A Model for Predicting Boreal Vegetation Dynamics and Management Requirements on Electric Transmission Right-of-Ways, Interlake Region, Manitoba

by

David John Walker

A thesis presented to the University of Manitoba in partial fulfillment of the requirements for a degree of Master of Science in the Faculty of Graduate Studies

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'Twas brillig, and the slithy toves
Did gyre and gimble in the wabe:
All mimsy were the borogoves,
and the mome raths outgrabe.

'Beware the Jabberwock, my Son!
The jaws that bite, the claws that catch!
Beware the Jubjub bird, and shun
The frumious Bandersnatch!'

He took his vorpal sword in hand:
Long time the manxome foe he sought-
So rested he by the Tumtum tree,
And stood awhile in thought.

And, as in uffish thought he stood,
The Jabbarwock with eyes of flame,
Came whiffling through the tulgey wood,
And burbled as it came!

One, two! One two! And through and through
The vorpal blade went snicker-snack!
He left it dead and with its head
He went galumphing back.

'And hast thou slain the Jabberwock?
Come to my arms, my beamish boy!
O frabjous day! Callooh! Callay!'
He chortled in his joy.

'Twas brillig, and the slithy toves
Did gyre and gimble in the wabe:
All mimsy were the borogoves,
and the mome raths outgrabe.

-Lewis Carroll 1872.

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Abstract

The objective of this study was to develop a predictive model of vegetation dynamics and management requirements on a HVDC electrical transmission corridor through the boreal forest of the Interlake region, Manitoba. The model was based on correlations between forest vegetation (obtained through ground truthing) and LANDSAT TM image analysis. Thirty sites along the transmission right-of-way (ROW) were selected for ground truthing. At each site, transects were established in the forest and adjacent ROW, and vegetation (species percent cover in quadrats) and edaphic information collected. The sites were classified using cluster analysis, based on the forest vegetation data. Three recently burned sites were obvious outliers, and were treated separately in subsequent analyses. Three forest vegetation groups were recognised: dry coniferous, wet coniferous, and mixed forest. Ordination methods were used to reduce the dimensionality of the data so as to simplify subsequent analyses. Discriminant analysis of the forest and ROW vegetation indicated statistically significant discrimination of the three vegetation groups in two-dimensional ordination space. Correspondence between the forest and adjacent ROW vegetation was tested using canonical correlation analysis. The results showed a statistically significant correlation ($R^2 = 0.77$, $p < 0.01$) between vegetation of the forest and that of the adjacent ROW. The strength of this relationship suggested that a model to predict ROW vegetation based on forest vegetation could be developed.

Tree recruitment on the ROW was summarized for each vegetation group. Wet coniferous sites had the highest tree density, and dry coniferous sites the lowest. Vegetative propagation (suckering or layering) was the predominant recruitment method in the wet coniferous and mixed forest sites. The results also indicated that black spruce was not affected by current management techniques designed to reduce ROW tree density. At the recently burned ROW sites, post-fire recruitment of jack pine was high.

LANDSAT TM spectral reflectances (bands 3, 4 and 5) for 25 of the 30 forest sites were analyzed to determine their correlation with the forest vegetation. Multiple discriminant analysis indicated statistically significant discrimination of the vegetation groups based on the three LANDSAT bands. Based on these results, a predictive discriminant classification model based on spectral reflectances in bands 3, 4 and 5 was developed. Using a Mahalanobis distance criterion, the model correctly classified 21 of the 25 forest sites. A test of model robustness was undertaken by classifying an independent random sample of 40 sites. All but two of these 40 sites were successfully classified at the $\alpha = 0.05$ probability level.

The predictive model is based on observed high correlations between forest and ROW vegetation, and between forest vegetation and LANDSAT TM spectral reflectances (bands 3, 4, 5). Using the model, sites along the HVDC right-of-way in the Interlake region can be classified into one of three vegetation groups. Once classified, ROW vegetation and tree recruitment at the site is predictable, which in turn suggests specific management requirements. The model could also be used to predict specific management requirements for a newly developed ROWs in the region.

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Chapter 1

Introduction and Literature Review

1.1 Background

Manitoba Hydro right-of-way (ROW) corridors, built and maintained for the transport of energy, are similar in many respects to other right-of-way corridors as described by Niering & Goodwin (1974). The right-of-way under consideration in this study extends for approximately 900 km, from Winnipeg (≈ 50°N, 97°W) to Jenpeg on the Nelson river drainage basin (≈ 54°N, 99°W), and spans five vegetation zones (Weir 1983) (**Fig. 1.1**). In the province of Manitoba, 12% of all ROW land is used for electrical transmission (≈ 29,000 ha in 1971). The Winnipeg-Jenpeg high-voltage direct current (HVDC) corridor totals ≈ 11,000 ha in area (Sims 1977). Available seed sources from adjacent forest stands and environmental conditions in this region of the province promote the establishment of tree species such as *Picea mariana* (black spruce), *Pinus banksiana* (jack pine) and *Populus tremuloides* (trembling aspen) on the hydroelectric right-of-ways. The tall stature of tree species (>4.5 m) interferes with the wires by causing a grounding arc that drains energy and may start fires (B. Mann, Manitoba Hydro, Winnipeg 1994 pers. comm.). This, together with the requirement of maintaining access to the ROW for line repairs (Niering & Goodwin 1974), necessitates periodic tree removal as a ROW maintenance policy.

1.2 Boreal Forest Vegetation Dynamics

Boreal Forest Background

The boreal forest covers most of Manitoba's land surface (Weir 1983). The vegetation of the Manitoba Hydro HVDC ROW, which is located primarily within a broad band of boreal vegetation, has been the subject of several previous studies (Sims 1977; Magnusson & Stewart 1987; MacLellan 1982).

The surficial geology of the boreal forest in the interlake region of Manitoba is dominated by highly calcareous glacial till (Weir 1983). Soil is poorly developed and the depth to bedrock along the HVDC ROW is between 0 cm (in dry sites) and 100 cm (in wet sites). The dominant soils are Gray Luvisols in well drained areas and Fibrisols where drainage is poor (Clayton *et al.* 1977).

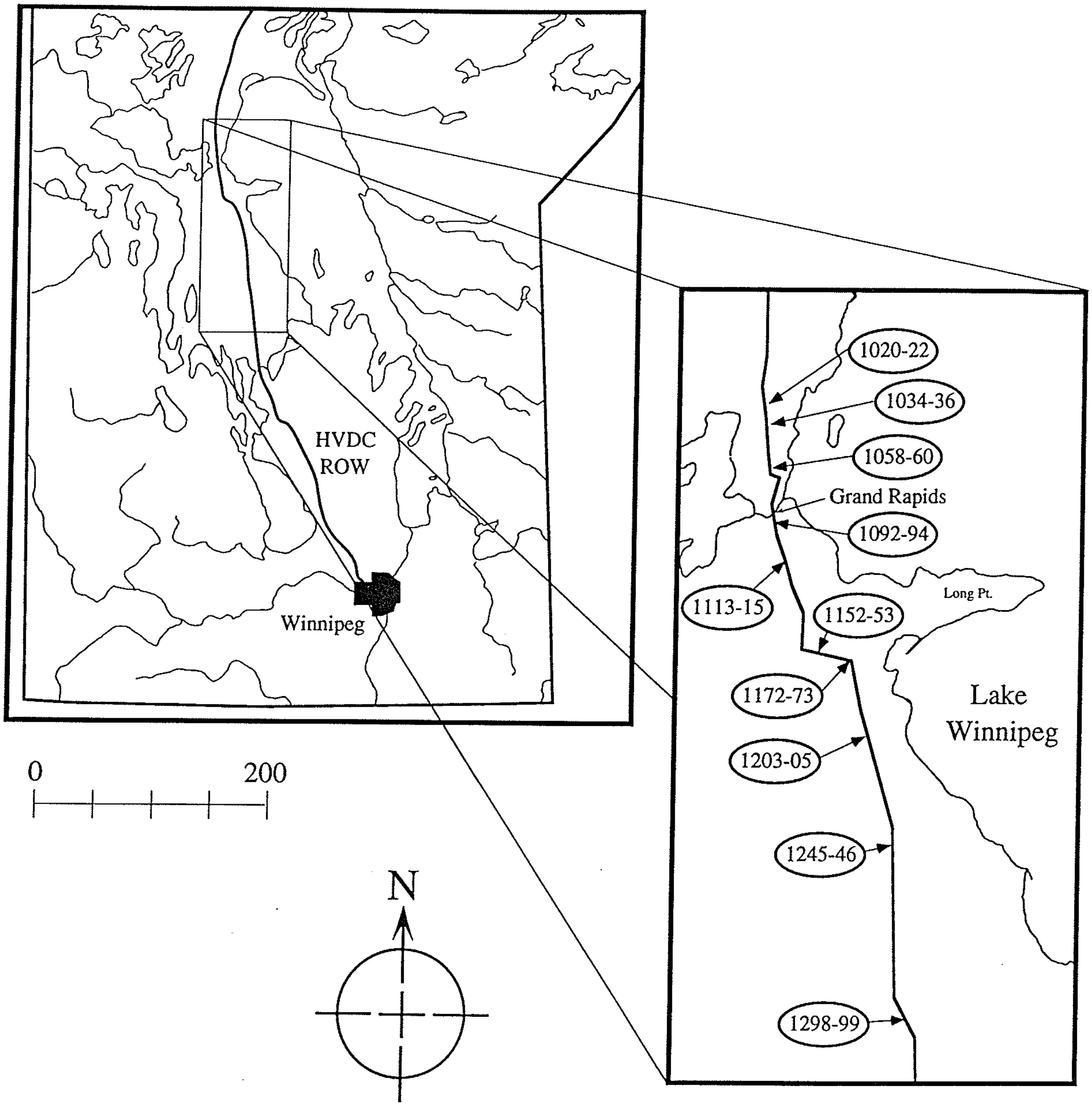


Figure 1.1: Map of Southern Manitoba and the Interlake indicating the extent of Manitoba Hydro's High Voltage DC right-of-way in this region. The inset shows the study area, locations of the 10 main access points are indicated.

Climate plays an important role in determining the extent of boreal forest systems (Kimmins 1987). The dominance of various coniferous species within a region has been shown to be highly correlated with the environment (Lenihan 1993).

The boreal forest is considered a 'disturbance ecosystem' that has evolved under conditions of environmental stress, in particular periodic forest fires (Rowe 1956b). In many cases, fire results in complete burning of the organic component of the soil, leaving the mineral base and resulting in rapid mineral nutrient flux (Kimmins 1987). Species such as *Pinus banksiana* require a mineral substrate for successful germination (Revel *et al.* 1984). The fire - regeneration cycle is an important part of the successional dynamics of the boreal forest, since fire occurs on average every 110 (Kimmins 1987) to 150 (Bergeron & Dubuc 1989) years. The biology of the tree species colonizing the ROW will be examined more fully in the section 1.3.

This Thesis will briefly summarize various successional hypotheses and examine the role of biotic factors such as propagule dispersal and competition in this process.

Definitions of Succession

In the following discussion the terms 'succession' and 'secondary succession' are used synonymously, since examples of true primary succession in nature are rare (Houston & Smith 1987). Succession can be defined as the pattern of change that takes place within a specific community following a radical disturbance (e.g. fire) or opening of a patch (e.g death of an individual tree). It is generally measured in terms of compositional change of the colonizing flora and/or fauna (Horn 1974). If the environment remains stable over time, this compositional change will slow sufficiently or cease entirely. The community is then said to have reached the 'climax' stage (Horn 1974). Several models and definitions of succession have been proposed, and all are potentially relevant to vegetation dynamics of managed hydro right-of-ways:

1. Drury & Nisbet (1973) regard succession as a 'stressor' operating over the lifetime of the community. They feel that discrete climax communities in the traditional sense do not occur. Instead, 'climax' communities are indiscrete and vary from one area to another.

2. Egler (1954) proposed that succession is the product of differential species longevity. His 'initial floristic composition' hypothesis states that most species enter the community at an initial period, rather than continually. As a result, the longest living species tends to be dominant in the community climax.

3. Horn (1974) considers succession to be a stochastic process of continuous species replacement. Because openings or 'patches' in communities are transient, species adapted to utilizing such patches must produce copious seed and disperse this seed widely. Climax communities, which are considered to be widespread and persistent over time, are dominated by long-lived, competitive species. Thus succession is viewed as the continuous replacement of 'gap' adapted species by 'climax' adapted species. Horn (1974) also felt that canopy development in forests was important in later stages of succession.

4. The 'relay floristics' (Odum 1969) and 'facilitation pathway' (Nobel & Slatyer 1980) models propose that ecological succession is a process of facilitated replacement. In this model, early species along a successional continuum facilitate colonization by later successional species.

5. The 'resource competition' (Tilman 1985) and 'tolerance pathway' (Houston & Smith 1987; Nobel & Slatyer 1980) models state that species succession is dependent on the species resource requirements and changes in resource availability over time.

As Drury & Nisbet (1973) point out, many of these models cannot be directly tested because the evidence used in developing them are obtained from the measurement of contemporaneous plots.

Perhaps a better approach to studying disturbance communities is to not make *a priori* assumptions about mechanisms or processes. Instead, one should simply examine a species' attributes that define its role in succession (Revel *et al.* 1984; Noble & Slatyer 1980). Revel *et al.* (1984) view community development following disturbance as a function of the requirements for plant growth and survival. These are:

1. availability of propagules.
2. growth and reproduction requirements.
3. competitive ability.

Similarly, the model of Noble & Slatyer (1980) proposes that succession in disturbed areas can be predicted based on the following 'vital attributes':

1. method of arrival and persistence of a species.
2. capacity of a species to establish, grow and reproduce once established.
3. time taken for a species to reach reproductive age.

Propagules

Propagule dispersal and establishment play an important role in vegetation succession. Dispersal of plant species can occur in one of two ways, firstly through seed bank sources and secondly through vegetative propagation (MacLellan 1982; Noble & Slatyer 1980; Kimmins 1987). In forested areas, the seed rain is normally localized so that most of the seed lands near the parent plant (Cavers & Benoit 1989). The composition of the seed bank varies both seasonally and over successional stages. Thompson & Grime (1979) found that seed banks for herbaceous species at ten study sites could be broken into two groups, 'transient' and 'persistent' seed bank species. The first group is characterized by seeds that remain viable for only one growing season. Most species in this group produce large seeds that germinate immediately or following a single cold period. Conversely, the seed of 'persistent' species remains viable for a number of years. Species such as *Pinus banksiana* are unusual in that they persist on the parent (in serotinous cones) and are released (and immediately germinate) following a fire (Kimmins 1987).

Vegetative reproduction and persistence are also important (Noble & Slatyer 1980; Revel *et al.* 1984; Kimmins 1984). Many fire-adapted species regenerate from below-gound parts such as rhizomes, and can therefore rapidly recolonize an area. Clonal propagation by roots is important in *Populus tremuloides* in surviving disturbances such as herbivory (Revel *et al.* 1984) and fire (Bell 1991). In ericaceous species, Matlack *et al.* (1993) found that the ability to survive a fire depended on the severity of the blaze and root or rhizome depth.

Competition

Resource competition in plants may involve competition for light, nutrients or water, or any combination thereof (Keddy 1991). Competition may be between individuals of the same (intraspecific) or different (interspecific) species. For example, in densely stocked jack pine stands intraspecific competition results in predictable spatial patterns of self-thinning (Kenkel 1988), while interspecific competition with grasses is often detrimental to jack pine seedlings (Bell 1991). In jack pine, it has been hypothesized that cone serotiny and other pyric adaptations may aid in avoiding competition with other species (Kimmins 1984).

Resource competition is favoured by Tilman (1985) and Houston & Smith (1987) as one of the main driving forces of succession. In Tilman's (1985) model, succession of different species is explainable in terms of differential utilization of mineral nutrients by species in the community. The supply rate of nutrients is determined by the environment. Tilman (1985) modelled resource utilization in terms of consumption vectors, where the direction of a vector and its magnitude are determined by the ratio of the consumed resources. As resources are consumed, the plant assemblage most capable of growing at that combination of nutrient levels survives. This model attempts to explain why succession, though it often appears to be an orderly process, has a strong stochastic component (see also Horn 1974). Resource ratio models predict that even small differences in resource availability can result in quite different species assemblages (Houston & Smith 1987).

Succession in the Boreal Forest

Several recent studies have examined succession in the boreal forest with respect to changes in nutrient status (Paré *et al.* 1993; Fulton 1991), understory (De Grandpré *et al.* 1993) and successional pathways (Bergeron & Dubuc 1989). All of these studies were concerned with change after forest fire. In the boreal forest Paré *et al.* (1993) found that the soil at several sites increased in organic matter and total nutrient availability over time since fire. However, P and K availability decreased substantially. Changes in N levels and its role in succession were modelled by Fulton (1991). He found that there was a convergence between stand structure and composition over time despite differences in the intensity of initial disturbance. An understory vegetation survey (De Grandpré *et al.* 1993) was done concurrently with the nutrient study (Paré *et al.* 1993). De Grandpré *et al.* (1993) found that successional stages could be predicted on the basis of species lifehistory traits. Although vegetative composition of the study plots varied widely, the species that persisted in the climax stage were the longest living species that had established initially. De Grandpré *et al.* (1993) concluded that an Eglerian succession model best explained the data. Successional processes were examined by ordination techniques in Bergeron & Dubuc (1989). They found that under similar abiotic conditions, there are many successional pathways. However, final species composition depended on the life span of individuals.

1.3 Boreal Tree Species of the Interlake

The following sections focus on boreal forest ecosystems and the vital attributes (Noble & Slatyer 1980; Revel *et al.* 1984) of the dominant tree species.

Picea mariana - black spruce

Description

Picea mariana is a small to medium-sized conifer with a dense crown of upwardly angled branches (Bell 1991). The lower branches droop downwards, the lowest often growing into the substrate. Branchlets are often puberulent and the leaves are bluish-green and glaucous (Scoggan 1979). Cones are small and rounded usually no more than 1.5 cm long.

Distribution and Habitat

Although wide ranging in Canada, this species is restricted to the boreal forest. In Manitoba, it grows from the tree line to Riding Mountain in the west and to the Whiteshell area in the east. *Picea mariana* grows in a number of habitats, from dry gravels and sands to boggy sites high in organic matter.

Propagation and Growth

Picea mariana produces large numbers of seeds that on release germinate under favourable conditions. The species also reproduces vegetatively through a process known as layering. A layer is created when a lower branch grows down into the substrate or is buried under accumulating moss (Stanek 1961). Under continuous contact with a moist substrate, the branch develops roots. A layer will grow slowly for many years as long as it remains physiologically attached to the parent plant. A layer can become independent through rotting off of the connections or death of the parent plant (Stanek 1961). Layered stands of *Picea mariana* are unevenly aged and can, under disturbance such as clear cutting, increase in wood volume more efficiently than seed-origin individuals (Morin & Gagnon 1991). Both layer and seed origin trees are slow growing, adding as little as 0.25 mm in diameter per year. Sapling growth is slow, with the species attaining a height of only ≈ 2.5 cm after several years (Bell 1991).

Competition

Picea mariana can grow under very low light conditions, although it grows best in full sunlight (Bell 1991). During early development it can be suppressed by 'crushing' under leaf litter (Bell 1991).

Herbicide and Disturbance Biology

Picea mariana is considered to be tolerant of many of the current herbicide formulations. As well, under mechanical disturbance or cutting the layers are often released from physiological dominance of the parent tree (Bell 1991; Morin & Gagnon 1991).

***Pinus banksiana* - jack pine**

Description

Pinus banksiana is a medium to large-sized conifer with an open crown of spreading to ascending branches (Bell 1991). The leaves are greenish-yellow with a slight twist. The cones are incurved and remain indehiscent for many years (Scoggan 1979).

Distribution and Habitat

In Canada, *Pinus banksiana* is most common in the southern boreal forest. In Manitoba it is found northward to near the tree line, and extends south into the Riding Mountain region in the west and the Sandiland area in the east. It is most commonly found on dry mineral substrates, typically on sand and other glacio-fluvial deposits (Bell 1991). However, in extreme northern regions it is often replaced by *Picea mariana* in such areas.

Propagation and Growth

Pinus banksiana produces copious quantities of seed in serotinous cones (Kimmins 1987). The cones normally open immediately following a forest fire, which allows the seeds to germinate in a low-competition environment. The species has evolved a number of features to increase inflammability (Kimmins 1987). After a fire, regeneration is rapid and the stand densities are often high. Self-thinning is common in maturing stands (Kenkel 1988). Like most pine, the species does not reproduce vegetatively in nature (Bell 1991). Jack pine is relatively fast-growing, though grow rates decline after 50 (Bell 1991) to 70 (Yang & Hazenberg 1991) years.

Competition

Pinus banksiana is highly shade-intolerant and grows rapidly in the first few years to avoid light competition (Bell 1991). Several species are known to compete with *Pinus banksiana,* including grasses, sedges, *Corylus* spp., *Rubus* spp., *Prunus* spp. and other tree species (Bell 1991).

Herbicide and Disturbance Biology

This species is considered to be highly sensitive to most herbicides (Bell 1991). It does not reproduce vegetatively and the cones are highly serotinous, populations do not recover rapidly from mechanical disturbance.

Thuja occidentalis - eastern white cedar

Description

Thuja occidentalis is a small to medium-sized conifer with an open crown of ascending branches. The leaves are yellow-green and scale-like, and the cones are small with rounded scales (Fowells 1965).

Distribution and Habitat

Thuja occidentalis is generally restricted to the southern boreal forest of eastern Canada. In Manitoba, it is restricted to the south-eastern portion of the province with a large disjunct population along the The Pas moraine (Scoggan 1979). It tends to grow in slightly alkaline to neutral, wet glacio-fluvial deposits and swamps (Fowells 1965; Matthes-Sears & Larson 1991).

Propagation and Growth

Thuja occidentalis produces reasonable quantities of seed (Fowells 1965). The species can also layer in wet habitats; layering may account for 60% of the stems in some swamps. The species grows very slowly, with increases in diameter averaging only 0.84 mm per year (Fowells 1965).

Competition

This species is capable of growing under extreme competition for years, and is generally disease free. However, it is susceptible to periodic fluctuations in the water table (Fowells 1965).

Herbicide and Disturbance Biology

Little information has been found regarding the herbicide tolerance of this species. Its ability to layer at a young age (at 5 years) likely helps the population to survive disturbance. Fowells (1965) reports that stands subject to repeated wind disturbances tend to layer more frequently than undisturbed stands.

Populus tremuloides - trembling aspen

Description

Populus tremuloides is a medium to large-sized deciduous tree (Bell 1991). The leaves are suborbicular in shape with a compressed petiole. The seeds have a white pappus and are produced in capsules each spring (Bell 1991).

Distribution and Habitat

In Canada, *Populus tremuloides* occurs throughout the boreal forest and into the parkland regions adjacent to the southern grasslands of the prairie provinces. It is common throughout Manitoba except in the Hudson Bay lowlands. The species grows in a number of habitats and on many different soil types, although it prefers loamy soil (Bell 1991).

Propagation and Growth

Populus tremuloides is a prolific seed producer, and may release up to 1.6 million seeds per year (Bell 1991). Despite this, the predominant means of propagation in the species is vegetative regeneration. Root 'suckers' are produced in large numbers during the growing season following a major disturbance such as fire or cutting. Clear-cut areas can have sucker densities as high as 70,000 stems/ha (Bell 1991). The suckers and seedlings are capable of rapid growth in early development.

Competition

Competition for moisture with grasses inhibits the growth of *Populus tremuloides* seedlings. However, a sucker that remains connected to the parent plant may grow up to 2 m in its first year (Bell 1991). Suckers have been shown to be suppressed by dense stands of shrubs such as *Alnus* spp. and *Corylus cornuta* .

Herbicide and Disturbance Biology

The species displays a variety of responses to herbicide treatment (Bell 1991). Some clones may be entirely resistant to a herbicide and another may be competely killed. Mechanical disturbance of *Populus tremuloides* results in sucker production in proportion to the degree of disturbance (Bell 1991).

1.4 Right-of-Way Management

The environmental impact of ROW development can be considered in terms of both aesthetic change and biotic disturbance. The aesthetic impact of ROW development is difficult to quantify (Johnston 1973; Niering 1958), although aesthetic perception is predictable when an individual's background (cultural group, income level, etc.) is known (Jackson & Hudman 1978). Although aesthetic impact may drive public perceptions more than questions of biodiversity, biotic changes are the focus of this thesis.

Biotic (floristic and faunal) changes differ from aesthetic ones in being quantifiable but are in many cases unpredictable. In general, several phases of ROW clearance can be considered distinct relative to the type and intensity of biotic disturbance. These are:

1. Initial line clearance, including construction of towers and access roads, can have a profound effect on the landscape and the ecosystem. For instance, the flux of nutrients after clearing is similar to that which occurs following a fire (Magnusson & Stewart 1987).

2. Impacts that are related to the physical presence of the established corridor on the landscape.

3. Subsequent line maintenance and vegetation control. For example, on the Manitoba HVDC line there was a primary spraying of the herbicide Picloram in the 1970's and a follow-up spray in 1979-1981.

Several immediate effects on the flora and fauna have been noted in areas sprayed with the herbicide Picloram. For some animal species there is reduced forage, but ROW management may actually favour other species such as the goldfinch and other ruderal seed eaters (Johnston 1973). Floristic composition also changes, since Picloram is effective against most dicotyledons and coniferous species but not monocotyledons (Sims 1977). As a result, adoption of a herbicide management approach results in an increase in abundance of grass species, as observed by Egler (1954). This is attributable to herbicide resistance in grasses and other members of the Cyperales (Egler 1954). In the United States, herbicide treatment is known to favour certain broadleaf species (e.g. sassafras, hazelnut and hawthorn; Johnston 1973). Thus, unlike the natural boreal forest communities where fire is the primary driving force in succession (Rowe 1956; Kimmins 1987), vegetation composition of boreal forest ROWs might be expected to be determined by herbicide resistance. Johnston (1973) found that herbicide use resulted in certain communities spreading at the expense of others, resulting in a reduction in ROW biodiversity and landscape heterogeneity over time. He referred to the resultant community as a "herbicide climax".

Dispersal mechanisms in plants are not initially altered by ROW development. As in natural communities, the primary sources of species recruitment on ROWs are the seed bank and vegetative propagules, with the adjacent forest serving as an important seed source (MacLellan 1982). However, the reduction of competition for space and light immediately following ROW clearing increases the likelihood of weed invasion (MacLellan

1982). Species colonizing and migrating along a ROW corridor will likely disperse in a manner similar to plants colonizing cultivated arable land. Cavers & Benoit (1989) considered the following factors:

1. The greater the distance to a seed source, the lower the probability of a given volume of seed landing in an area. Most dispersing species have highest density within a few meters of the site of first entry, even species with long-distance dispersal mechanisms.

2. Tall vegetation along the margin of an open area acts as a catchment for seeds. Given that a ROW is a long, narrow corridor, it is likely that the dominant seed source will always be the adjacent forest. However, ruderal species may migrate along the ROW over time.

1.5 STABLE PLANT COMMUNITIES

Definitions of Stability

A simple definition of a stable community is one that is resistant to invasion by other species, which is also the definition of a climax plant community (Horn 1974). In a climax forest, canopy trees resist the invasion of new species by shading out the forest floor, often to the detriment of their own progeny. Another definition of stability is resistance to perturbation (Horn 1974). To explain this more fully, consider perturbation of an early successional vs. climax community. In both cases an early successional community will result, but greatest change in community composition will of course occur in the climax community (Horn 1974). Thus, a late successional community is less 'stable' relative to perturbation, but more 'stable' with respect to invasion (Horn 1974). In general, perturbation-resistant communities are species rich, whereas invasion-resistant communities tend to be monodominant (Horn 1974).

A stable community need not necessarily be one dominated by 'climax' species. Indeed, Noble & Slatyer (1980) define an 'inhibition pathway' as one in which 'climax' species are inhibited by the colonizing community. For example, stable shrub and herb communities have been created through the selective use of herbicides (Neiring & Goodwin 1974; Pound & Egler 1953).

Stable ROW Plant Communities

As already mentioned, stability can be considered in terms of resistance to both perturbation and invasion. From a ROW management perspective, perturbation and invasion resistance must be balanced. Because hydro line maintenance results in low but regular community disturbance, the ROW vegetation should be resistant to perturbation. At the same time, the ROW vegetation should be resistant to invasion by trees (i.e. able to suppress tree invasion). Grass-herb communities show both of these characteristics, and were the favoured ROW vegetation earlier this century (Egler 1954). Grass communities have the advantage of being resistant to herbicides, but need to be maintained using these chemicals if they are to compete effectively with woody perennials over long periods (Niering 1958; Egler 1954). Ethier (1979) supports this view, but demonstrated that grasslands are open to invasion by pine species. Other studies have demonstrated that grasses (e.g. little bluestem, quackgrass) can suppress red pine (Kelertas 1979), and that nursery grown jack pine are inhibited by grasses (Bell 1991).

In North America, some shrub communities on ROWs may also show stable properties (i.e resistance to both perturbation and invasion). In the eastern United States, 25 year old stable communities dominated by nannyberry (*Viburnum lentago*) were reported by Niering & Egler (1955). In Newfoundland ROWs, speckled alder (*Alnus rugosa*) communities on wet sites have resisted tree invasion for 50 yrs, while on drier sites sheep-laurel (*Kalmia angustifolia*) resists tree colonization 'indefinitely' (Kelertas 1979). A number of other shrub species have a demonstrated ability to suppress tree growth (Johnston 1973). Species native to Manitoba include pin cherry (*Prunus pensylvanica*), red osier dogwood (*Cornus stolonifera*), hawthorns (*Crataegus* spp.), mountain maple (*Acer spicatum*), ironwood (*Ostrya virginiana*), smooth sumac (*Rhus glabra*), alders (*Alnus* spp.), hazelnut (*Corylus cornuta*), elderberry (*Sambucus racemosa*), viburnums (*Viburnum* spp.) and honeysuckles (*Lonicera* spp.).

For the purposes of this study a 'stable shrub and herb community' is one which resists the invasion of tree seedlings. This can be directly measured as the number of trees recruiting into an area of a given vegetation type.

Alternative ROW Management Strategies

Jackson & Hudman (1978) suggested that ROW's be constructed so as to mimimize the aesthetic impact, but did not consider impacts on the vegetation. Egler (1954) suggests that selective practices be used at all stages of ROW development, and that the environmental impact of clearance be minimized to promote the establishment of a stable vegetation. The following ROW development-management scenario is recommended (Egler 1954):

1. Utilize selective cutting methods in the initial line clearing.

2. Use selective herbicides to remove undesirable species from the selectively cut areas, and for routine brush control.

3. Plant vegetation screens at strategic locations.
4. Improve routine clearing techniques.
5. Incorporate modified poles and structures at locations and in sizes so as to accommodate beautification.

Niering (1958) recommended that a sound ROW management practice begin with the determination and mapping of natural and semi-natural communities on the ROW. Once mapped, techniques to maintain the areas should be tailored to the vegetation present. Selective maintenance is recommended wherever possible. Such a management scenario allows for the continued growth of desirable shrub species while reducing the biological and aesthetic impacts of ROW development.

Nowak *et al.* (1992) examined cost-effective maintenance scenarios on recently cleared ROW's in New York state. They examined selective vs. non-selective, and stem-foliar vs. basal, applications of the herbicide Picloram in ROW study plots. They found that selective stem-foliar applications were most effective in eliminating undesirable species while having minimum impact on desirable species. They further examined the cost of stem-foliar vs. basal herbicide applications as a function of tree height and tree density. It was found that the relative cost of basal application decreases as tree height increases, while the cost of foliar spraying decreases as tree density increases.

1.6 Remote Sensing

Introduction

This study uses data from the LANDSAT Thematic Mapper (TM) to develop a practical model for predicting vegetation change and management along hydroelectric ROWs in central Manitoba. This approach was chosen because remotely sensed TM images provide a visual description of landscape pattern. LANDSAT imagery summarizes the location, geographical extent and landscape patterns, as well as providing information on current environmental conditions (e.g. soil moisture, cloud cover) and changes in communities over time (Ustin *et al.* 1993; Ranson & Williams 1992). Furthermore, remote sensing technology can provide the large sample size and repeated measurements required to measure the extent and state of the boreal forest (Ranson & Williams 1992).

The system of earth orbiting satellites known as LANDSAT was first launched in the early 1970's. The satellites, which were to function as part of the Earth Observational Satellite Series (EOSAT), were to collect data on vegetation and landforms that could be used by researchers in the earth sciences (Wickland 1991). LANDSAT is considered a passive remote sensing platform since the sensors measure reflected incident sunlight from ground or cloud surfaces. This differs from systems such as RADARSAT, which emits an initial signal that is reflected back (Ranson & Williams 1992). LANDSAT 1, launched on July 23, 1972, carried a Multispectral Scanner (MSS) sensor. LANDSAT MSS measures reflectance within three spectral bands in the visible spectrum, at a ground resolution of 80 x 80 m (Budd 1991). In 1982, a new class of Thematic Mapping sensors (TM) were launched on LANDSAT 4. LANDSAT TM, which operates at a ground resolution of 30 x 30 m, samples within seven spectral bands: bands 1 to 3 are in the visible spectrum, band 4 in the near infrared, and bands 5 and 7 in the shortwave infared portion of the spectrum (**Figure 1.2**) (Ranson & Williams 1992; Budd 1991). Because of its greater spatial resolution and its ability to sample infrared bands, LANDSAT TM has largely replaced MSS in mapping of vegetation and landforms.

Satellite imagery of the Earth is based on the principal that when electromagnetic energy strikes an object it is either reflected, refracted, transmitted or absorbed (Barrett & Curtis 1992). An object absorbing energy is heated, resulting in emission of light at a longer wavelength. All bodies radiate energy in wavelengths proportional to their temperature (Barrett & Curtis 1992). This is summarized by Wien's displacement law:

$$\lambda_{\max} = \frac{C_3}{T}$$

where λ_{max} is the maximum wavelength of peak radiant existence, C_3 is a constant (2897 mm K), and T is the absolute temperature of the body. The Earth (and objects on its surface or within its atmosphere) emit energy in the infared portion of the spectrum. Thus, the spectral reflectance (or more properly, the signature spectrum (SS)) of a remotely sensed body is a composite measure of its reflectance and its emitted energy. The signature spectrum of an object is specific for a given set of environmental parameters such as temperature and moisture levels (Barrett & Curtis 1992).

Signature Spectra and Vegetation

The signature spectra for plant species or vegetation type is often unique (Markon 1992; Thomson *et al.* 1985; Treitz *et al.* 1992; Rencz 1985), despite the fact that it is the result of processes that are the same for all plants across the visible, near-infared and middle-infared spectra. In the visible spectrum (TM bands 1-3), plant pigments absorb the majority of incident radiation. As a result, much of the reflected visible light is attributable to scattering in the upper canopy (Ranson & Williams 1992; Kleman 1987; Everitt & Richardson 1987). The 'greenness value' within the visible spectrum, a measure of the

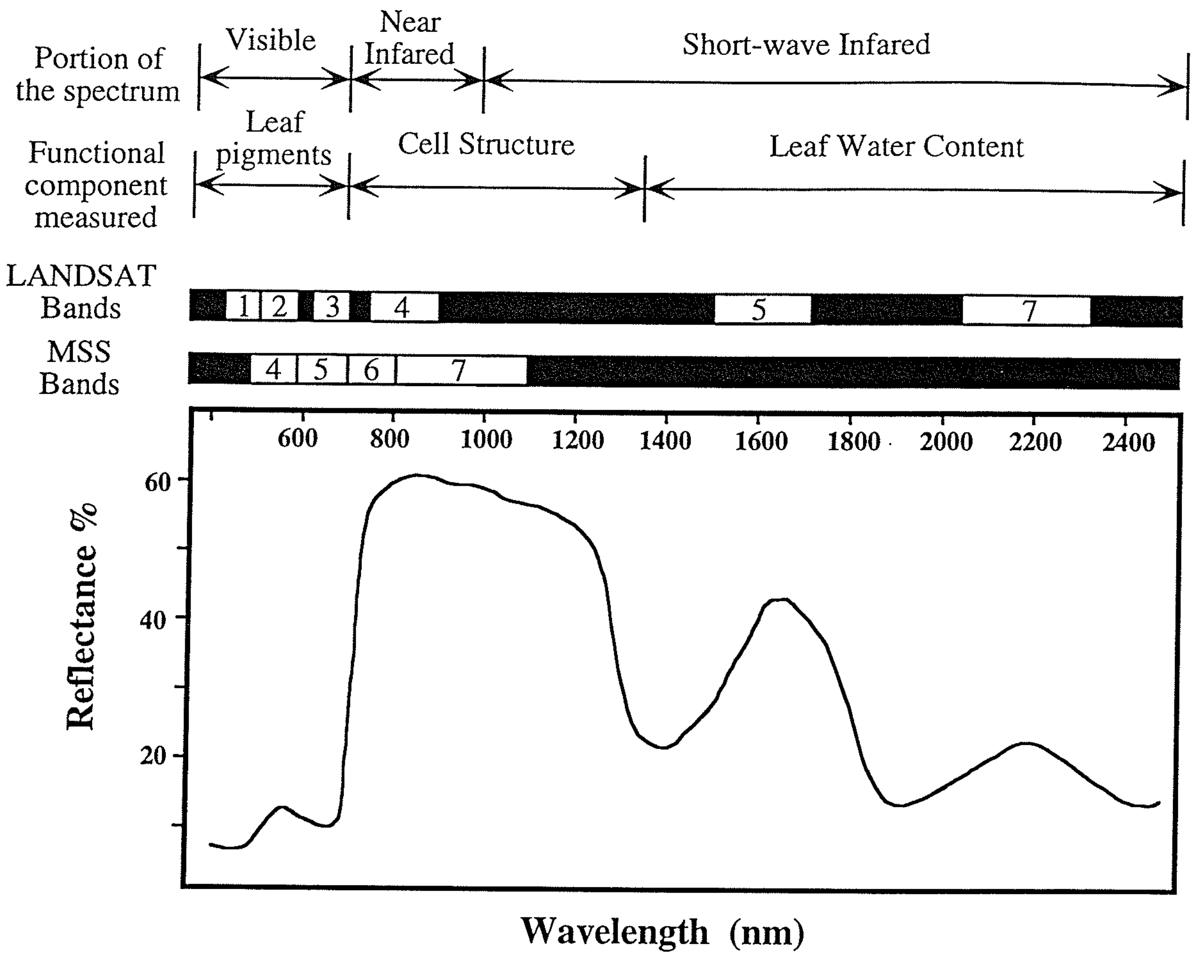


Figure 1.2: The average spectral reflectance for vegetation between 400 and 2400 nm is given. The major divisions of the spectrum are given at the top of the diagram, with the corresponding functional component for that spectral region indicated beneath. The bands sampled by LANDSAT TM and MSS sensors are indicated by number in the white boxes. The length of the box corresponds to the band width sampled.

amount of reflected green light, is important in separating vegetation from soil effects, especially with MSS data (Jackson 1983; Huete *et al.* 1984).

The internal structure of leaves determines the level of reflectance in the near infared (TM band 4) portion of the spectrum (Ranson & Williams 1992). Because very little incident radiation is absorbed in this region of the spectrum, reflected radiation can penetrate through several layers of a vegetation canopy and so reveal vegetation structure (Ranson & Williams 1992). In the middle infared (TM bands 5-7), the most important factor determining reflectance is vegetation moisture content. Because of the correlation between tissue moisture content and photosynthetic rate, the middle infared bands can be used to infer the relative photosynthetic activity of a community (Ranson & Williams 1992).

Various gross anatomic features of vegetation can also influence spectral reflectance. Everitt & Richardson (1987) found that seven rangeland plants could be separated spectrally based on the degree of leaf pubescence. When plant moisture was taken into account, they found that it was possible to spectrally distinguish densely, sparsely and non-pubescent plant species. As well, forest gaps, leaf shape, and the physical structure of the leaf cuticle can all affect spectral reflectance (Peterson & Running 1989).

Vegetation Indices

A number of vegetation indices have been proposed to standardize the way in which spectral signatures are classified, for both LANDSAT MSS and TM bands (Perry & Lautenschlager 1984; Huete *et al.* 1984; Jackson 1983). Vegetation indices developed for interpreting MSS data are generally influenced by the soil spectral reflectance in areas of low vegetation cover (Huete *et al.* 1984; Jackson 1983; Perry & Lautenschlager 1984). Most of these indices are based either on band ratios or use the coefficients of linear combinations of the bands, the latter being determined using principal components analysis (Perry & Lautenschlager 1984).

The most frequently used ratio technique is know as the normalized difference vegetation index (NDVI). It is computed as:

$$NDVI = \frac{(L_{NearIR} - L_{Red})}{(L_{NearIR} + L_{Red})}$$ (Ranson & Williams 1992; Perry & Lautenschlager 1984).

where L is spectral reflectance. In croplands, natural grasslands and deciduous forests, this index is positively correlated with leaf area index (LAI; a measure of the area of photosynthetic surface per unit area of ground). However, recent studies in the North

American boreal and Pacific coast forests have indicated a negative correlation between NDVI and LAI for coniferous species (Ranson & Williams 1992).

Applications of Remote Sensing in Vegetation Science

A large number of recent studies have utilized satellite imagery to examine vegetation and landscape structure. Data obtained from satellite imagery has considerable utility in the documentation and management of vegetation at the landscape level. The following brief review focuses on studies that are most relevant to the objectives of this thesis.

Gross *et al.* (1987) applied the band ratio method (NDVI index) to LANDSAT TM data to estimate biomass of *Spartina alternifolia* (smooth cord grass) in North American saltmarsh ecosystems. Their calculated biomass estimates were within 13% of those based on ground harvest data. From these results, the authors suggested that accurate biomass estimates (required for developing a biogeochemical cycling model of marshland ecosystems) could be obtained using LANDSAT data.

Rencz (1985) applied the band ratio method in a study monitoring temporal changes in forest cutovers in Nova Scotia. It was found that biomass of coniferous forest was difficult to accurately predict using MSS data. However, estimated projected cutover sizes were within 10% of their actual values, suggesting that classified LANDSAT images can be used to directly update forest inventory databases.

LANDSAT has also been used in rangeland management studies. Thomson *et al.* (1985) used LANDSAT TM bands 4 and 5 to examine changes in rough fescue (*Festuca* sp). grasslands over the growing season. They were able to accurate estimate dead biomass using these spectral bands, and were able to accurately predict grazing patterns on the landscape. Thomson *et al.* (1985) concluded that LANDSAT TM imagery is a significant and important tool for rangeland managers.

In Manitoba, Dixon *et al.* (1984) used LANDSAT MSS data to map forest fuel types in determining areas most susceptible to fire. In their study, four different forest types were recognised in the Cormorant Lake and Flin Flon regions of west-central Manitoba. They found that the softwood group was the most difficult to separate spectrally, with the greatest amount of overlap occuring in the near and middle infared bands. Their study recognised seven other classes, including 'cutovers', 'burn sites', and 'roads'. Such anthropogenic and natural disturbances were apparently large enough to be resolved by the 80 x 80 m MSS pixels.

A series of Manitoba peatland inventories using LANDSAT were undertaken by Dixon & Stewart (1984, 1986, 1988) in the northern boreal, south-eastern boreal and Interlake regions of the province. The first two studies, which used LANDSAT MSS data, were able to recognise several bog classes including 'open bog', 'treed bog' and 'shrubby bog'. However, they found strong overlap between wet coniferous stands (black spruce, larch) and dry coniferous stands dominated by jack pine (see also Dixon *et al.* 1984). The third study (Dixon & Stewart 1988) used LANDSAT TM data. This resulted in a better separation of 'bog' and 'fen' stands. Their LANDSAT TM classification recognised more vegetation groups than could be photo-interpreted and were combined to determine the overall accuracy of the classification (Dixon & Stewart 1988). Linear regressions were performed on the TM classified bog area versus the area calculated from aerial photos. A strong relationship ($r^2 > 0.88$) was found, suggesting that LANDSAT can be used to accurately estimate peatland harvesting stores.

Similar studies to those already discussed for Manitoba were done in Minnesota (Moore & Bauer 1990) and Wisconsin (Bolstad & Lillesand 1992) on forest vegetation. Moore & Bauer (1990) compared the capabilities of LANDSAT TM and MSS data to classify vegetation in Itasca State Park. They found that LANDSAT TM data improved the accuracy of the vegetation maps by 7 to 15% over MSS data. As well, they concluded that the optimal combination of bands for this purpose was one from each of the visible range, near infrared and middle infrared regions of the spectrum. A second study in Wisconsin used LANDSAT TM in conjunction with a geographic information system (GIS) to improve classifications (Bolstad & Lillesand 1992). They used soil texture data integrated with known soil-vegetation responses overlaid onto the LANDSAT vegetation groups. A probable vegetation association for each region could then be predicted.

LANDSAT TM can also detect variation within understory vegetation. Stenback & Congalton (1990), used seven band combinations for the identification of understory vegetation. They found that band combinations which used 4 or 5 different bands could discriminate vegetation classes more accurately than when only three were used (except the combination 2,3,4 and 7 which scored the lowest). The combination 3,4 and 5 (which was used in this thesis) was able to correctly identify understory vegetation associations 66.7% of the time. Overall classification of the overstory as well as the understory for the same area was 84.3% (Stenback & Congalton 1990). They concluded that LANDSAT TM could be used to assess understory as well as overstory and that band 5 was very important in this respect.

LANDSAT TM has also been used to assess conifer regeneration in Oregon (Fiorella & Ripple 1993a,b). In their studies, they tried several different methods to examine forest regeneration. They found that poorly regenerated stands could be separated from well regenerated stands by using a ratio of bands 4 and 5 (which they called the 'structural index'). These two bands showed the greatest spectral variability for a given region, were capable of distinguishing different degrees of stratification within a forest and were highly correlated with tree age (r = .96) (Fiorella & Ripple 1993a,b).

LANDSAT satellite imagery is a powerful tool for the analysis of vegetation structure and composition at the landscape level. Indeed, LANDSAT permits whole new questions to be asked in ecology at a spatial scale not previously possible.

1.7 OBJECTIVES

The objectives of this thesis are:

1. to determine vegetation trends of boreal forest vegetation alongside and adjacent to the HVDC line in central Manitoba.

2. to classify sites into forest vegetation types, and to relate these types to environmental factors and rates of tree colonization on cleared and managed right-of-way corridors.

3. to correlate the trends in vegetation between forest and ROW vegetation.

4. to establish a correspondence between signature spectra (SS) and the dominant cover types, and determine whether predictable and distinct groups are present.

5. to develop a predictive numerical model of vegetation change and maintenance requirements for Hydro right-of-way corridors in central Manitoba.

Chapter 2

Materials and Methods

2.1 Study Area

Background

This thesis focusses exclusively on the Manitoba Hydro HVDC right-of-way, which because of its width (125 to 150 m) is readily located on a LANDSAT TM scene (pixel resolution of 30 x 30 m). The establishment of this right-of-way began in the winter of 1967 when initial forest clearing for the line started (Maclellan 1982; B. Mann, 1994 pers. comm.). The HVDC line starts at the Raddison generating station near Gillam (56°22'N and 94°36'W) and ends at the Dorsey receiving station (50°00' N and 97°25'W) near Winnipeg, a distance of nearly 900 km. The transmission line corridor consists of bipoles 1 and 2, which are twinned steel towers approximately 65 to 75 meters apart. The towers of a given bipole line are spaced between 325 and 475 m apart. The smallest distances are associated with the shorter 'type SA' towers (34 m tall), and the larger distances with the 'type A' towers that are 45 m in height (MacLellan 1982). Towers along the HVDC right-of-way are sequentially numbered, from 1 (Raddison generating station) to 2000 (Dorsey station). Because the tower numbers are unique, they are used in this study to identify the sample sites.

Between the Minago River and Winnipeg the HVDC ROW is parallelled to the west by a 230 kV alternating current (AC) line with a 60 m wide ROW. Both right-of-ways are accessible from the west by Provincial Highway 6. Access points to the ROWs have been improved in recent years by the building of culverts and gravelled approaches along the highway. Access points occur every 5 to 10 km along the ROWs except in extensive bog-fen areas. Access along the line itself is via a maintenance corridor that runs down the centre of the HVDC right-of-way. The present study was restricted to the most accessible parts of ROW in the northern Interlake region.

Geology and Physiography

The study area is in the northern Interlake region, bounded by latitudes 52° and 53° 30' N and longitudes 99° and 100°W. Most of the region has low undulating relief, with the exception of a steep escarpment located along the south side of The Pas moraine (Klassen 1966). The area is underlain primarily by Silurian dolomite, with Ordovician dolomite to the west along Lake Winnipeg and Devonian limestone in the extreme south. The bedrock determines the topography at a large scale, with the microtopography influenced primarily by glacial features.

Most of the area to the south of the The Pas moraine is overlain by 0.25 to 1.5 m of ground morainic drift (Klassen 1966). It is considered part of the Interlake plain, typified by features of low relief. In areas of locally higher relief, the wave action of glacial Lake Agassiz has eroded the fine sediments leaving exposed gravel. Provincial Highway 6 and the ROWs generally follow these gravel ridges, but much of the area is poorly drained resulting in extensive boggy-fen development (Klassen 1966). Zones of clayey morainic drift are generally dominated by mixed coniferous-deciduous forests, which are replaced as moisture levels increase by bogs dominated by black spruce (*Picea mariana*). Marketable stands of *Pinus banksiana* (jack pine) are commonly found on well-drained gravelly soils.

The Pas moraine represents an abrupt change in relief, rising by 30 m above the plain to the south, a gradient of ≈0.075. On the north side of the moraine, the slope is far more gradual (a gradient of ≈0.02 m, Klassen 1966). This escarpment is composed of thick till deposits overlain with a complex of beach ridges of well sorted rock and gravel (Klassen 1966). The crest of moraine is composed of till and gravel forming a well defined ridge and swale topography. The ridges are 500 m apart and orientated in the direction of the last glacial ice flow. Black spruce bogs dominate the poorly drained areas between these ridges, while upland forests of jack pine and black spruce occur on the ridges themselves.

Northward from The Pas moraine is the Cedar Lake plain (Fraser *et al.* 1985). It is formed on an outcrop of Ordovician dolomite and limestone exposed at the surface. The southern edge of this plain is bordered by Saskatchewan river valley. The generally low relief of this area is punctuated by bedrock ridges up to 20 m in height and mesa-like outcrops (Klassen 1966). In some areas a deep till has been deposited between these bedrock ridges, but most of the region is flat limestone plain dominated by open jack pine stands.

Climate and Fire History

Mean monthly temperature and precipitation data (1966-1990) for the Grand Rapids Hydro meteorological station (53°09'N 99°17'W, 223 m above sea level) is presented in **Fig. 2.1**. It is the only meteorological station in the northern Interlake area. The yearly mean temperature for the region is 0.5°C. The mean daily maximum temperature in July is 23.7°C, and the mean daily minimum in January is -24.7°C. Total annual precipitation is 483.4 mm, of which 365.8 mm falls as rain and 116.2 cm (rain equivalent of 11.62 cm) as snow. Maximum rainfall occurs in June (75.2 mm) and the maximum snowfall in November (23.1 cm). During the summer of 1989 when the Landsat image was taken, the

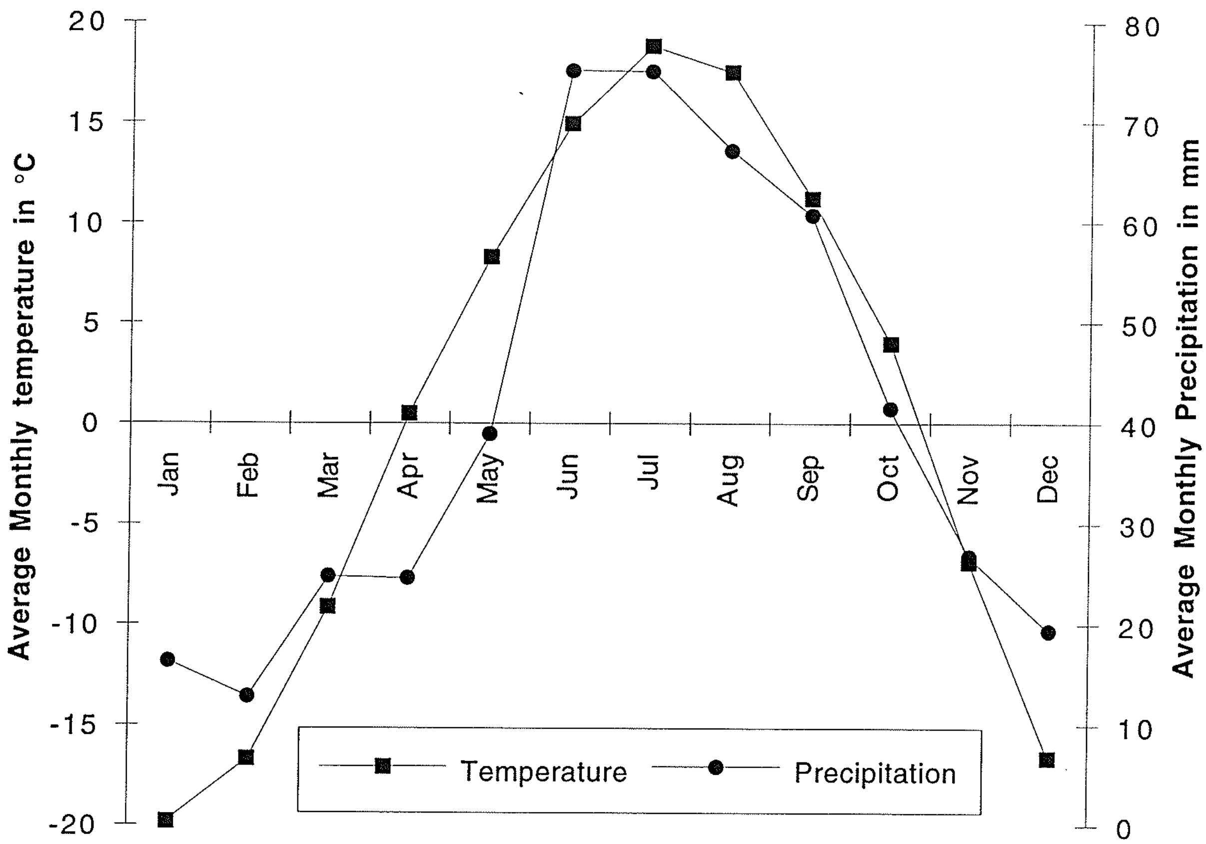


Figure 2.1: The mean monthly precipitation and temperature for the Grand Rapids area Manitoba (Data Obtained from Environment Canada Grand Rapids Meterological Station).

mean July temperature was 21.5°C and the August mean was 18.2°C. Precipitation for that same period was 17.2 mm in July and 137.0 mm in August. Temperatures were above average for this period and precipitation was below average.

During the summers of 1992 and 1993 (when vegetation sampling was undertaken) the mean monthly temperatures in July were 15.4°C and 16.7°C respectively, and in August 16.5°C and 16.7°C respectively. The precipitation for July was 88.7 mm in 1992 and 150.4 mm in 1993, and the August precipitation was 21.3 mm and 123.8 mm for 1992 and 1993 respectively. Both of these years the temperature was below average and the rainfall was average to above average.

Much of the Interlake region is exposed to frequent forest fires which can be widespread but are generally low in intensity (G. Peterson, 1994, Mb. Dept. Forestry, pers. comm.). During 1929 most of the Interlake, from Gypsumville to the escarpment of The Pas moraine, was burnt. The north facing side of The Pas moraine approximately 40 km north of the crest was burned in a high intensity forest fire on July 18 1989. The limestone plain from Grand Rapids south, and extending over 40 km northwards, was burnt in a series of forest fires in 1937 (Manitoba Department of Forestry, Fire History Maps).

Herbicide and Maintenance History

Herbicide treatment began on the right-of-way in 1973, when the region between towers 965 and 1122 was sprayed with 2,4,-dichloro-phenoxyacetic acid (2,4-D) (MacLellan 1982). However, most of the present study region was treated between 1979 and 1981. The most commonly used method of application in the Interlake area was the selective spraying of liquid herbicide from a bog tractor (MacLellan 1982). A complete program of herbicide use was started in 1979 from just south of Devil's Lake (Tower 1317) to The Pas moraine (Tower 1173) using Tordon 101 (a mixture of 2,4-D and picloram). This form of application was also used in the following year on the ROW from Tower 972 to 1078 (MacLellan 1982). A solid form of Tordon was used on Towers 1100 through 1133 in 1981.

At present, the most common method used in line maintenance is V-blading, using a specially equipped tractor. The tractors blade is V-shaped in outline, with a longer lower portion that is sharp and a shorter upper portion. Trees are removed by bulldozing, with the lower blade cutting the tree at the base and the upper blade pushing it over. Line treatments are done in the winter when the soil is frozen, as this gives better site access and minimises soil damage (B. Mann, 1994, Mb. Hydro, pers. comm.). However, this maintenance method results in swathes of organic debris, and in hummocky areas soil damage is still a problem. During the winter of 1992 and 1993 V-blading was scheduled between towers 1173 and 1230. Several study plots within this region were marked with flagging tape so they would not be bladed. Unfortunately, the original maintenance area was extended northwards from Grand Rapids to beyond tower 1020. As a result, survey plots in this area were lost.

Site Selection

During May 1992, fifteen HVDC line access points were examined as potential study sites. Of these, ten access points were selected based on homogeneity of vegetation and topography over several hundred meters. The most southern access point is ≈ 68 km north of the town of Gypsumville, the furthest north ≈ 27 km north of Grand Rapids. All sites occur within the Cedar Lake LANDSAT TM scene track 33, frame 23+6 seconds (August 7 1989). They were sprayed with Tordon 101 within a 2 year period (though sites 1113, 1114 and 1115 received Tordon in solid form).

At each of the ten access points, three ROW-forest sampling sites were established (total of 10 x 3 = 30 sampling sites). The first ROW sample site was adjacent to and east of the base of the nearest tower (e.g. tower 1021). The second and third sample sites were similarly established adjacent to the closest tower to the north (e.g. tower 1020) and south (e.g. tower 1022) of the first, respectively. At each ROW sample site, an adjacent forest sample site was chosen 15 m into the forest east of the ROW. Only forest to the east side of the line was sampled, since it was felt that the forest to the west side of the HVDC line ROW would have disturbance features and edge effect problems associated with the presence of the nearby AC line ROW (generally only 100 meters away) and Provincial Highway 6.

2.2 SITE DESCRIPTIONS

Sites 1020, 1021 and 1022 (53°25' N and 99°20' W)

a) Location

These three sites, located 27 km north of Grand Rapids, were accessed by a small road servicing several nearby homes on Buffalo Lake. ROW and forest quadrats were placed 10 m to the north of these towers.

b) Topography

These sites were located on the limestone plain just north of a 12.5 m limestone cliff, and separated from it by an arm of Buffalo Lake. From tower 1020 to 1022 the elevation gradually drops from 264.9 m above sea level to 256.3 m. Immediately to the west of the HVDC line at tower 1020 the elevation rises by ≈ 6 m.

c) Geology, Drainage and Soils

Water flow parallels the ROW, with fairly good drainage at sites 1020 and 1021 giving way to increasingly poor drainage toward site 1022. Because the topography rises to the west, water also has a tendency to drain onto the ROW from that direction. This causes temporary pools to form before draining into the arm of Buffalo lake south of tower 1022. The soils are predominantly rocky surface till with a high proportion of sand overlying deeper deposits of fine clay. Organic accumulation is low for sites 1020 and 1021 (< 5 cm) but exceeds 5 cm at site 1022.

d) Vegetation

The ROW vegetation at sites 1020 and 1021 is a low shrub-graminoid cover (mostly dead culms), *Arctostaphylos uva-ursi*, Lichen spp. and the occasional large individual of *Juniperus communis*. The predominant forest vegetation is *Pinus banksiana* with a few scattered individuals of *Picea mariana*. The age of the stand is between 45 and 50 years. At site 1022 poorer drainage and pooling of water in some areas results in a different species composition on the ROW. *Populus tremuloides*, *Larix laricina*, *Picea mariana* and *Pinus banksiana* were colonizing the ROW at this site. Shrubs (*Salix spp.* and *Potentilla fruticosa*) were much more common at this site than at 1020 and 1021. The forest at this site was a dense stand of *Picea mariana* with pockets of *Pinus banksiana*, between 40 and 50 years old.

e) Maintenance and Fire History

Tordon 101 herbicide spraying occurred in 1980 and blading was done during the winter of 1992. None of the established study plots survived the blading, although a number of the younger trees were apparently undamaged. Soil damage at site 1022 was extensive with large swathes of dead organic debris (often a half meter thick) and fallen trees. The last recorded burn was in 1937, although the stand age indicates a possible unrecorded disturbance event in the early 1940's.

Sites 1034, 1035 and 1036 (53°20' N and 99°20' W)

a) Location

These sites are located 20 km north of Grand Rapids. They were accessed by a series of roads into a gravel pit east of the study area. ROW and forest quadrats were placed 10 m to the north of the towers.

b) Topography

These sites are located on a limestone plain at an elevation of 259.4 m. Elevation between the towers 1034 and 1036 varies by less than 1 m. The west side of the ROW is approximately 0.3 m higher than the east.

c) Geology, Drainage and Soils

Despite the low relief the drainage is quite good for most of the ROW in this area. However, scattered depressions are often filled with water. A very thin till overlying primarily limestone regolith and bedrock ensures relatively good site drainage. Organic accumulation is low (< 5 cm) at sites 1034 and 1035, but several depressions adjacent to site 1036 have enhanced organic accumulations.

d) Vegetation

The ROW vegetation at sites 1034 through 1036 is dominated by graminoids (live and dead culms), with colonizing *Picea mariana* and *Pinus banksiana*. The forest at these sites varies considerably. Site 1034 is composed of 90-year-old *Picea mariana* intermixed with 17-year-old trees. Site 1035 is a dense stand of *Pinus banksiana* between 45 and 47 years old, while site 1036 is a mixed forest of *Populus tremuloides* (age unknown), *Picea mariana* (45-50 years old) and *Pinus banksiana* (45-50 years old).

e) Maintenance and Fire History

These sites were sprayed in 1980 with Tordon 101 and bladed in the winter of 1992. The last two recorded burns in the area were in 1929 and 1937. The stand age indicates a possible unrecorded disturbance event in the early 1940's.

Sites 1058, 1059, 1060 (53°15' N and 99°20' W)

a) Location

These sites, located ≈ 9 km north of Grand Rapids, were accessed from a road into a gravel pit east of site 1058 and extending back onto the ROW at site 1059. At sites 1058 and 1060, the ROW and forest transects were located 10 m north of the towers. The ROW transect at site 1059 was located 30 m north of the tower base so as to place it in the center of the gravel pit. The gravel pit site was chosen to ensure that at least one ground sample would have the maximum reflectance on the LANDSAT TM image. The forest transect was located 10 m south of the tower to avoid a roadway to the north.

b) Topography

The elevation at site 1058 is 251.1 m above sea level. Elevation drops to 248 m at site 1059, and to 246.9 m at site 1060. A ridge of unconsolidated gravel till, 3 m in height, is located just south of site 1060. It crosses the ROW and then arcs to parallel the ROW for several meters. The forest vegetation transects were placed along this ridge. Between site 1060 and tower 1061 (not sampled) the elevation drops by 16 m. The west side of the ROW at sites 1058 and 1059 is 1 m and 1.8 m higher than the east respectively. Because of the gravel ridge the east side of the ROW at site 1060 is 1.8 m higher than the west side.

c) Geology, Drainage and Soils

Dolomitic limestone and regolith is exposed and very little till has accumulated. This, combined with the elevation drop to the south, results in rapid drainage and very dry conditions during the summer. There is some organic accumulation between limestone boulders, but the major accumulations are inorganic fine limestone sands.

d) Vegetation

Sites 1058 and 1060 have a low shrub cover of *Arctostaphylos uva-ursi*, and lichens are a major ground cover component. Site 1059 is nearly 100% bare ground with a few scattered colonizing individuals of *Populus balsamifera*. The forest at site 1058 is mostly upland *Picea mariana* of various ages (ranging from 117 to 55, with a large percentage being ≈ 70 years old). The forest at site 1059 is a mixture of *Picea mariana* and *Pinus banksiana* between 50 and 55 years old. *Picea mariana* (50 to 55 years old) dominates the forest at site 1060; however, *Betula papyrifera* and very large *Juniperus communis* are also present.

e) Maintenance and Fire History

These sites were sprayed in 1980 with Tordon 101 and bladed in the winter of 1992. The last recorded burn for this area was in 1937.

Sites 1092, 1093, 1094 (53°10' N and 99°15' W)

a) Location

These sites are located 5 km south of Grand Rapids. They were accessed by a road servicing the Grand Rapids Provincial campground. Transects were located 10 m north of the tower on the ROW and in the forest, except for the forest transect at site 1094 (located to the south of the tower to avoid a fire road). Provincial Highway 6 is east of the HVDC ROW.

b) Topography

A limestone terrace, created by the erosion of the Saskatchewan River, separates sites 1092 (elevation ≈ 244 m) from sites 1093 and 1094 (≈ 250 m a.s.l). The limestone terrace rises sharply ≈ 60 m south of tower 1093. The east and west sides of the ROW do not differ appreciably in elevation.

c) Geology, Drainage and Soils

An accumulation of till covers the bedrock at site 1092, and this remains quite thick up to the base of the limestone terrace. At the top of the terrace, dolomitic limestone is exposed at the surface with small amounts of till accumulating in the cracked surface. Drainage at sites 1093 and 1094 is quite good due to the greater relief and unconsolidated blocky limestone regolith. Organic accumulation at 1093 and 1094 occurs only between blocks of limestone. At site 1092 drainage is impeded by the till and low relief, resulting in pools of water and hummock formation. The organic layer is up to a half meter thick, but at the bottom of open pools the bedrock is exposed.

d) Vegetation

The ROW vegetation varies considerably from sites 1092 to 1094. Site 1092 is typified by boggy vegetation with ericoid shrubs, *Sphagnum* spp. to the south of the transect area and *Betula glandulosa* in the area sampled. The forest is composed of *Picea mariana* (45 to 49 years old), *Larix laricina* and *Salix* spp. Sites 1093 and 1094 have a low cover of *Arctostaphylos uva-ursi* and lichen mats, with some colonizing *Picea mariana* also present. The forest at site 1093 is dominated by *Pinus banksiana* 45 years old, many of which are diseased. *Pinus banksiana* also dominates the forest at site 1094, but the trees are 93 years old.

e) Maintenance and Fire History

The ROW at these sites were sprayed in 1980 with Tordon 101. Two burns, one in 1937 and another in 1961, are recorded for these sites.

Sites 1113, 1114, 1115 (53°5' N and 99°15' W)

a) Location

These sites are located 15 km south of Grand Rapids, and 1 km north of where the HVDC line crosses Provincial Highway 6. They were accessed by travelling up a maintenance road down the centre of the ROW. Transects were located 10 m south of the towers on the ROW and in the forest. At these sites, Provincial Highway 6 parallels the ROW to the east.

b) Topography

Topography is flat, with the elevation between sites 1113 (248.7 m) and 1115 rising by only 1.1 m. The east and west sides of the ROW do not differ appreciably in elevation. However, the elevation drops by 11 m at an escarpment ≈ 3 km west of the ROW.

c) Geology, Drainage and Soils

An accumulation of till covering the bedrock impedes drainage in depressions. Sites 1113 and 1115 drain reasonably well, but a local depression near site 1114 impedes drainage and keeps the area wet for most of the year. The soil is composed of bands of silt and clay interspersed with unconsolidated gravels. A few erratic boulders and limestone debris, probably deposited by glaciers, dots the landscape. The organic layer in depressions on the ROW is between 10 and 25 cm thick, especially in clay-dominated areas. In the forest areas, the organic layer has been burned off by a recent fire.

d) Vegetation

The vegetation on the ROW in sites 1113 through 1115 is predominantly graminoid, with a few ruderal perennial species such as *Cirsium arvense* and *Sonchus arvensis* present. *Pinus banksiana* is actively recruiting onto the ROW at all sites, but especially at 1113 where their are several individuals per square meter. The forest at these sites is completely burned. Based on the remaining stumps, the forest at site 1113 was predominantly *Pinus banksiana*, that of 1114 was composed of *Picea mariana*, and 1115 a mixture of these two species.

e) Maintenance and Fire History

A solid form of Tordon was applied to these ROW sites in 1981. The area was burned in 1963 and again on July 18, 1989. The site was chosen because of the recent burn, so that data from a burned area could be used in conjunction with the LANDSAT image.

Sites 1152, 1153, 1154 (52°55' N and 99°10' W)

a) Location

These sites are located 20 km south of Grand Rapids. Access was along a borrow pit road that had been modified by Manitoba Hydro to gain access to the ROW. Transects were placed 10 m north of the towers on the ROW and in the forest.

b) Topography

The sites are characterized by an undulating series of drumlinized ridges and swales (Fraser *et al.* 1985). The towers are placed on the ridges (approximately 283.4 m above sea level) and are separated by boggy-fens (≈ 280 m above sea level). A drop in elevation to the northeast results in the fens terminating and small bodies of open water developing.

c) Geology, Drainage and Soils

The ridges are composed of unconsolidated gravel and sand of lacustrine origin and are well drained. A coarse loamy soil with a thin organic layer is found on the ridges (Fraser *et al.* 1985). The poorly-drained depressions between the ridges have an organic soil approximately 1 m thick.

d) Vegetation

The ROW vegetation on the ridges consists primarily of herbaceous species such as *Galium boreale* , *Comandra umbellata* and *Fragaria virginiana Arctostaphylos uva-ursi* and *Rubus idaeus* are also common. The forest on the ridges is composed of *Pinus banksiana*, *Picea mariana* and *Thuja occidentalis*. Most trees are 90 years old. In the boggy inter-ridge areas of the ROW graminoid species are common. The associated forest consists of stunted trees of *Picea mariana* .

e) Maintenance and Fire History

The line was treated with Tordon 101 at these sites in 1979. No major fires have been recorded for the area.

Sites 1172, 1173, 1174 (52°52' N and 99°3' W)

a) Location

These sites are located 32 km south of Grand Rapids, at the junction of Provincial Highway 6 and the Long Point road. They were accessed directly from the Long point road where it crosses the right-of-way. On the ROW, transects were located 10 m north of the towers except at tower 1173, where the transects were moved 15 m further north to avoid a disturbed area. The forest transects were placed north of the towers in a similar pattern.

b) Topography

These sites are located on the south facing slope of The Pas moraine. Elevation readings at sites 1172, 1173 and 1174 are 260.6 m, 256.3 m and 239 m a.s.l.

respectively (a relief drop of ≈ 21 m over 1030 m). Small ridges of lacustrine deposits (relief < 0.5 m) parallel the moraine along its slope face. The east-west slope of the ROW is negligible.

c) Geology, Drainage and Soils

The escarpment face is composed of well-drained beach ridges of unconsolidated gravel and sand, interspersed with till accumulations (Fraser *et al.* 1985). Groundwater seepage from the Cedar Lake plain results in the formation of pools of water between the gravel ridges, even along the slope face. A coarse loamy soil has developed on the escarpment at site 1173. At sites 1172 and 1174 the morainic deposits are overlain by an organic soil ≈ 0.25 m thick.

d) Vegetation

The ROW vegetation at site 1172 consists mainly of graminoids and a large population of colonizing *Picea mariana*. At site 1173, the ROW vegetation is a mixture of graminoids, *Arctostaphylos uva-ursi, Juniperus horizontalis* and *Parnassia paucifolia.* The tree species colonizing the ROW are *Pinus banksiana*, *Picea mariana* and *Thuja occidentalis*. At 1174, the ROW vegetation is primarily graminoid with a shrub cover of *Betula glandulosa, Potentilla fruticosa, and Salix* spp. Colonizing tree species include *Populus tremuloides, Populus balsamifera and Picea mariana.* All three forest sites are a mixed forest of *Picea mariana*, *Pinus banksiana* and *Thuja occidentalis*, the latter being more common at site 1173. Stand ages are ≈ 85 years at site 1172 and 95 years at sites 1173 and 1174, although some individuals at sites 1173 are over 120 years old

e) Maintenance and Fire History

The right-of-way in this area was treated with Tordon 101 in 1979. No major fires have been recorded for the area.

Sites 1203, 1204, 1205 (52°48' N and 98°58' W)

a) Location

These sites are located 40 km south of Grand Rapids and 121 km north of Gypsumville. They were accessed from Provincial Highway 6 using a Manitoba Hydro road. ROW and forest transects were located 10 m north of the towers.

b) Topography

The relief is low. Elevation ranges between 242.3 m a.sl. (site 1203) and 243.5 m (site 1205).

c) Geology, Drainage and Soils

This region consists of gently undulating morainic deposits overlain by accumulations of clay (Fraser *et al.* 1985). Glacial erratics are present and dot the landscape. The area is imperfectly drained due to the limited run-off of water from the clay surface. The soil ranges from a fine loam to a fine clay-organic mixture (Fraser *et al.* 1985).

d) Vegetation

The ROW vegetation of these sites is dominated by graminoid and herbaceous species. *Populus tremuloides* and *Picea mariana* are actively colonizing the right-of-way. The forest is a mixture of *Populus tremuloides* (45 years old), *Picea mariana* (50 to 54 years old) and *Pinus banksiana* (50 to 54 years old).

e) Maintenance and Fire History

These sites were treated with Tordon 101 in 1979. The area was burned in 1929.

Sites 1245, 1246, 1247 (52°32' N and 98°54' W)

a) Location

These sites, located 94 km north of Gypsumville, were accessed from a borrow pit and logging road off Provincial Highway 6. At these sites the highway parallels the ROW to the east. Both ROW and forest transects were located 10 m north of the towers.

b) Topography

The study sites are of low relief, with elevations ranging between 250.2 m and 252.4 m. There is no appreciable east-west slope on the ROW.

c) Geology, Drainage and Soils

These sites are characterized by a gently undulating morainic till with accumulations of clay. An outcrop of unconsolidated gravel and sand is present near site 1245. The soil is imperfectly drained due to the low permeability of the clay deposits, resulting in the pooling of water in depressions. The soil ranges from a fine loam to a fine clay-organic mixture (Fraser *et al.* 1985).

d) Vegetation

The ROW sites are dominated by graminoid and herbaceous species, with shrubs such as *Amelanchier alnifolia*, *Prunus virginiana* and *Rosa acicularis* are frequent. *Populus tremuloides* is colonizing the ROWs, particularly at site 1245. In addition, *Picea mariana* is colonizing at site 1247, and *Pinus banksiana* is found at low densities on all

ROW sites. The forest at sites 1245 and 1246 is a mixture of *Populus tremuloides*, *Pinus banksiana* and *Betula papyrifera*. Most of the trees are ≈ 45 years old, but many of the hardwoods at these sites are only 20 years old. The understory at these two sites is rich in shrubs (mostly tall *Alnus rugosa* and *Corylus cornuta*). The forest at site 1247 is a senescent *Pinus banksiana* stand (≈ 130 years old) with an understory of *Picea mariana* ≈ 44 years old.

e) Maintenance and Fire History

This area was treated with Tordon 101 in 1979, and was burned in 1929. A localized fire was also recorded in 1971.

Sites 1297, 1298, 1299 (52°20' N and 98°54' W)

a) Location

These sites are located 68 km north of Gypsumville. A Manitoba Hydro line road off Provincial Highway 6 was used to gain access to these sites. ROW and forest transects were located 10 m north of the towers.

b) Topography

The area is of low relief (260.6 ± .3 m a.s.l.). To the west of the ROW the land rises by ≈ 1.5 m.

c) Geology, Drainage and Soils

A calcareous loamy and moderately stoney till underlies these study sites (Fraser *et al.* 1985). This till is exposed at the bottom of shallow pools, and is found at the surface immediately west of the ROW. On the ROW itself, drainage is impeded resulting in accumulations of *Sphagnum* peat up to 1 m in thickness.

d) Vegetation

Graminoid species dominate the ROW vegetation, with a high density of colonizing *Picea mariana* at all sites. Along the western side of the ROW (where the organic layer is thin) *Pinus banksiana*, *Arctostaphylos uva-ursi* and *Juniperus horizontalis* are found. The forest at all sites is dominated by *Picea mariana* of varying age (means of 130, 50, and 150 years at 1297, 1298 and 1299 respectively).

e) Maintenance and Fire History

This area was treated with Tordon 101 in 1979, and was burned in 1929.

2.3 Field Sampling

ROW Vegetation Transects

ROW vegetation cover data were collected during the summer of 1992. At each site, three parallel line transects 50 m in length and 10 m apart were laid out. Quadrats (1 x 2 m) were placed along each transect at regular 5 m intervals, for a total of ten quadrats per transect and 30 quadrats per site. Percent cover (to the nearest 2%) was estimated for each species within each of the two 1 x 1 m subunits of the quadrat, and the mean of the two values recorded. Percent cover of bare ground, dead organic material (designated as necromass), and exposed rock was also recorded, the sum of these components represents the non-living cover types. Species not identifiable in the field were recorded and stored in plastic bags for later identification at the University of Manitoba Herbarium. Species nomenclature and identification follow Scoggan (1979).

Forest Vegetation Transects

Forest vegetation data were collected during the fall of 1992 and the summer of 1993. At each site, two parallel line transects 50 m in length and 15 m apart were laid out. A 5 x 5 m quadrat was placed every 10 m along the transects to record percent cover of trees over 1 m in height (total of 5 quadrats per transect). Canopy cover was estimated by projecting the crown to ground level and estimating the number of square meters of the surface covered by the tree. Canopy closure is estimated as 100% minus the area of the quadrat not covered by the canopy. At the NE and SE corners of each 5 x 5 m quadrat, a 1 x 2 m quadrat was located to record percent cover of all species under 1 m in height. Again, percent cover was estimated to the nearest 2%. A total of ten 5 x 5 m and twenty 1 x 2 m quadrat were recorded at each site.

ROW Tree Recruitment

ROW tree recruitment information was collected during the summer of 1993. Sampling was restricted to those sites that were not V-bladed during the winter of 1992. Because the ROW was partially V-bladed at sites 1172 through 1174 and 1203 through 1205, a 50 x 20 m quadrat (oriented perpendicular to the ROW) was used to obtain recruitment information. At sites 1093, 1094, 1152, 1153, 1245, 1245, 1246, 1297, 1298 and 1299, 130 x 10 m quadrats (oriented perpendicular to the ROW) were used. All trees within a quadrat were cut at their base, placed in plastic bags according to species and were transported to the University of Manitoba. The rings were counted with the aid of a dissecting microscope equipped with an eyepiece micrometer. Basal diameter (BD) was measured for some of the *Picea mariana* individuals, using a 30 cm ruler for BD >1.0 cm and eyepiece micrometer for BD < 1.0 cm.

Forest Stand Ages

Information on forest stand ages were obtained in spring, 1993. At each site, a 50 m transect parallel to the vegetation transects was laid out and the tree closest to each 5 m interval was cut down (total of 10 trees per site). Species and height were recorded, and a cross-section of the tree was removed, labelled and placed in a plastic bag. For each cross-section, a ring count was later made with the aid of a dissecting microscope.

Soil Samples

In the spring of 1993, two replicate soil cores were collected at each tower site on the both ROW and forest vegetation transects. Each core was 10 cm x 10 cm x 10 cm. The cores were taken ≈ 10 m from the starting point of a vegetation transect. The replicate cores were placed in plastic bags, kept cool, and transported to the University of Manitoba for laboratory analysis, as outlined in the following section.

2.4 Soil Analysis

Nutrient Analyses

Soil nutrient analyses (nitrogen, phosphorus, potassium and sulfate) were performed on the replicate soil cores using the methods outlined in Burchill (1991). Analyses were performed by Norwest laboratories, Winnipeg. Nitrate and available phosphorus were determined using the sodium bicarbonate method, which is appropriate for soils of pH > 7.0 (McRae 1988). 2.5 grams of soil and 1.0 gram of activated charcoal was combined with 50 ml of 0.5 M $NaHCO_3$. This was shaken for 30 minutes and filtered using Whatman No. 30 paper. Determination of ion concentration was done using an Techicon Auto Analyzer. For sulfate analysis, $CaCl_2$ was used for extraction (25 g soil plus 50 ml $CaCl_2$). The extract was then filtered and sulfate determined using the Autoanalyzer with barium chloride as an indicator. Potassium was analyzed using flame photometery. A subsample 2.5 ml of soil was reacted with 25 ml of 1 N NH_4OAc and then filtered after 30 minutes of agitation.

Conductivity and pH

Soil pH and conductivity were determined using the dilution extract technique described by Sonneveld & Van Den Ende (1971). Five grams of soil was sieved through a 1 mm mesh and placed in 25 ml of distilled water. This solution was shaken for one hour, vacuum-filtered through Whatman No. 1 paper. pH and conductivity were measured using the Corning Check-mate 90. Conductivity was determined using an air-calibrated Corning conductivity probe. The Corning pH probe was calibrated using standard solutions of pH 4.1 and 7.0.

Bulk Density and Organic Matter Content

Soil bulk density was determined by massing a known volume of soil and drying it at 110°C. The bulk density is the ratio of dry soil mass divided by the volume of the container (McRae 1988). Percent soil moisture was also calculated (the ratio of wet to dry soil mass).

Organic content was determined using 5 g of oven-dried soil. The soil was ground, screened using a 1 mm mesh, and then placed in an oven at 500°C for 12 hours (a temperature of 500°C was recommended by Andrejko *et al.* (1983) to prevent the ignition loss of $CaCO_3$).

2.5 Remote Sensing Methodology

Background

The most common techniques used to classify a remotely sensed image involves either supervised classification or unsupervised classification (Peterson & Running 1989). Unsupervised classification involves an initial clustering of the pixel data (Peterson & Running 1989). Classes are based on the clusters and then the area is ground truthed to determine what the class represents (Thomas *et al.* 1987). Supervised classifications are based on 'training areas' for which the vegetation is known (Peterson & Running 1989; Markon 1992). Training areas represent regions of homogeneous vegetation cover (Dixon *et al.* 1984; Darby 1990). The rest of the image is then classified by these groups using a classification criterion, such as parallelepiped or maximum likelihood (Thomas *et al.* 1987).

Equipment

The digital images were analysed at the Manitoba Remote Sensing Centre on the Dipix ARIES II system. Images were displayed in colour raster format, and individual pixels selected using the ARIES II HIPAD graphics tablet.

Image Analysis

The LANDSAT TM image analysed in this study was captured on August 7, 1989 (track 33, frame 23 + 6 seconds). The area covered in the image includes most of the northern Interlake region, extending from approximately 120 km north of Gypsumville to 40 km north of Grand Rapids. The image (hereafter referred to as the Cedar Lake scene) was composed of TM bands 3, 4 and 5. The Cedar Lake scene was geometrically corrected using the Digital Image Correction System (DICS). The DICS image is a raster dataset with coordinates given in lines and pixels, each pixel having a size of 30 x 30m on the ground.

Nondecimated subareas (subareas of the image displayed at 30 x 30 m pixel resolution) of the Cedar Lake image were examined to locate the ground-truthed sites. Topographic maps, aerial photographs and forest inventory maps were used as a guide to locate major landform and vegetation features on the TM image. When a site was located the line and pixel coordinates were recorded. Due to potential error in location, several adjacent pixels were chosen at each site and their values averaged. All 30 sites were located on the TM image, however sites 1021 and 1022 had to be discarded due to cloud cover. A pixel 'dump' task was run on the remaining sites and the reflectance for each of the three TM bands recorded.

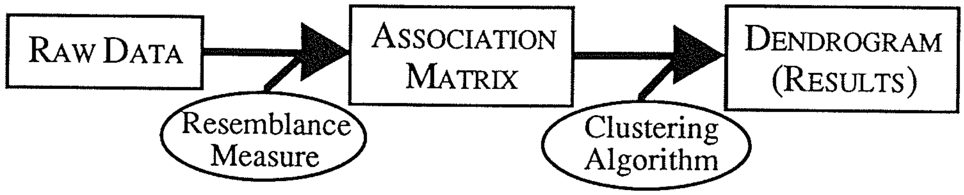
The study first attempted a supervised classification procedure on the TM image. Classes were based on the cluster analysis results for the ROW vegetation data collected in the summers of 1992 and 1993. A 'training area' was defined for each ground truthed site established in 1992.

Once the sites on a sub-area were located and a training area was established, a parallelepiped classifier batch program was run to thematically classify the entire image into the groups established. The Parallelepiped classifier classifies an area according to a mean and acceptable limit specified by the user. Pixels are considered members of the group if they fall within the minimum and maximum boundaries (Thomas *et al.* 1987). For this analysis, the minimum and maximum values are the band spectral reflectances for pixels within the training areas. There was a multiclassification problem encountered at this stage that made the resulting map uninterpretable. Although LANDSAT TM data has narrower spectral bands than MSS data, its smaller pixel size leads to a more pronounced problem with edge effect (Peterson & Running 1989). For this reason I chose to perform a direct analysis of the pixel dump data.

2.6 Data Analysis

Cluster Analysis

Cluster analysis is a numerical classification procedure for placing each of n individuals into one of k non-overlapping categories (where $k < n$). Most clustering methods work from a resemblance matrix between individuals, rather than from the raw data itself:



The clustering algorithm used in this study was sum of squares (minimum variance) clustering, a hierarchical agglomerative method based on minimizing the increase in the error sum of squares at each fusion (Ward 1963; Orlóci 1967). A number of studies have indicated the general utility and robustness of this clustering strategy (e.g Kuiper & Fisher 1975). The resemblance measure used was Czekanowski's percent similarity (also known as the Bray-Curtis similarity coefficient), computed between two sites *j* and *k* based on their species composition:

$$PS_{jk} = \frac{2\Sigma(MINX_{ij}, X_{ik})}{\Sigma(X_{ij} + X_{ik})} \qquad \text{(summation i = 1 to p)}$$

Where p is the number of species and X_{ij} is the i^{th} species at site j. This coefficient ranges from zero (for sites with no species in common) to one (for sites with identical species composition).

A square root transformation was performed on the data to downweight the importance of common species with high cover. Initial analyses indicated that the three recently burned sites (sites 1113, 114 and 1115) were strong outliers. They were therefore not included in the final classification. The analysis was performed on a data matrix of 27 sites and 79 species using the SYNTAX-IV program package (Podani 1989). In this study, cluster analysis is used to classify sites based on the forest vegetation, in order to delineate major boreal vegetation types present in the Interlake region.

Correspondence Analysis (CA)

Numerical strategies that attempt to achieve a representation of data structure in a lower dimensional space, while retaining as much of the trended variation in the data as possible, are known collectively as ordination methods (Orlóci 1978). Correspondence analysis (also known as reciprocal averaging or RA, Hill 1973) is an ordination method useful in summarizing nonlinear vegetation data. The objective of correspondence analysis is to partition the total contingency chi-square (χ^2) of a p x n matrix **X** into a series of linearly additive components:

$$\chi^2 = \chi_1^2 + \chi_2^2 + \ldots + \chi_k^2 = X..(R_1^2 + R_2^2 + \ldots + R_k^2) \qquad \text{(where k = MIN \{p,n\}).}$$

The R^2 values are squared canonical correlations that measure the relationship between the row and columns of the data set, and X.. is the sum of all elements in the matrix. Partitioning of the contingency chi-square is accomplished through an eigenanalysis of a square symmetric matrix **S**, the elements of which are defined as:

$$\mathbf{S} = \mathbf{UU'} \quad \text{where} \quad U_{ij} = \{[X_{ij} / (X_{i.}X_{.j})^{1/2}] - [(X_{i.}X_{.j})^{1/2} / X_{..}]\}$$

The eigenvalues $\lambda_i = R_i^2$ (range 0 to 1). The eigenvectors of **S** are used to obtain component scores for the individuals; component scores for the variables can also be computed (Orlóci 1978: 162). In this study a variant of correspondence analysis known as detrended correspondence analysis (DCA; Hill & Gauch 1980) was used. In some cases, 'detrending', which empirically corrects for some theoretical and computational faults of CA, can improve ordination results (Kenkel & Orlóci 1986).

Vegetation heterogeneity of the sites was summarized using DCA. Two ordinations were performed, one based on the ROW vegetation and the other based on the forest vegetation. In both cases, the burn sites (1113, 1114 and 1115) were not included. A square root transformation was performed on the data prior to analysis. The first two component axes were used in presenting the results.

Canonical Correspondence Analysis (CCA)

This variant of CA is used to examine the relationship between two sets of variables measured on the sites (e.g. vegetation data, and environmental data). It differs from CA in that the vegetation ordination axes are constrained by the environmental data. Specifically, the method uses multiple regression analysis to calculate a derived environmental variable that: (a) is a linear combination of the environmental variables, (b) minimizes the ratio of the within-species to total species variance (Ter Braak 1987).

In this study, CCA is used to relate environmental (primarily soil) information to vegetation trends of the forest and ROW. The vegetation data sets and standardization were the same as used in DCA. Five environmental variables were used: pH, conductivity (μm), bulk density, %moisture and %organic matter.

Multiple Discriminant Analysis (MDA)

This method, also known as canonical variates analysis, is closely related to the multivariate analysis of variance (Gittins 1985). The objective of MDA is to maximally distinguish two or more natural groups of individuals in a multivariate space. This is accomplished by finding discriminant axes (similar to ordination axes) that maximize the between-groups variance relative to the variance within groups. The method also determines which of the p variables are most useful in discriminating the g groups.

In MDA, group discrimination is determined by comparing the within-groups pooled cross-products matrix $\mathbf{W}$ to the between-groups matrix $\mathbf{B}$. This is accomplished numerically by performing an eigenanalysis of the matrix product $\mathbf{W}^{-1}\mathbf{B}$:

$$(\mathbf{W}^{-1}\mathbf{B} - \mathbf{I}\lambda_i)\mathbf{k}_i = 0$$

where $\mathbf{k}_i$ is an eigenvector of discriminant weights, and λ_i is an eigenvalue. A maximum of t = MIN (g-1, p) eigenvalues are extracted. The eigenvalue λ_i is the ratio of the between-groups sum of squares to the within-groups sum of squares for the i^{th} discriminant axis. The statistical significance of discriminant axes can be tested using Heck's θ (Morrison 1990). In this study, MDA was used to confirm the significance of discrimination of the vegetation classes from the cluster analysis in ordination space. It was also used to test whether there were significant differences in spectral reflectances of TM bands 3, 4 and 5 between the forest vegetation types as defined by cluster analysis.

Canonical Correlation Analysis

Canonical correlation is used to quantify the relationship between two sets of variables, denoted by $\mathbf{X}$ (with p variables) and $\mathbf{Y}$ (with q variables), each measured on n individuals. The method examines the linear relationship between the variable sets $\mathbf{X}$ and $\mathbf{Y}$ by maximizing the product moment correlation between two derived linear composites, $\mathbf{V}_1 = \mathbf{a}_1 \mathbf{Y}$ (for variable set $\mathbf{Y}$) and $\mathbf{U}_1 = \mathbf{b}_1\mathbf{X}$ (for variable set $\mathbf{X}$). The vectors $\mathbf{a}_1$ and $\mathbf{b}_1$ contain simple variable weights. In general, it is possible to find successive pairs of these maximally correlated linear composites ($\mathbf{U}_i$ and $\mathbf{V}_i$) subject to their being uncorrelated with previously found linear composite pairs. Like ordination axes, these linear composites (also known as canonical variates) are extracted in decreasing order of importance. In total, a maximum of t = MIN (p,q) pairs of linear composites can be found.

Canonical correlation analysis involves the eigenanalysis of the characteristic equation:

$$\{\mathbf{R}_{XY}\,\mathbf{R}_{YY}^{-1}\,\mathbf{R}_{YX} - \lambda_i\,\mathbf{R}_{XX}\}\,\mathbf{b}_i = 0$$

where $\mathbf{R}_{XX}$ = $\mathbf{X}$-set correlation matrix, $\mathbf{R}_{YY}$ = $\mathbf{Y}$-set correlation matrix, and $\mathbf{R}_{XY} = \mathbf{R}'_{YX}$ cross-set correlation matrix. The square root of eigenvalue λ_i, known as the i^{th} canonical correlation, has two interpretation: (a) the product moment correlation between the paired linear composites (canonical variates) $\mathbf{U}_i$ and $\mathbf{V}_i$; (b) the multiple correlation between the i^{th} canonical variate and the complete set of variables in the other set.

The canonical correlation is a measure of correlation between linear composites, but not between the variable sets themselves. This latter quantity, known as the redundancy or explained variance, is the proportion of the total variance of a given variable set which is predictable from a given canonical variate from the other variable set. The total redundancy (over all canonical variates) measures the amount of variance in one variable set which is accounted for by all variables of the other set.

In this study, canonical correlation analysis is used to quantify the relationship between the forest and ROW vegetation. Because of the large number of species, the analysis was based on site scores on the first two DCA ordination axes were used as the variable sets **X** (forest variables) and **Y** (ROW variables). The sites were plotted with respect to the first pair of canonical axes U_1 and V_1 and the canonical correlation and redundancy determined.

Principal Components Analysis (PCA)

Principal components analysis (PCA) is an ordination method that rigidly rotates the original p axes such that linear variation is maximized along the derived component axes. The orthogonal component axes are 'extracted' or found in order of diminishing importance. If the data has an underlying linear structure, the first few component axes will offer a reasonable 'picture' of the data. PCA performs an eigenanalysis of a dispersion (correlation or covariance) matrix **S**:

$$|\mathbf{S} - \lambda \mathbf{I}| = 0 \qquad \text{(where } \lambda \text{ is a vector of } p \text{ eigenvalues).}$$

The eigenvalues have the property that their sum equals the sum of the diagonal elements of S. This implies that the method merely repartitions the variance into linearly uncorrelated components, which represent linear transformations of the original variable axes. An eigenvalue λ_i represents the variance of the i^{th} component axis.

In this study, PCA (using a correlation matrix) is used to summarize the relationship between the sites based on the signature spectra for Landsat TM bands 3, 4 and 5 (three variables). A total of 25 sites were ordinated. The following sites were not included in the ordination:

1113, 1114, 1115 - burned sites.

1021, 1022 - clouds over these sites on the LANDSAT TM image.

Classification Model - Discriminant Functions

A discriminant functions classification model (Morrison 1990) was developed to predict the vegetation type (and management scenario) for an 'unknown' site based on spectral reflectance values of LANDSAT TM bands 3, 4 and 5. The model uses a multiple-group classification rule based on the minimum squared Mahalanobis distance:

$$D_i^2 = (\mathbf{x} - \overline{\mathbf{x}}_i)' \mathbf{S}^{-1} (\mathbf{x} - \overline{\mathbf{x}}_i)$$

calculated from uncorrelated linear compounds of the three TM bands (Kshirsagar & Arseven 1975). The compound coefficients are elements of the vector $\mathbf{k}_i$ as determined by the eigensolution of the equation:

$$\{\mathbf{W}^{-1}\mathbf{B} - \mathbf{I}\lambda_i\}\mathbf{k}_i = 0$$

where $\mathbf{W}$ = pooled within-groups cross-products matrix.
$\mathbf{B}$ = between-groups cross-products matrix.
λ_i = ith eigenvalue (characteristic root).
$\mathbf{k}_i$ = ith set of compound discriminant coefficients.

The elements of $\mathbf{k}_i$ are scaled to result in a mean within-groups variance of unity. This is accomplished by standardizing the coefficients such that:

$$\mathbf{k}_i' \mathbf{W} \mathbf{k}_i = 1$$

where i = 1 to g (the number of groups). Kshirsagar & Arseven (1975) used all characteristic roots and vectors in obtaining a solution, but Morrison (1990: 283) shows that s = MIN (p, g-1) variates produce the same classification. In this model, $p = 3$ and $g = 3$, so that $s = 2$ variates are required.

For an 'unknown' site X_j with band values X_1 = band 3, X_2 = band 4, and X_3 = band 5, the new derived variates are given by:

$$U_1 = k_{11}X_1 + k_{12}X_2 + k_{13}X_3$$
$$U_2 = k_{21}X_1 + k_{22}X_2 + k_{23}X_3$$

The squared Mahalanobis distance between a given group i and the 'unknown' site simplifies to (Kshirsagar & Arseven 1975):

$$D_i^2 = (n - p - 2)\{(U_1 - \overline{U}_{1i})^2 + (U_2 - \overline{U}_{2i})^2\}$$

where $\overline{U}_{1i}$ is the derived variate for the centroid of group *i*, and *n* is the sample size.

Assignment of the 'unknown' site is made to the group with the smallest D_i^2. Under the assumption of multivariate normality, D_i^2 is distributed as the χ^2 distribution with *s* degrees of freedom (Tatsuoka 1971: 218). The likelihood that the 'unknown' site X_j belongs to group *i* is proportional to:

$$p(X_j|H_i) = \exp(-\chi_{ij}^2 / 2)$$

where χ_{ij}^2 is the squared Mahalanobis distance of unknown site X_j with respect to group *i*. This probabilistic measure can be used as a criterion for determining 'goodness of fit' to the model. Specifically, for a given X_j, if all values (i = 1 to g) of $p(X_j|H_i) < (\alpha = 0.05)$ then no assignment should be made.

Once an individual X_j is assigned to group m, the Bayesian misclassification probability (with respect to group m) is given by:

$$1 - p(Hm|Xj) = \frac{p(X_j|H_m)}{\sum_{i=1}^{g} p(X_j|H_i)}$$

under the assumption of equal prior probability of group belonging. This is the *a posteriori* probability that X_j does not belong to group m.

An equivalent assignment rule is based on the discriminant functions:

$$W_{12} = U_1(\overline{U}_{11} - \overline{U}_{12}) + U_2(\overline{U}_{21} - \overline{U}_{22}) - 0.5(\overline{U}_{11} - \overline{U}_{12})(\overline{U}_{11} + \overline{U}_{12}) - 0.5(\overline{U}_{21} - \overline{U}_{22})(\overline{U}_{21} + \overline{U}_{22})$$
$$W_{13} = U_1(\overline{U}_{11} - \overline{U}_{13}) + U_2(\overline{U}_{21} - \overline{U}_{23}) - 0.5(\overline{U}_{11} - \overline{U}_{13})(\overline{U}_{11} + \overline{U}_{13}) - 0.5(\overline{U}_{21} - \overline{U}_{23})(\overline{U}_{21} + \overline{U}_{23})$$

The following assignment rules are used:

Assign to population 1 if $W_{12} > 0$ and $W_{13} > 0$.
population 2 if $W_{12} < 0$ and $W_{13} > W_{12}$
population 3 if $W_{13} < 0$ and $W_{12} > W_{13}$.

The model was tested by determining *a posteriori* group membership for each of the 25 sites used in the analysis. In addition, 40 randomly chosen sites (not used in developing the model) were classified using the model. No assignment was made if $p(X_j|H_i) < 0.05$, i =1 to *g*.

2.7 METHODOLOGICAL APPROACH

The following is a stepwise summary of the methodological approach used in this thesis.

1. DELINEATE AND DESCRIBE FOREST VEGETATION TYPES WITHIN THE STUDY AREA.

(a) **Sum of squares cluster analysis** of 27 sites, based on the forest vegetation survey results.
Objective: delineation of vegetation types (see Results). The groups provide the basis for the development of the classification model outlined in step 5.

(b) **Tabulate means for species** and environmental factors for each of the vegetation types.
Objective: to summarize differences in species composition and environmental factors between the vegetation types.

(c) **Tabulate tree recruitment** trends for each of the vegetation types.
Objective: to summarize differences in tree recruitment, in terms of species, density and age-class distributions.

2. SUMMARIZE ROW AND FOREST VEGETATION TRENDS AMONG THE SITES .

(a) **DCA ordination** of the forest vegetation (same data set as that used in step 1a).
Objective: to summarize trends among the 27 sites in a reduced ordination space.

(b) **Multiple discriminant analysis** on the forest vegetation DCA results.
Objective: to test whether the vegetation types are significantly discriminated in the two-dimensional ordination space.

(c) **Canonical correspondence analysis** of the forest vegetation and environmental factors.
Objective: to determine which environmental factors are most important in explaining trends in forest vegetation.

(d) **Detrended correspondence analysis** ordination of the ROW vegetation (27 sites).
Objective: to summarize ROW vegetation trends among the 27 sites.

(e) **Multiple discriminant analysis** on the ROW vegetation DCA results.
Objective: to test whether the vegetation types are significantly discriminated in the two-dimensional ROW ordination space. This provides an indirect test of whether the ROW vegetation is related to that in the forest (since classification into vegetation types was based on forest vegetation only).

3. QUANTIFY AND SUMMARIZE THE RELATIONSHIP BETWEEN TRENDS IN THE ROW AND FOREST VEGETATION.

(a) **Canonical correlation analysis** of the two-dimensional DCA ordinations based on the ROW and forest vegetation.
Objective: provides a direct test of the relationship between ROW and forest vegetation. If a significant relationship is found, a model can be developed to predict ROW vegetation and management requirements based on forest vegetation type.

4. DETERMINE WHETHER THE THREE VEGETATION TYPES ARE DISTINGUISHABLE BASED ON THE LANDSAT TM SIGNATURE SPECTRA (BANDS 3, 4 AND 5).

(a) **Principal components analysis** of 25 sites based on the signature spectra for bands 3, 4 and 5 (three variables).
Objective: to determine correlations among the three band spectra, and to summarize trends in the sites based on their signature spectra.

(b) **Multiple discriminant analysis** of PCA results (step 4a).
Objective: to test whether the vegetation types are significantly discriminated in the two-dimensional PCA (LANDSAT TM) space. This is a necessary requirement in the development of a predictive classification model (step 5).

5. DEVELOP AND TEST A CLASSIFICATION MODEL FOR PREDICTING VEGETATION TYPE BASED ON OBSERVED LANDSAT TM SPECTRAL SIGNATURES (BANDS 3, 4 AND 5).

(a) **Discriminant functions** classification model based on multiple discriminant analysis results in step 4b.
Objective: to test whether LANDSAT TM forest vegetation information can be used to predict ROW vegetation (and ROW management strategies) along Hydro right-of-ways in the Interlake region of Manitoba.

Chapter 3

Results

3.1 Classification of Forest Sites

The cluster analysis of the 27 sites based on forest vegetation is presented in **Fig. 3.1**. From these results, three distinct vegetation groups were recognised: dry coniferous (12 sites), wet coniferous (8 sites), and mixed forest (7 sites). **Table 3.1** summarizes mean tree and tall shrub cover, and canopy closure estimates, for each vegetation group. Vegetation composition (using life form - growth form designations; see **Appendix 1** for a complete species list) of the forest and adjacent right-of-way for each group is summarized in **Table 3.2**. Information on soil parameters and unvegetated ground cover for the forest and adjacent right-of-way are presented in **Table 3.3** and **Table 3.4** for each group. The following is a summary description of the three vegetation groups.

Dry Coniferous

1. Location

The majority of these twelve sites are at the northern end of the study area. They range between 52°55'N, 99°10'W (site 1154) and 53°25'N, 99°20' W (site 1020).

2. Topography

Topographic features within this vegetation group are somewhat variable. The northernmost sites occur on dry, flat limestone plains, while sites further south and along the The Pas moraine occur on drumlinized ridges and swales. Most of the sites are reasonably flat, although sites 1034, 1035, 1058, 1094 are found on more broken ground. Sites 1060 and 1093 are in close proximity to steep embankments.

3. Geology, Drainage and Soils

All the sites within this group occur on dry, well-drained uplands. The more northerly sites are found on dolomitic limestone exposed at or near the surface, while those near the The Pas moraine occur on unconsolidated stoney glacial till. Exposed rock is more prevalent on the ROW than in the forest, while soil organic matter content, soil moisture and conductivity are higher in the forest than on the ROW (**Table 3.3**). Soil compaction and/or loss has occurred on the ROW, resulting in a slight increase in soil bulk density compared with the forest sites. Soil nutrients are fairly limited in this group, in general availability of nutrients is more restricted in the ROW than in the forest (**Table 3.4**).

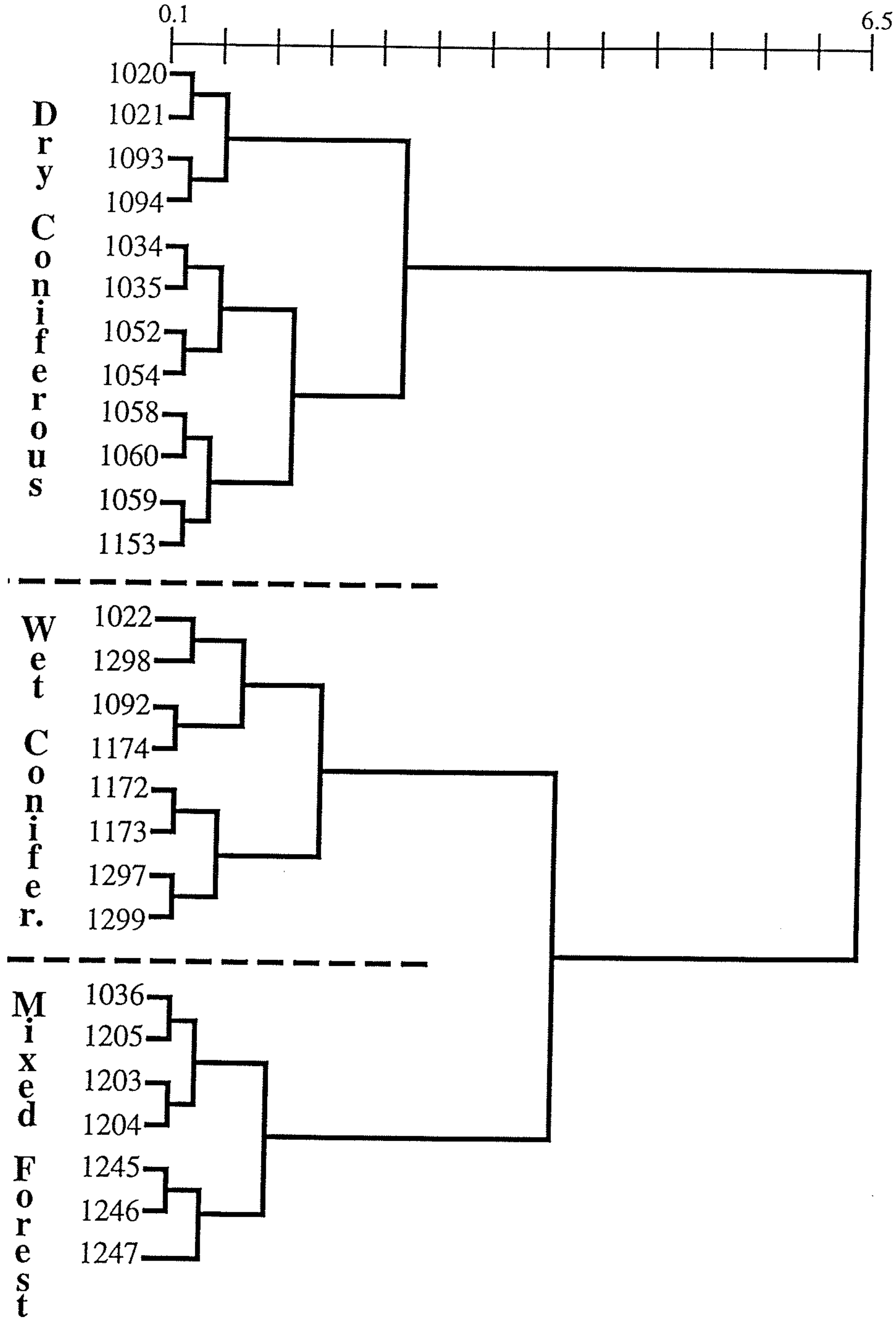


Figure 3.1: Sum of squares cluster analysis of the square-root transformed forest vegetation cover data. Three groups are recognised, separated by dotted lines. Dry Conifer - represents dry sites with a high conifer component (primarily *Pinus banksiana*), Wet Conifer - boggy sites dominated by *Picea mariana* and Mixed Forest - sites with a *Populus tremuloides* and conifer mix.

Table 3.1: Mean tall shrub (height > 1 m) and tree cover in the forest for the three vegetation groups defined. The total cover for the trees and shrub species is given.

Tall Shrubs	**Dry Coniferous**	**Wet Coniferous**	**Mixed Forest**
Alnus crispa	0.0	0.0	12.3
Alnus rugosa	0.1	2.5	0.0
Amelanchier alnifolia	0.3	0.0	1.7
Betula glandulosa	0.0	0.3	0.0
Betula papyrifera	2.0	0.0	0.0
Corylus cornuta	0.0	0.0	3.0
Prunus pensylvanica	0.1	0.0	0.2
Salix spp.	0.0	0.3	0.1
Tree Species	**Dry Coniferous**	**Wet Coniferous**	**Mixed Forest**
Larix larcina	0.2	3.3	0.0
Picea glauca	0.1	0.4	2.7
Picea mariana	26.0	36.0	26.1
Pinus banksia	21.6	5.2	18.2
Populus balsamifera	0.2	0.6	0.2
Populus tremuloides	0.6	0.0	25.1
Thuja occidentalis	0.2	3.3	0.0
Totals	**Dry Coniferous**	**Wet Coniferous**	**Mixed Forest**
Tree canopy closure	48.8	48.7	72.3
Shrub canopy closure	2.5	3.1	17.3

Table 3.2: Vegetation and non-living cover types summarized as mean cover, for both the Forest and the ROW groups. The three groups are Dry Coniferous (Dry Con.), Wet Coniferous (Wet Con.) and Mixed Forest (Mixed For.). The vegetation has been summarized by life history traits and habit. For the complete species list see Appendix 1.

	Forest			*ROW*		
Cover Type	*Dry Con.*	*Wet Con.*	*Mixed For.*	*Dry Con.*	*Wet Con.*	*Mixed For.*
Non-Living Cover Types	23.48	27.14	47.67	46.45	45.38	38.59
Larix larcina	0.17	3.89	0.00	0.00	0.05	0.00
Conifer Shrubs	6.21	9.18	0.93	2.09	2.18	0.18
Conifer Evergreen Trees	55.67	56.67	49.61	1.95	4.04	0.67
Deciduous Herbs	3.16	4.64	5.76	7.62	6.71	21.81
Deciduous Shrubs	6.41	8.94	39.64	2.05	5.11	4.89
Deciduous Trees	3.32	0.66	25.62	1.51	1.27	0.49
Evergreen Dicot. Shrubs	17.65	20.09	1.50	12.35	8.34	5.32
Lichen species	17.30	1.64	0.03	13.07	2.33	0.99
Lily and Orchid species	0.01	0.00	0.08	0.19	0.58	0.00
Grass species	2.55	9.33	3.69	9.75	18.48	24.48
Bryophyte species	31.02	27.82	18.90	0.71	2.42	0.79
Total Deciduous species	15.62	27.46	74.79	21.12	32.69	51.67
Total Evergreen species	79.53	85.94	52.04	16.39	14.56	6.17
Total Tree species	59.16	61.22	75.24	3.46	5.36	1.16
Total Cover species	166.93	169.99	193.43	97.74	97.38	98.20

Table 3.3: Cover components of the non-living cover types from Table 3.2 and soil measures averaged for each of the three groups. The soil variables presented in the table were those measured at the University of Manitoba. Note: Disturbed ground represents areas damaged by maintenance vehicles. As well, Bare ground in the forest represents soil and partially decayed leaves. On the ROW, necromass is composed primarily of dead graminoid culms. For the complete list of sites and soil measures see Appendix 2.

	Forest			*Row*		
Non-living Cover Types	*Dry Con.*	*Wet Con.*	*Mixed For.*	*Dry Con.*	*Wet Con.*	*Mixed For.*
Bare Ground	16.13	16.77	43.26	0.64	0.06	0.30
Necromass-Wood	6.48	6.49	4.24	4.41	3.94	0.45
Necromass-Culms	0.00	0.00	0.00	21.41	32.46	36.65
Needles	0.33	2.41	0.00	0.00	0.00	0.00
Rocks	0.53	0.00	0.18	18.04	1.74	0.25
Disturbed Ground	0.00	0.00	0.00	1.96	6.17	0.95
Water	0.00	1.48	0.00	0.00	1.02	0.00
Soil Measures	*Dry Con.*	*Wet Con.*	*Mixed For.*	*Dry Con.*	*Wet Con.*	*Mixed For.*
%Organic matter	18.6	75.5	13.2	15.5	58.9	12.3
% Moisture	25.4	41.1	22.1	22.8	47.6	25.7
Bulk density	0.6	0.2	0.5	0.8	0.3	0.6
Conductivity µS	165.0	396.4	106.1	114.5	308.4	96.5
pH	6.9	6.5	6.4	6.9	6.9	6.9

Table 3.4: The results from NorWest labs for soils selected among the forest groups. Both the forest and ROW values are presented. The sample size is given along the top row. Note: A value of 1.0 ppm for Nitrate represents an upper limit, some cores had values less than this.

	Dry Conifer		***Wet Conifer***		***Mixed Forest***		***Burn Sites***	
Soil measure	*Forest*	*ROW*	*Forest*	*ROW*	*Forest*	*ROW*	*Forest*	*ROW*
Cores Analysed	4	5	4	3	1	1	1	1
Nitrate (ppm)	1.0	1.0	1.0	1.7	1.0	1.0	1.0	1.0
Phosphate (ppm)	1.8	1.4	2.8	4.0	3.0	2.0	6.0	3.0
Potassium (ppm)	123.0	116.4	127.3	111.3	83.0	339.0	139.0	91.0
Sulfate (ppm)	10.5	5.0	12.0	8.0	6.0	7.0	6.0	6.0

4. Vegetation

The forest vegetation at these sites is predominantly coniferous (mean of 55.7% coniferous trees and 6.2% coniferous shrubs, mostly *Juniperus* spp.; **Table 3.2**). *Pinus banksiana* and *Picea mariana* are the most common tree species (**Table 3.1**). The majority of angiosperms shrubs are low-lying, dryland evergreen ericaceous species such as *Arctostaphylos uva-ursi*; very few tall shrubs (> 1 m) are present (**Table 3.1**). Stand age averages ≈ 45 years, although sites 1152 and 1154 contain a number of individuals of *Picea mariana* that are ≈ 90 year old.

On the adjacent right-of-ways sites, bryophytes virtually disappear (from a mean cover of 31% in the forest to < 1% on the ROW). Grasses and deciduous herbs have higher cover on the ROW, while conifer and deciduous shrubs have lower cover (**Table 3.2**). Much of the ROW remains unvegetated (18% bare rock, 21.5% Necromass-Culms and Wood; see **Table 3.3**).

5. Maintenance and Fire History

All the sites were sprayed with Tordon 101 in 1979 (sites 1152 through 1154) or 1980 (all other sites). Most were V-bladed during winter of 1992-1993 (exceptions: sites 1154, 1152, 1094 and 1093). They were burned during the 1930's and possibly during the 1940's (exceptions: 1152 through 1154, where no fires have been recorded).

Wet Conifer

1. Location

The eight sites occupy one of two distinct physiographic regions: The Pas moraine (sites 1172 through 1174, 52°52'N and 99°3'W), and the Interlake plain (sites 1297 through 1298, 52°20'N and 98° 54'W). Sites 1022 and 1092 are much further north than the others.

2. Topography

Sites 1022 and 1092 are both near the base of a limestone cliff, while sites 1172-1174 are on the south-facing slope of the The Pas moraine. Sites 1297 through 1299 are on the Interlake plain.

3. Geology, Drainage and Soils

Most of the sites in this class occur in low-lying poorly drained areas. However, 1172 to 1174 are found on the face of The Pas Moraine. In all cases, soil water content is high (**Table 3.3**), reflecting the 'boggy' nature of these sites and the high soil organic matter content (75% in the forest and 59% on the ROW). Mean soil conductivity is more that twice that of the other groups (**Table 3.3**). Because of the calcareous substrate, these conifer bogs have a near-neutral pH. Nutrient availability is generally greater in the forest than on the ROW, with the exception of phosphate (**Table 3.4**).

4. Vegetation

The forest vegetation is dominated by *Picea mariana*, although *Thuja occidentalis* is locally common at sites 1297 through 1299. The forest understory is dominated by low ericaceous 'bog' shrubs (e.g. *Ledum groenlandicum*), coniferous shrubs (mainly *Juniperus* spp.), and bryophytes (mainly *Sphagnum* spp.). The tall shrub *Alnus rugosa* (mean cover of 2.5%) is occasionally encountered. Stand ages are greater than for the other two groups; this likely reflects the relative fire-resistance of these wetter sites. Several of the trees were over 120 years in age.

Changes in the adjacent ROW vegetation include the virtual disappearance of *Sphagnum* spp. (from 27% cover in the forest to < 3% on the ROW), a decline in evergreen shrub cover, and an increase in graminoid cover (from ≈ 9% mean cover in the forest to over 18% on the ROW). Lily and orchid species, which were rarely present in forest, were commonly found along the ROW, though their cover was low. Approximately 45% of the ROW is unvegetated, the majority of this being necromass associated with graminoid culms (**Table 3.3**).

5. Maintenance and Fire History

All sites were sprayed with Tordon 101, either in 1980 (sites 1022 and 1092) or 1979 (all other sites), and most were V-bladed during the winter of 1992-1993 (exceptions: sites 1297 through 1299). These regions were recorded as having burned in the 1930's, expect for sites 1172 through 1174.

Mixed Forest

1. Location

Most of the seven sites are located in the southern portion of the study area. Site 1036 is somewhat further north than the others.

2. Topography

All seven sites in this group occur in areas with very low relief (elevational variation < 1 m per km).

3. Geology, Drainage and Soils

This group is exclusive to the Interlake plain on loamy to slightly clayey-loamy soils, except for site 1036 (Cedar lake plain) which occurs on sandy-clayey glacial till. The sites are well to imperfectly drained, the clayish subsoil preventing excessive water penetration. The forest soils are low in organic matter. Soil conductivity values, for both forest and ROW soils, are lower than the other two groups. The nutrients at these sites are generally intermediate, although lack of replication makes it difficult to interpret the NorWest soil data (**Table 3.4**).

4. Vegetation

The dominant forest tree species are *Populus tremuloides*, *Picea mariana* and *Pinus banksiana* (**Table 3.1**). Deciduous tall shrubs are common at these sites, the main species being *Alnus crispa* (mean cover of 12.3%) and *Corylus cornuta* (mean cover of 3%). Tree and shrub canopy closure is much higher than in the other forest groups (**Table 3.1**), and as a result understory cover is low (mean 'bare ground' cover is 43%, **Table 3.3**). Stands are generally young (≈ 45 year in age), though some individuals of *Pinus banksiana* individuals were older than 130 years.

Changes in the adjacent ROW vegetation include a considerable drop in deciduous shrub cover (mean cover of ≈ 40% in the forest, to ≈ 4% on the ROW) and a concomitant increase in graminoid cover (from 3.7% cover in the forest to 24.5% on the ROW; **Table 3.2**). ROW vegetation cover is higher than the other two groups (≈ 38% unvegetated cover vs. > 45% for the other two groups).

5. Maintenance and Fire History

The sites were sprayed with Tordon 101 in 1979 or 1980 (site 1036). Sites 1036, and 1203 through 1205, were bladed in the winter of 1992 - 1993. All sites were burned during the 1930's, and there was a small spot fire near site 1245 in the 1970's.

Burn Sites

Three forest-ROW sites (1113 through 1115) were burned in 1989, and for this reason were not included in the cluster analysis. A complete description of these sites is given in the previous chapter and is not repeated here. **Table 3.5** summarizes the vegetation and edaphic features of the forest and ROW of these sites.

1. Soils

In the post-fire environment, the amount of bare soil was greater in the 'forest' areas (mean cover of 33% vs. 13.5% on the ROW), indicating that the ROW vegetation

Table 3.5: Summary of the Forest and ROW average cover for (A) the burn sites using the species types from Table 3.1; (B) the edaphic factors and associated environmental parameters. 'Bare ground' includes both soil and partially decayed leaves. For the complete list of vegetation see Appendix 1 and for soil measures see Appendix 2.

A. Burn Species	*Forest*	*ROW*
Non-living cover types	55.62	59.91
Bryophyte species	20.22	4.36
Conifer evergreen trees	0.67	0.21
Deciduous herbs	13.90	6.20
Deciduous shrubs	2.42	0.59
Deciduous trees	0.40	0.02
Evergreen dicot. shrubs	0.13	0.83
Grass/Carex species	3.77	22.23
Lichen species	0.20	0.09
Lily and orchid species	0.12	2.02
Total deciduous species	16.72	6.81
Total evergreen species	0.80	1.04
Total tree species	1.07	0.23
Total Cover	116.02	104.54
B. Burn Environmental	*Forest*	*ROW*
Bare ground	33.25	13.46
Necromass - culms	0.00	41.13
Necromass - wood	19.23	1.11
Needles	0.98	0.00
Rock	2.15	4.21
pH	6.83	6.94
Conductivity µS	168.00	149.18
% Organic matter	10.38	13.17
% Moisture	22.22	30.52
Bulk density	0.63	0.61

recovered more quickly from the fire. Accumulation of necromass, primarily grass culms, was ≈ 41% on the ROW. The presence of charcoal beneath this grass litter indicated that this biomass accumulated over the last 4 years. Conductivity was higher than for the dry conifer and mixed forest groups, but percent soil organic matter was lower. Although there is a lack of adequate replication, phosphate availability appears higher in this group than in the others (**Table 3.4**).

2. <u>Vegetation</u>

Over half the substrate in both the forest and ROW was devoid of living vegetation. Most was in the form of leaf litter on the ROW, whereas in the forest much of it was bare ground and necromass-wood (mainly burned tree trunks). Bryophytes (mainly *Bryum* and *Ceratodon* spp.) were actively colonizing the forest sites (> 22% cover, vs. 4.4% cover on the ROW). Herbaceous cover was greater in the forest sites (14% vs. 6.2% on the ROW), whereas graminoid cover was much higher on the ROW (> 22% vs. < 4% in the forest). This likely reflects differences in vegetation that existed prior to the fire, and the vegetative recovery of graminoid species on the ROW. Available evidence indicates that these sites were intermediate between the dry and wet coniferous groups prior to the fire. Both the ROW and forest sites were being invaded by tree saplings (mainly *Pinus banksiana*).

3.2 RIGHT-OF-WAY RECRUITMENT

Tree recruitment for each of the four groups (dry conifer, wet conifer, mixed forest and burn sites) has been summarized using age and frequency histograms. Total sample sizes and tree densities for each group are summarized in **Table 3.6**. The following sections summarize tree recruitment trends for each group.

<u>Dry Coniferous</u>

This group has the lowest tree recruitment (**Table 3.6**). The major species are *Pinus banksiana* (275 /ha), *Picea mariana* (249 /ha), and *Betula papyrifera* (60 /ha). The age-frequency trends are summarized in **Fig. 3.2**. Relatively few trees survived the last herbicide (Tordon 101) application, and most were *Picea mariana* individuals. Some interesting recruitment trends subsequent to the herbicide application are apparent. Recruitment of *Picea mariana* has been fairly consistent, whereas *Pinus banksiana* recruitment increased rapidly about 5 to 7 years following the herbicide application (a similar, though less dramatic, trend is seen for *Betula papyrifera*). For all species, tree recruitment on the ROW sites has declined in recent years.

Table 3.6: Absolute numbers of trees counted in the ROW recruitment study and the standardized density of individuals per hectare at a species level. The total ROW area sampled (in ha) for each group is also given.

Absolute number counted	Dry Coniferous	Wet Coniferous	Mixed Forest
Total ROW area sampled in ha	0.5620	0.8940	0.8500
Betula papyrifera	34	-	-
Larix laricina	1	116	1
Picea mariana	140	1540	378
Pinus banksiana	155	161	111
Populus balsamifera	-	-	107
Populus tremuloides	-	25	419
Thuja occidentalis	-	258	-
Density of trees per hectare	**Dry Coniferous**	**Wet Coniferous**	**Mixed Forest**
Betula papyrifera	60	-	-
Larix laricina	2	136	1
Picea mariana	249	1812	423
Pinus banksiana	276	189	124
Populus balsamifera	-	-	120
Populus tremuloides	-	29	469
Thuja occidentalis	-	304	-
Total trees per ha	587	2471	1136

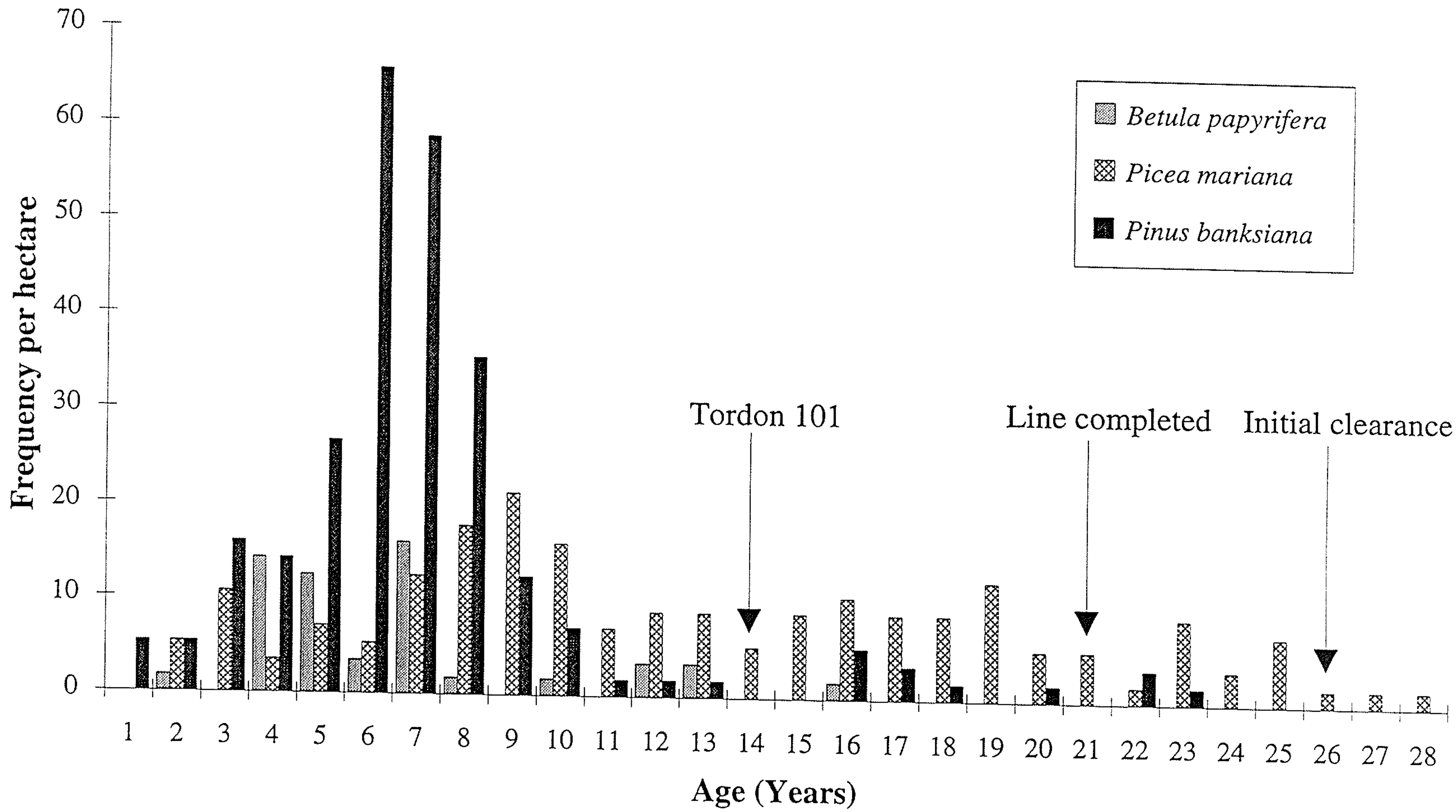


Figure 3.2: Right-of-way recruitment for Dry Coniferous sites. Important events during the last 26 years are indicated on the graph by arrows. The total sample size for this group was 330 trees, over an area of 5620 m^2. A single 7 year old individual of *Larix laricina* was not graphed.

Wet Coniferous

Recruitment was highest for this group (**Table 3.6**). *Picea mariana* was the most common species, although *Thuja occidentalis* was also commonly found at sites 1297 through 1299 (**Fig. 3.3**). Mean density for *Picea mariana* was > 1800 trees/ha. Some of the ROW trees were more than 30 years old, but were growing slowly. Most individuals of this species grow slowly, though a few 'lead' trees may grow rapidly (**Fig. 3.4**). As a result, the relationship between age and basal diameter is not linear. From **Fig. 3.3**, it is apparent from the results that *Picea mariana* has been actively colonizing the ROW since its establishment in 1967, and that the seems to be largely unaffected by the Tordon herbicide. The apparent

decline in its numbers in recent years may be an artifact (see Discussion). The presence of *Thuja occidentalis* (303 trees/ha) is restricted to sites on the The Pas moraine. In the years immediately following herbicide applications, *Populus tremuloides* and *Pinus banksiana* have increased in numbers on these ROW sites.

Mixed Forest

Recruitment in these sites is relatively high (1136 trees/ha; **Table 3.6**). The most common species colonizing the ROW are *Populus tremuloides* and *Picea mariana*, although *Pinus banksiana* and *Populus balsamifera* are also frequently encountered (**Fig. 3.5**). Most of the survivors from the last Tordon herbicide application are *Picea mariana*, but recruitment of this species has declined over the last 15 years. The other three species show an increase in recruitment a few years following herbicide application, particularly *P. tremuloides*. The apparent recent decline in recruitment of these species may be a sampling artifact (see Discussion).

Burn Sites

Post-fire recruitment in the forest of these sites was high. Recruitment on the ROW was somewhat lower, likely reflecting the lack of a localized seed source. Standardized densities on the ROW were 94.9 trees/ha for *Pinus banksiana*, 62.3 trees/ha for *Picea mariana* and 7.5 trees/ha for *Populus tremuloides*. The age distributions for the species are presented in **Fig. 3.6**. Note that a few individuals of *Picea mariana* and *Pinus banksiana* apparently survived the fire, but that the majority of recruitment occurred soon after the fire.

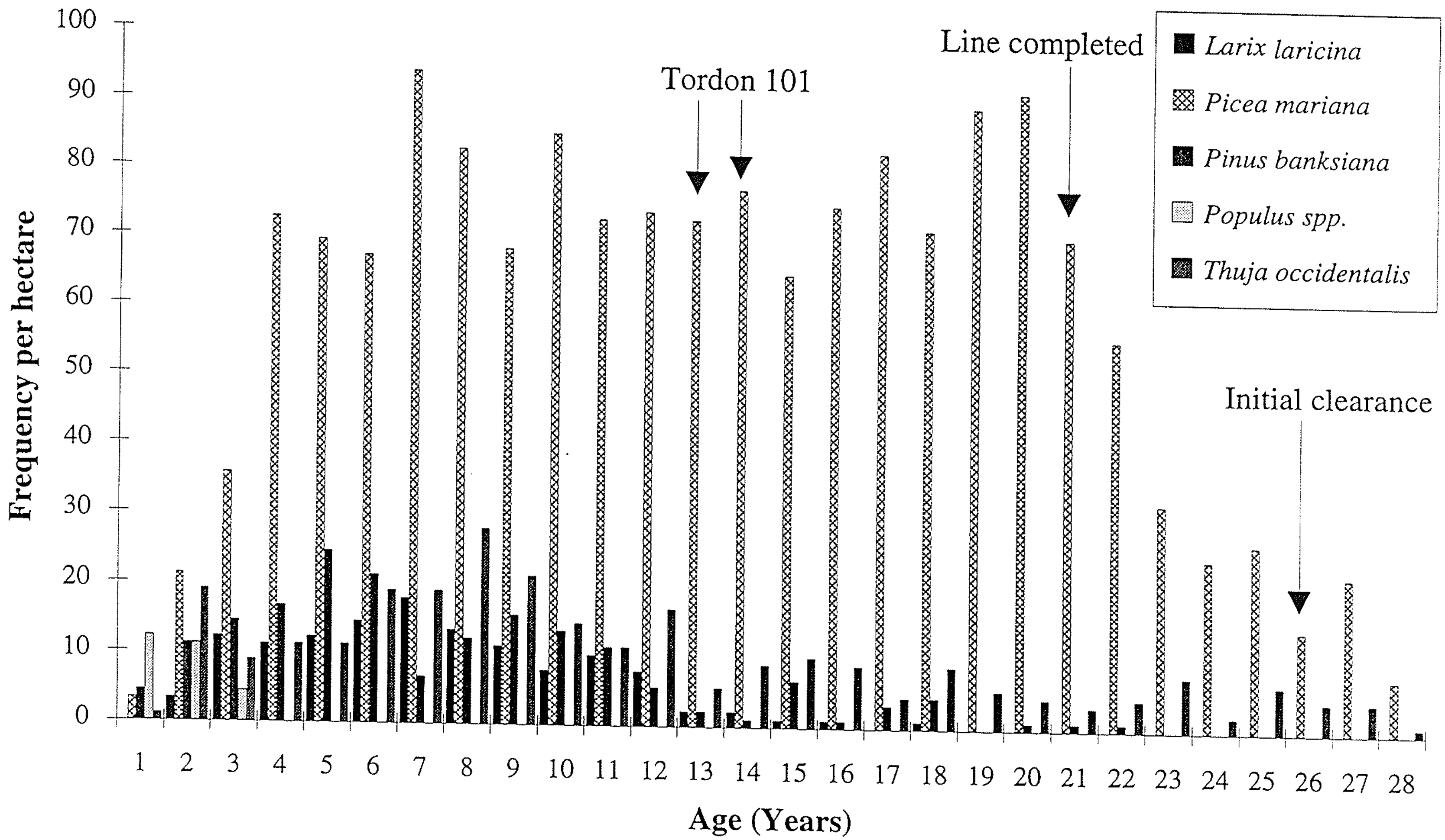


Figure 3.3: Right-of-way recruitment for Wet Coniferous sites. Important events during the last 26 years are indicated on the graph by arrows. The total sample size for this group was 2100 trees over, an area of 8940 m^2. Most of the individuals colonizing the ROW are small *Picea mariana*.

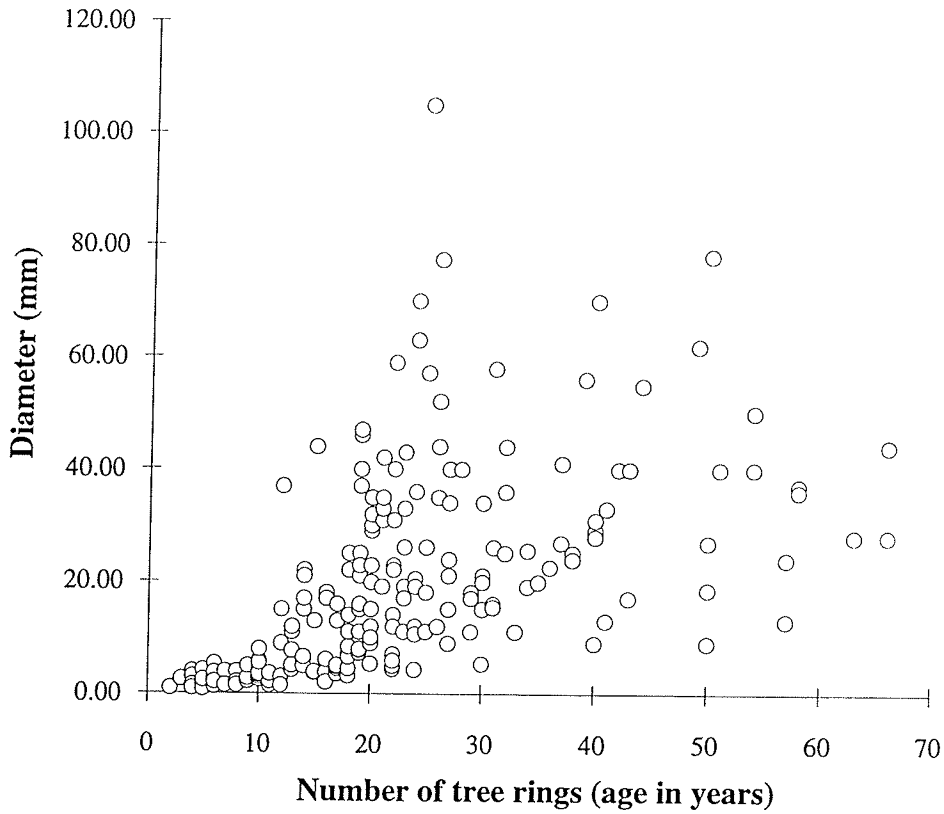


Figure 3.4: Basal diameter of Black Spruce (mm) plotted against the tree age. Two Hundred and sixteen trees were collected in a 20 m × 50 m quadrat at site 1172. A regression of age versus number of rings was performed, the r^2=0.29.

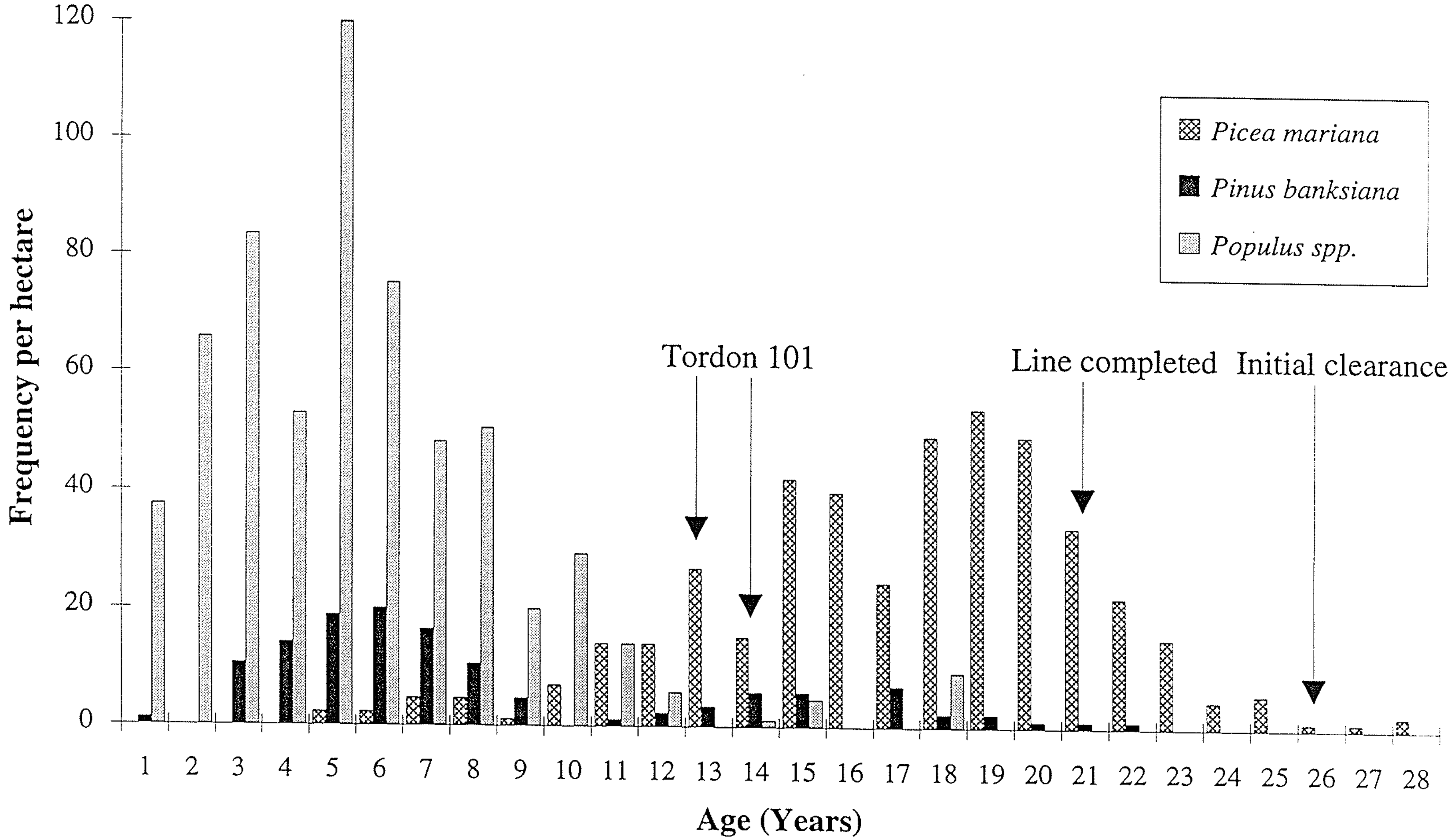


Figure 3.5: Right-of-way recruitment for Mixed Forest sites. Important events during the last 26 years are indicated on the graph by arrows. The total sample size for this group was 1015 trees over, an area of 8500 m^2. A single 7 year old individual of *Larix laricina* was not graphed.

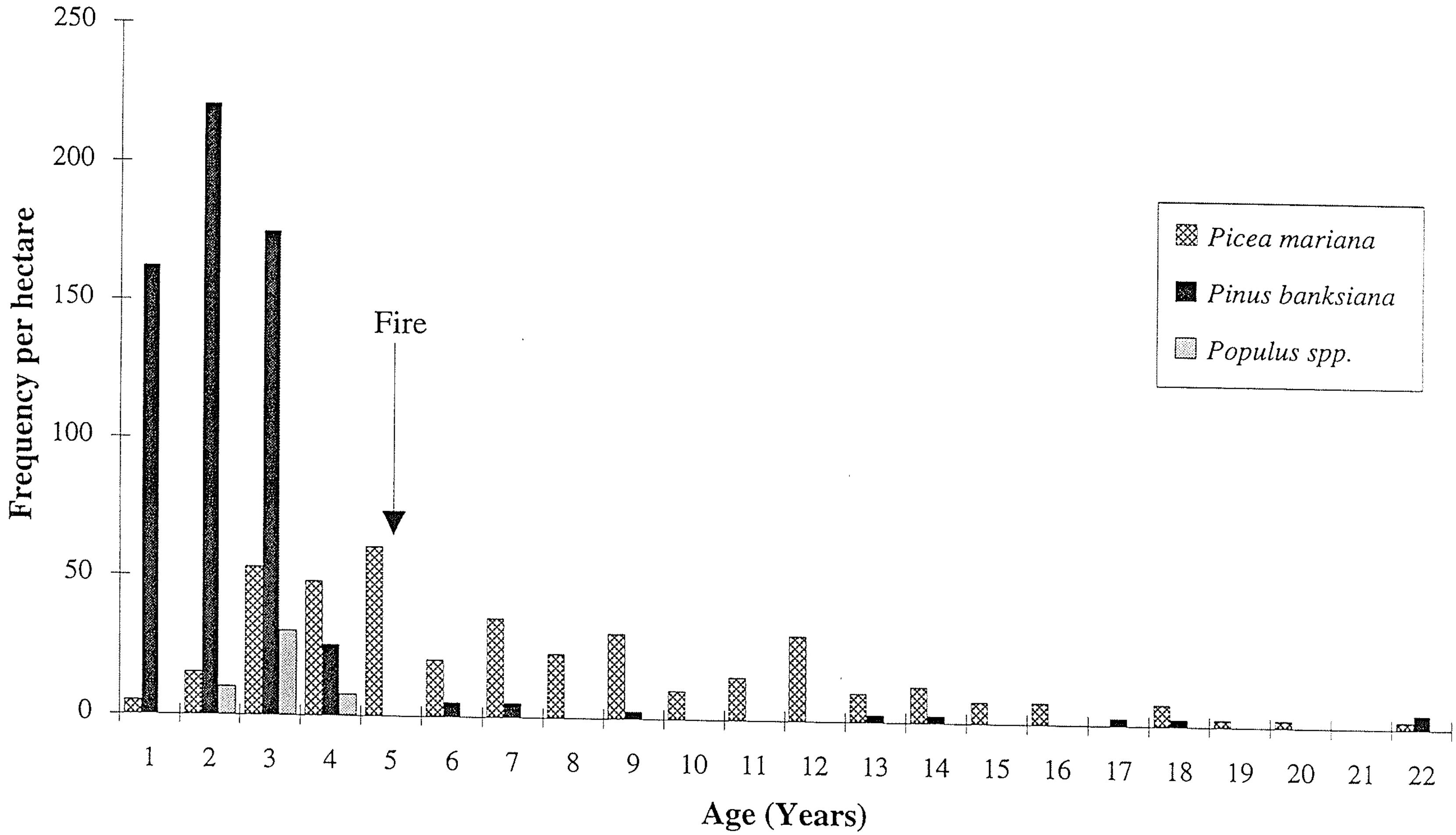


Figure 3.6: Right-of-way recruitment for the burn sites. Important events during the last 26 years are indicated on the graph by arrows. The total sample size for this group was 418 trees, over an area of 3940 m^2. This included 241 *Pinus banksiana*, 158 *Picea mariana* and 19 *Populus tremuloides*.

3.3 ORDINATION RESULTS

3.3.1 DCA of Forest Sites

The first two axes of the ordination configuration of the 27 sites are presented in **Figure 3.7**. Site numbers and corresponding group affinities are also shown. The three groups are well separated on the ordination diagram, although there is some overlap. For example, site 1153 (dry conifer) is closely adjacent to sites 1172 and 1173 (wet conifer). Similarly, sites 1020 and 1021 (dry conifer) are adjacent to sites of the mixed forest group. This indicates that the group structure designation, while useful, represents a partitioning of continuous vegetation variation. A multiple discriminant analysis was performed to test the significance of the three-group discrimination in the two-dimensional DCA space. The computed Heck $\theta = 0.792 > \theta_{0.05} = 0.320$, indicating statistically significant discrimination. The corresponding discriminant functions indicated that group discrimination occurs mainly along the first DCA axis.

3.3.2 CCA of Forest Sites

The relationship between forest vegetation and edaphic factors is summarized in a two-dimensional ordination biplot (**Fig. 3.8**). Each edaphic factor is represented as the apex of a vector. The length of the vector represents variable 'strength' (in the sense of explaining vegetation variation), while vector direction indicates the direction of increases in the variable on the ordination diagram. The ordination results indicate strong group separation. The wet conifer group is particularly well separated (exception is site 1022), which is associated with high percent soil organic matter and moisture. The dry conifer group is negatively correlated with the soil organic matter, but positively correlated with soil bulk density. The clay-rich mixed forest sites are also positively correlated with soil bulk density.

3.3.3 DCA of Right-of-Way Sites

The first two axes of the ordination configuration of the 27 ROW sites are presented in **Fig. 3.9**. The three vegetation groups are superimposed on the ordination scattergram. Multiple discriminant analysis indicated that these three group are statistically significant (Heck $\theta = 0.788 > \theta_{0.05} = 0.320$), and that group discrimination occurs mainly along the first DCA axis. Since the vegetation groups were defined based on forest vegetation, group discrimination in 'ROW vegetation space' offers indirect evidence that the forest vegetation can be used as a predictor of ROW vegetation.

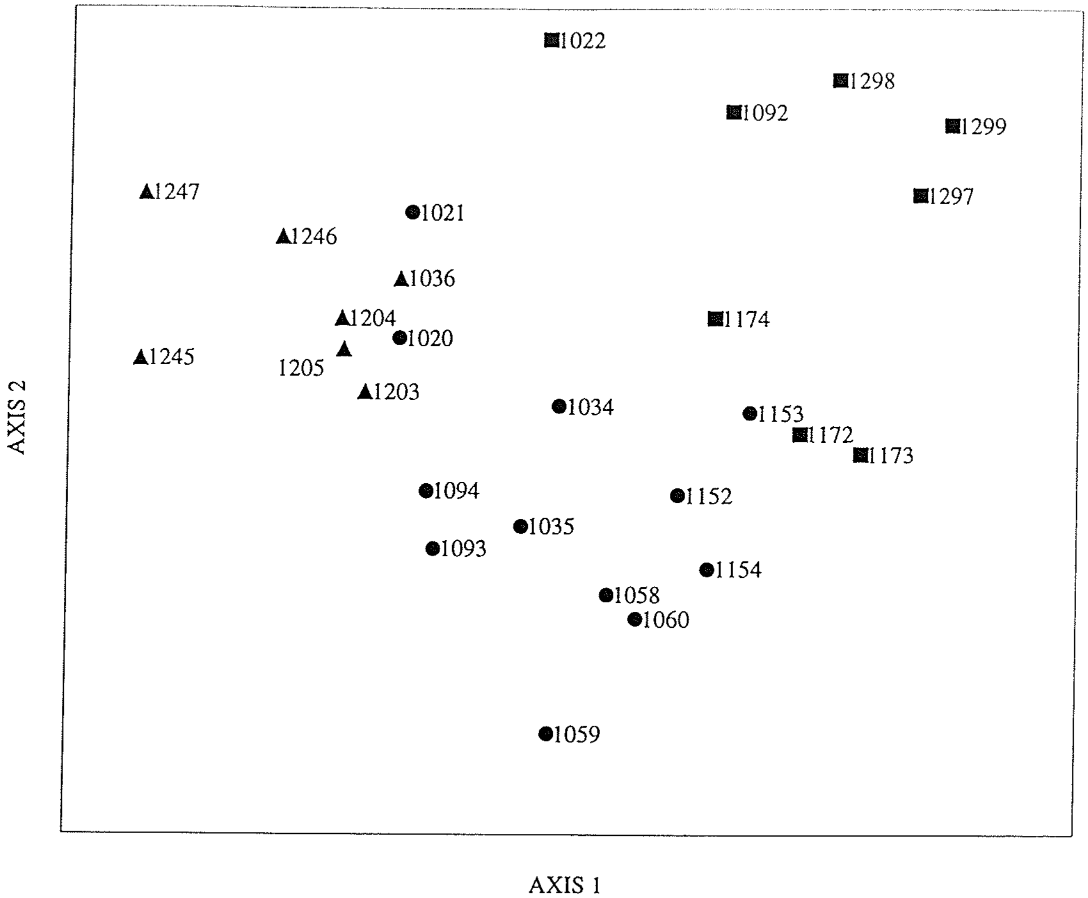


Figure 3.7: Detrended Correspondence analysis of the forest vegetation (square-root transformed) axis 1 vs. 2. The first axis extracted 20.8 % of the variance, the second 7 %. Groups are indicated by the shapes of the points, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲).

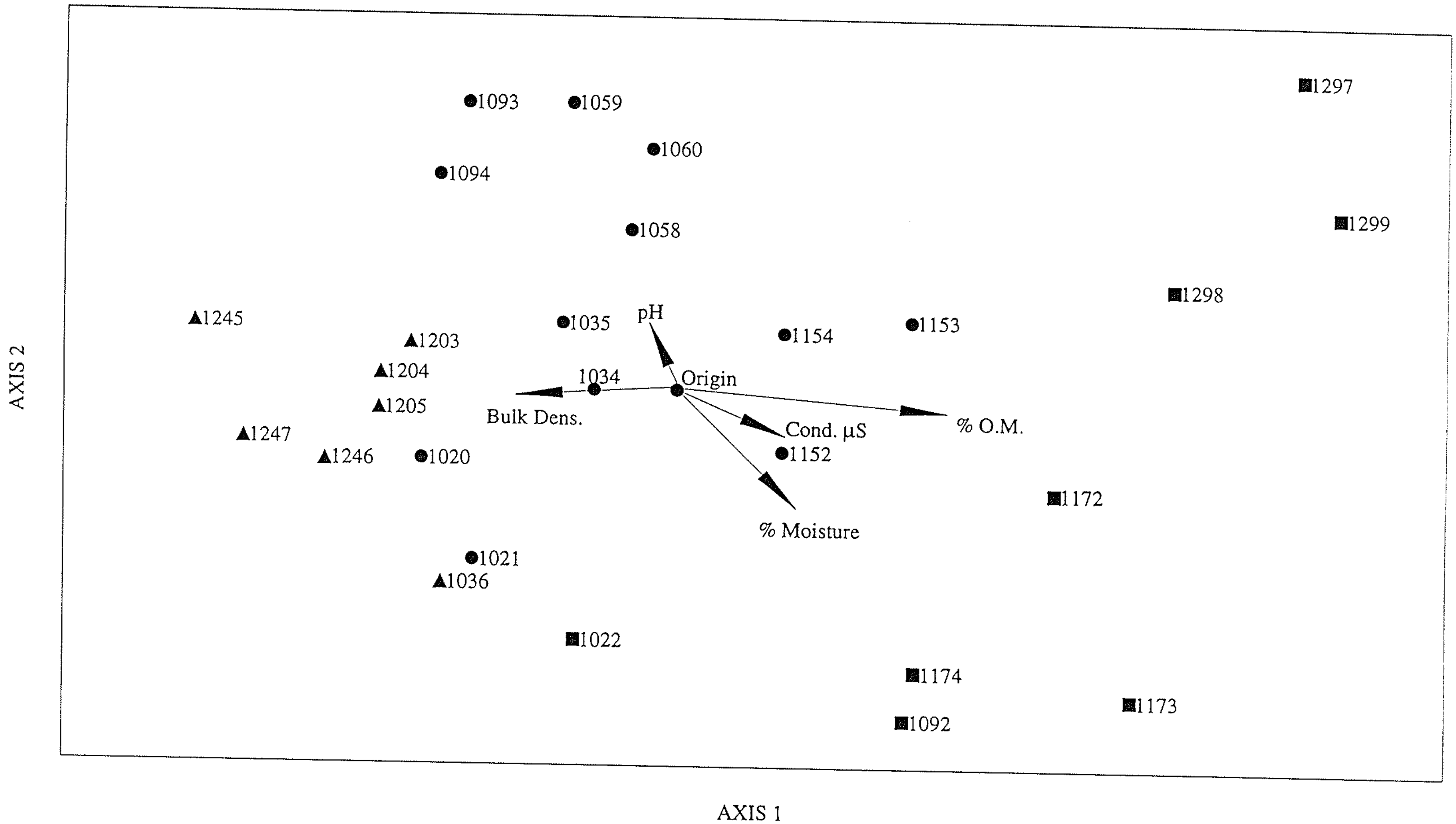


Figure 3.8: Canonical Correspondence analysis biplot scores for the forest vegetation data and the forest soil data. Environmental data points are at the tip of the subtending arrow. The site number or edaphic factor measured are given beside their respective points; Bulk density=Bulk Dens., Cond. µS=Conductivity (µS), % Moisture=% moisture, %O.M.=%organic matter and pH=pH. Group affinites are indicated by different shapes, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲). The first axis accounted for 55.9% of the species-environment relation and the second axis 15.6%.

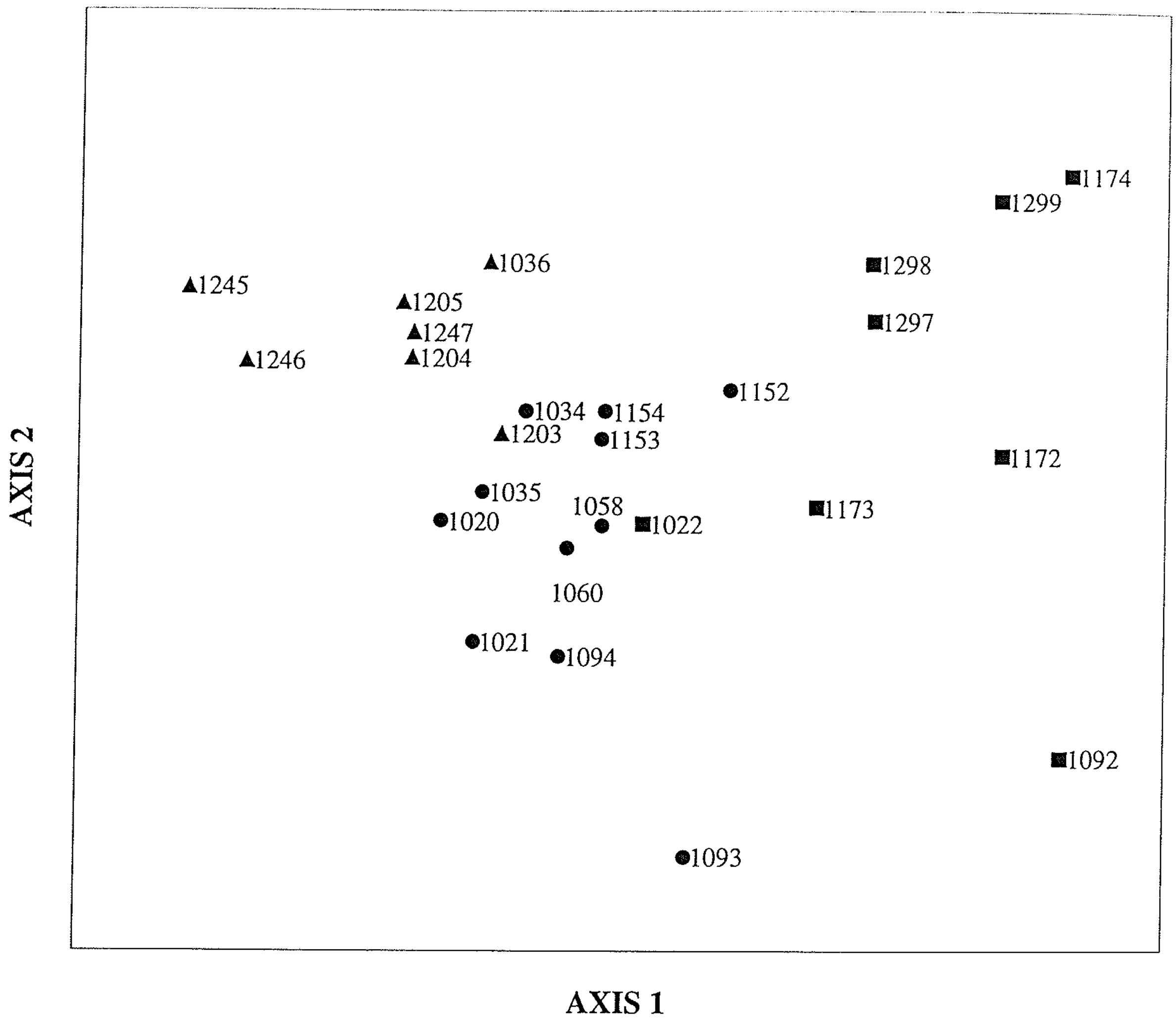


Figure 3.9: Detrended Correspondence analysis of the Right-of-way vegetation (square-root transformed), axis 1 vs. 2. The first axis extracted 17.1 % of the variance and the second axis extracted 8.7 % . Groups are indicated by the shapes of the points, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲).

3.3.4 CCA of Right-of-Way Sites

The relationship between ROW vegetation and edaphic factors is summarized in a two-dimensional ordination biplot (**Fig. 3.10**). As with the forest data, the wet coniferous group is well separated along the first axis (exception: site 1022), reflecting higher levels of soil organic matter, moisture and conductivity. The dry conifer and mixed forest groups are associated with higher soil bulk density. The mixed forest and dry conifer groups separate along a pH gradient, the mixed forest sites having a more alkaline soils.

3.3.5 CA Ordination of Forest and Right-of-Way Sites

The first two axes of the combined forest-ROW ordination (burn sites included) are presented in **Fig. 3.11**. Not surprisingly, the first axis completely separates the forest and ROW sites, based primarily on the large differences in tree cover. Along the second axis, groups are arranged in the same order as the first axis of the DCA's (compare to **Figs. 3.7** and **3.9**).

The degree to which vegetation 'changes' when a forest site is cleared to build a ROW can be estimated as the length of the trajectory from its 'forest' to 'ROW' position on the DCA ordination. This was computed as a Euclidean distance, after standardizing the ordination scores. The standardization used was:

$$St.Weight = \frac{Sitescore}{Sitescore_{\max} - Sitescore_{\min}} \times Eigenvalue$$

where *Sitescore* is the score for a given point, ($Sitescore_{max}$ - $Sitescore_{min}$) is the range of sitescores on the axis, and *Eigenvalue* is the eigenvalue of the axis (used as a standardizing function). Distances were calculated for each forest-ROW combination and compared across the four vegetation groups (**Fig. 3.12**). Mean trajectory length for three of the groups (burn, dry conifer and wet conifer) was between 0.25 and 0.30, but was significantly greater (ANOVA, $p < 0.001$) for the mixed forest sites (mean length ≈ 0.47). This result indicates that mixed forest sites undergo the greatest change in vegetation composition following forest clearing, which may be related to a decrease in shrub cover on the ROW.

3.3.6 Canonical Correlation between Forest and ROW Vegetation

The apparent relationship between ROW and forest vegetation (Section 3.3.3) was statistically established by performing a canonical correlation analysis between the two-dimensional DCA forest and ROW scores. The first canonical correlation axes in the forest and ROW ordination spaces are plotted against each other in **Fig. 3.13**. The canonical

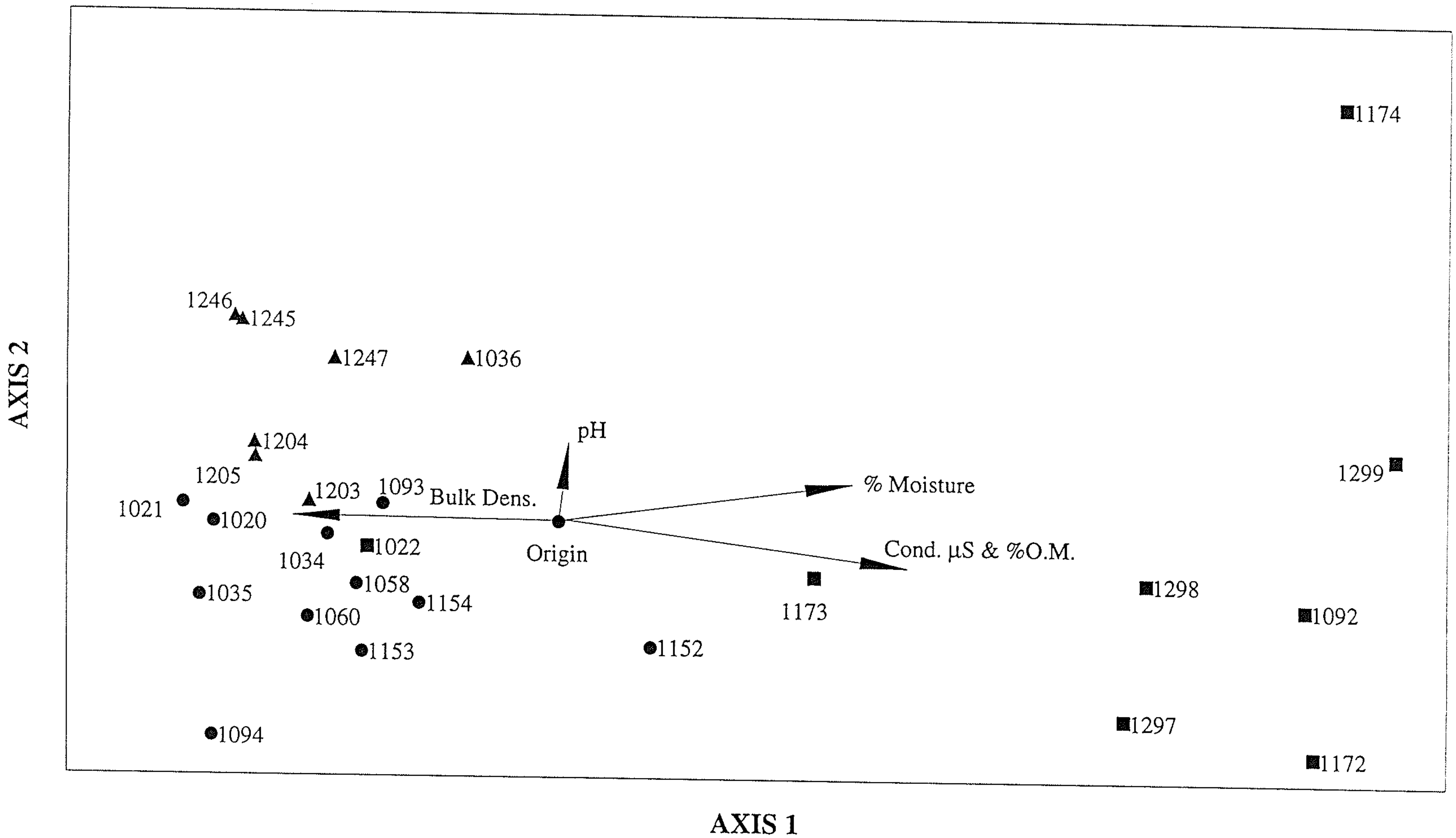


Figure 3.10: Canonical Correspondence analysis biplot scores for the ROW vegetation data and the ROW soil data. Environmental data points are at the tip of the subtending arrow. The site number or edaphic factor measured are given beside their respective points; Bulk density=Bulk Dens., Cond. µS=Conductivity (µS), % Moisture=% moisture, %O.M.=%organic matter and pH=pH.. Group affinity is indicated by the shape of the point, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲). The first axis accounted for 46.8% of the species-environment relation and the second axis 18.6% .

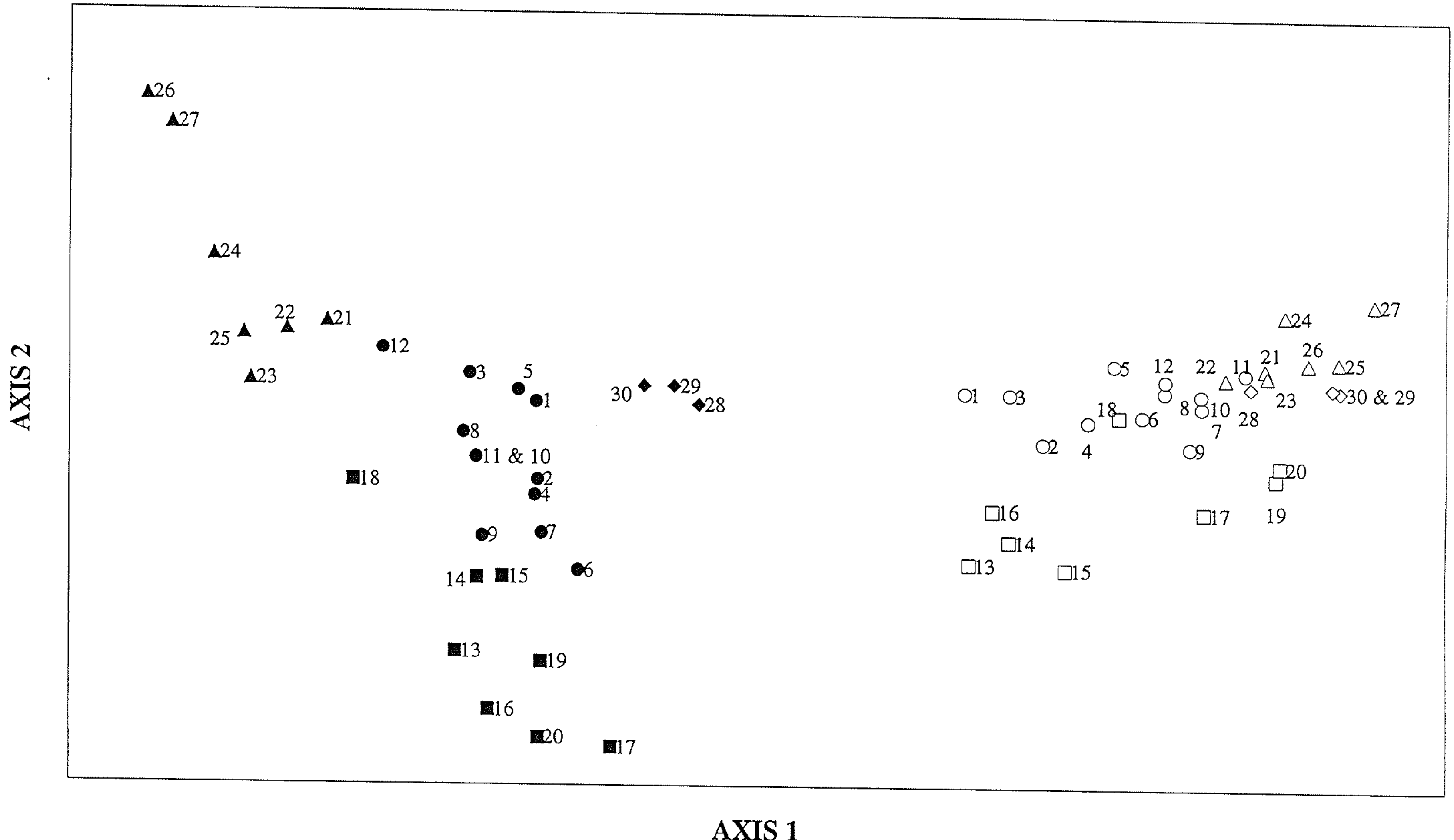


Figure 3.11: Plot of the first two ordination axes for the Forest and ROW combined Correspondence Analysis. Groups are indicated by the shape of the points, Dry Conifer sites (●), Wet Conifer sites (■), Mixed sites (▲) and the Burn sites (◆). The solid symbols represent forest sites and the hollow symbols are ROW sites. The site number is given by a code adjacent to the point: 1-1020; 2-1021; 3-1034; 4-1035; 5-1058; 6-1059; 7-1060; 8-1093; 9-1094; 10-1152; 11-1153; 12-1154; 13-1022; 14-1092; 15-1172; 16-1173; 17-1174; 18-1297; 19-1298; 20-1299; 21-1036; 22-1203; 23-1204; 24-1205; 25-1245; 26-1246; 27-1247; 28-1113; 29-1114; 30-1115. The variance extracted by the first axis was 15.9% and 10.9% was extracted by the second axis.

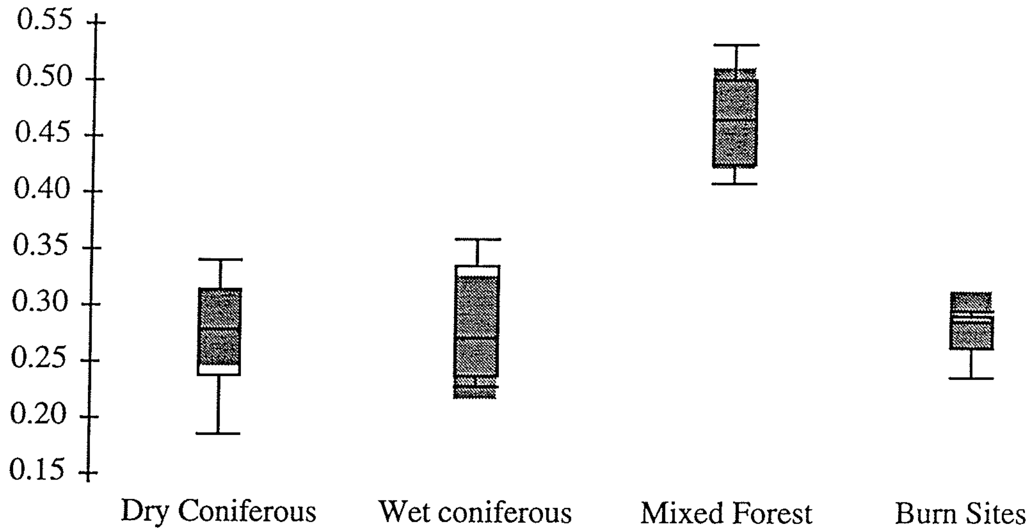


Figure 3.12: Boxplots of the standardized distances calculated from the first two axes of the combined ROW and Forest Cover Correspondence analysis site scores. The solid horizontal line in the box represents the median of the Group distances. The shaded area is the 95 % confidence interval about the median. Fifty percent of the data values occur within the top and bottom of the box and 75 % occur within the range indicated by the top and bottom brackets.

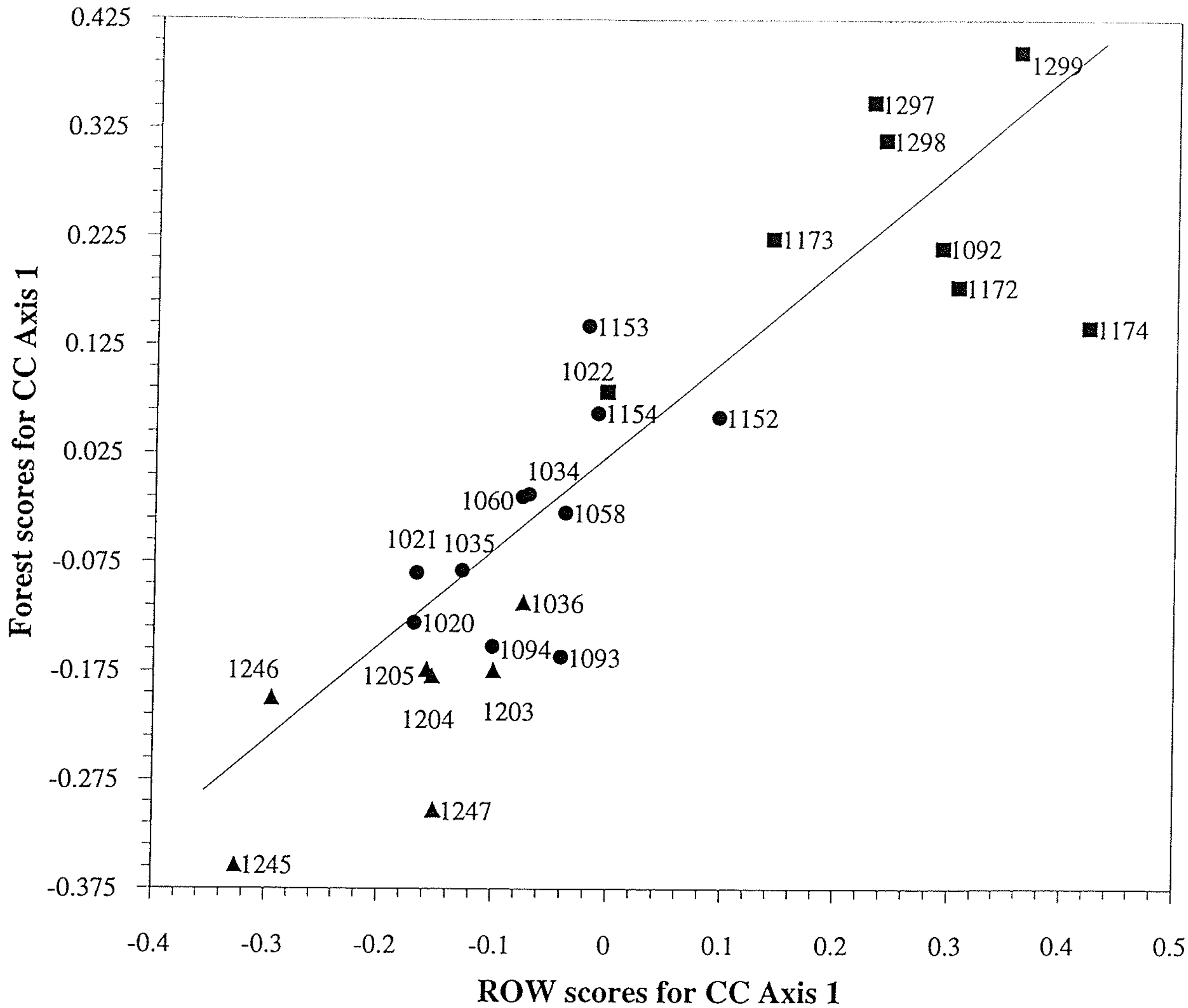


Figure 3.13: The first two axes for the Canonical Correlation of the ROW and Forest data. The R^2 value for the Forest-ROW relationship is 0.77. Note: The burn sites were not used in this analysis. Groups are indicated by shapes, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲).

correlation is highly statistically significant ($R^2 = 0.77$, $\chi^2 = 36.37 > \chi^2_{0.05,4} = 9.49$), and redundancy is 43%. These results confirm a strong correspondence between the forest and ROW sites, suggesting that a model to predict ROW vegetation trends based on forest vegetation can be constructed.

3.4 Classification Model - Discriminant Functions Using TM Bands

3.4.1 Thematic Mapper Reflectances for the Three Forest Groups

An investigation of TM band reflectance values (forest pixel data) was undertaken to determine whether the three forest vegetation groups differed in their spectral reflectances. For each forest group, a boxplot was produced (**Fig. 3.14**). The results are summarized as follows:

- Band 3 (red light)

  Reflectance in this spectral range was highest for the wet conifer group. The mixed group showed the least variability in this band, though two sites (1203 and 1036) were outside the range of 75% of the data.

- Band 4 (near infrared)

  The lowest spectral reflectance was found in the dry conifer group (mean = 49) than the other two groups. Site 1298, a boggy region, was an outlier in the wet conifer group. The mixed group showed the greatest variability in band 4 reflectance, and had the largest mean reflectance value (71.4).

- Band 5 (short-wave infrared)

  The groups showed considerable overlap in this spectral range. Reflectance values for the dry conifer group were generally lower except two outliers (sites 1094 and 1034).

A principal components analysis (using product moment correlation) was also performed on the data (variables = 3 bands, individuals = 25 sites). The results revealed that ≈ 94% of the variance was accounted for on the first two principal components, indicating redundancy in the spectral reflectances in the three bands. This is explored further in the following section.

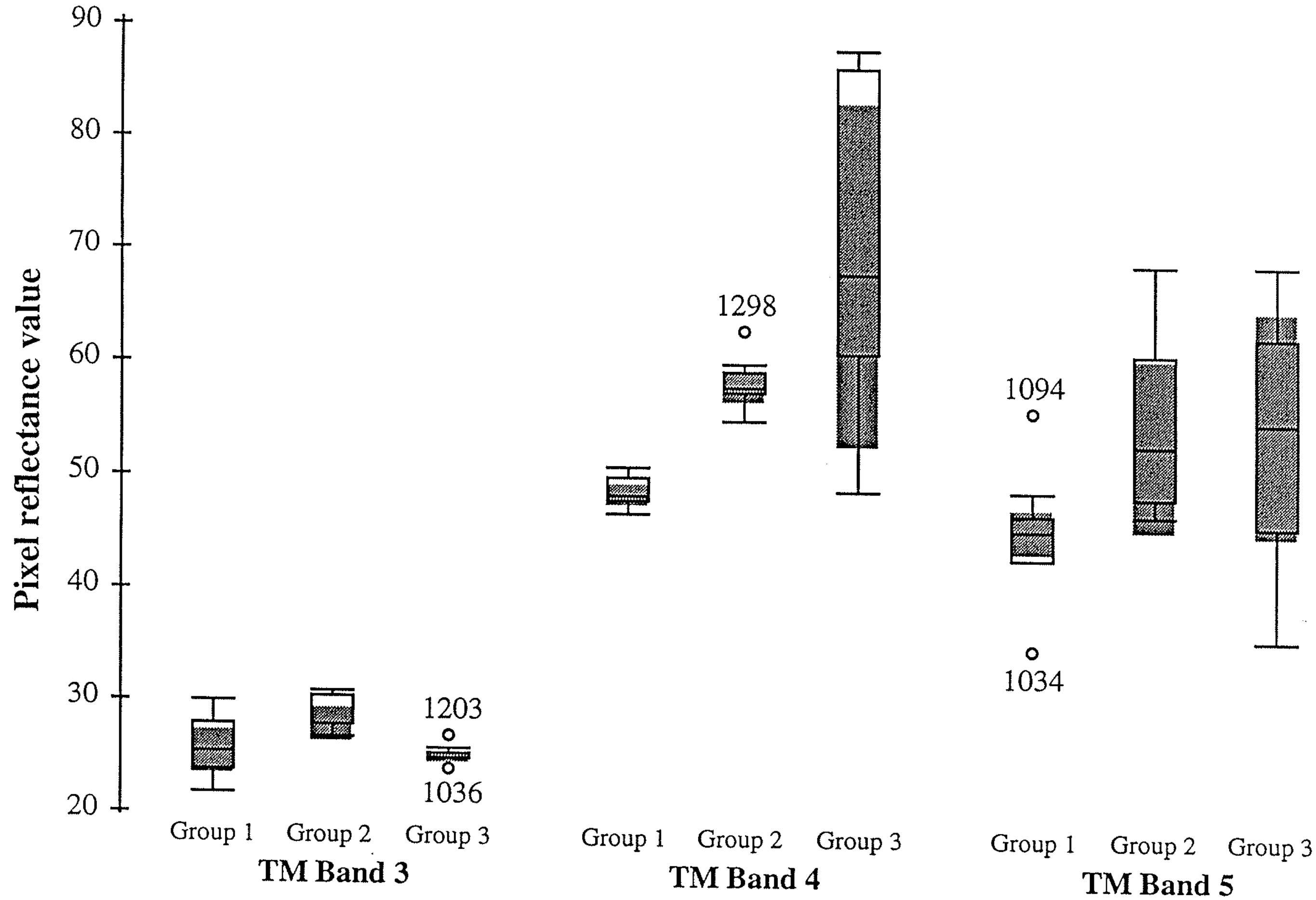


Figure 3.14: Side by side boxplots of the Landsat TM band values for each of the three groups. Group 1= Dry Conifer, Group 2 = Wet Conifer and Group 3 = Mixed forest. The line in the centre of the box is the mean, the top and bottom of the box enclose 50% of the values and the top and bottom of the arms encompasses 75% of the data. The shaded portion is the 95% confidence interval about the mean. Open circles indicate outliers, the numbers correspond to the associated sites.

3.4.2 Forest Groups Discriminant Analysis Based on TM Bands

The multiple discriminant analysis results indicated that the three forest vegetation groups can be successfully discriminated using the three TM band reflectance values (Heck $\theta = 0.692 > \theta_{0.05} = 0.415$). Site and vegetation groups in the two-dimensional discriminant space were transformed into their U-space co-ordinates and graphed (**Fig. 3.15**). Most of the discrimination (85.8%) occurs along the first discriminant axis. Bands 3 and 5 were positively weighted on this axis, while band 4 is strongly negatively weighted. Band 3 is strongly positively weighted on the second discriminant axis. The mixed forest group sites are restricted to the negative end of the first discriminant axis, reflecting their high band 4 reflectance values. There is very little overlap between the mixed forest and the two conifer groups, with the exception of a single outlier (site 1036). For the two conifer groups, dry conifer sites have the highest weight on the first discriminant axis, while wet conifer sites are weighted higher weighted on the second discriminant axis (corresponding to higher band 3 reflectance values for this group). There is some overlap between the two conifer groups, however, especially sites 1299 (wet conifer) and 1154, 1093 (dry conifer). The separability of the forest vegetation groups on the discriminant plot of the pixel values suggests that a model based on the TM results could be developed.

3.4.3 Discriminant Functions Classification Model

Using the methods outlined in Section 2.6, the following two standardized derived variates were calculated from the multiple discriminant results

$$U_1 = 0.02561(X_1) - 0.03683(X_2) + 0.02069(X_3)$$
$$U_2 = 0.10783(X_1) + 0.01333(X_2) - 0.00884(X_3)$$

where X_1, X_2 and X_3 are reflectance values for TM Bands 3, 4 and 5 respectively. The discriminant functions are:

$$W_{12} = 0.109311(U_1) - 0.297100(U_2) + 0.994587$$
$$W_{13} = 0.710512(U_1) - 0.083675(U_2) + 0.629546$$

For these functions, group assignments are:

dry coniferous if $W_{12} > 0$ and $W_{13} > 0$
wet coniferous if $W_{12} < 0$ and $W_{13} > W_{12}$
mixed forest if $W_{13} < 0$ and $W_{12} > W_{13}$

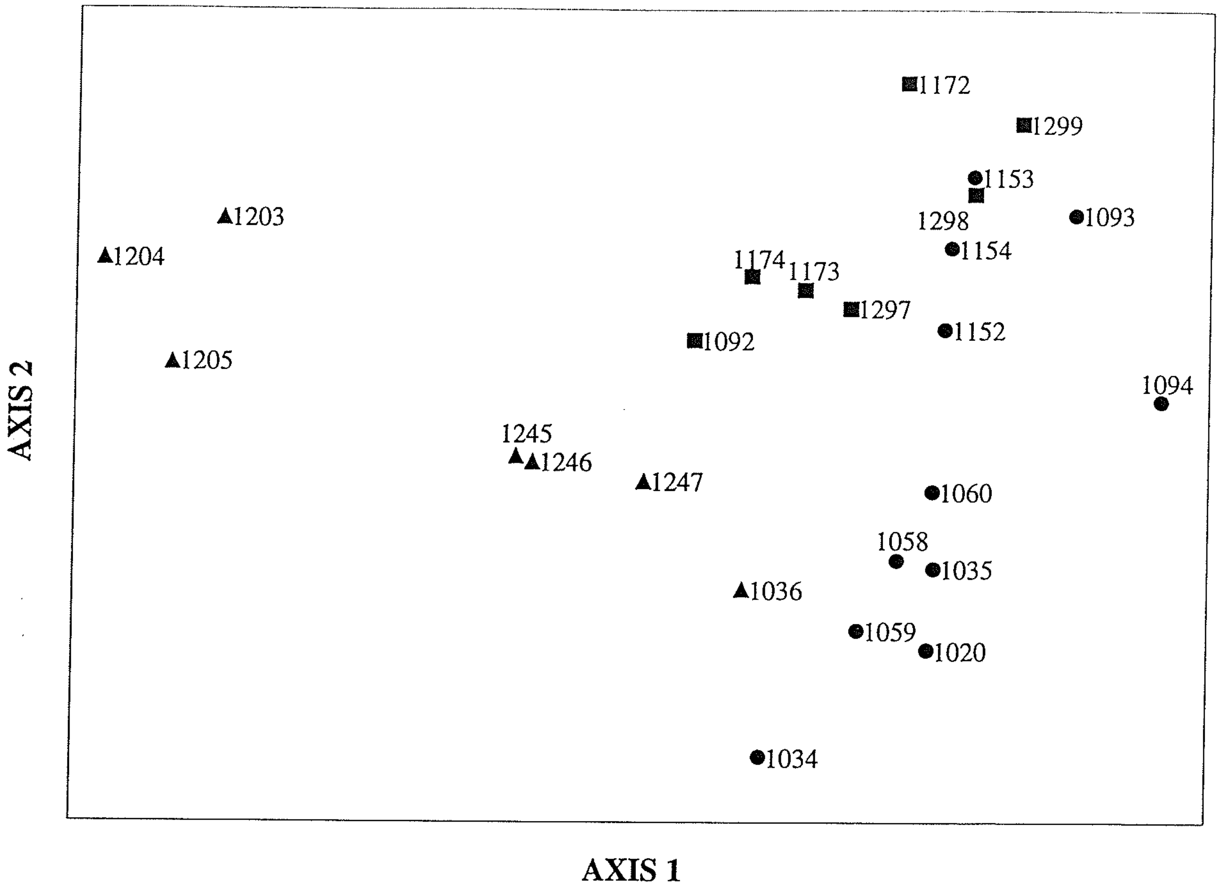


Figure 3.15: Plot of the U scores for the Forest pixel data. The configuration presented is the spherized discriminant weights for the sites on the first two axes. Group affinity is indicated by the shape of the point, Dry Conifer sites (●), Wet Conifer sites (■) and Mixed sites (▲). The tower number for each site is given adjacent to the point.

The squared Mahalanobis distances are calculated as:

Dry conifer: $D^2 = 22\{(-0.158343 - U_1)^2 + (3.120736 - U_2)^2\}$
Wet conifer: $D^2 = 22\{(-0.267654 - U_1)^2 + (3.417829 - U_2)^2\}$
Mixed forest: $D^2 = 22\{(-0.868855 - U_1)^2 + (3.204411 - U_2)^2\}$

with assignment being made to the group for which D^2 is a minimum.

3.4.4 Discriminant Functions Classification: Examples

Example 1: TM band values near the means for the dry coniferous group:

TM Band	3	4	5
Reflectance Value	27	50	45

Note: constants are given in boldface.

$U_1 = \mathbf{0.02561}(27) - \mathbf{0.03683}(50) + \mathbf{0.02069}(45) = \underline{-0.21898}$
$U_2 = \mathbf{0.10783}(27) + \mathbf{0.01333}(50) - \mathbf{0.00884}(45) = \underline{3.18011}$

$W_{12} = \mathbf{0.109311}(-0.21898) - \mathbf{0.2971}(3.18011) + \mathbf{0.994587} = \underline{0.0258}$
$W_{13} = \mathbf{0.710512}(-0.21898) - \mathbf{0.083675}(3.18011) + \mathbf{0.629546} = \underline{0.2079}$

Since W12 > 0 and W13 > 0 assignment to the dry coniferous group is indicated. An alternative to determining group affinity involves computing squared Mahalanobis distances:

Dry conifer $D^2 = 22\{(\mathbf{-0.158343} + 0.21898)^2 + (\mathbf{3.120736} - 3.18011)^2\} = \underline{0.1584}$
$p(X_1|H_1) = 0.9238$

Wet conifer $D^2 = 22\{(\mathbf{-0.267654} + 0.21898)^2 + (\mathbf{3.417829} - 3.18011)^2 = \underline{1.2980}$
$p(X_1|H_2) = 0.5226$

Mixed forest $D^2 = 22\{(\mathbf{-0.868855} + 0.21898)^2 + (\mathbf{3.204411} - 3.18011)^2 = \underline{9.3038}$
$p(X_1|H_3) = 0.0095$

The smallest D^2 is associated with dry conifer, indicating assignment to that group. The Bayesian misclassification probability is $\{1-(0.9238/1.4559)\} = 0.3654$.

<u>Example 2</u>: TM band values near the means for the wet coniferous group:

TM Band	3	4	5
Reflectance Value	29	57	56

Note: constants are given in boldface.

$U_1 = \mathbf{0.02561}(29) - \mathbf{0.03683}(57) + \mathbf{0.02069}(56) = \underline{-0.1980}$
$U_2 = \mathbf{0.10783}(29) + \mathbf{0.01333}(57) - \mathbf{0.00884}(56) = \underline{3.3918}$

$W_{12} = \mathbf{0.109311}(-0.1980) - \mathbf{0.2971}(3.3918) + \mathbf{0.994587} = \underline{-0.0348}$
$W_{13} = \mathbf{0.710512}(-0.1980) - \mathbf{0.083675}(3.3918) + \mathbf{0.629546} = \underline{0.2051}$

Since $W_{12} < 0$ and $W_{13} > 0$ assignment to the wet coniferous group is indicated.
Squared Mahalanobis distances are:

Dry conifer $D^2 = 22\{(\mathbf{-0.158343} + 0.1980)^2 + (\mathbf{3.120736} - 3.3918)^2\} = \underline{1.6522}$
$p(X_2|H_1) = 0.4377$

Wet conifer $D^2 = 22\{(\mathbf{-0.267654} + 0.1980)^2 + (\mathbf{3.417829} - 3.3918)^2\} = \underline{0.1210}$
$p(X_2|H_2) = 0.9413$

Mixed forest $D^2 = 22\{(\mathbf{-0.868855} + 0.1980)^2 + (\mathbf{3.204411} - 3.3918)^2\} = \underline{10.6744}$
$p(X_2|H_3) = 0.0048$

indicating assignment to the wet coniferous group; Bayesian misclassfication = 0.3198.

<u>Example 3</u>: TM band values near the means for the mixed forest group:

TM Band	3	4	5
Reflectance Value	25	72	54

Note: constants are given in boldface.

$U_1 = \mathbf{0.02561}(25) - \mathbf{0.03683}(72) + \mathbf{0.02069}(54) = \underline{-0.8943}$
$U_2 = \mathbf{0.10783}(25) + \mathbf{0.01333}(72) - \mathbf{0.00884}(54) = \underline{3.1782}$

$W_{12} = \mathbf{0.109311}(-0.8943) - \mathbf{0.2971}(3.1782) + \mathbf{0.994587} = \underline{-0.0474}$
$W_{13} = \mathbf{0.710512}(-0.8943) - \mathbf{0.083675}(3.1782) + \mathbf{0.629546} = -\underline{0.2718}$

Since $W_{13} < 0$ and $W_{12} > W_{13}$ assignment to the mixed forest group is indicated.

Squared Mahalanobis distances are:

Dry conifer $D^2 = 22\{(\mathbf{-0.158343} + 0.8943)^2 + (\mathbf{3.120736} - 3.1782)^2\} = \underline{11.9878}$
$p(X_3|H_1) = 0.0025$

Wet conifer $D^2 = 22\{(\mathbf{-0.267654} + 0.8943)^2 + (\mathbf{3.417829} - 3.1782)^2\} = \underline{9.9022}$
$p(X_3|H_2) = 0.0071$

Mixed forest $D^2 = 22\{(\mathbf{-0.868855} + 0.8943)^2 + (\mathbf{3.204411} - 3.1782)^2\} = \underline{0.0286}$
$p(X_3|H_3) = 0.9858$

indicating assignment to the mixed forest group; Bayesian misclassification = 0.010.

3.4.5 Model Verification

The model was first tested by performing an *a posteriori* classification of the 25 sites used in its development (**Table 3.7**). Four of the 25 sites were misclassified. Site 1036 (mixed forest) was classified as a dry coniferous site by the model. This site is unusual in having a dense deciduous shrub cover with a mature jack pine overstory. The other three misclassified sites (1153, 1154 and 1093) all belong to the dry coniferous group, but the model classified them as wet coniferous sites. Some difficulty in distinguishing the two coniferous groups was anticipated, since these two groups overlapped to some extent in discriminant space. This is reflected in the relatively high Bayesian misclassfication probabilities for some of the coniferous sites (**Table 3.7**). The TM reflectance values of the three misclassified conifer sites were more similar to values from wet coniferous sites (**Fig. 3.14**). These three sites were comparatively mesic: sites 1153 and 1154 were mature upland sites dominated by black spruce, while site 1093 was near the banks of the Saskatchewan River.

To test the robustness of the model, TM reflectance values were recorded for 40 randomly selected forest sites along the HVDC ROW. These values were then used to classify each site using the squared Mahalanobis distance. A given site X_j was considered 'unclassifiable' if $p(X_j|H_i) < 0.05$, for all three vegetation groups (i = 1 to g). If the 25 sample sites used in the model are 'representative' of the expected variation in TM reflectance values of forest vegetation, the model should be able to successfully classify most of the 40 randomly selected sites. The 40 site values and classification results are

Table 3.7: Summary of the Mahalanobis distances, probability of belonging and Bayesian misclassification for the sites used in the model. The sites are organized into site class boxes based on their vegetation groups. The Mahalanobis distance from the site to the centroid of each group is given on the first line. The shortest Mahalanobis distance is in bold typeface and represents the predicted group affinity. Underneath each distance measure is the probability of belonging to that group. A Bayesian misclassification probability (1-P(X|m)) for the prediction is given in the column on the right of each site class box.

Dry Coniferous Sites

Site	Dry Con.	Wet Con.	Mix. For.	1-P(X|m)
1020	**1.52**	7.29	12.43	0.057
	0.469	0.026	0.002	
1034	**4.90**	11.49	9.62	0.116
	0.086	0.003	0.008	
1035	**0.51**	4.84	11.29	0.107
	0.775	0.089	0.004	
1058	**0.52**	4.46	9.85	0.130
	0.770	0.107	0.007	
1059	**1.51**	6.45	9.53	0.093
	0.470	0.040	0.009	
1060	**0.06**	2.96	10.44	0.193
	0.972	0.227	0.005	
1093	2.98	**1.79**	17.84	0.356
	0.225	0.408	>0.001	
1094	**1.88**	4.71	21.12	0.196
	0.390	0.095	>0.001	
1152	**0.66**	0.68	10.79	0.499
	0.719	0.713	0.005	
1153	3.21	**0.62**	13.77	0.216
	0.201	0.735	0.001	
1154	1.76	**0.34**	11.76	0.330
	0.414	0.845	0.003	

Wet Coniferous Sites

Site	Dry Con.	Wet Con.	Mix. For.	1-P(X|m)
1092	2.97	**1.48**	3.10	0.480
	0.227	0.476	0.212	
1172	5.72	**0.97**	13.22	0.087
	0.057	0.615	0.001	
1173	1.90	**0.25**	6.23	0.328
	0.387	0.884	0.044	
1174	2.76	**0.50**	4.92	0.302
	0.251	0.777	0.085	
1297	1.26	**0.24**	7.50	0.386
	0.534	0.886	0.024	
1298	2.82	**0.57**	13.54	0.246
	0.244	0.753	0.001	
1299	4.68	**1.47**	16.97	0.167
	0.096	0.481	>0.001	

Mixed Forest Sites

Site	Dry Con.	Wet Con.	Mix. For.	1-P(X|m)
1036	**2.26**	5.67	5.50	0.275
	0.323	0.059	0.064	
1203	22.64	15.63	**2.93**	0.002
	>0.001	>0.001	0.232	
1204	29.12	22.02	**4.76**	>0.001
	>0.001	>0.001	0.093	
1205	23.57	18.84	**2.46**	>0.001
	>0.001	>0.001	0.292	
1245	7.09	6.47	**0.48**	0.080
	0.029	0.039	0.787	
1246	6.53	6.14	**0.65**	0.104
	0.038	0.046	0.724	
1247	3.48	4.22	**2.23**	0.476
	0.176	0.121	0.327	

presented in **Appendix 3 B.** and summarized here:

Group	Number of sites assigned
Dry Coniferous	21
Wet Coniferous	9
Mixed Forest	8
Unclassifiable	2

Only two of the 40 sites could not be assigned to one of the three groups at the $\alpha = 0.05$ probability level, indicating that the model is representative for the Interlake region. One of the unclassified sites was recently burned and had low reflectance values in bands 4 and 5. The other site was a wet fen with high cover of open water, and had high reflectance in band 3.

Chapter 4

Discussion

4.1 Classification and Ordination of Forest Vegetation

Classification

The three forest vegetation groups delineated in this study, which correspond to gradients in soil moisture (wet to dry) and coniferous to deciduous cover, are consistent with previous vegetation studies in boreal forest ecosystems (e.g. Larsen 1980; Lenihan 1993; Arris & Eagleson 1989). The dominance of coniferous species throughout much of the boreal forest is thought to be a function of moisture, temperature and other prevailing climatological conditions (Lenihan 1993).

In central Manitoba, Magnusson & Stewart (1987) found that a wet to dry gradient was important in classifying different associations within peatland communities, while MacLellan (1982) found a distinct separation between of coniferous and deciduous sites. The vegetation groups used in this study were based on tree associations that are typical of the boreal forest in central Manitoba (MacLellan 1982; Lenihan 1993), with the exception of *Thuja occidentalis* which is only found in the The Pas moraine region (Fowells 1965).

Ordination

The ordination results (**Figs. 3.7, 3.9**) clearly indicate significant discrimination among the groups, but also suggest that the group structure represents a partitioning of a continuum of vegetational variation. The group assignments are admittedly utilitarian in objective, though they appear to be robust. There are several outlier sites in both the forest and ROW ordinations. For the forest vegetation, the wet coniferous and mixed forest groups are the most discrete in the ordination space. Several of the dry conifer sites show some overlap with the other two groups. For example, sites 1021 and 1020 are associated with sites from the mixed forest group. This reflects the presence of a measurable cover of *Populus tremuloides* in the forest canopy at these sites (**Appendix 1**). Site 1153 is similar to sites from the wet conifer group, and has a vegetation composition showing overall similarity with that of sites 1172 and 1173.

A high percentage cover of 'non-living' cover-types (e.g. bare ground, open rock) was found at both the ROW and forest sites. Bare ground cover values of the wet conifer group are comparable to those found by Magnusson & Stewart (1987). In this study, forest 'bare ground' values included both humus and partially decomposed necromass. In general, a large proportion was necromass. Bare ground cover was slightly higher on the

ROW, in contrast with the results obtained by De Grandpré *et al.* (1993). However, in this study most of the ROW necromass was undecayed grass culms, which were not a factor in their study.

The reduction in shrub cover on the ROW, with a corresponding increase in monocot cover (**Tables 3.1, 3.2**), is consistent with the 'herbicide climax' (Johnston 1973). Since the herbicide used on the ROW is specific to dicots and conifers, increases in cover of monocot species such as *Cypripedium* spp., *Tofeldia glutinosa*, and *Maianthemum canadense* are likely attributable to herbicide application. A strong decrease in bryophyte and lichen cover was also seen on the ROW. This may be the result of disturbance (Paré *et al.* 1993), herbicide effects, or changing environmental conditions following the removal of tree cover.

Edaphic Factors

The parent material of the Interlake region is limestone, unlike much of the boreal forest in eastern Canada that occurs primarily on granitic substrates. Substrates in the boreal forest regions of Ontario and Québec are characteristically acidic (e.g. Verry & Timmons 1982). The nature of the substrate has important influences on various edaphic features, particularly soil pH. In this study, pH values were generally near neutral (pH = 7.0), only dropping below the pH of rainwater at a few of the wet coniferous (boggy) sites (**Appendix 2**). Similar values were found for the Waterhen region of Manitoba (Fraser *et al.* 1985). Soil pH was generally higher on the ROW than in the adjacent forest (**Table 3.3**), probably due to a decrease in soil organic matter (Kimmins 1987). Soil pH was the most variable of the soil factors measured in this study, but this variation was poorly correlated with vegetation trends (**Figs. 3.8, 3.10**).

On granitic substrates, nutrient-impoverished wet conifer boggy sites tend to have a low conductivity (Verry & Timmons 1982). However, in this study the highest conductivity measures were obtained in the wet coniferous sites; this is attributable to the underlying calcareous parent material (Fraser *et al.* 1985). The other two vegetation groups had low soil conductivity (especially dry coniferous rocky sites), which may reflect weathering and removal of soil ions. The ability of clay particles to attract ions (Kimmins 1987) may account for the intermediate conductivity values in the mixed forest group.

Soil nutrient status in the study area was low, particularly for nitrate-nitrogen and inorganic phosphorus (**Table 3.4**). Soil nitrogen showed no trend between groups, or between forest and ROW sites. Since soil nitrogen occurs in several forms other than nitrate (Kimmins 1987), it is possible that available nitrogen is greater than that measured. The soils of the Waterhen area (Fraser *et al.* 1985) have somewhat higher nitrate values than those measured in this study, but are still comparatively low. Soil phosphate was positively correlated with soil conductivity (highest in wet coniferous sites, lowest in dry coniferous sites). Soil phosphate was higher in the forest than adjacent ROW sites at the dry coniferous, mixed forest and burn sites. Paré *et al.* (1993) found the opposite result, with recently disturbed sites having higher soil phosphate than adjacent forested sites. Soil potassium levels were also low, and were generally higher in the forest than on the adjacent ROW sites.

Percent soil organic matter content was high at most of the wet coniferous sites, reflecting the accumulation of poorly-decomposed *Sphagnum* peat so characteristic of boreal wetlands (Kenkel 1987). High fire frequency and the rocky substrate of dry coniferous sites results in low organic matter accumulation. While organic matter accumulation at the mixed forest sites was also low, a well developed but very thin (2 - 3 cm) organic layer has developed at the soil surface. In general, forest sites had higher soil organic matter content than adjacent ROW sites, in agreement with results obtained by Paré *et al.* (1993).

4.2 VEGETATION CORRELATIONS BETWEEN FOREST AND ROW

4.2.1 Vegetation Change in Species Space

The ordination of the combined forest and ROW vegetation (**Fig. 3.11**) provides a convenient summary of vegetation change between the ROW and forest sites. This method of summarizing vegetation dynamics can lead to the recognition of complex pathways (Bergeron & Dubuc 1989). In this study, measures were taken only once so the pathway is a simple vector connecting the forest and adjacent ROW sites. The relative length of the vector connecting paired forest-ROW sites quantifies the degree of vegetation change following a complex disturbance scenario (e.g. initial tree removal, continued physical disturbance, herbicide application). Mean vector lengths between paired forest-ROW sites were similar for the two coniferous groups, but were much higher for the clay-dominated mixed forest group (**Fig. 3.12**). In contrast, Bergeron & Dubuc (1989), working in the boreal forest of Québec, found that sites on clay soil had similar trajectories to those on morainic deposits. In the present study, greater vegetation change in the mixed forest group likely reflects a change from a well-developed shrub layer in the forest to a virtual absence of these species on the ROW.

In **Fig. 3.11**, the 'spread' in the ordination space of the ROW sites is less pronounced than that of the forest vegetation. This indicates that vegetational variation of the forest vegetation is greater than that on the ROW. Convergence of the ROW vegetation maybe attributable to the development of a 'herbicide climax' along the entire right-of-way.

4.2.2 Mechanisms to Explain the High Correlation between Forest and ROW

This study found a statistically significant correspondence ($R^2 = 0.77$) between ROW sites and adjacent forest sites. It is important to ask what mechanisms allow different vegetation types to occur in each ROW group, while maintaining a high correlation with the forest sites. An obvious similarity between paired forest-ROW sites is correspondence in environmental trends (**Fig. 3.8, 3.10**). The influence of abiotic processes on eco-physiology and vegetation development in the boreal forest has been investigated in terms of both climate (e.g. Arris & Eagleson 1989; Fulton, 1991) and nutrient status (e.g. Lenihan 1993; Paré *et al.* 1993). Collins & Pinder (1990) concluded that vegetation dynamics, and persistence of forb species, are influenced by nutrient status and climate. Since vegetation structure and composition is at least in part a function of environmental conditions, some correspondence of forest and ROW vegetation is to be expected. This is reflected in the similarity in overall species composition for adjacent forest and ROW sites. Except for changes in percent cover, there are relatively few differences in species composition between ROW and forest (**Appendix 1**). This may reflect at least in part a common propagule source (MacLellan 1982; Inouye *et al.* 1987) and vegetation development in accordance to the 'initial floristic composition' model (Egler 1954).

4.2.3 Succession on the ROW

Twenty years after ROW establishment, the vegetation on the right-of-way is qualitatively (if not quantitatively) similar to that of the adjacent forest. This finding lends support to, but is not proof of, an Eglerian model of succession (Egler 1954). Kelertas (1979) felt that both the 'initial floristic composition' and 'relay floristics' models are important in explaining vegetation dynamics of ROWs. The high degree of redundancy between the Forest and ROW vegetation data may also support 'initial floristic composition' as a successional model. Redundancy is a measure of shared information, in a 'relay floristic' succession only a small subset of species exists at any one point in time. Therefore, there should be minimal redundancy between vegetation data collected at different stages of succession. However, in this study the redundancy was 43%, almost half of the vegetational information was shared between the forest and the ROW. In a recent study of boreal forest succession on various surficial deposits, Bergeron & Dubuc (1989) concluded that the Eglerian model, in combination with the 'tolerance' model of succession (Connell & Slatyer 1977), offered a good explanation of vegetation dynamics following disturbance. However, herbicide-arrested succession on ROWs combined with a

Vegetative propagation and propagule germination in disturbed sites along the ROW may be important. For example, *Populus tremuloides* has in recent years been increasing on the wet conifer group ROWs, although it is rare or absent from the adjacent forest. Chance dispersal onto disturbed substrates reflects a stochastic process similar to that described by Horn (1974).

4.3 Tree Recruitment on the ROW

This study found little evidence for the development of a stable shrub community on the ROW as described in some previous studies (e.g. Niering & Goodwin 1974; Pound & Egler 1953). The ROW vegetation in this study is physiognomically similar to that summarized by Bramble *et al.* (1990). These authors found that certain grass-herb combinations inhibited tree seedling germination and development on ROWs. Unlike many other ROW studies, they also quantified tree colonization in terms of density and height classes. However, their study was different from the present study in a number of ways. All species colonizing in their study were hardwoods whose age could be approximated from measured heights. In this study, the majority of the colonizing trees were conifers, and there was little correspondence between tree age and size (**Fig. 3.4**). For example, *Picea mariana* grows slowly and often forms layers that grow at very different rates (Stanek 1961; Morin & Gagnon 1991).

In the following sections, tree recruitment is discussed further for each of the three vegetation groups. Summaries are by vegetation group, since tree recruitment trends in boreal forest are dependent on both environmental (e.g. edaphic) conditions and on the ecology of the colonizing species.

4.3.1 Dry Coniferous

Recruitment at these sites is relatively low. Most of the trees growing on the ROW are *Pinus banksiana*, despite that fact that both it and *Picea mariana* have similar cover in the adjacent forest sites (Table 3.2). This is explained by the greater affinity of *Pinus banksiana* for mineral substrates compared to *Picea mariana* (Bell 1991). While ROW colonization is relatively low, the trees that do establish grow quite rapidly. Forest fires, which release seed from the serotinous cones of *Pinus banksiana* and *Picea mariana*, would greatly increase recruitment on these dry mineral sites; at the three burn sites studies (sites 1113 through 1115), recruitment (mostly *Pinus banksiana*) increased to a maximum of 1060 trees/ha.

At these sites, few individuals of *Pinus banksiana* survived herbicide application, reflecting its low tolerance to herbicides (Bell 1991). Recruitment of *Pinus banksiana* peaked a few years following the application of herbicide, indicating that removal of vegetation cover promotes tree recruitment onto the exposed unvegetated mineral substrates.

4.3.2 Wet Coniferous

Recruitment at these sites is high and dominated by *Picea mariana* (**Fig. 3.3**). The ability of this species to propagate vegetatively through layering probably accounts for its high recruitment on the ROW. Because many of the ROW trees likely developed from layers, the age histograms must be interpreted with caution. For example, the apparent decline in recruitment in recent years may be spurious, since young layers not fully independent of the parent plant and would be classified as branches in the field. That is, a layer is not considered to be independent (or even partially independent) until it produces roots, by which time several growth rings are usually present in the branch stem. As a result, the peak in frequency of individuals 4 - 6 years of age may simply reflect the average time required for a tree branch to become a layered individual.

V-blading can result in an apparent increase in *Picea mariana* recruitment by 'releasing' layered branches from apical dominance of the parental main stem (**Fig. 4.1**). The large number of survivors from recent V-blading at site 1173 underscores this point. The two species that dominated following blading (*Picea mariana* and *Thuja occidentalis*) both layer prolifically (Fowells 1965).

Picea mariana is relatively tolerant of most herbicides (Bell 1991), and as a result a number of older trees are present along the ROW even after herbicide application (**Figs. 3.3, 3.4**).

4.3.3 Mixed Forest

Site recruitment is relatively high and in recent years has been dominated by *Populus tremuloides*, although a number of individuals of *Picea mariana* that survived herbicide application are found (**Fig. 3.5**). *Populus tremuloides*, which has a high affinity for clay-rich sites, produces prolific root suckers that can grow to several meters in a single season (Bell 1991). An apparent decline in recruitment of this species (Fig. 3.5) may be an artifact, reflecting the difficulty in accurately aging this species by counting growth rings (Peterson & Peterson 1992). Recruitment of *Picea mariana* has declined since the last herbicide application, which may reflect increased interspecific competition, the 'smothering' effect of increased leaf litter (Bell 1991), or the limited ability of the species to layer on clay substrates. It seems likely that many of the older individuals of this species are layers released following herbicide application or V-blading.

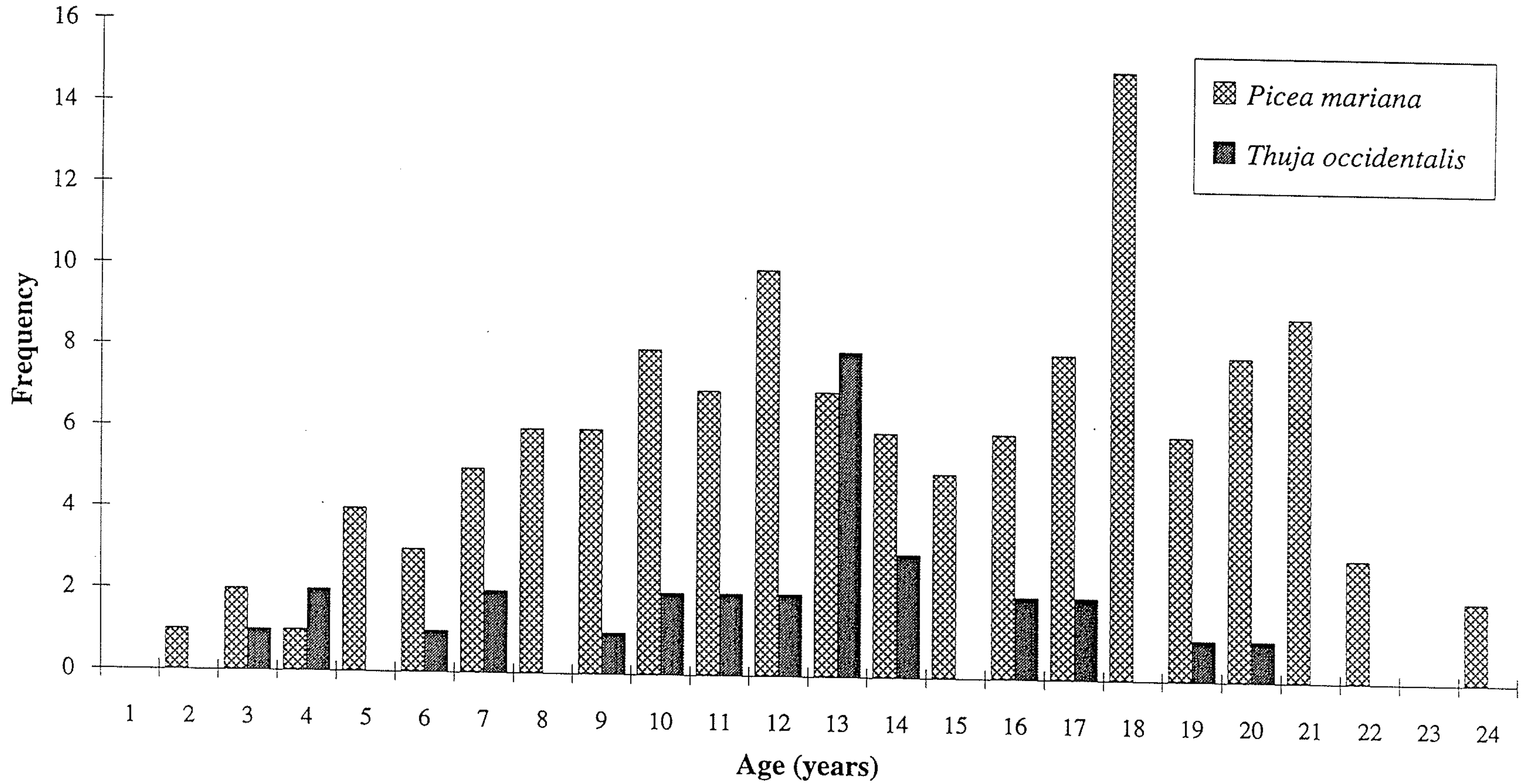


Figure 4.1: The recruitment of trees onto the ROW at 1173 data was collected in a 20 m × 40 m quadrat. This site was bladed during the winter of 1992 to 1993. The data was collected during the summer of 1993. Survivorship of *Picea mariana* and *Thuja occidentalis* was quite high, both species layer readily.

As with the other two groups, some individuals of *Picea mariana* are herbicide tolerant. A few individuals of *Populus tremuloides* apparently survived herbicide application, but the vast majority have colonized the ROW following the last herbicide application. Recruitment of both *Pinus banksiana* and *Populus balsamifera* also increased following herbicide application.

4.4 CLASSIFICATION MODEL

4.4.1 Comparison with Other Approaches

Techniques based on a supervised classification were used in this study to analyse the LANDSAT TM images. Such an approach is commonly used because it is rapid and generates classes with known vegetation characteristics (Chuvieco & Congalton 1988). A supervised classification approach has been used to classify forest cover types in both Minnesota and Wisconsin (Moore & Bauer 1990; Bolstad & Lillesand 1992). A disadvantage of the approach is that the groups so derived are often composed of several spectral classes (Chuvieco & Congalton 1988), and for this reason many LANDSAT studies begin with an unsupervised classification (e.g. Stenback & Congalton 1990; Fiorella & Ripple 1993a,b). The obvious disadvantage of an unsupervised approach is a lack of information on vegetation variability; it is conceivable that different vegetation types could have similar spectral reflectance characteristics.

The spectral combination of LANDSAT bands 3, 4 and 5 has been shown to be a good combination for vegetation classification. Stenback & Congalton (1990) compared several three-band combinations and found that the band 3-4-5 combination gave an overall satisfactory classification of both overstory and understory vegetation.

The results of this study demonstrate statistically significant discrimination between forest vegetation groups, and a high correlation between forest and adjacent ROW vegetation. Furthermore, information on tree recruitment and maintenance recommendations can be derived for the three groups. Thus a supervised classification based on the actual forest vegetation was preferable to one produced using only spectral reflectance values (Chuvieco & Congalton 1988).

4.4.2 Model Development

No single spectral reflectance band was able to successfully discriminate among all three forest vegetation groups (**Fig. 3.14**). A multivariate discriminant analysis approach was better able to distinguish the groups, indicating that each spectral reflectance band contains unique information that is useful in discriminating the vegetation. Even so, there are a few site misclassifications in the discriminant model. This is to be expected given that the classification was based on vegetation data, whereas the discriminant model was based on TM band reflectance values (Mather 1987). However, the misclassification rate in this study was low, suggesting a close correspondence between TM spectral reflectances (bands 3, 4 and 5) and boreal forest vegetation in the Interlake region of Manitoba.

Three of the four misclassified sites (1153, 1154 and 1093) were in the dry conifer group, but the discriminant model classified them as belonging to the wet conifer group (though misclassfication probabilities were high). All three were mesic upland sites containing older jack pine and/or black spruce, and showed some affinity to the wet conifer group (**Fig. 3.15**). The LANDSAT TM image in the region of site 1093 has an almost 'pastey' colouration, perhaps attributable to low thin cloud cover. This may have affected the band values for the site. The other misclassified site was 1036 (mixed forest, but classified as a dry coniferous site). While this site contained deciduous shrubs and trees, it also had an overstory of mature jack pine that may have affected spectral reflectance.

In general, the model is able to successfully distinguish between deciduous and coniferous sites, and between dry jack pine forest and boggy black spruce sites. However, mesic sites containing mature upland black spruce and/or jack pine stands are more difficult to classify. Fiorella & Ripple (1993b) found that old-growth forest images tend to have greater shadow contrast than even-aged mature stands, and that this results in spectral band convergence. In Manitoba boreal forest, Dixon *et al.* (1984) also found that it was difficult to separate upland black spruce forest from other conifer types.

4.4.3 Model Verification and Improvement

Model verification was undertaken by classifying an independent random sample of 40 sites. Only two sites did not fit into one of the three vegetation classes at the $\alpha = 0.05$ level, suggesting that the 25 sites used in model development are representative of the vegetational variation found in the study area. The model was not developed to include disturbed sites, and as a result cannot therefore classify burned or clear-cut sites.

A number of strategies could be used in an attempt to improve the model. These include the use of a relational database in a GIS program (e.g. Bolstad & Lillesand 1992), increasing the sample size (number of sites), and using additional LANDSAT TM bands.

4.4.4 Management Implications and Recommendations

Based on the results of this study, an overall management framework is proposed for right-of-ways in the Interlake region (**Fig. 4.2**). The first step involves obtaining Landsat TM spectral values for bands 3, 4 and 5. These three values can then be entered into the

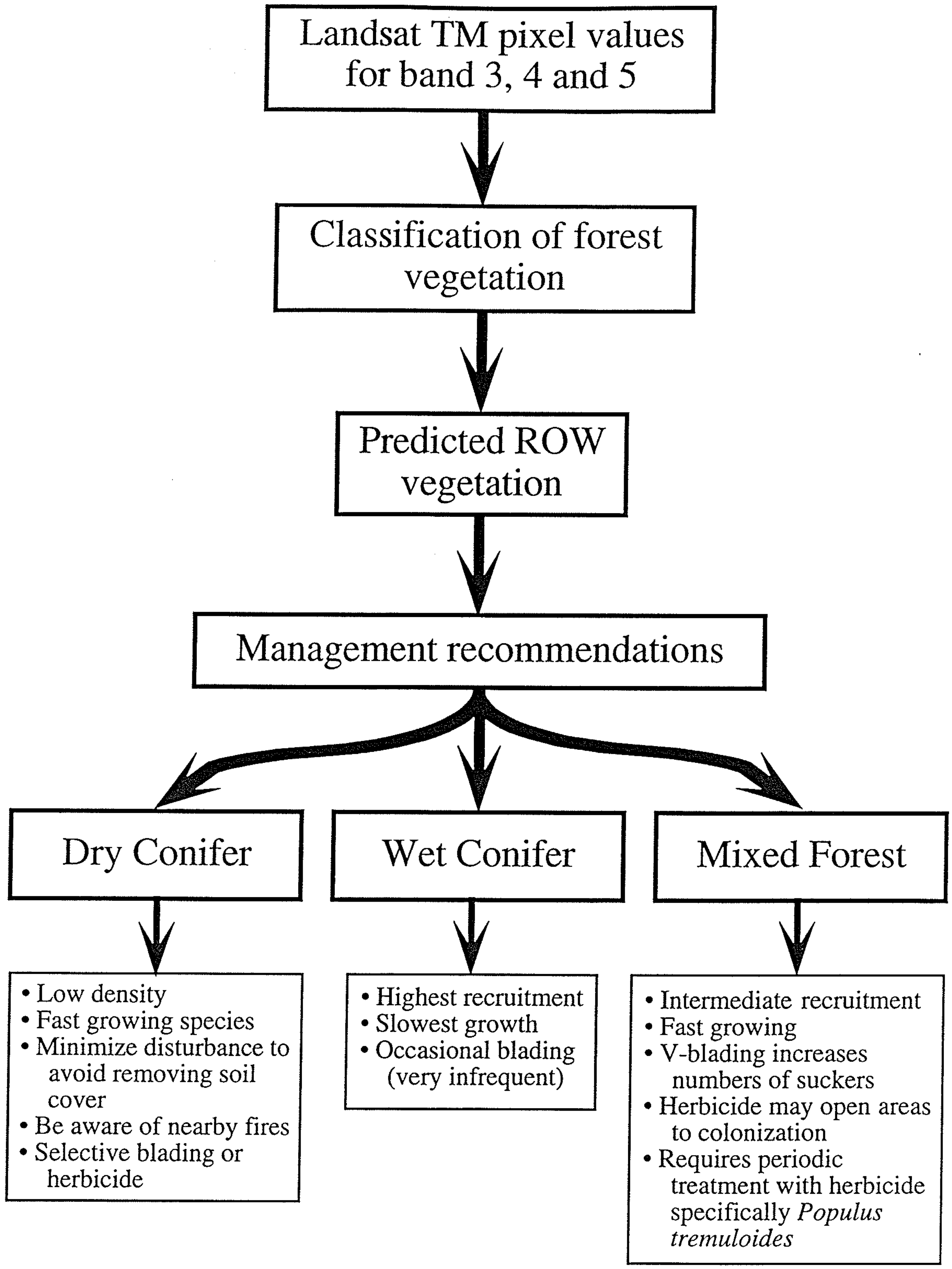


Figure 4.2: A brief synopsis of the ROW vegetation predictive model as presented in this paper. The major characteristics of each group are presented and the suggested maintenance proceedure required to remove the trees.

discriminant classification model to determine its probable vegetation group designation. The following ROW management recommendations for the three vegetation groups are based on the vegetation survey results of this study:

Dry Coniferous

Although tree recruitment onto the ROW is low for this vegetation group, individuals are relatively fast-growing, particularly *Pinus banksiana* . Based on age-height correlations for jack pine, a treatment frequency of 15-20 years is recommended. Given the relatively low stem density and larger stature of recruiting trees, spot application of herbicide at the base of each tree is recommended (c.f. Nowak *et al.* 1992). Broadcast spraying of herbicide is not recommended, as this kills the extant vegetation and promotes establishment of tree seedlings (particularly jack pine) on the exposed mineral substrates. Winter V-blading is another option, but care should be exercised so as to avoid disturbing the substrate and exposing mineral soils on which tree seedlings will establish. If the forest adjacent to a dry coniferous group ROW is burned, a complete V-blade treatment should be considered after 8 to 12 years to remove jack pine trees that germinated immediately following the fire.

Wet Coniferous

Tree density on the ROW of this vegetation group is high, but dominated by slow-growing individuals (mostly *Picea mariana*). Because tree growth is slow at these sites, treatment of ROW vegetation should only be required every 25-30 years. The whole area should be winter V-bladed, but care should be taken that the blade does not come into contact with the surface soil. It should be noted that V-blading is unlikely to remove individual trees, since the remaining lower branches of a tree will simply form new individuals (clones) through layering. However, V-blading will effectively remove taller individuals that interfere with hydroelectric transmission. Herbicide use in wet conifer sites is not recommended. Herbicide has little if any impact on *Picea mariana*, and may promote the invasion of *Pinus banksiana* and *Populus tremuloides* on the exposed soil surfaces.

Mixed Forest

Tree recruitment on the ROW is relatively high for this group, but tends to be patchy. Local areas of *Populus tremuloides* occur at high density, usually adjacent to the forest and likely established through root suckering. Herbicide should be applied locally to these aspen patches to prevent their spreading. Broadcast spraying of herbicide over the entire row is not recommended, since this simply promotes the establishment of grasses that are not resistant to further aspen invasion (a broadcast herbicide treatment also promotes the establishment of *Pinus banksiana* and *Populus balsamifera*, **Fig. 3.5**). To minimize aspen encroachment, a closed vegetation cover of low deciduous shrubs should be promoted by limiting herbicide use. Winter V-blading should be discouraged in mixed forest sites, as it promotes prolific sucker development in trembling aspen (Bell 1991).

Chapter 5

Summary and Conclusions

1. The boreal forest vegetation adjacent to the Manitoba Hydro HVDC line in the Interlake region, Manitoba was classified into three broad vegetation groups: (a) dry coniferous, upland stands dominated by jack pine and/or black spruce; (b) wet coniferous, poorly drained lowlands dominated by black spruce and larch; and (c) mixed forest, with a mixed coniferous-deciduous canopy and a deciduous shrub understory.

2. Ordination (using detrended correspondence analysis) was able to appreciably reduce the dimensionality of the vegetation data while retaining a significant discrimination between the three vegetation groups.

3. The three vegetation groups, delineated using species composition in the forest, appeared to correspond closely to the vegetation of the adjacent ROW. This was confirmed using canonical correlation analysis, which demonstrated a statistically significant linear relationship ($R^2 = 0.77$, $p < 0.01$) between the forest and ROW vegetation data sets. From this result, it was concluded that the ROW vegetation and tree recruitment could be predicted based on knowledge of the adjacent forest vegetation.

4. The three vegetation groups had very different tree recruitment dynamics. ROW sites of the dry coniferous group had a low recruitment rate, and overall tree density was low (mean = 587 trees/ha). The dominant species on the ROW is *Pinus banksiana* (jack pine). Wet coniferous ROW sites had the highest overall recruitment rates, and the highest tree density (mean = 2471 trees/ha). These sites are dominated by slow-growing *Picea mariana* individuals. This species is able to propagate vegetatively through a process known as branch layering, which may account for its high recruitment. Tree recruitment in the mixed forest ROW sites was dominated by *Populus tremuloides*, which probably invades ROW sites primarily by the vegetative propagation method of root suckering. Recruitment density is relatively high (mean = 1136 trees/ha). Evidence from recently burned sites indicates a dramatic increase in recruitment of *Pinus banksiana* onto the ROW.

5. LANDSAT TM spectral reflectances differed between the three vegetation groups. Band 3 (red light) showed the least variability, bands 4 (near infrared) and 5 (middle infrared) the greatest. Multiple discriminant analysis of the three vegetation groups, based on spectral reflectances in the three bands, was statistically significant.

6. A discriminant classification model was developed. It utilizes the Mahalanobis distance to classify sites into one of the three vegetation groups, based on observed spectral reflectance values in LANDSAT TM bands 3, 4 and 5. The model was able to correctly classify 21 of the 25 sites used in the discriminant analysis. A test of model robustness was made by classifying an additional 40 randomly selected sites. All but two of these sites were successfully classified ($\alpha > 0.05$) by the model. Based on this result, it was concluded that the original 25 sites used in model development are representative of forest-ROW vegetation in the Interlake region of Manitoba.

7. Based on the findings of this study, it is concluded that vegetation cover and tree recruitment on the Manitoba Hydro right-of-ways in the Interlake region can be successfully predicted from LANDSAT TM spectral reflectance data. The classification model presented, in combination with tree recruitment dynamics for each vegetation group, can be used to predict line maintenance requirements for extant and proposed Hydro developments.

References

Andrejko, M. J., F. Fiene and A. D. Cohen. 1983. Comparison of Ashing Techniques for Determination of the Inorganic Content of Peats. In: Testing of Peats and Organic Soils. P. M. Jarrett (Ed.). ASTM Special Technical Publications. Philadelphia, Pa. 241 pages.

Arris, L.L. & P.S. Eagleson. 1989. Evidence of a physiological basis for the boreal-deciduous forest ecotone in North America. Vegetatio 82: 55-58.

Barrett, E.C. & L.F. Curtis. 1992. Introduction to environmental remote sensing. Third edition. Chapman & Hall, New York. 426 pages.

Bell, F.W. 1991. Critical silvics of conifer crop species and selected competitive vegetation in northwestern Ontario. Canada-Ontario Forest Resource Development Agreement Technical Report No. 19. Northwestern Ontario Forest Technology Development Unit. Thunder Bay, Ontario. 177 pages.

Bergeron, Y. & M. Dubuc. 1988. Succession in the southern part of the Canadian boreal forest. Vegetatio 79: 51-63.

Bolstad, P.V. & T.M. Lillesand. 1992. Improved classification of forest vegetation in northern Wisconsin through a rule-based combination of soils, terrain, and LANDSAT Thematic Mapper data. Forest Science 38: 5-20.

Bramble, W.C., W.R. Byrnes & R.J. Hutnik. 1990. Resistance of plant cover types to tree seedling invasion on an electric transmission right-of-way. Journal of Arboriculture 16: 130-135.

Budd, J.T.C. 1991. Remote sensing techniques for monitoring land-cover. Pages 33-59 In: Monitoring for conservation and ecology. Goldsmith, F.B. (ed.). Chapman & Hall, New York.

Burchill, C. 1991. Vegetation-environment relationships of an inland boreal salt pan. M.Sc. thesis, University of Manitoba, Wiinipeg, Manitoba.

Cavers, P.B. and D. C. Benoit. 1989. Seed banks in arable land. In: Ecology of Soil Seed Banks. M. A. Leck, V. T. Parker and R. L. Simpson (Eds.). Academic Press Inc. Toronto. 462 pages.

Chuvieco, E. & R.G. Congalton. 1988. Using cluster analysis to improve the selection of training statistics in classifying remotely sensed data. Photogrammetric Engineering and Remote Sensing 54: 1275-1281.

Collins, B.S. & J.E. Pinder. 1990. Spatial distribution of forbs and grasses in a South Carolina oldfield. Journal of Ecology 78: 66-76.

Collins, B.S. & S.T.A. Pickett. 1988. Demographic responses of herb layer species to experimental canopy gaps in a northern hardwoods forest. Journal of Ecology 76: 437-450.

Connell, J. H. & R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. The American Naturalist 111: 1119-1144.

Darby, W.R. 1990. Testing predictions of habitat suitability for White-tail deer derived from Landsat MSS imagery. Ph.D. Thesis. University of Manitoba. 213 pages.

De Grandpré, L., D. Gagnon & Y. Bergeron. 1993. Changes in the understory of Canadian southern boreal forest after fire. Journal of Vegetation Science 5: 803-810.

Dixon, R. & J.M. Stewart. 1984. Peatland inventory of Manitoba. I. The Pas using LANDSAT. Manitoba Natural Resources Surveys and Mapping, Winnipeg, Manitoba. 32 pages.

Dixon, R. & J.M. Stewart. 1986. Peatland Inventory of Manitoba. II. South-east Manitoba using LANDSAT. Manitoba Natural Resources Surveys and Mapping, Winnipeg, Manitoba. 53 pages.

Dixon, R. & J.M. Stewart. 1988. Peatland Inventory of Manitoba. III. Interlake Region using LANDSAT. Manitoba Natural Resources Surveys and Mapping, Winnipeg, Manitoba. 22 pages.

Dixon, R., W. Shipley & A. Briggs. 1984. LANDSAT: a tool for mapping fuel types in the boreal forest of Manitoba: a pilot study. Manitoba Natural Resources, Surveys and Mapping. Winnipeg, Manitoba. 33 pages.

Drury, W.H. and I.C.T. Nisbet. 1973. Succession. Journal of the Arnold Arboretum Harvard University. 54: 331-368.

Egler, F.E. 1954. Vegetation science concepts. I. Initial floristic composition: a factor in old field vegetation development. Vegetatio 4: 412-417.

Ethier, D.W. 1979. Successional developments following vegetation control on Hydro rights of way. Ontario Hydro, Northwestern Region. Thunder Bay, Ontario. 26 pages.

Everitt, J.H. & A.J. Richardson. 1987. Canopy reflectance of seven rangeland plant species with variable leaf pubescence. Photogrammetric Engineering and Remote Sensing 53: 1571-1575.

Fiorella, M. & W. Ripple. 1993a. Analysis of conifer forest regeneration using LANDSAT Thematic Mapper data. Photogrammetric Engineering and Remote Sensing 59: 1383-1388.

Fiorella, M. & W. Ripple. 1993b. Determining successional stage of temperate coniferous forests with LANDSAT satellite data. Photogrammetric engineering and remote sensing 59: 239-246.

Fowells, H.A. 1965. Silvics of forest trees of the United States. Agriculture Handbook No. 271. Division of Timber Management Research, Forest Service, Washington, D.C. 762 pages.

Fraser, W.R., L.A. Hopkins, R.E. Smith, A. LeSann & G.F. Mills. 1985. Soils of the Waterhen area. Manitoba Department of Agriculture. Winnipeg, Manitoba. 136 pages.

Fulton, M.R. 1991. Simulation modeling of the effects of site conditions and disturbance history on a boreal forest landscape. Journal of Vegetation Science 2: 603-612.

Gittins, R. 1985. Canonical analysis. A review with applications in ecology. Springer, Berlin. 351 pages.

Hill, M.O. & H.G. Gauch. 1980. Detrended correspondence analysis, an improved ordination technique. Vegetatio 42: 47-58.

Hill, M.O. 1973. Reciprocal averaging: a neglected method of ordination. Journal of Ecology 61: 237-249.

Horn, H.S. 1975. The ecology of secondary succession. Annual Review of Ecology and Systematics 5: 25-37.

Houston, M. & T. Smith. 1987. Plant succession: life history and competition. The American Naturalist 130: 168-198.

Huete,A.R., D.F. Post & R.D. Jackson. 1984. Soil spectral effects on 4-space vegetation discrimination. Remote Sensing of Environment 15: 155-165.

Inouye, R.S., N.J. Huntly, D. Tilman, J.R. Tester, M. Stillwell & K.C. Zinnel. 1987. Old-field succession on a Minnesota sand plain. Ecology 68: 12-26.

Jackson, R.D. 1983. Spectral indices in n-space. Remote Sensing of Environment 13: 409-421.

Jackson, R.H. & L.E. Hudman. 1978. Assessment of the environmental impact of high voltage transmission lines. Journal of Environmental Management 6: 153-170.

Johnston, P.A. 1973. Ecological effects of herbicide sprayings in shaping plant communities on transmission line rights-of-way. M.Sc. thesis, West Virginia University, Morgantown, VA. 197 pages.

Keddy, P.A. 1991. Competition. Chapman & Hall, London. 202 pages.

Kelertas, R.A. 1979. Shrub stability in utility rights-of-way under selective vegetation management techniques. Ontario Hydro, Dept. of Transmission Environment. 7 pages.

Kenkel, N.C. & Orlóci, L. 1986. Applying metric and nonmeteric multidimensional scaling to ecological studies: some new results. Ecology 67: 919-928.

Kenkel, N.C. 1987. Trends and interrelationships in boreal wetland vegetation. Canadian Journal of Botany 65: 1-22.

Kenkel, N.C. 1988. Pattern of self-thinning in jack pine: testing the random mortality hypothesis. Ecology 69: 1017-1024.

Kimmins, J.P. 1987. Forest Ecology. Macmillan, New York. 531 pages.

Klassen, R.W. 1966. Surficial Geology of the Waterhen-Grand Rapids area, Manitoba. Paper 66-36. Geological Survey of Canada, Department of Energy Mines and Natural Resources. Winnipeg, Manitoba. 6 pages.

Kleman, J. 1987. Directional reflectance factor distributions for two forest canopies. Remote Sensing of Environment 23: 83-96.

Kshirsagar, A.M. & E. Arseven. 1975. A note on the equivalency of two discrimination procedures. The American Statistician 29: 38-39.

Kuiper, F.K. & L. Fisher. 1975. A Monte Carlo comparison of six clustering procedures. Biometrics 31: 777-783.

Larsen, J.A. 1980. The boreal ecosystem. Academic Press, New York. 500 pages.

Lenihan, J. M. 1993. Ecological response surfaces for North American boreal tree species and their use in forest classification. Journal of Vegetation Science 4: 667-680.

MacLellan, P. 1982. Floristic variation along the HVDC transmission line right-of-way in Mantioba. M.Sc. thesis, University of Manitoba. 181 pages.

Magnusson, B. & J.M. Stewart. 1987. Effects of disturbances along hydroelectrical transmission corridors through peatlands in northern Manitoba, Canada. Arctic and Alpine Research 19: 470-478.

Markon, C. 1992. Land cover mapping of the upper Kuskokwim resource management area, Alaska, using LANDSAT and a digital data base approach. Canadian Journal of Remote Sensing 18: 62-71.

Mather, P. 1987. Computer processing of remotely-sensed images. An introduction. John Wiley & Sons, Toronto. 352 pages.

Matlack, G.R., D.J. Gibson & R.E. Good. 1993. Clonal propagation, local disturbance, and the structure of vegetation: eicaceous shrubs in the Pine barrens of New Jersey. Biological Conservation 63: 1-8.

Matthes-Sears & D. Larson. 1991. Growth and physiology of *Thuja occidentalis* L. from cliffs and swamps: Is the variation habitat or site specific? Botanical Gazette. 152: 500-508.

McRae, S. G. 1988. Practical Pedology. Ellis Horwood Ltd. Toronto pp. 253.

Moore, M.M. & M.E. Bauer. 1990. Classification of forest vegetation in north-central Minnesota using LANDSAT multispectral Scanner and thematic Mapper Data. Forest Science 36: 330-342.

Morin, H. & R. Gagnon. 1992. Comparative growth and yield of layer- and seed-origin black spruce (*Picea mariana*) stands in Québec. Canadian Journal of Botany 22: 465-473.

Morrison, D.F. 1990. Multivariate statistical methods. Third edition. McGraw-Hill, New York. 495 pages.

Niering, W.A. & R.A. Goodwin. 1974. Creation of relatively stable shrublands with herbicides: arresting "succession" on rights-of-way and pastureland. Ecology 55: 784-795.

Niering, W.A. 1958. Principles of sound right-of-way vegetation management. Economic Botany 12: 140-144.

Noble, I.R. & R.O. Slatyer. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43: 5-21.

Nowak, C.A., L.P. Abrahamson, E.F. Neuhauser, C.G. Foreback, H.D. Freed, S.B. Shaheen and C.H. Stevens. 1992. Cost effective vegetation management on a recently cleared electric transmission line right-of-way. Weed Technology: 826-837.

Odum, E.P. 1969. The strategy of ecosystem development. Science 164: 262-270.

Orlóci, L. 1967. An agglomerative method for classification of plant communities. Journal of Ecology 55: 193-215.

Orlóci, L. 1978. Multivariate analysis in vegetation research. Junk, The Hague. 451 pages.

Paré, D., Y. Bergeron & C. Camiré. 1993. Changes in the forest floor of Canadian southern boreal forest after disturbance. Journal of Vegetation Science 4: 811-818.

Perry, C.R. & L.F. Lautenschlager. 1984. Functional equivalence of spectral vegetation indices. Remote Sensing of Environment 14: 169-182.

Peterson, D.L. & S.W. Running. 1989. Applications in forest science and management. Pages 429-465 In: Asrar, G. (ed.). Theory and applications of optical remote sensing. John Wiley & Sons, Toronto.

Peterson, E.B. & N.M. Peterson. 1992. Ecology, management, and use of aspen and balsam poplar in the prairie provinces. Northwest Region Special Report No. 1. Northern Forestry Centre, Forestry Canada. 252 pages.

Podani, J. 1989. SYNTAX-IV. Computer programs for data analysis in ecology and systematics on IBM-PC and Macintosh computers. ICEM, Trieste, Italy.

Pound, C.E. & F.E. Egler. 1953. Brush control in southeastern New York: fifteen years of stable tree-less communities. Ecology 34: 63-73.

Ranson, K.J. & D.L. Williams. 1992. Remote sensing technology for forest ecosystem analysis. Pages 267-290 In: Shugart, H.H., R. Leemans and G.B. Bonan (eds.). A Systems Analysis of the Global Boreal Forest. Cambridge University Press, New York.

Rencz, A.N. 1985. Multitemporal analysis of LANDSAT imagery for monitoring forest cutovers in Nova Scotia. Canadian Journal of Remote Sensing 11: 188-191.

Revel, R.D., T.D. Doughert. & D.J. Downing. 1984. Forest frowth and revegetation along seismic lines. University of Calgary Press, Calgary. 228 pages.

Rowe, J.S. 1956a. Uses of undergrowth plant species in forestry. Ecology 37: 461-473.

Rowe, J.S. 1956b. Vegetation of the southern boreal forest in Sasketchewan and Manitoba. Ph. D. thesis, University of Manitoba. Winnipeg, Manitoba.

Scoggan, H.J. 1979. Flora of Canada. National Museum of Canada. Ottawa, Canada.

Sims, R.A. 1977. Aspects of plant community relationships for selected peatland transmission line right-of-way plots in mid-Manitoba. M.Sc. thesis, University of Manitoba. Winnipeg, Manitoba.

Sonneveld, C. & J. van den Ende. 1971. Soil analysis by means of a 1:2 volume extract. Plant and Soil 35: 505-516.

Stanek, W. 1961. Natural layering of black spruce in northern Ontario. Forestry Chronicle 37: 245-258.

Stenback, J.M. & R.G. Congalton. 1990. Using thematic mapper imagery to examine forest understory. Photogrammetric Engineering and Remote Sensing 56: 1285-1290.

Tatsuoka, M.M. 1971. Multivariate analysis: techniques for educational and psychological research. J. Wiley and Sons, New York. 310 pages.

Ter Braak, C.J.F. 1987. The analysis of vegetation-environment relationship by canonical correspondence analysis. Vegetatio 69: 69-77.

Thomas, I.L., V.M. Benning & N.P. Ching. 1987. Classification of remotely sensed images. Adam Hilger, Bristol. 268 pages.

Thompson, K. and J. P. Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. Journal of Ecology. V. 67: 893 - 921.

Thomson, K.P.B., C. Gosselin, B.W. Adams & I. Sutherland. 1985. Thematic mapper data used for rangeland management in rough fescue grasslands in western Canada. Canadian Journal of Remote Sensing 11: 162-175.

Tilman, D. 1985. The resource-ratio hypothesis of plant succession. The American Naturalist 125: 827-852.

Treitz, P. M., P.J. Howarth, R.C. Suffling & P. Smith. 1992. Application of detailed ground information to vegetation mapping with high spatial resolution and digital imagery. Remote Sensing of Environment 42: 65-82.

Treitz, P.M. & P.J. Howarth. 1985. The capabilities of two airborne multispectral sensors for classifying coniferous forest species. 19th International Symposium on Remote Sensing of Environment. Ann Arbor Michigan, Oct. 21-25, 1985. Pages 335-350.

Ustin, S.L., M.O. Smith & J.B. Adams. 1993. Remote sensing of ecological processes: a strategy for developing and testing ecological models using spectral mixture analysis. Pages 339-357 In: J.R. Ehleringer and C.B. Field (eds.). Scaling Physiological Processes: Leaf to Globe. Academic Press, San Diego.

Verry, E.S. & D.R. Timmons. 1982. Waterborne nutrient flow through an upland-peatland watershed in Minnesota. Ecology 63: 1456-1467.

Ward, J.H. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association 58: 236-244.

Weir, T.R. 1983. Manitoba Atlas. D.W. Friesen and Sons. Ltd. Altona, Mb. 157 pages.

Wickland, D.E. 1991. Mission to planet earth: the ecological perspective. Ecology 72: 1923-1933.

Yang, K.C. & G. Hazenberg. 1991. Sapwood and heartwood width relationship to tree age in *Pinus banksiana*. Canadian Journal of Forest Research 21: 521-525.

Appendices

Appendix 1 A: The average species cover for the forest sites, organized by group affinities. This is the data set used in the vegetation analyses.

Forest Species	Dry Coniferous												Wet Coniferous								Mixed Forest							Burn Sites		
	1020	1021	1034	1035	1058	1059	1060	1093	1094	1152	1153	1154	1022	1092	1172	1173	1174	1297	1298	1299	1036	1203	1204	1205	1245	1246	1247	1113	1114	1115
Alnus rugosa																						5.5			30.8	5.3	7.3			
Alnus crispa			0.2										8.0	0.2					0.5											
Amelanchier alnifolia	4.3	2.0	0.4	1.8		0.2		1.3	1.6	0.1												1.8	4.3	0.6	9.9	7.0	14.6		0.1	
Apocynum androsaemifolium	0.3							0.2	0.9													0.8	0.4		0.2		0.1			
Aralia nudicaulis	0.2													1.0								0.2	3.0	2.3	9.1					
Arctostaphylos alpina										0.1	0.4				1.1	1.9	2.0													
Arctostaphylos uva-ursi	17.9	8.2	5.1	10.9	21.7	19.9	19.5	29.6	35.7	2.2	20.3	3.0		2.0	1.5	8.2	0.4						2.1	0.3	0.8	0.8		0.4		
Aster spp.			0.1									0.1		0.1									0.1							0.2
Bare Ground	23.1	17.0	18.4	2.0	7.2	18.8	12.4	45.5	30.1	8.0	10.7	0.6	53.4	5.5	22.8	3.9	4.7	12.0	17.1	15.0	41.3	33.1	53.3	63.0	22.1	47.6	42.6	15.3	52.0	32.6
Betula glandulosa										0.1	4.2			5.3	2.6	6.8	1.5	9.8	14.3	7.6										
Betula papyrifera							0.5	0.4	3.0					0.3														0.2		
Carex spp.		0.3						0.5		1.0	8.7	0.5		3.0	0.8	0.2	1.8	1.6	6.4	11.3								0.9	0.3	0.8
Chamaedaphne calyculata															0.7	0.1			0.3											
Cladina spp.	1.3	1.5	3.4	11.5	25.0	12.0	29.8	0.7	0.3	19.3	37.3	41.2	1.3		3.5	5.8	0.1	2.6												
Comandra umbellata		0.2						0.1					1.1																	
Cornus canadensis		5.1						0.6		0.4	2.3	0.2	1.3	2.6	0.4		3.1				4.0	0.9	1.9	2.4	2.3	2.9	1.6	0.2		
Cornus stolonifera		0.2					0.1	1.8	0.3					1.9									0.3							
Corylus cornuta																											6.5			
Necromass-Wood	0.8	3.7	7.2	9.5	8.3	1.3	4.0	4.5	11.8	8.9	5.7	12.3	10.1	4.1	1.2	9.6	1.8	7.9	15.9	1.6	1.5	2.3	6.7	3.9	5.4	7.3	2.8	13.5	12.2	32.0
Empetrum nigrum																		1.0												
Epilobium angustifolium		0.8																					0.1	0.3				9.3	7.4	18.7
Fragaria virginiana		0.6										0.4		0.2			0.6					1.1	0.4	0.6	0.8			0.3	0.4	
Galium boreale		0.3																										4.3	0.5	
Grass spp.	3.6	2.5	6.6	1.4				2.9	1.0	0.8	0.4			3.0	2.1	1.3	3.1	5.6	8.1	15.0	0.1	0.9	1.5	0.4	5.6	4.9	12.6	1.6	4.6	3.2
Juncus balticus																		4.9	0.6											
Juniperus communis	3.5	6.9	4.2		7.6	6.0	14.5	6.2	6.2	3.3	4.2	0.8	4.8	1.0		5.4	1.0	0.4				6.5								
Juniperus horizontalis					0.8	1.5	4.1			0.3	4.5	0.3		5.3	17.1	2.0	5.6	12.3	2.8	15.9										
Larix laricina																0.1		2.1		2.4										
Ledum groenlandicum										3.1	3.2	1.9		4.1	13.1	12.6	0.8	27.3	21.2	4.9						0.2	1.8			
Lichen spp.						21.8		2.8																		0.2		0.6		
Linnaea borealis	0.1	0.5			0.4				1.7	0.9	0.4			0.5			0.3		0.2		1.0		0.5			3.1		0.1		
Lonicera spp.		0.1		0.1						0.8	1.5			0.8	0.6	0.3	0.5	0.6	5.6											
Maianthemum canadense		0.1																					0.1		0.5			0.4		
Mitella nuda														0.5			0.2													
Moss spp.	37.6	26.9	54.0	64.3	29.6	17.4	19.5		2.8	72.7	20.9	26.9	16.5	12.8	35.3	29.3	58.5	27.0		1.0	50.6	30.1	5.2	20.6	6.0	17.2	2.8	38.1	14.0	8.6
Sphagnum spp.													2.0	1.0		13.8		12.8	0.5	12.3										
Needles cover		4.0												16.8		2.5												2.9	0.1	
Petasites palmatus		0.8												0.1			0.7													
Picea glauca	1.5												1.4																	
Picea mariana	2.0	1.8	5.3	4.8	19.3	7.7	15.3	2.5	0.9	11.5	11.9	7.7	2.3	11.5	20.1	4.3	2.1	11.6	7.6	15.5		9.6	6.9			0.3	1.8			
Pinus banksiana		0.1						0.2	0.4																			0.4	1.5	0.2
Populus balsamifera		0.2			0.1																									
Populus tremuloides		0.3																									0.3	0.7	0.1	0.3
Potentilla fruticosa		2.0		0.2	1.1	3.2	0.7	0.6	0.1	2.9	8.5	2.8	2.1	9.3	4.7	1.4	3.1	0.3	2.4	0.3								0.5	0.3	0.1
Prunus pensylvanica	0.3								0.3																0.7		1.0			
Prunus virginiana					0.2		0.1		1.3														0.2							
Rhamnus alnifolia											0.3			0.3			0.6			0.5							0.3			
Rock cover					0.1	1.3		5.1																			1.3	1.9	4.0	0.6
Rosa acicularis	1.4	1.8	3.1	2.0	1.2	0.5	0.2	3.1	4.0			0.2	1.7	0.4	0.1		1.5				2.0	4.6	11.6	2.1	10.0	6.3	1.9	3.1	0.9	2.4
Rubus acaulis												0.2					0.8						0.3	0.4	1.7					
Rubus idaeus													0.2								1.2									
Rubus pubescens		2.2							0.1		0.4		0.2	0.3							0.8						1.8	0.1	0.2	0.2
Salix spp.	1.8	0.7	0.3						1.4	0.2	0.8		1.9	5.7	0.3	0.7	3.3	0.3	0.5							0.1				
Sanicula marilandica																								0.5	0.1			0.2		
Sarracenia purpurea																		0.3		0.7										
Scirpus caespitosus											0.7				0.2	0.1			1.3	4.8										
Shepherdia canadensis	2.1	12.2		2.1	0.4		0.5	2.2	5.9	0.2	1.1		1.6	0.2			0.4	0.1	0.7			0.4	2.1	0.2	1.0	0.8	0.2			
Symphoricarpos alba	1.0	0.8	0.2	0.7		0.2	0.1	0.3	0.2				0.3								0.6	0.1	0.8	0.1	0.6	0.7	4.2			
Tree *Alnus rugosa*																			0.2						54.5	13.6	18.2			
Tree *Alnus crispa*			1.6										14.9	2.8				0.4	1.8											
Tree *Amelanchier alnifolia*	1.6	1.2				0.4																				2.4	9.2			
Taraxacum officinale																													0.1	
Tree *Betula glandulosa*																		0.8	1.0	0.4										
Tree *Betula papyrifera*							7.2	2.4	14.0					0.3																
Tree *Corylus cornuta*																											21.1			
Thuja occidentalis										0.9		0.8			4.5	10.1	4.5													
Tree *Larix laricina*											2.0			1.3	4.0	1.6		11.6	3.9	4.2										
Tree *Picea glauca*	0.8	0.5											2.4	0.4												18.4	0.4			
Tree *Picea mariana*	10.2		29.6	18.6	25.2	39.6	37.5	12.8	6.0	43.4	32.4	56.4	36.7	69.8	55.9	12.7	61.2	25.2	10.4	15.9	47.0	23.0	36.8	50.0	1.6	22.8	1.6			
Tree *Pinus banksiana*	23.6	26.2	14.0	49.5	17.6	23.6	1.6	35.2	33.6	24.0	7.2	2.8	22.0	2.4	7.6	4.5	1.2		3.9		28.4	24.0	7.2	14.4	32.4	13.6	7.2			
Tree *Populus balsamifera*	1.6	1.0											3.2	0.4			1.2									1.6				
Tree *Populus tremuloides*	2.0	5.6																			14.8	24.1	34.0	19.6	22.0	9.7	51.7			
Tree *Prunus pensylvanica*	1.6																										1.6			
Tree *Salix spp.*														1.6					0.6		0.4									
Tree *Thuja occidentalis*										2.0					3.3	22.7														
Vaccinium myrtilloides	0.2		0.1	0.3											1.7	0.7		0.4	2.3			3.6	0.3		0.2	0.2	4.2			
Vaccinium vitis-idaea											1.6	0.3			5.5	4.1	0.8	0.7	0.9											
Viburnum edule																								3.0						
Water cover																	2.5	0.8	0.3	8.3										

Appendix 1 B: The average species cover for the ROW sites, organized by group affinities. This is the data set used in the vegetation analyses.

ROW Species	Dry Coniferous												Wet Coniferous								Mixed Forest							Burn Sites		
	1020	1021	1034	1035	1058	1059	1060	1093	1094	1152	1153	1154	1022	1092	1172	1173	1174	1297	1298	1299	1036	1203	1204	1205	1245	1246	1247	1113	1114	1115
Achillea millefolium	0.1				0.1				0.1								0.4				1.5		0.1	0.3	1.2	2.7	0.7	1.0	1.1	0.4
Alnus crispa		0.3													0.2															
Amelanchier alnifolia	0.6	1.9		0.6		0.1		0.6	0.2			0.2		0.1									0.1	0.1		1.2	0.8	0.1		
Andromeda polifolia														1.2																
Anemone canadensis	0.3			0.1	0.1				0.1													0.1		2.0	0.4	0.1				
Antennaria neglecta	0.5	0.7	0.1	1.7	2.5		0.2		0.9	0.6	8.4	0.5	0.2								0.1							2.0	0.3	0.1
Apocynum androsaemifolium	0.1				0.2		0.1		0.1													0.1		0.1	0.5	1.3				
Arctostaphylos alpina														0.2	0.2		0.8													
Arctostaphylos uva-ursi	29.6	13.7	8.9	15.6	15.0		13.7	26.6	7.3	0.5	7.4	5.6	17.5	4.3		7.5	2.9				1.5	6.7	16.4	2.3		4.2	6.1	2.5		
Aster spp.	1.2	0.2	1.4	2.1	0.9		0.3		0.7	0.8	0.3	1.7	0.1			1.3	1.1	0.3	0.9	0.1	1.7	1.1	11.7	9.0	0.6	4.9	12.7	0.5	0.6	0.8
Bare ground	0.3	4.3			0.6			2.5					0.2			0.3			0.1		2.1							1.8		0.1
Betula glandulosa										1.3				10.0	8.5	1.2	1.9	0.3		0.1										
Betula papyrifera								2.5	2.1					0.9																
Campanula rotundifolia												0.1									0.1		0.1	0.3	0.9	0.4	0.2		0.1	
Carex spp.	4.4	2.6	3.4	1.3	6.5	0.1	1.2	0.3	3.0	8.1	4.6	9.4	1.4	0.5	17.5	3.2	7.9	4.4	6.0	9.8	3.9	1.3		1.1	0.4	1.1	5.9	6.1	4.9	4.7
Chrysanthemum leucanthemum									0.3																					
Cirsium arvense												0.1						0.6	0.1	0.1					3.1	2.4	2.4			
Cladina spp.	5.5	21.7	5.5	13.5	22.9		18.8	2.0	4.3	4.8	12.9	5.2	9.1		4.2	2.6					0.3	0.1								
Comandra umbellata	1.4	0.7	1.3	0.6	0.3			0.3		1.3	0.2	0.6	0.3	0.5		1.5		0.3			0.1	2.8		1.5			2.7	2.3	1.3	0.5
Cornus canadensis								0.7	0.1						0.2	0.2														
Cornus stolonifera					0.1			1.7						0.4																
Cypripedium calceolus					0.1					0.1	0.1							0.1		0.1										
Disturbed Ground	1.6		2.0	1.3	2.1		0.8	2.7	2.6	4.2	3.2	2.9	15.5	23.9	0.3	4.6	0.1	0.3	0.2	4.5	1.7	1.0	0.4	1.3	0.5	1.5	0.3	17.8	12.9	7.8
Epilobium angustifolium									1.4					0.1											0.1					0.1
Equisetum arvense																	3.8			0.2										
Erigeron philadelphicus	0.1																													
Eriophorum angustifolium														0.1	0.2			0.4												
Eriophorum vaginatum																				0.1										
Fragaria virginiana	1.0	0.6	2.4	2.3	0.7		1.8	0.6	3.3	2.1	3.6	6.1	2.0		0.4	3.0	2.8	0.7	0.3		2.6	19.8	4.5	5.1		0.1	0.6	1.3	0.7	1.2
Fruticose Lichen	4.4	1.0	2.6	8.6	8.3		2.1			2.3	3.8	6.2	2.7									1.1	2.8	1.3			1.3			
Galium boreale	2.7	2.9	1.4	0.6	0.5		0.4	0.4	1.7	0.6	0.6	0.5	3.0	0.1		4.7	1.9		0.1		0.9	4.9	1.5	4.9	3.7	4.3	5.1	0.2	0.1	0.3
Grass spp.	9.2	2.0	16.8	7.5	1.4		7.8	0.5	1.9	9.6	8.3	7.2	1.9	0.8	11.1	3.0	3.5	20.7	18.1	15.2	28.3	14.6	24.7	22.4	26.3	23.8	17.6	11.3	15.4	24.3
Heuchera richardsonii					0.1			0.1																						
Juncus balticus														2.9	0.5	0.2	2.9	4.5	5.5	1.1										
Juniperus communis	0.4	0.3			3.7	0.1	7.9	1.7	3.3	0.1	0.6	0.6	0.3		1.8	3.3		0.3				0.3		0.9						
Juniperus horizontalis		0.3			2.5		0.9			2.3	0.1	0.2		0.1		10.8	0.3	0.2	0.3											
Larix laricina																	0.4													
Ledum groenlandicum								0.6						3.0	6.7	0.6	0.1	0.1	0.3	0.2										
Lichen spp.			0.2																									0.3		
Lilium philadelphicum									0.1																			0.1		
Linnaea borealis					0.1			2.4						0.3																
Lonicera spp.	0.1													1.2	0.4	1.0	1.4								0.1		0.7			
Maianthemum canadensis	0.7		0.1	0.1	0.1		0.2	0.3	0.2		0.4	0.1	1.4	0.2														1.9	0.1	
Melilotus alba																	0.7										0.5			0.1
Moss spp.			0.5		1.4		0.5			1.7	3.0	1.3	2.4	0.5	1.4	2.5	6.1	1.2	0.9	4.4	5.2					0.3		3.2	2.8	7.1
Necromass-Culms	27.1	17.0	38.4	28.8	12.3		19.9	14.0	8.3	34.1	20.8	36.1	14.5	8.9	32.3	21.4	26.9	50.9	59.4	45.4	44.4	31.7	32.0	39.0	40.1	34.2	35.0	32.4	48.2	42.8
Necromass-wood	2.4	8.1	8.0	4.6	4.3		5.0	4.9	2.6	3.9	4.2	4.9	3.0	15.6	0.9	4.6	0.4	1.0	1.3	4.8	0.1	0.7	0.3	0.5	1.0	0.3	0.2	1.5	1.3	0.5
Parnassia glauca										0.2				0.2						0.4										
Petasites palmatus														0.1		0.3	0.2													
Picea mariana		0.1	0.2	0.9	3.9	0.1	0.1		0.6	2.3	0.4	0.2	7.6		7.8	1.6	4.4	1.0		2.5			1.1	1.9			0.1	0.3		
Pinus banksiana	0.5	7.7	0.1		2.8		1.9	1.7					2.8			1.2						1.5				0.1		0.3		
Polygala senega	0.3	0.2	0.5	1.2									0.2									0.3						1.0	0.4	
Populus balsamifera						0.1			0.1				0.1				2.4							0.1						
Populus tremuloides		3.4						9.5	0.3				5.2	0.1			1.5					1.2	0.6				1.5	0.1		
Potentilla fruticosa		1.6			0.7	0.5	1.0	1.5	0.2	0.7	1.9	0.5	0.3	5.0		7.0	3.4	1.1										0.3	0.3	0.1
Prunus pensylvanica								0.2	0.7																					
Prunus virginiana							0.1		0.2																1.6	4.2				
Rhamnus alnifolia											0.3			0.7		1.2	0.5					0.1								
Rock cover	0.9	2.5	0.9	3.4	3.3	96.0	12.1	19.2	46.8	13.7	8.8	8.9	1.1	4.5		3.4	2.8	2.1		0.1		0.3	0.6	0.8		0.1		4.9	5.7	2.0
Rosa acicularis	0.2	1.5	0.3	0.6	0.1		0.4	0.8	2.4	0.1	0.1	0.1	0.2	0.2		0.8	0.1				0.1	4.4	0.4	0.2	1.4	4.6	2.5			
Rubus idaeus							0.1		0.4	1.4	0.5	0.8			0.1				0.1		0.1	0.1								
Salix spp.	0.2			0.1		0.1		1.1		0.4		0.3	2.2	10.0	3.4	1.0	9.0	1.1	1.0	3.1	0.5	5.7	0.2			1.3		0.9	0.1	
Sanicula marilandica	0.1	1.0	0.1																						0.2		0.1	0.2		
Scirpus caespitosus														0.3	0.2		0.9		0.5	2.7										
Shepherdia canadensis	0.8	1.0	0.1	0.4				0.9	0.3		0.5		0.1	0.2								0.1								
Smilacina stellata																		2.5	0.2	0.2								1.5		2.3
Smilacina trifolia																				0.1										
Solidago spp.					0.2		0.1		0.4	0.4	0.4	0.3						0.1					0.1						0.1	0.1
Sonchus arvensis	0.2								0.2	0.8	0.9	0.4						0.8		0.7	0.1			0.2	3.7	1.3	0.1		0.1	1.2
Steironema ciliatum																								0.9				0.1		0.1
Symphoricarpos albus											0.4														2.9	0.8				
Taraxacum officinale			0.1				0.2			0.2		0.2	0.1								1.4	0.4	0.4	0.8	2.5	1.4	1.5			0.5
Thuja occidentalis											0.1					3.2	0.2													
Trientalis borealis														0.1			0.1	1.0	1.1	0.1										
Vaccinium myrtillifolia	0.1														0.2															
Vicia spp.	0.5		0.1																		0.6		0.5	0.2	5.1	1.5				0.2
Viola adunca										0.1								0.3		1.8					0.1					
Water cover																	6.6			1.6										
Zigadenus elegans			0.1								0.3		1.3			0.1												0.1	0.1	
Zizia aurea	0.2	0.3	0.1																		1.0									

Appendix 2: The average soil data for the forest and ROW sites. Sites are ordered by group affinities. The abbreviations used are Cond. µm-Conductivity, %O.M.-%Organic matter, %Moist.-%Moisture and Bulk D.-Bulk Density.

Site	Forest					ROW				
	pH	Cond. µS	%O.M.	%Moist.	Bulk D.	pH	Cond. µS	%O.M.	%Moist.	Bulk D.
1020	6.46	122.53	13.8	30.2	0.554	6.80	92.18	5.4	17.7	0.720
1021	6.79	68.80	9.1	30.8	0.754	6.76	83.25	9.3	28.9	0.749
1034	6.92	197.60	7.0	27.5	0.690	6.85	157.70	7.9	21.6	0.661
1035	6.90	96.85	5.9	33.1	0.909	6.77	68.28	5.1	12.5	0.877
1058	6.65	172.80	43.7	17.4	0.200	7.01	105.40	14.0	25.0	0.567
1059	7.14	149.70	18.2	22.2	0.567	6.90	94.55	1.5	1.3	1.729
1060	7.45	434.50	38.4	19.0	0.184	6.86	103.05	36.4	25.0	0.266
1093	6.87	133.10	19.8	9.6	0.461	7.01	160.80	18.4	20.5	0.445
1094	7.03	129.05	22.1	27.7	0.459	6.96	89.34	45.3	10.7	0.419
1152	6.84	137.65	26.0	50.2	0.841	6.87	139.40	21.8	56.7	0.946
1153	6.70	154.60	4.1	16.8	1.022	6.50	104.50	8.6	21.9	0.897
1154	6.80	182.70	15.1	20.6	0.935	7.01	176.10	12.4	32.0	1.010
1022	6.77	153.28	15.6	39.3	0.651	6.62	102.55	8.7	28.4	0.869
1092	5.68	1478.00	88.0	40.2	0.096	6.88	409.50	59.4	40.1	0.167
1172	4.88	277.50	90.0	25.7	0.089	5.85	551.00	75.5	53.7	0.145
1173	7.06	198.50	73.9	66.9	0.139	6.83	242.00	69.7	55.9	0.172
1174	7.29	207.50	78.2	67.8	0.136	6.97	176.75	28.5	73.6	0.365
1297	7.49	354.00	93.1	27.8	0.045	6.87	321.00	76.3	32.1	0.120
1298	7.34	330.50	79.6	35.7	0.138	7.35	267.00	71.9	45.6	0.154
1299	5.16	171.65	85.8	25.4	0.050	7.43	397.50	80.9	51.5	0.100
1036	6.67	106.10	9.6	43.6	0.653	6.30	92.25	24.0	74.5	0.346
1203	6.48	143.10	15.1	10.4	0.451	6.84	79.15	6.3	10.2	0.811
1204	6.05	190.55	11.9	16.2	0.502	6.85	73.20	11.4	16.5	0.570
1205	5.75	113.60	23.2	12.6	0.361	6.93	105.20	16.5	12.6	0.509
1245	6.76	73.70	10.7	21.7	0.538	7.07	89.20	7.1	20.8	0.787
1246	6.45	62.83	12.4	21.7	0.441	6.98	92.75	15.0	24.3	0.470
1247	6.54	53.15	9.4	28.5	0.661	7.01	144.05	5.7	20.7	0.828
1113	6.63	158.00	7.0	16.6	0.733	7.14	117.25	17.5	31.1	0.498
1114	7.08	133.00	8.5	20.2	0.670	7.01	128.30	12.5	31.5	0.554
1115	6.79	213.00	15.7	29.9	0.472	6.66	202.00	9.6	29.0	0.763

Appendix 3 A: The average pixel reflectance for the sites. Sites are ordered by group affinities. Values between 0 and 255 are given for each of bands 3, 4 and 5.

Site	Forest			ROW		
	Band 3	Band 4	Band 5	Band 3	Band 4	Band 5
1020	24	48	45	42	70	111
1034	22	47	35	41	67	110
1035	25	47	43	42	70	109
1058	25	50	46	45	68	110
1059	24	51	46	92	95	191
1060	26	51	49	45	69	109
1093	30	53	58	39	64	100
1094	28	48	56	47	64	117
1152	28	49	45	46	64	111
1153	30	50	47	45	64	115
1154	29	48	43	45	62	110
1092	27	59	48	36	69	86
1172	31	58	56	40	69	105
1173	28	55	47	37	71	91
1174	28	58	49	39	70	97
1297	28	57	53	39	64	103
1298	30	63	69	41	66	106
1299	31	60	66	39	64	99
1036	24	49	36	41	75	107
1203	27	88	69	42	79	113
1204	26	87	61	40	88	114
1205	25	86	64	41	81	112
1245	25	68	54	36	73	101
1246	25	68	55	35	70	103
1247	25	54	38	38	68	104
1113	41	35	94	40	45	112
1114	34	27	75	43	44	111
1115	32	25	67	41	41	108

Appendix 3 B: The calculated Mahalanobis distances, probability of belonging and misclassification probabilities for the 40 randomly selected sites.

Sample	LANDSAT			Mahalanobis			Prob. of Belonging			Misclass.
	B3	B4	B5	Dry	Wet	Mix.	P(x|Dry)	P(x|Wet)	P(x|Mix.)	1-P(x|m)
1	28	55	53	0.944	0.347	9.567	.624	.841	.008	.429
2	29	65	59	4.579	0.686	5.404	.101	.710	.067	.192
3	29	53	54	1.496	0.996	14.148	.473	.608	.001	.438
4	27	57	50	1.515	0.623	5.489	.469	.732	.064	.421
5	28	53	56	0.326	1.883	13.306	.849	.390	.001	.315
6	27	52	57	0.352	2.890	14.782	.839	.236	.001	.220
7	26	48	38	0.502	2.330	6.765	.778	.312	.034	.308
8	25	55	47	1.328	3.030	4.863	.515	.220	.088	.374
9	27	54	51	0.229	1.137	9.331	.892	.566	.009	.392
10	26	73	55	12.341	8.742	0.194	.002	.013	.907	.016
11	27	57	48	1.731	1.465	4.132	.421	.481	.127	.533
12	25	69	50	10.038	7.823	0.017	.007	.020	.991	.026
13	26	66	50	7.558	5.604	0.327	.023	.061	.849	.090
14	29	47	57	3.147	5.813	24.614	.207	.055	>.001	.209
15	24	46	44	2.260	9.080	14.919	.323	.011	.001	.034
16	27	47	56	1.962	6.669	21.943	.375	.036	>.001	.087
17	23	67	53	8.671	11.568	2.780	.013	.003	.249	.061
18	22	47	33	4.397	9.981	7.674	.111	.007	.022	.204
19	25	51	41	1.304	4.500	6.415	.521	.105	.040	.219
20	24	63	50	5.516	7.846	2.535	.063	.020	.281	.228
21	25	52	53	0.867	6.028	13.084	.648	.049	.001	.072
22	25	47	45	0.759	5.707	12.623	.684	.058	.002	.080
23	25	47	46	0.697	5.624	13.397	.706	.060	.001	.080
24	25	48	43	0.270	3.654	9.698	.874	.161	.008	.162
25	27	50	54	0.549	3.011	15.781	.760	.222	>.001	.226
26	26	49	42	0.354	2.872	7.832	.838	.238	.020	.235
27	29	48	45	1.148	0.778	12.783	.563	.678	.002	.455
28	35	61	69	17.067	8.864	31.061	>.001	.012	>.001	.016
29	33	58	62	8.968	3.357	20.810	.011	.187	>.001	.057
30	25	76	58	13.770	10.890	0.179	.001	.004	.914	.006
31	26	58	46	2.960	2.391	2.533	.228	.303	.282	.627
32	27	49	47	0.020	2.466	11.726	.990	.291	.003	.229
33	26	89	65	29.023	22.246	4.624	>.001	>.001	.099	>.001
34	26	57	43	2.931	3.154	2.500	.231	.207	.287	.604
35	26	45	38	0.010	2.490	10.361	.995	.288	.006	.228
36	29	51	58	2.296	2.947	19.679	.317	.229	>.001	.419
37	26	52	43	1.063	2.317	5.138	.588	.314	.077	.399
38	29	23	58	37.315	47.800	88.284	>.001	>.001	>.001	.005
39	32	52	56	6.262	2.589	20.289	.044	.274	.000	.138
40	26	54	45	1.372	2.683	4.598	.504	.261	.100	.418