979). The results of this study indicate that although colonization and growth of trees occurred on the sites, the patterns and processes of stand development differ greatly from those observed in normal forests. This conclusion is considered to be the most significant result of this investigation, given the major objective of the study.

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