Utilizing remotely sensed imagery and GIS for mapping ecological and social attributes in sustainable forest management and rural livelihoods

by

Grant S. J. Wiseman

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

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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MASTER OF SCIENCE

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Abstract

The goal of this thesis is to utilize remotely sensed imagery and GIS for delineation of ecological information and social attributes in Sustainable Forest Management (SFM) and rural livelihood improvement. The thesis focuses on two case studies: **Case Study 1** – Boreal Forest of Manitoba, Canada and **Case Study 2** – Tropical Rain Forest of Kalimantan Timur, Indonesia. The specific objectives of Case Study 1 are to provide SFM the required information at the ecosite level through the use of existing GIS inventory data and remotely sensed imagery. The second Case Study aims to develop a geomatics methodology to identify rattan in the rain forests of Kalimantan Timur using Radarsat imagery.

SFM planning requires an ecological approach to terrestrial and wetland ecosystem classification and mapping. However, within the existing Forest Resource Inventory (FRI) database critical ecological attributes required for the accurate delineation of ecosites are not available using traditional aerial photograph interpretation techniques. Remotely sensed imagery is examined to determine if it is able to provide understory ecoelements by overcoming scaling property problems. Principal Components Analysis (PCA) is preformed on multitemporal Landsat 7 ETM+ imagery to identify understory phonological changes at two different scales. A Canonical Correlation Analysis (CanCor) is used to quantify the relationship between optical interpreted understory imagery and Landsat ETM+ data. Utilization of a Digital Information Model (DEM) allows topology measurements to be made for the generation of six enduring landscape features: 1) Peak, 2) Ridge, 3) Pass, 4) Plane, 5) Channel and 6) Pit. Identifying relationships between boreal tree and wetland species to their surrounding landform features enables mapping forested areas at the ecosite scale. A Canonical Correspondence Analysis (CCA) is used to determine relationships between FRI species and landform features.

The traditional livelihoods of the Dyak tribal people in Kalimantan Timur, Indonesia depend on a diverse income portfolio that includes raw rattan as a significant component. The government of Indonesia has placed a ban on the export of rattan due to a perceived shortage. This policy was not supported by a quantitative analysis of the rattan stock as there are currently no tools to provide accurate estimates. Continual cloud cover make it nearly impossible to utilize optical remote sensing imagery in isolated tropical regions while low level aerial photo acquisition is simply too expensive. Radarsat-1 imagery possesses cloud penetrating ability as it utilizes microwave radiation and is relatively inexpensive. However, image speckle is inherent in Synthetic Aperture Radar (SAR) data making it difficult to interpret. Five filtering techniques are evaluated using varying kernel sizes to determine which algorithm reduces speckle within Radarsat-1 imagery and maintains spatial properties of dry rice fields (Ladang) within Kalimantan Timur, Indonesia. Multiple Discriminate Analysis (MDA) and PCA are presented as a quantitative evaluation of filter speckle suppression based on segmentation and data recovery ability at varying kernel sizes for a multitemporal multi-incident angle SAR dataset.

For Case Study 1, new geomatic techniques were able to delineate ecological attributes including understory characteristics and enduring landform features. This information combined with the existing FRI layer may be used to identify ecosites in a Decision Support System (DSS) for ecosite delineation. Once ecosites can be physically identified, the boreal forest can be managed in a spatial and ecological manner. For Case Study 2, the Gamma filter at the 11 x 11 kernel sized proved to be the most effective filtering technique to remove inherent speckle from SAR imagery. Identification of rattan stock may now take place to generate an accurate inventory in Kalimantan Timur, Indonesia. With proper management of this essential resource the rural livelihoods of the Dyak tribal people should be improved. The filtering evaluation methodology may also be used to determine the optimal filter for other small scale cultural features in tropical environments when using SAR imagery.

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Chapter 1

Introduction and Literature Review

Abstract

A synopses of key tools used for mapping ecological and social attributes in Sustainable Forest Management (SFM) and rural livelihoods are reviewed including remote sensing, Geographical Information Systems (GIS) and a variety of multivariate statistical analyses. The SFM and social problems affecting **Case Study 1** – Boreal Forest of Manitoba, Canada and **Case Study 2** – Tropical Rain Forest of Kalimantan Timur, Indonesia are identified and examined. The objectives of this thesis are to acquire detailed information at the ecosite level through the use of existing GIS inventory data and remotely sensed imagery for sustainable forest management and to: b) develop a geomatics methodology to identify cultural features in the rain forests.

1.1 Introduction

This thesis explores the uses of geomatic technology to promote sustainable forest management and to improve rural livelihoods in two case studies. A case study method was used because the research was exploratory with the intention of applying successful results to larger areas (Yin 2003). Results from study sites may be implemented to other locations with similar ecological and social conditions. Careful selection of the study area locations was taken to ensure wide spread use of the results may be employed.

Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba
Case Study 2 - Rain Forest: Remote Sensing of Cultural Features in Kalimantan Timur

Serious information gaps exist within both case study locations and data which to base managerial decisions is needed (Belcher 2001, Walker 2001). Geomatics must be explored to determine if it can provide the information required for sustainable development (Franklin 2001). In each case study new geomatic methodologies and techniques are applied to provide information to decision makers for sustainable management of the forests in each region of the world. The resulting knowledge gained will allow for improved consideration of a broader range of values that forests provide including ecological, social, cultural, and economic values.

In the boreal forests of Canada the relationship between people and the forest is dependent on the forestry company's ability to manage the forest in an economically and environmentally friendly manner (Canadian Forest Association 1990). Improved understanding of how ecosystems work at the broadest scale right down to individual ecoelements at the most discrete level is critical to the sustainable management of forests (Kohm and Franklin1997). The boreal forest is the largest ecosystem within Manitoba and occupies over one third of the entire province (Smith 1998). Proper understanding of this vast system is needed for its long-term future.

SFM indirectly affects the livelihoods of Canadians in many ways. A large portion of Canadian citizens rely on the lumber industry for jobs, be it for a logging company, pulp and paper company, or a transport company, these people are dependent on our forest for their livelihoods (Canadian Forest Association 1990). There is also the mass public who purchase the products of the timber industry who expect a low cost (Natural Resources Canada 2006). Forestry companies can only provide a well priced product if they meet strict sustainable licensing agreements with the federal and provincial governments (ISO 1997, Canadian Lumber Association 2007). Tourism is the fastest growing industry in the world, and ecotourism and other forms of nature-based tourism is the fastest growing segment of this market (Slater 1991). Recreational uses of the forest such as hunting, fishing and hiking are examples of what sustainable forest management aims to protect (Canadian Forest Association 1990).

In the tropical rain forests of Indonesia the relationship people have to the forest is vastly different than Canada. While forest companies here are subject to the same strict government guidelines as to quantity and location of the forest which can be harvested, these regulations are often ignored with little or no consequence (Casson and Obidzinski 2002). Left to deal with the aftermath are the indigenous people whose livelihoods are directly dependent upon the forest (Belcher 1998). Many people gain employment from the logging industry in Indonesia but the majority of raw material is exported (FAO 2000). Few jobs are created in the product sector relative to the world industry leading countries (Barbier 1995).

What is extremely different about Indonesia is the amount of people who depend on the forest for sustenance to simply survive (Dewi In Press,). Rural villages typically depend on local available products for subsistence and disposable income (Ames 1998). There is a direct one-to-one relationship with the forest to provide food, shelter and any sort of limited timber products for income such as rattan (*Calamus* spp.) (Dewi 2006). The rattan trade has played a long and vital role in the local and national economy (Pambudhi 2004). Currently no inventory of rattan exists within Indonesia and thus the government has stopped all export of the product severely limiting many peoples only source of income (Belcher 2001). Kushwaha (1996) uses GIS and remote sensing to promote sustainable rural growth in the developing world because of the practicability and soundness of the methods. Non-government organizations are looking to geomatics to provide a way of identifying this resource to the people of Indonesia and the world market (FAO 2000).

1.2 Background Ecology

1.2.1 Ecological Landscapes

The International Organization for Standardization (ISO), the Canadian Lumber Association, the Canadian Forest Association and other forest certification bodies recognize the need to manage natural resources at the ecological landscape level (Boyce and Haney 1997). This has become one of the guiding principals of ecosystem management (Kohm and Franklin 1997). Within Canada alone there is a total of 418 million hectares of forested land (Canadian Council of Forest Ministers 2000). To understand the ecological functions of a forest one must breakdown the forest into manageable units. **Table 1.1** shows the scale of all ecological land classifications in the Ecological (Biophysical) Land Classification in Canada (ELC). There are a total of fifteen terrestrial and five aquatic ecozones across Canada ranging in size from 10,000 to 1,000,000 km^2 and can span several provinces (Canadian Heritage 2007). Ecozones are subdivided by ecoprovince which are 10,000 – 100,000 km^2 in size. A series of subdivisions follows beginning with ecoregions, subdivided by ecodistricts, ecosections and ecosites. Ecosites range on average from 10 to 100 ha in size and are the most practical way to represent similar ecological conditions that are unique to a unit of land (Model Forest Network 2002). At the smallest level there is the ecoelement which is a unit of land at a scale that enables forest management practices to be developed and applied (Zoladeski 1995, Racey 1996). Some ecological conditions that define ecoelements include soil type, soil texture, soil moisture, understory species, landscape position, tree species composition and tree stand age (Hall 2000).

Ecological land classification in Canada has, to date, focused at the very general (ecozone and ecoregion) or site specific (ecoelement) levels of classification. In 1995, Forest Ecosystem Classification (FEC) Vegetation Types (V-Types) and Soil Types (S-Types) were described for Manitoba (Zoladeski 1995), and represent the most detailed level (ecoelement) of the classification and mapping system in use. The FEC system provides a useful methodology for classifying forest sites based upon characteristics of the overstory and understory vegetation and the underlying soils at the plant community level. The ecosites, comprised of ecoelements, are primarily a mapping unit consisting of a set of ecological factors and ranges 5-8 ha in size, to hundreds of hectares (Racey 1996). It is expected that ecosites will become the operational land unit upon which to plan, monitor, and report elements of ecological, social, cultural and economic sustainability. A series of 40 terrestrial and wetland ecosites were generated for the boreal forest of Manitoba and are listed in **Appendix A** (Walker 2002).

1.2.2 Sustainable Forest Management

Sustainable Forest Management (SFM) is the methods and practices employed by the governing body of a forested area that promotes economic revenues while maintaining the existing ecological integrity on a long term time scale (Canadian Council of Forest Ministers 1995). There is an increasing demand on Canadian natural resources not only economically but also from a recreational, social and cultural perspective (Brundtland 1987, Varma 2000, Campbell 2006). Resulting from these external forces there is a strong push to move towards scientific management of forested lands and to better understand ecosystem functionality (Noss 1995). Integrated forest management requires an integrated dataset that identifies the opportunities, constraints and conflicts associated with the diverse uses and values associated with the forest resource (Walker 2002). This scientific approach is incorporated in SFM and demands readily available, cost effective, consistent and accurate information to base managerial decisions (Franklin 2001). Geomatics must be looked at to provide this critical information (Kushwaha 1996).

1.3 Remote Sensing

Remote sensing is the process where information is gathered about an object from a distance without physically touching the object (Schott 1997). This includes human beings using our eyes to visually recognize our surroundings or the use of a digital camera to take a picture of an event. More commonly, remote sensing is the term used to collect information from the earth's surface using either an aerial or spaceborne platform. The two most likely sources of remote sensing are aerial photographs or satellite images. Each of which play a vital role in the sustainable development and management of natural resources around the world.

The ability of satellite sensor systems to measure ecosystems functions are limited as these systems generally record reflected radiation from the surface (Brasswell 1996, Greg 1997). Incident energy is the sum of reflected, absorbed and transmitted energy from a surface (**Figure 1.1**). Reflected energy or spectral response is then derived from incident energy less absorbed and transmitted energy (Lillesand and Kiefer 2000).

$$E_R(\lambda) = E_I(\lambda) - [E_A(\lambda) + E_T(\lambda)] \qquad \textbf{[Equation 1.1]}$$

Incident energy can be naturally occurring sunlight where passive sensors receive reflected energy (Richards and Jia 1999). Active sensors send pulses of electromagnetic energy to the surface and receive any reflected information (Barnsley and Kay 1990). Over the past three decades, there has been widespread use of remote sensing imagery to classify the land surface (Wulder 2003). The spectral response of each pixel in a scene is used to assign the pixel to one of a number of classes, using various classification techniques (Goodchild 1994). All of these techniques can be considered to be reduction methods with a primary goal of reducing data into a form where humans can interpret it. It is also important to note these techniques must be reproducible to have any scientific value.

1.3.1 Landsat

The Landsat series of satellites has been at the forefront of countless earth observation projects since its inception in 1972 (Star 1997). McCloy and Hall (1991) used Landsat imagery to map the density of woody vegetative cover. Strahler (1981) stratified natural vegetation for forest and rangeland inventory using Landsat imagery. Landsat has also been used in combination with soil and terrain data to improve classification of forest vegetation (Bolstad and Lillesand 1992).

Evolving from the Return Beam Vidicon (RBV) sensor and the Multispectral Scanner (MSS) sensor on board Landsat 1, to the Thematic Mapper (TM) sensor's debut on Landsat 4 in 1982, to the Enhanced Thematic Mapper Plus (ETM+) on board Landsat 7 in 1999, there is no question Landsat has been instrumental in the way we see our planet (Lillesand and Kiefer 2000). The ETM+ sensor has eight channels with three colour bands, blue (band 1, 0.45-0.52 μm), green (band 2, 0.52-0.60 μm) and red (band 3, 0.63-

0.69 μm), followed a near-infrared channel (band 4, 0.76-0.90 μm), a mid-infrared channel (band 5, 1.55-1.75 μm), and a shortwave infrared channel (band 7, 2.08-2.35 μm) with 30 m resolution (**Figure 1.2**). Channels 1-5 and 7 have a 30 m spatial resolution. Additionally ETM+ has a thermal channel (band 6, 10.4-12.5 μm) and has a 120 m spatial resolution while band 8 is a panchromatic channel (0.50-0.90 μm) and a spatial resolution of 15 m.

The terrestrial surface reflectance response varies across the electromagnetic (EM) spectrum and is related to the surface composition and structure (**Figure 1.2**). Band 3 occupies the red portion of the electromagnetic spectrum and has a very low vegetative reflectance value due to high absorption of both blue and red energy for photosynthesis. Band 4 represents near-infrared energy and has a very high reflectance value as its leaves strongly reflect near-infrared energy due to their internal composition. At 1.4 μm and 1.9 μm there are sharp declines in reflectance that occur due to the presence of water within vegetation that strongly absorbs at those spectral frequencies. Band 5 is sensitive to mid-infrared wavelengths and band 7 records shortwave infrared data. Both peaks occur due to the inability of water to absorb electromagnetic energy at 1.65 μm and 2.2 μm (Lillesand and Kiefer 2000). As a result, Band 3 is able to identify leaf pigments, band 4 is sensitive to cell structure and bands 5 and 7 are able to detect levels of water content in leaves.

1.3.2 Radarsat

Optical techniques have focused on the visual and infrared portions of the EM spectrum but more recently there has also been the introduction of microwave energy to collect information of the earth's surface (Sardar 1987). Radar imagery utilizes microwaves which have longer wavelengths in the EM spectrum (0.75-100 cm) and have the ability to penetrate cloud, smoke and haze (Lewis 1976). Radar imagery is very useful where traditional optical sensors cannot penetrate local atmospheric interference (Ahmed 1990).

Radarsat launched in 1995 is an active sensor meaning it sends a pulse to the ground and receives the information that is reflected back (CCRS 2000). Radarsat utilizes the C band wavelength (3.75-7.5 cm) and does not look straight down or nadir but sends and receives wavelengths from the side (CCRS 2000) (**Figure 1.3**). Unlike Landsat where there are only a few spatial resolutions, Radarsat has seven different beam modes and a variety of beam positions for each mode (**Figure 1.4**). For the purposes of this thesis only the standard beam mode is used with a variety of beams position as described in Chapter 5.

1.4 Geographic Information Systems

Current GIS data are critical for SFM and planning of rural livelihoods. GIS can be described simply as a decision support system involving the integration of spatially referenced data in a problem solving environment (Stars 1990). This is a rather broad description but through the wide spread use of GIS its definition must be vague to incorporate all the function a GIS provides (Chrisman 1997). Two most common types of spatial information that may be used by a GIS are raster and vector data models.

1.4.1 Raster Data

Raster data structures are a georeferenced digital image where each square pixel is given a reflectance value (Drury 1998). These images are intended to create a continuous cover where each pixel in the image represents a feature on the surface (Sabins 1997). Generally, satellite images are used to generate raster data based on reflectance value of ground objects through a process known as remote sensing. When many pixels share the same reflectance value they are classified into themes such as trees, grasslands, roads, etc. and are known as thematic maps (Lillesand and Kiefer 2000). Most remote sensing imagery is in raster based format and has been used extensively in a wide variety of forestry applications ranging from modeling the effect of photosynthetic vegetation properties (Steltzer and Welker 2006) to operational mapping of the land cover of the forested areas (Wulder 2003). Heiler and Miguel-Ayanz (1998) use raster based satellite imagery for change detection analysis of forestry systems.

1.4.2 Digital Elevation Model

A Digital Elevation Model (DEM) is a raster based layer that represents the earth's surface in 3-dimensions (Chrisman 1997). Very similar to an image, a DEM models a surface with square pixels in a grid-like fashion but also has an added elevation value associated with each individual pixel (Evans 1980). Each pixel now represents an area in the easting (X) and northing (Y) direction as well as the height (Z) of the area in a continuous data layer (Skidmore 1998). Relational statistics such as slope and aspect of the area can now be derived from neighboring pixel elevation values (Wood 1996). From topology of slope and aspect landscape features can be generated for modeling purposes (Zevenbergen and Thorne 1987). Zoladeski (1998) uses landform of the boreal forest to associate forest stand types and soil conditions for improved forest management decision making.

1.4.3 Vector Data

The vector data model represents space as a series of discrete entity defined point, line or polygon units which are geographically referenced by a coordinate system (Star 1990). A point is simply a location with a geographic location such as shelter, well or washroom. Often Global Positioning System (GPS) points are used to generate new point data (Chrisman 1997). Lines are defined as all linear features built up from straight line segments made up of two or more point coordinates such as roads, railway tracks or trails (Star 1990). Polygons are simply enclosed lines that capture an area such as a wildlife corridor or prescribed burning area (Richards and Jia 1999). The key advantage of the vector data structure is that a point, line or polygon entity may have multiple attribute data associated with it in a related database file (Wood 1996a). Unlike raster data where individual pixels can only have one value assigned to them directly in the image file, vector data can have multiple values assigned to an entity in the database file (Chrisman 1997). A tree stand polygon can have many attributes associated with it such as species type, stand age, soil texture, soil moisture, and landscape feature (Zoladeski 1995). The vector data model allows for all information to be retained with each individual tree stand polygon (Goodchild 1994).

1.4.4 Forest Resource Inventory

One example of a vector dataset is the Forest Resource Inventory (FRI) layer generated by Manitoba Forestry of Manitoba Conservation. Aerial photography has played a key role in the development of forest inventories. Countless efforts have been made to map out tree information in a spatial manner using air photos as the base layer (Wulder 2003). Generally aerial photography of a forest is provided to an image interpreter who is able to visually confirm the ground information (Manitoba Land Initiative 2004). The FRI consists of polygons representing tree stands derived from human interpretation of aerial photographs. Each polygon has several attributes associated with it including species types, landform, stand height, year of origin, vegetation type, area and perimeter (Manitoba Land Initiative 2004). The FRI is useful from a tree harvesting standpoint but does not incorporate enough environmental ancillary information to support decision making required for sustainable forestry management.

1.5 Analytical Methods

There is a disconnect between information acquired through field sampling, remote sensing and GIS technologies and understanding and interpreting these datasets (Franklin 2001). One such solution to this increasing problem is the use of multivariate statistics and their unique ability to examine relationships between multi-source datasets simultaneously (Legendre and Legendre 1998). The methods are comprised of mainly multivariate statistics which interprets data in multiple dimensions (Hardle and Simar 2003). Each procedure attempts to reduce data from multiple dimensions for human comprehension (Pielou 1984). Relationships within or between each dataset are exposed using either covariance and/or correlation. Covariance can be interpreted as a measure of dependency between random variables (Hardle and Simar 2003). Correlation does the same but has the advantage of being independent of the scale, meaning changing the scale of the variables measurement does not change the value of the correlation (Hardle and Simar 2003). Ordination is the name given to the process of ranking or ordering a series of data (Gauch 1982). Ranking ecological data is not possible as multiple species data are intermixed at various locations with no fundamental order (Nichols 1977).

1.5.1 Principal Components Analysis

Principal Components Analysis (PCA) is an ordination technique that repartitions variance of a dataset. PCA plots the data with no weighting of any kind into *p*-dimensional space with the original axes being rotated to account as much variance as possible (Pielou 1984) (**Figure 1.5**). This is accomplished by generating either a correlation matrix or a covariance matrix from the principal components scores (Pielou 1984). The first principal component axis is intended to account for the most variance, followed by the second and so on until all variance within the dataset is accounted for (Pielou 1997). Generally the first three axes are retained as they account for the vast majority of the information and are easy to interpret visually (Lillesand and Kiefer 2000). The first Principal Component (PC) axis holds the largest percentage of data variance and the second PC axis accounts for the second largest data variance down to the last PC bands which is generally just noise (Santisteban and Munoz 1978).

1.5.2 Correspondence Analysis

Correspondence Analysis (CA) is commonly referred to as Reciprocal Averaging (RA) and is a form of ordination (Hill 1973). Data is transformed from a multidimensional cluster of points to a manageable number of dimensions using the reciprocal averaging technique which aims to maximize the correlation between species scores and location scores. (Anderberg 1973). First, test values are selected for species scores, the same for location, then a second set of scores are calculated for species and again for the location. This continues in a reciprocal fashion until scores maintain a consistent value and location can then be ranked by correlation (Pielou 1984).

1.5.3 Multiple Discriminate Analysis

Multiple Discriminate Analysis (MDA) attempts to maximally discriminate data into separate groups (Legendre and Legendre 1998). MDA is a multivariate method used to maximize the ratio of the between to within group sum of squares, unlike PCA which partitions total variance. MDA like PCA however, uses eigen analysis to rotate the axes into discriminate space, in practice the Single Value Decomposition (SVD) statistic is used (Pal and Pal, 1993). The SVD statistic is an alternative to eigen analysis and quantifies how well groups of data are preserved. The larger the SVD value the tighter the groups, the smaller the value the looser the groups (Legendre and Legendre 1998). The MDA technique is an important and well developed area of image recognition (Nhat and Lee 2005).

1.5.4 Canonical Correspondence Analysis

Canonical Correspondence Analysis (CCA) is similar to a Correspondence Analysis (CA) in that there is a series rankings using the reciprocal averaging technique, but the original dataset is now constrained by a second matrix (Braak 1986). Cajo and Braak (1987) use CCA to detect species and environment relations but also investigate specific questions about the response of species to environmental variables. Generally, the original dataset is the ecological data and the second dataset is one related to the corresponding environmental location or variables (McCune and Grace 2002). Braak (1996) has called CCA the method of direct gradient measurement since the environment data is constraining the species data. Some very direct conclusions can be made between the original and second datasets.

1.5.5 Canonical Correlation Analysis

Canonical Correlation Analysis (CanCor) is a method for quantifying the relationship between two sets of variables (Jakubauskas 1996). Stevens (1992) states CanCor is appropriate to use when trying to describe the existence and makeup of mutually independent relationships between two datasets. Jakubauskas (1996) uses CanCor to identify the relationship between coniferous forest spectral and biotic characteristics. The goal is to interpret and understand the relationships between the two sets of variables (Wuensch 2006). Lesser and Parker (2006) used CanCor to reduce the number of steps in analyzing the relationships of biological and climatic variables and maximized the covariance between the two data sets. Miles and Ricklefs (1984) used CanCor to identify the correlation between ecology and morphology in deciduous forest birds. Lee (1999) was successful in extracting landcover information from Landsat imagery using CanCor.

In **Equation 1.1** for X the first data set canonical weights or coefficients are represented by a1, a2, ...ap and b1, b2, ...bm for the second data set Y and are arranged in such a way to maximize their correlation (Wuensch 2006).

$$CV_{X1} = a_1X_1 + a_2X_2 + ... + a_pX_p \qquad CV_{Y1} = b_1Y_1 + b_2\,Y_2 + ... + b_m\,Y_m \qquad \textbf{[Equation 1.1]}$$

Where CV_{X1} and CV_{Y1} are the first canonical pairing (Jakubauskas 1996). The remaining data is analyzed to find similar matching canonical variates choosing one linear combination over another to maximize the correlation between the two canonical variates until a critical cutoff is reached (Wuensch 2006).

1.6 Objective

The goal of this thesis is to utilize remotely sensed imagery and GIS for mapping ecological information and social attributes in sustainable forest management and rural livelihoods. Serious information gaps exist within the selected study areas and the need for data to base managerial resources decisions is desperately needed. Geomatics must be utilized to provide the information required for sustainable development and rural development. I have focused my efforts on two very different forest types each with different management problems. I feel applying my geomatics research will only improve the quality of the environment and the lives of the people who depend on the forest for their livelihood. These objectives can be broken down into the following sub-goals for each case study:

Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba: To identify ecoelements that comprises ecosites on which to base Sustainable Forest Management decisions. SFM is intended to ensure conservation of biological diversity, wildlife habitat and wetland components, outdoor recreation and ecotourism opportunities, aboriginal spiritual and cultural sites, and aesthetic values. This requires up to date data that incorporates a broad range of user ecological and social values. Case study 1 focused on the ecological attributes used to delineate and characterize ecosites. The two main sub-objectives are:

1) Determine scale properties of ecological elements within the boreal forest
2) Identify the relationship between boreal forest communities and surrounding enduring landscape features

Case Study 2 - Rain Forest: Remote Sensing of Cultural Features in Kalimantan Timur: Determine social values with respect to rattan production in former ladang in Kalimantan. The main sub-objectives in case study 2 are:

1) To improve ladang identification in remotely sensed imagery through the development of an objective method of assessing multi-incident and multitemporal SAR data

Tables

Table 1.1: Ecological (Biophysical) Land Classification in Canada ranging from the largest category (Ecozone) to the smallest (Ecoelement). FEC vegetation types are considered ecoelements and reside within ecosites (Adapted from Racey 1996).

Classification Unit	Appropriate Scale	Recommended Tools	Example of Management Applications
Ecozone	1:3,000,000 10,000 – 1,000,000 km^2	Ecological Stratification Working Group (1995)	Ecological context for Manitoba
Ecoprovince	1:1,000,000 10,000 – 100,000km^2	Ecological Stratification Working Group (1995)	Ecological context for Manitoba
Ecoregion	1:500,000 1000 – 10,000 km^2	Ecological Stratification Working Group (1995)	Strategic and regional land use planning
Ecodistrict	1:250,000 – 1:500,000 100 – 10,000 km^2	Ecological Stratification Working Group (1995)	Strategic and regional land use planning
Ecosection	1:100,000 – 1:250,000 1000 – 10,000 ha	Enduring features database (Manitoba Parks)	Major landform contributions for enduring features, broad habitat trends, watershed evaluation
Ecosite	**1:10,000 – 1:20,000 10 – 100 ha**	**Terrestrial and Wetland Ecosites of Manitoba (to be developed in this project)**	**Harvest and silvicultural ground rules, stand productivity, biodiversity values, wildlife habitat and wetland components, recreational opportunities, aboriginal cultural and spiritual sites, aesthetic values**
Ecoelement	1:2,000 – 1:10,000 100 – 100,000 m^2	Forest Ecosystem Classification for Manitoba (Zoladeski et al. 1995)	Stand and sub-stand level studies of succession, competition, productivity, habitat and soil / vegetation interaction

Figures

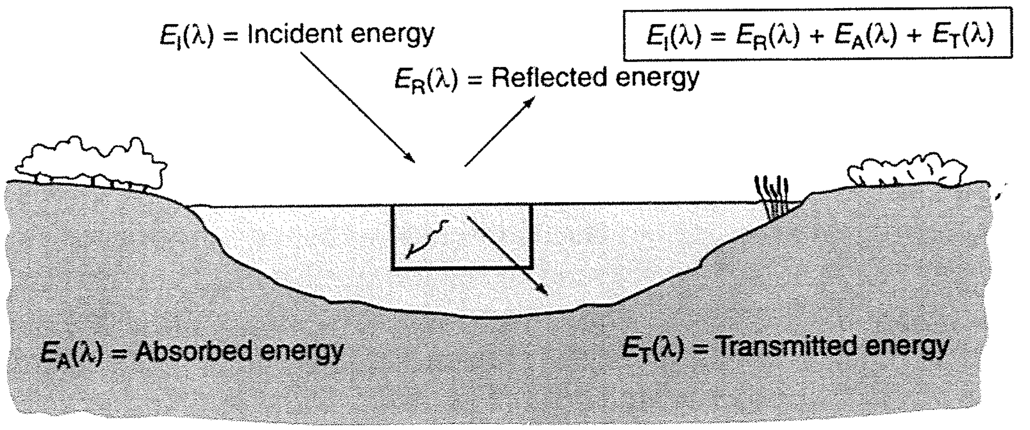

Figure 1.1: Incident energy ($E_I(\lambda)$) being reflected ($E_R(\lambda)$), absorbed ($E_A(\lambda)$) and\or transmitted ($E_T(\lambda)$) once it encounters the Earth's surface. Most remote sensing sensors record the amount of reflected energy. $E_R(\lambda) = E_I(\lambda) - [E_A(\lambda) + E_T(\lambda)]$ (Lillesand and Kiefer 2000, Reprinted with permission of John Wiley & Sons, Inc.).

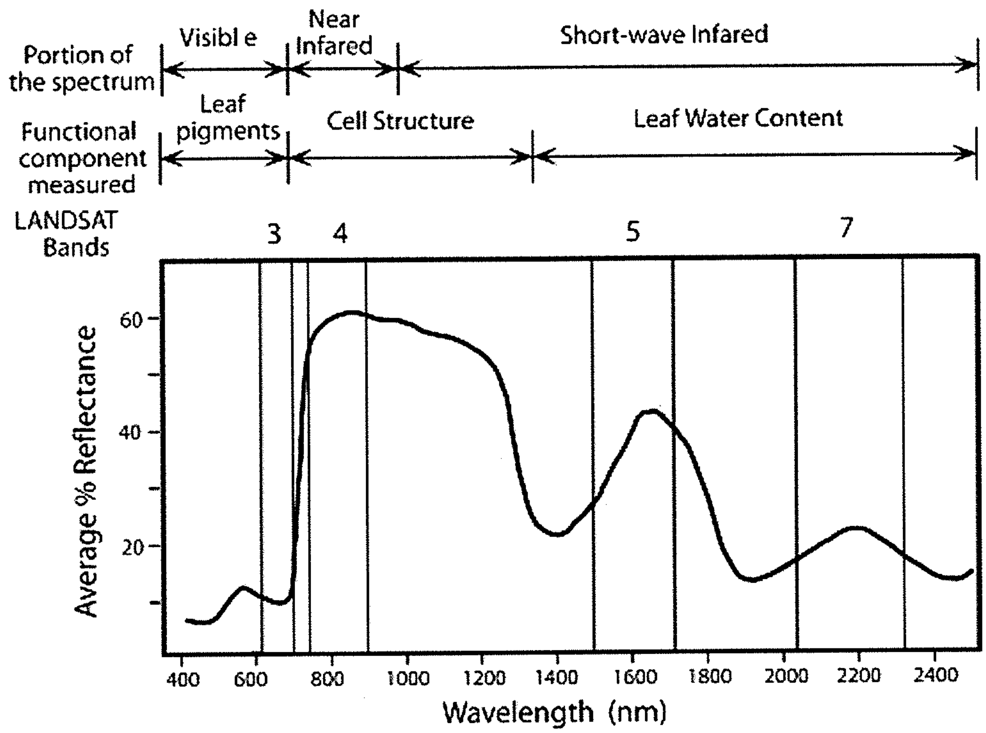

Figure 1.2: Average spectral reflectance for terrestrial surfaces and the associated Landsat ETM+ bands. Portion of electromagnetic spectrum where Landsat bands collect reflected energy (X axis, top) and is given in wavelength micrometers (X axis, bottom). Percentage of energy reflected by vegetation is given on the Y axis. Band 3 is sensitive to leaf pigments, Band 4 collects cell structure information, and Bands 5 and 7 gain leaf water content information.

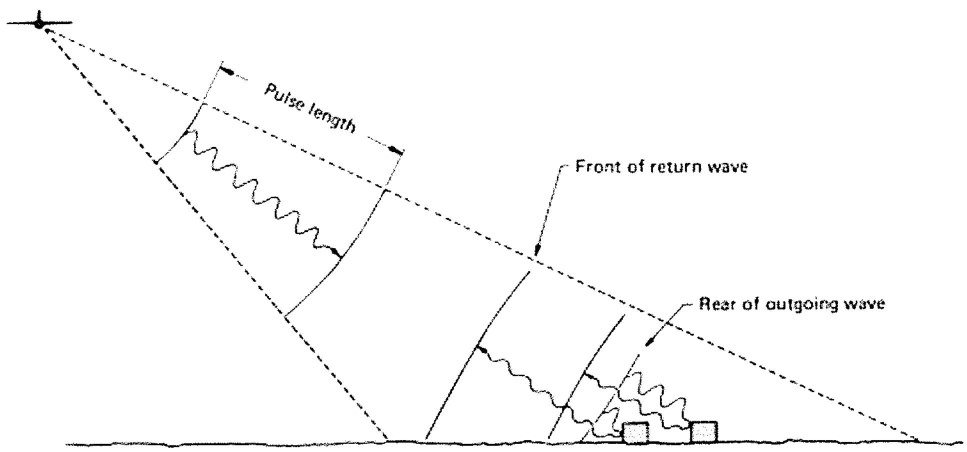

Figure 1.3: Theory of Active Side-Looking Radar. A pulse is sent from aeroplane or satellite sensor and interacts with an object on the ground. The pulse is absorbed, transmitted, scattered or reflected back to the sensor. The pulse is reflected back from the top of an object before the bottom causing a layover effect (Lillesand and Kiefer 2000, Reprinted with permission of John Wiley & Sons, Inc.).

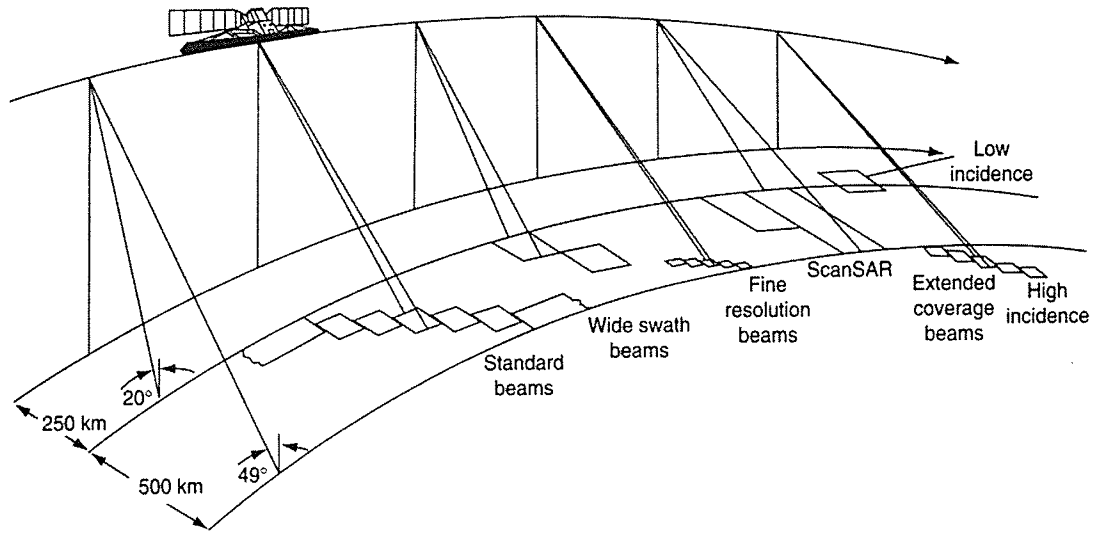

Figure 1.4: The available Radarsat imagery types all come in the C-band frequency (5.6 cm) with HH polarization and ascending\descending data acquisition orbital paths. The Fine beam mode has an 8 m pixel resolution, 50 km swath width and 37° – 47° incident angle range. The Standard beam mode has a 12.5 m resolution, 100 km swath width and 20° – 49° incident angle range. The Wide swath beam has a 25 m resolution, 150 km swath width and 20° – 49° incident angle range. The ScanSAR Narrow beam mode has a 50 m resolution, 300 km swath width and 20° – 49° incident angle range. The ScanSAR Wide beam mode has a 100 m resolution, 500 km swath width and 20° – 49° incident angle range. The extended beam mode has greater incident angle range (Lillesand and Kiefer 2000, Reprinted with permission of John Wiley & Sons, Inc.).

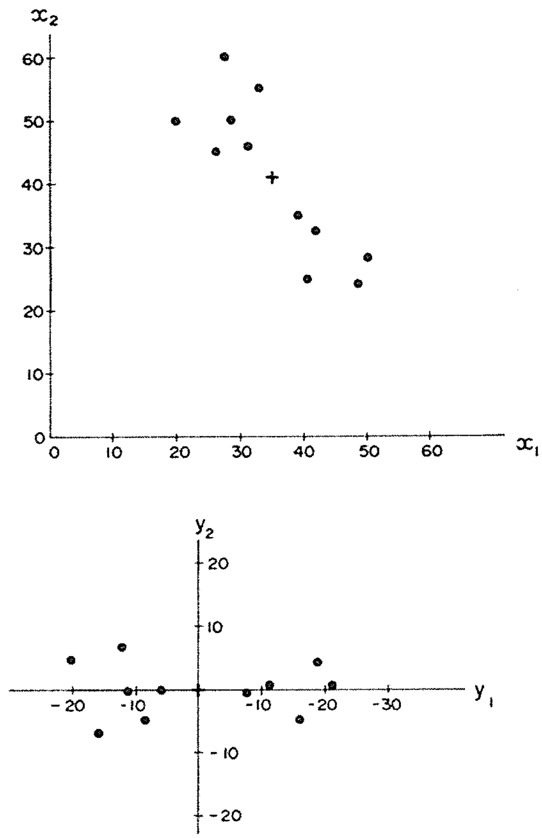

Figure 1.5: Example of a two dimensional biplot with points plotted along the $\mathbf{x}_1$ and $\mathbf{x}_2$ axes (top). Same dataset rigidly rotated into its principle components along $\mathbf{y}_1$ and $\mathbf{y}_2$ axes (bottom). The structure of the dataset remains the same with only the axes changing position resulting in new values for each point within the dataset (Pielou 1977, Reprinted with permission of John Wiley & Sons, Inc.).

Chapter 2

Study Areas

2.1 Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba

2.1.1 Introduction

The study area for **Case Study 1** was found within Boreal Shield Ecozone 90, Lac Seul Upland Ecoregion and ultimately in the Wrong Lake Ecodistrict (Smith 1998). Because of scale the methodologies in this thesis were field tested and may be applied across Manitoba. The testing area of interest is located approximately 160 km directly northeast of Winnipeg or 5 km directly east of the town of Bisset (**Figure 2.1**). It is a 10 km by 10 km area within Manitoba's boreal forest over Canadian Shield consisting of conifer stands in the south section transitioning into mixedwood stand at the centre and finally into pure deciduous stands in the north section (Zoladeski 1998), (**Figure 2.2**). There is also a complex wetland system consisting of lakes, rivers, marshes, fens, bogs and swamps (Harris 1996). A small population base of mainly aboriginal communities exists east of Lake Winnipeg (Douglas and McIntyre 2004) and the area also attracts many outdoor enthusiast for fishing, hunting and camping excursions (Campbell 2006).

2.1.2 Climate

The study area has a mean annual temperature of 1.9°C (Environment Canada, 1993) with a mean July daily high temperature that ranges between 18.9°C and 21°C and an average January daily high temperature that varies between -17.8 °C and -18.9 °C (Weir 1983). The average frost free days per year are 107 (Land Resource Unit 1999) The average annual precipitation ranges between 508 and 559 mm with the majority coming in the form of rainfall, 305 to 357 mm between the months of May and September (Environment Canada 1993).

2.1.3 Physiography and Surficial Geology

Weir (1983) has classified the area to have Precambrian, Paleozoic, and Mesozoic bedrock with various lithologies, variable topologies and slopes. The area has many extrusions of batholthis granite of granitoid gneiss, metasedimentary rocks of drived gneiss and many schists and migmatites are found throughout the rolling topography (Zoladeski 1995).

2.1.4 Soils

Brunisols dominate the study area landscape which are coarse textured and are dystric in nature (Weir 1983). Brunisolic soils tend to be acidic and lack a well developed mineral-organic surface horizon, typically forming directly on parent material and tend to be associated with forest vegetation (Canadian System of Soil Classification 1990). The Brunisols that have developed from bedrock are shallow, patchy, and have heavy amounts of rubble material (Smith 1998). Poorly drained Gleysols are associated with lowlands while Gray Luvisolic soils are common in moderately well to imperfectly drained uplands areas (Canadian System of Soil Classification 1990). Both Gleysols and Luvisols are found with glaciolacustrine sediments (Smith 1998). There are also many intrusions of organic soils found throughout the area (Land Resource Unit 1999). Frequently in depressional areas Fibrisolic and Mesisolic organic soils are commonly saturated for most of the year and have a thick organic rich top level occur (Canadian System of Soil Classification 1990).

2.1.5 Vegetation

The area is predominately coniferous with black spruce (*Picea mariana*), white spuce (*Picea glauca*) and balsam fir *(Abies balsamea)* as the dominate species in most mesic locations with longer fine return cycles (Zoladeski 1995). Jack pine *(Pinus banksiana)* thrives in recent burn areas along with trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*) and balsam poplar *(Populus balsamifera)* while tamarack *(Larix* *laricina)* is commonly found in low lying areas (Harris 1996). Continual fires have resulted in fragmented forest cover with black spruce in lowland and jack pine and aspen in the frequently burned highlands (Smith 1998).

2.1.6 History

The exposed Precambrian rock resulted from repeated advances and retreats of ice-age glaciers constantly scrapping off any newly deposited soil (Douglas and McIntyre 2004). This undulating ecozone is filled with many waterways including lakes, rivers, steams and wetlands which account for 20 percent of the Canadian Shield (Douglas and McIntyre 2004). Fire is a major natural component to the boreal forest with 9,000 to 12,000 fires burning 2 to 7 million hectares annually with 85% of those fires are triggered by lightning (Boucher 2003, Douglas and McIntyre 2004).

2.1.7 Field Methods

Data collected from the boreal forest was extensive as outlined in the field sheets in **Appendix B** (Walker 2002). Following procedures designed by Zoladeski (1998) a 10 m by 10 m plot was laid out at each site where soil, vegetation and landscape characteristics were examined. This was done three times within each FRI polygon visited using a hand held GIS and GPS to navigate. Using keys as a guide areas were classified by ecosite type using Saskatchewan's ecosites guidelines (Beckingham 1996), the Manitoba vegetation classification parameters (Zoladeski 1998) as well as our own Manitoba ecosite classification specifications (Walker 2002).

2.2 Case Study 2 – Rain Forest: Remote Sensing of Cultural Features in Kalimantan

2.2.1 Introduction

Case Study 2 is located on Kalimantan in central Indonesia and was approximately 100 km^2 centered by the village of Mencimai (0° 17' S, 115 ° 40' E), (**Figure 2.3**) within the district of Kutai Barat and province of Kalimantan Timur. The area is accessible by the South Mahakam River and a recently paved road. The project site was chosen for its extensive Ladang network which is critical to the livelihoods of community inhabitants. Residents are mainly indigenous people from Dayak tribes who live in scattered villages along rivers and increasingly by road (Belcher 2001). Ladangs are found on hillsides and typically found in areas easily accessible by local farmers (Belcher 2001).

2.2.2 Climate

Average monthly temperatures remain steady throughout the entire year ranging between 26 °C and 27°C (Stone 1997). The only variation of climate is the amount of precipitation received with two distinct wet seasons. The first is known as the west monsoon and brings the highest amount of rainfall between December and February while the second wet season known as the east monsoon brings relatively low rainfall from June to August (Stone 1997). Located below the typhoon belt, Kalimantan Timur does not receive torrential down pour storms common throughout many tropical regions and has dry seasons stretching from March to May and September to November (Stone 1997).

2.2.3 Surficial Geology and Soils

Unlike the volcanic rich island of Java lying to the south of Kalimantan across the Java Sea there is very little recent geological activity in Kalimantan Timur (Stone 1997). The landscape does have some small relief but for the most part it is mainly sedimentary rock and limestone rock with sandy to sandy loam soils but are considered nutrient poor compared to neighboring islands Sumatra and Java (Ulack and Pauer 1989). There are large coal deposits found throughout Kalimantan (Moore 1996).

2.2.4 Vegetation

The vegetation of Kutai Barat is indicative of Kalimatan Timur. *Dipterocarp* forest has been selectively logged causing an extremely heterogeneous canopy while the surface structure of Heath forest, found in nutrient poor soils, is generally homogeneous (MacKinnon 1996). There are over 3,000 different tree species types including rattan, ironwood, honey tree and teak as the more economically valuable species (Ulack and Pauer 1989). Hall (1964) categorizes nearly all of Kalimantan Timur as tropical evergreen forest with secondary forest with shifting cultivation.

2.2.5 History

Plant and animal diversity is extremely high on the island of Borneo due to land bridges connecting the island to Southeast Asia during the last ice age (Stone 1997). New flora and faunal species migrated to the island and prospered in the region's stable climate (MacKinnon 1996). Plant and animal diversity continued to prosper after the land bridges were flooded by the seas again after the ice age 18,000 years ago (Stone 1997).

2.2.6 Field Methods

Field data collection in Indonesia provided a variety of unique challenges from remoteness of the Dayak tribal people to the tropical climate. Field collection parameters within Indonesia were simplified with only a GPS point, a picture of the site using a digital camera and notes taken from dialog of tribal experts at each site from two interpreters of the local Dayak language to Indonesian and finally to English.

Figures

Figure 2.1: The study area is located approximately 160 km northwest of Winnipeg, Manitoba, Canada. The study area itself is 100 km^2 encompassing a portion of Nopiming Provincial Park. The town of Bissett located on Rice Lake is located in the north section of the study area with the Manigotagan River and Big Clearwater Lake found in the centre with Quesnel Lake located is the far southwest corner.

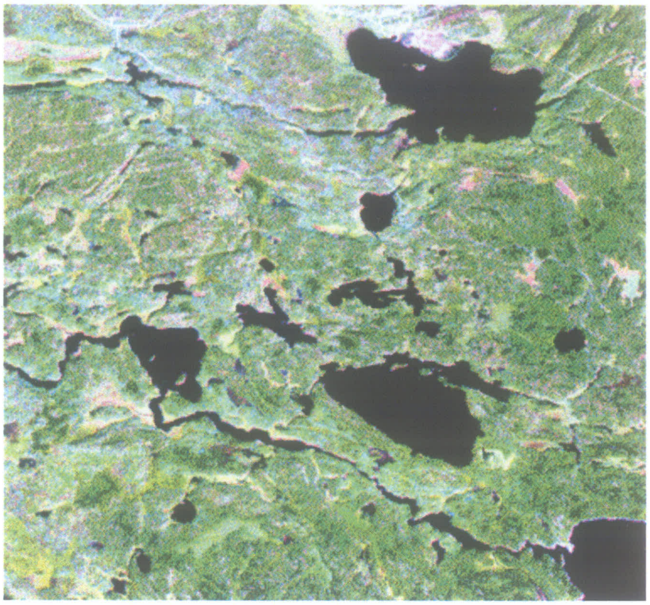

Figure 2.2: A false colour RGB Landsat 7 ETM+ image of the case study 1 study area. The dark blue areas represent water bodies, the green areas represent vegetation. The bright pink found near the top centre of the image is the town of Bissett, Manitoba located on Rice Lake.

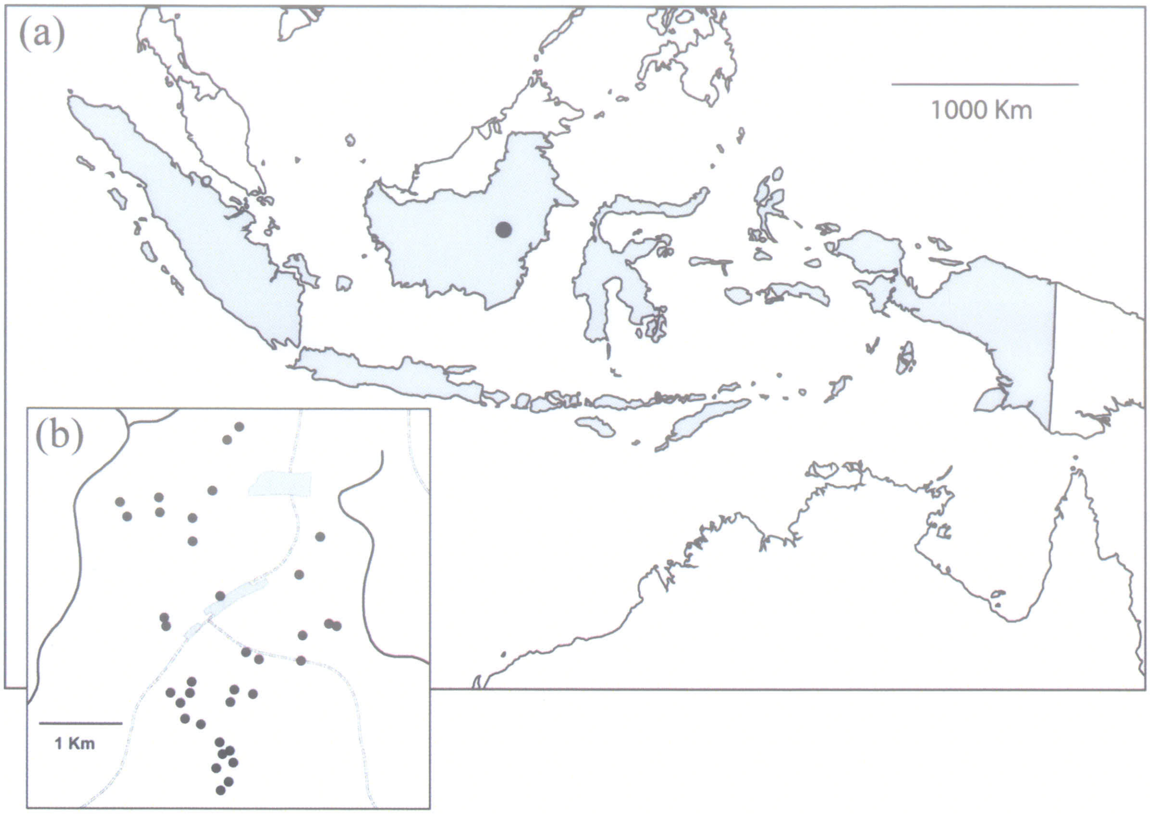

Figure 2.3: Location of the project study area: a) Indonesia (gray) including the island of Borneo with the study site (black dot); b) locations of the ladangs (black dots) in the area surrounding Menchimai and other small settlements (gray). Principal rivers (black lines) and road networks (dotted double lines) are also shown.

Chapter 3

Ecological Variable Stratification Utilizing Remotely Sensed Imagery and GIS Land Inventory

Abstract

Sustainable Forest Management (SFM) requires a scientific and quantifiable method to account for the ecology of boreal terrestrial and wetland ecosystems. Within the Forest Resource Inventory (FRI) critical ecological attributes such as understory composition, soil texture\moisture, and landform are obtained using human interpretation of aerial photographs. Remote sensing imagery is examined to determine if it is able to provide understory composition attributes by overcoming scale property problems. Principal Components Analysis (PCA) is preformed on multitemporal Landsat 7 ETM+ imagery to identify understory phonological changes at two different scales. A Canonical Correlation Analysis (CanCor) is also used to quantify the relationship between optical interpreted understory imagery and Landsat ETM+ data.

3.1 Introduction

Sustainable Forest Management (SFM) in the boreal forest requires an ecological approach to terrestrial and wetland ecosystem classification and mapping (Greg 1997). The development of ecosites that incorporate a broad range of biophysical and physical attributes can meet these management objectives (Walker 2002). However, within existing land information databases critical attributes required for the accurate delineation of ecosites are not available (Brasswell 1996). Serious information gaps exist with respect to understory composition, soil texture and moisture and site productivity (Iacobelli and Kavenaugh 1994, Ghitter 1995). Remote sensing data can potentially provide these site attributes, but the scaling properties and integration of these ecophysical variables within the sensor signature are poorly understood (Woodcock and Strahler 1987).

Ecosystems are complex areas comprised of many pieces of information ranging from a wide variety of environmental sources (Canadian Council of Forest Ministers 1995). The task of identifying ecophysical variables of the boreal forest using a variety of remote sensing techniques has proven to be extremely difficult (Wulder 2003). Most boreal forest studies focus on overstory factors and neglect understory parameters (Jakubauskas 1996). Surface conditions represent a complex mixture of vegetation, exposed soil or rock, water and shadows (Franklin 1996). The species composition, structure, density, and levels of photosynthetic activity of both the dominant vegetation and understory vegetation are a significant part of the signal recorded by the satellite remote sensing systems (Knipling 1970; Cochrane 2000; Steltzer and Welker 2006). Other conditions such as the brightness or high reflection of the exposed soil, rock and the amount and density of shadows present are integrated into a satellite observation of terrestrial ecosystems (Huete 1985; Brasswell 1996). Not only are the data recorded by a satellite sensor a result of complex surface interactions, but many important ecosystem processes cannot be directly measured (Barnsley and May 1990; Smith 1993). Soil processes, litter, and other dead biomass accumulation, for example, are not part of the signal received by satellite remote sensing systems (Brasswell 1996; Greg 1997).

Recent methods that have been somewhat successful are to approach the identification of ecophysical variables from a multitemporal and multispectral standpoint (Singh 1989; Heiler and Miguel-Ayanz 1998). The goal is to analyze a single area from multiple date satellite images using a series of reflectance bands to discover any temporal patterns that may exist and be used in identification (Johnson and Kaischke 1998). Reflectance information must be corrected for atmospheric contamination for multiple time periods as environmental conditions can vary greatly from season to season and year to year (Chavez 1988). Townsend (2001) used multitemporal and multispectral Landsat TM imagery to create a hierarchical classification of forested wetlands communities. By incorporating phonological differences into the classification process, more detailed spectral information about community types were extracted (Cochrane 2000). Multitemporal images greatly enhance the use of multispectral data classification by increasing the number of potential features to be input into a classification (Townsend 2001). This approach is not limited to

Landsat data. Cyr (1995) performed a supervised classification of multidate SPOT imagery on agricultural crops in a hilly environment of the Quebec Appalachians to assess soil erosion. Cyr (1995) found the use of multidate satellite imagery increased the precision of results because it offers the potential for monitoring the dynamics of vegetation development. Hall (2000) attempted to classify understory conifer trees within deciduous and deciduous dominated mixedwood stands using two-date leaf-on leaf-off Landsat TM images in combination with GIS vegetation inventory data. The incorporation of forest inventory parameters from GIS data into an evidential reasoning classifier resulted in a higher classification accuracy compared to the use of spectral data alone (Hall 2000).

3.2 Objectives

The goal of this chapter is to identify understory characteristics of boreal ecosites using remotely sensed imagery and GIS land inventory. Within the current Forest Resource Inventory (FRI) critical ecological attributes required for the classification of ecosites are acquired using subjective methods. Ecoelements such as understory composition, soil texture\moisture, and landform are obtained using human interpretation of aerial photographs. Remote sensing imagery is examined to determine if it is able to provide understory ecoelements associated to the Forest Ecosystem Classification (FEC) V-Types. Scaling issues of multilevel imagery must be overcome for this association to be made. Chapter objectives are to determine scale properties of ecological elements within the boreal forest through the following sub-objectives:

1) Determine how season and scale effects the identification of ecophysical variables and develop a new measure of sampling independent of the FRI.

2) Determine if understory ecoelements critical for ecosite delineation (Moss, Bare Rock/Lichen, Herb/Shrub and Grasses as used in the FEC) can be identified from a low altitude remote sensing platform.

3.3 Study Area

See Chapter 2.1 – Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba

3.4 Methodology

A series of sites in the boreal forest were established with ground and satellite imagery. At each site, ecophysical variables including species composition, stand age, height, vertical stratification, soil texture and moisture and drainage were measured. Aerial imagery was also acquired using a power paraglider equipped with a digital video camera. Ideally, generating a broad classification of understory species composition for a given test area would be a long term goal beyond the scope of this thesis. Instead, scaling correlations between ecosite attributes and remotely sensed imagery at two different scales are examined. Newly created understory database may be used in combination with the Forest Resource Inventory (FRI). Such a database will have broad application within sustainable forest management practices as well as provide a means to apply rule-based classifiers towards the task of mapping ecosites. The following is a list of understory ecoelement types with example species:

a) Moss – Feather Moss (*Hylocomium splendens, Pleurozium schreberi, Ptilium crista-castrensis*)
b) Bare Rock/Lichen – Ground Lichen (*Cladina mitis, Cladina stellaris, Cladina rangiferina*)
c) Herb/Shrub – Three-leaved Salmon's Seal (*Smilacina trifolia*), Wild Sarsaparilla (*Aralia nudicaulis),* Labrador Tea (*Ledum groenlandicum Oeder*), Speckled Alder (*Alnusrugosa*)
d) Grasses – Northern Brome (*Bromus Intermis*), Rough-leaved Rice Grass (*Oryzopsis asperifolia*)

3.4.1 Landsat 7 ETM+ Imagery

Landsat imagery has been instrumental in forestry applications over the 25 years (Richards and Jia 1999). Multitemporal Landsat 7 ETM+ imagery from spring 2001, summer 2002 and fall 2002 were acquired over the study site location. Images were corrected for atmospheric interference using a relative scattering model (Chavez 1988). Based on seasonality and amount of haze present in each image, individual bands were adjusted accordingly using dark order subtraction. This process uses an object within the satellite image with a known very low reflectance such as a clear lake or bare soil and compares the reflective values from a haze free day observed in image histogram and corrects for atmospheric interference (Edirisinghe 1999).

For this study only band 3 (0.63-0.69 μm), band 4 (0.76-0.9 μm), band 5 (1.55-1.75 μm) and band 7 (2.08-2.35 μm) were corrected and used in the multivariate analysis. Spectrally adjacent bands are often highly correlated meaning there is high redundancy adding unwanted noise to an image and reduces the classification strength (Cochrane 2000, Walker 2002) . For this reason Landsat band 1 (0.45-0.52 μm) and band 2 (0.52-0.6 μm) were not included in the analysis as their information is highly correlated with band 3. **Figure 3.1** outlines the workflow of **Chapter 3.4**.

3.4.2 Power Paragliding Data

A power paraglider (**Figure 3.2**) will potentially provide a new low level imaging platform at a cost effective price. The power paraglider was flown collecting digital optical video of the boreal forest consisting of coniferous, deciduous, mixed stands and a series of wetlands. The video tape was later digitally resampled into 552 individual images (**Figure 3.3**) and underwent ocular examination. The percentage of coniferous (spruce\pine), deciduous, mosses, grass, rock/lichen and shrub/herb were classified and recorded in a table with a unique identifier for each image.

Using Differential Global Positioning System (DGPS) and data acquisition time, the height of the power paraglider was recorded for each image extracted from the video tape. By subtracting ground elevation values obtained from a Digital Elevation Model (DEM) the height above ground was calculated. Height above ground and the focal length of the video camera lens system were used to obtain the Instantaneous Field Of View (IFOV) for each image (**Figure 3.4**). The IFOVs were then converted into a vector polygon layer and placed over the Landsat summer image to extract average reflectance values for each polygon. There were often multiple IFOV images for each FRI polygon and for direct comparison purposes, only one IFOV image was chosen at random to represent a FRI polygon.

3.4.3 Forest Resource Inventory

The Forest Resource Inventory (FRI) is the primary data layer source used for forest management in Manitoba. The FRI is a vector based file consisting of polygons representing tree stands derived from human interpretation of aerial photographs. At the time we were using a new version of the FRI where each polygon had several new attributes associated with it including soil moisture, landform, tree height, crown closure, year of origin, vegetation type (Manitoba Land Initiative 2004). Tree stand polygons also do not possess the ability to delineate much smaller vegetation types within a cluster of trees (**Figure 3.5**). Here the FRI is outlined in green and overlaid on top of a false colour Landsat image. Vegetation types denoted by V1, V5 and V13 represent changes in vegetation as outlined in the Forest Ecological Classification for Manitoba (FEC) (Zoladeski 1995). The change in colour on the Landsat image from dark blue to bright red indicates a change in an ecological properties but is ignored by the FRI polygon attributes.

Once Landsat images were corrected for atmospheric contamination and georectified, the Forest Resource Inventory (FRI) was overlaid within a GIS. A function commonly referred to as "Summarize by Zones" was used to average pixel reflectance values for 87 FRI polygons within the study site area for the Landsat spring 2001, summer 2002 and fall 2002 images for bands 3,4,5 and 7. Only Landsat pixels with greater than 50% area within a polygon were extracted and included in the calculation of average polygon reflectance (**Figure 3.6**). An average reflectance table was constructed consisting of 87 rows per season representing the 87 FRI polygons and 4 columns consisting of bands 3,4,5 and 7 for spring 2001, summer 2002 and fall 2002 (**Table 3.1**).

3.4.4 Multivariate Analysis

Multivariate analysis was used to compare the three seasons using a Principal Component Analysis (PCA). PCA is used to dampen noise between image bands and reduce dimensionality of a data set (Franklin 1986, Horler and Ahern 1986, Richards 1999). In the FRI and IFOV data set four Landsat ETM+ bands were utilized with some correlation but more importantly a PCA was used to extract image variance from four down to only one or two making the dataset much easier to interpret. Two separate PCAs were performed. The first was performed on the average reflectance of the FRI polygons and the second on the IFOV polygons. Both PCA used bands 3, 4, 5 and 7 for the spring, summer and fall. In the past PCA is normally performed to discover differences between images. Here we perform the analysis on bands to discover physiological differences of vegetation within seasons based on different scales. A Canonical Correlation Analysis (CanCor) was used to measure the correlation between the summarized summer Landsat image of FRI and IFOV polygons. CanCor is also useful when you have a series of multiple regressions on data that are explaining a series of variables that are potentially related. A second CanCor was performed on Landsat bands and ocular examined ecoelements.

3.5 Results

3.5.1 Season and Scale

The two separate seasonal PCA results of the FRI polygons and IFOV polygons show similar trends in variation having equal distributions on PCA axes 1 and 2 (**Figure 3.7** and **3.8**). For the PCA on the power paraglider IFOV polygons the first axis accounted for 48.3% of variance while axis two accounted for 37.8%. Axis one of the PCA on the FRI polygons accounted for 48.2% of variance and 40.0% was accounted for on axis two. In both analyses, data clustered into three distinguishable groups representing spring, summer and fall. Individual bands did not show a trend. **Figure 3.9** is a comparison of mean IFOV polygon reflectance and Landsat bands 3, 4, 5 and 7 for spring, summer and fall of black spruce, jack pine, trembling aspen and tamarack larch dominated tree stands.

3.5.2 Delineation of Ecoelements

The CanCor comparing summarized summer Landsat image of FRI and IFOV polygons showed a high correlation with a redundancy value of 73% and a canonical variate value of 0.89 (**Figure 3.10**). This would indicate the two polygon scales were detecting similar ground features. The second CanCor was performed on ecoelements summarized by IFOV polygons of summer Landsat. It showed high correlation with a redundancy value of 73% and a low canonical variate value of 0.29 demonstrating there is high redundancy between ecoelements and Landsat datasets but low correlation (**Figure 3.11**).

3.6 Discussion

3.6.1 Season and Scaling

When summarized seasonal Landsat image variance is extracted, regardless of polygon scale, the same trended variation is exposed. This conclusion is further supported by four different tree species having nearly an identical phenological trend from spring, summer and fall for Landsat bands 3, 4, 5 and 7 (**Figure 3.9**). There was an even shift by all species in spectral reflectance suggesting seasonality of ecoelements were not detected. The understory ecoelements within the study site were either rock\lichen or moss which has very little seasonal change or a deciduous species types. Overstory and understory deciduous species types change phonologically at nearly the same time (Rolstad 2002). This only leaves a short window of opportunity to capture phenological differences between overstory and understory species (Townsend 2001). The Landsat satellite had a 16 days repeat cycle causing the acquisition of the tree and understory deciduous species phenological difference to be very difficult. This also does not take into account cloud interference dates. It is possible this window was missed in both spring and fall resulting in a consistent reflectance shift for each type of boreal ecosite.

Eastwood (1998) was unable to distinguish old fire scars using multitemporal Landsat imagery. It is possible the 30 m resolution of Landsat is not able to capture differential community separation. Walker (2001) concluded it is also possible the Landsat sensor is as susceptible to forest structure as forest species diversity. Gerard (2003) concluded shortwave infrared (Landsat band 5) may be linked to forest structure and was a possible reason for Eastwood (1998) inconclusive results. Landsat band 5 also showed little correspondence to any understory ecoelement. The scales between the summarized summer Landsat image of FRI and IFOV polygons where extremely correlated and showed high redundancy on the first axes of the CanCor. The boreal forest is in essence a simple ecosystem with only a dozen or so naturally occurring tree species but is comprised of distinct discrete homogeneous sub-areas (Zoladeski 1995). Therefore even though the IFOV polygon only captured a small portion of the entire FRI polygon it was enough to capture a representative sample of the ecoelements that occur within an ecosite area. The FEC uses 10 m x 10 m plots to capture V-Types to represent sent much larger areas (Zoladeski 1998). We were successful in finding a new scale level that samples a large area in an accurate and timely manner. There was an issue of sampling with replacement when randomly selected IFOV polygons were chosen from within a FRI polygon.

3.6.2 Delineation of Ecoelements

The second CanCor shows correlation between spruce, moss, pine and rock/lichen in one direction as well as aspen, grass and shrub/herb in another direction in the vegetation dataset (**Figure 3.12**). Results also show correlation between band 3 and conifer species, spruce and moss, band 4 and deciduous species, grass and shrub\herb and band 7 and rock/lichen. The correlation between Landsat bands and ecoelements may be used in the initial stages of delineation of boreal ecosites. Band 3 is highly associated with 17 of the 24 conifer dominated terrestrial ecosites and 5 of the 16 conifer dominated wetland ecosites

(**Appendix A**). Band 3 is also correlated with coniferous dominated FEC ecoelement V-Types V19 to V33. Band 4 is best suited to delineate ecosites E-19 to E-21 and E-24 due to their strong presence of deciduous species, rich shrub and herb understories and ecosites E-29, E-30, E-32 and E-34 because of the high occurrence of shrub, willow or alder. Band 4 is also highly correlated with deciduous dominate FEC ecoelement V-Types V1 to V10. Band 7 may be useful for identifying ecosites E-2, E-4 and E-11 due to the high prominence of lichen or exposed bedrock in the understory and FEC ecoelement V-Type V26, Jack Pine-Black Spruce\Lichen.

Summary 3.6.3

Findings support the use of the power paraglider scale level to collect ecoelement data over the boreal forest. The ecoelements detected in the IFOV images can now be used to build a knowledge database to train Landsat imagery to detect understory ecoelements. Certain bands of Landsat imagery are sensitive to individual ecoelements which are critical in the delineation of ecosites. These Landsat\ecoelement relationships can now be utilized as a piece of evidence in a decision support model to delineate ecosites for sustainable forest management. Understory species can be used a biodiversity indicators of many other important ecological characteristics of the boreal forest (Vasudevan 2004). This ecological information is critical to the scientific approach of SFM. Understory attributes are only part of ecosite classification; another important ecoelement critical to ecosites identification is enduring landform features and is explored in **Chapter 4**.

Tables

Table 3.1: Average reflectance table of the 87 FRI polygons for Landsat bands 3, 4, 5 and 7 for spring 2001, summer 2002 and fall 2002.

	Band 3	***Band 4***	***Band 5***	***Band 7***
Spring 1 ***:*** ***Spring N***				
Summer 1 ***:*** ***Summer N***				
Fall 1 ***:*** ***Fall N***				

Figures

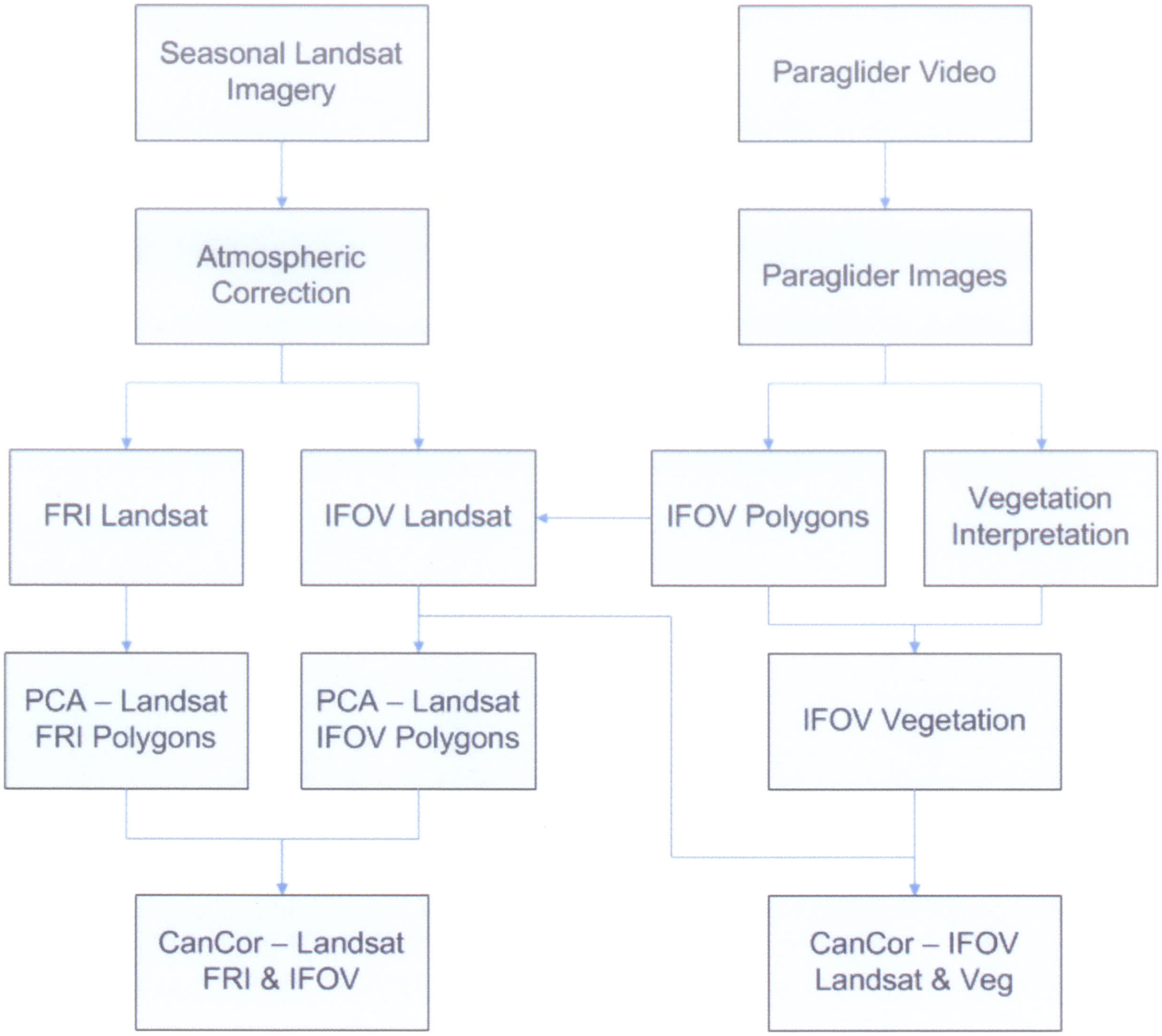

Figure 3.1: Work flow of Landsat imagery and power paraglider imagery. Landsat imagery was atmospherically corrected summarized by FRI and IFOV polygon layers. Paraglider video was resampled into images and optically interpreted for understory ecoelements. PCAs were performed on FRI and IFOV datasets. A CanCor was performed on FRI and IFOV summarized Landsat pixels and a second CanCor on IFOV polygons summarized by Landsat imagery and understory ecoelements.

Figure 3.2: Picture of power paraglider used for data collection in boreal forest.

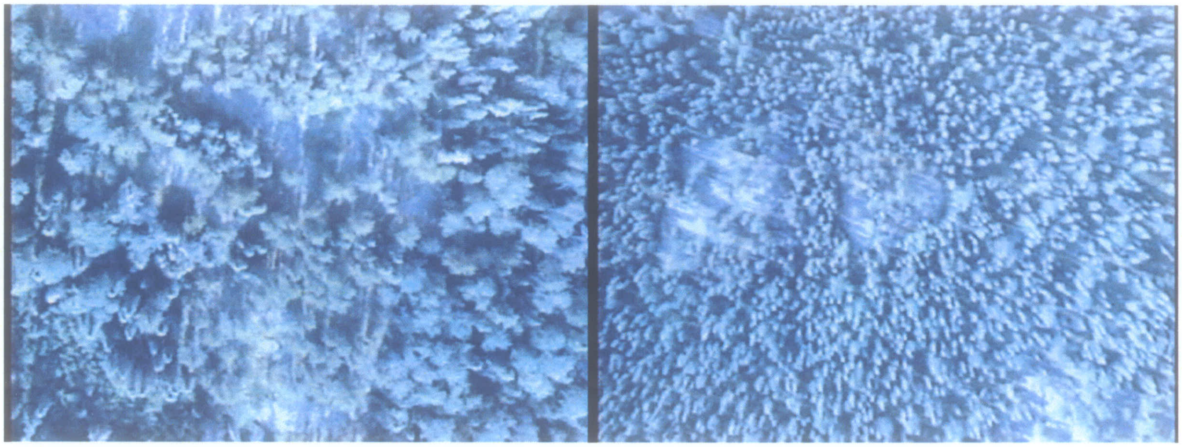

Figure 3.3: Example of the 552 images resampled from digital video tape. Image on the left overstory dominated by jack pine with occurrences of black spruce and the understory comprised mainly of lichen on igneous rock. The image on the right is dominated by black spruce in the overstory with moss in the understory.

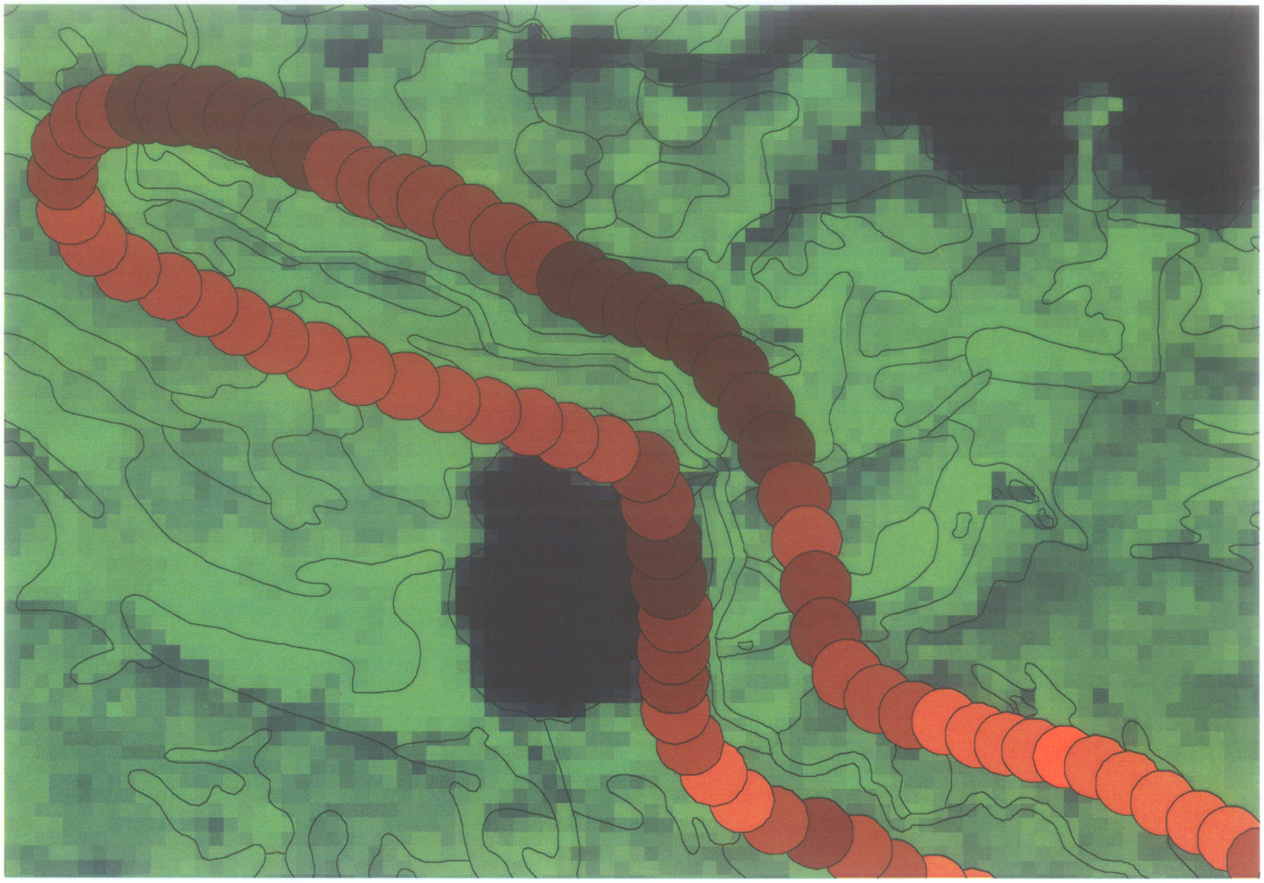

Figure 3.4: Instantaneous Field of View (red circles) for each image derived from height above canopy and the focal length of the video camera. Larger IFOV footprints appear in dark red while smaller IFOV polygons appear in light red. FRI polygon layer outlined by thin black lines. Both vector files are draped over a false colour Landsat band 3 image depicted in by vegetative areas (green) and water bodies (black).

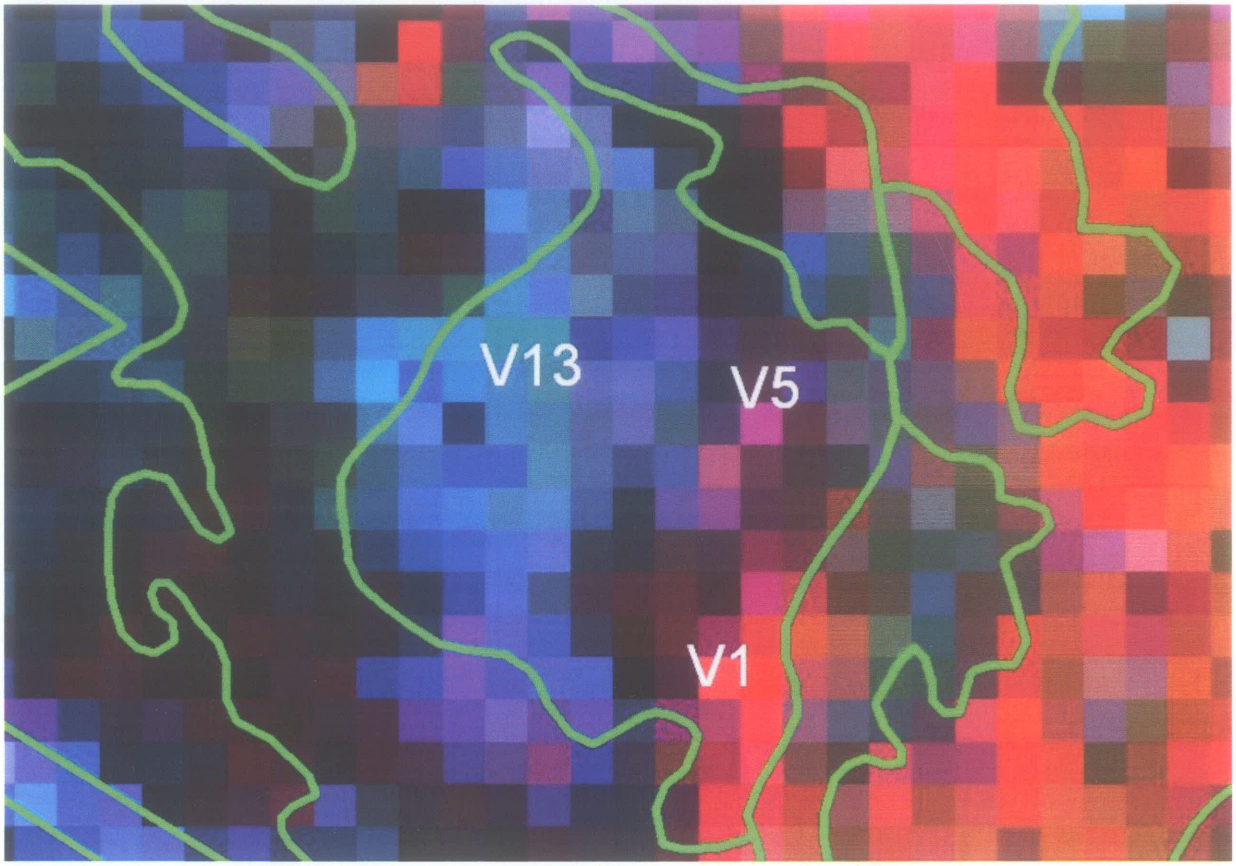

Figure 3.5: FRI polygon layer (green) superimposed over a false colour RGB Landsat image enhanced by an equal area histogram display. Dark blue pixels represent conifer species and bright red pixels represent deciduous vegetation. FEC V-Types V1-Balsam Poplar Hardwood and Mixedwood, V5-Aspen Hardwood and V-13, White Spruce Mixedwood\Feather Moss appear in white text.

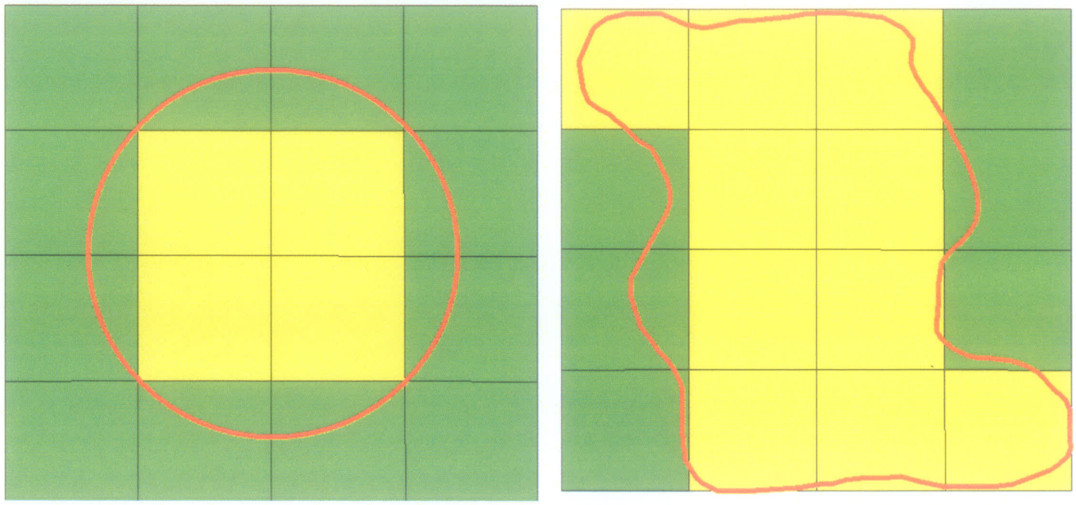

Figure 3.6: Summarize by zones methodology where red vectors represent different shaped polygons. Yellow pixels extracted by sum by zones process because 50% or more of the area occur within the polygons while green pixels are ignored because 51% or more of the area occur outside the polygons.

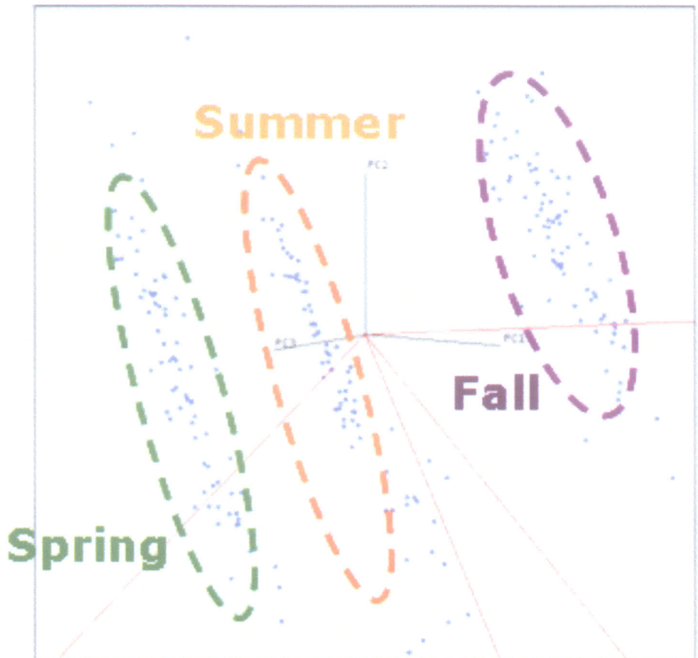

Figure 3.7: PCA result of spring (green), summer (orange) and fall (purple) Landsat images summarized by FRI polygons (blue). Landsat bands 3, 4, 5 and 7 appear as axes (red) along with new PCA axes PC1, PC2 and PC3 (grey).

Figure 3.8: PCA result of spring (green), summer (orange) and fall (purple) Landsat images summarized by IFOV polygons (blue). Landsat bands 3, 4, 5 and 7 appear as axes (red) along with new PCA axes PC1, PC2 and PC3 (grey).

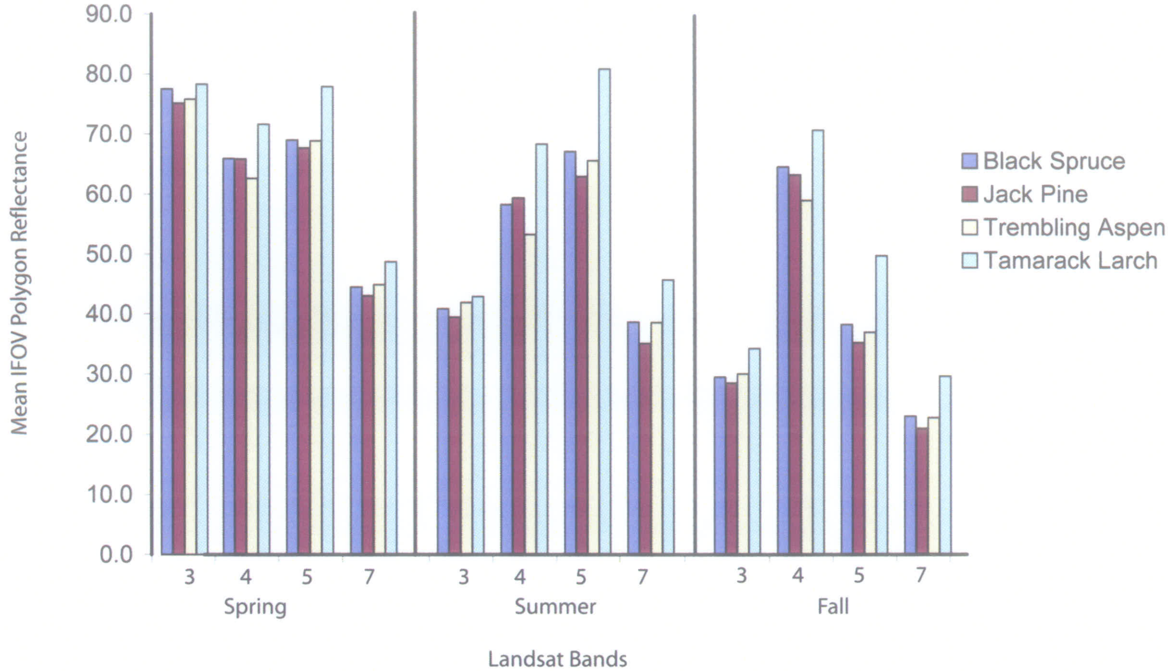

Figure 3.9: Comparison of mean IFOV polygon reflectance and Landsat bands 3, 4, 5 and 7 for spring, summer and fall of black spruce, jack pine, trembling aspen and tamarack larch dominated tree stands.

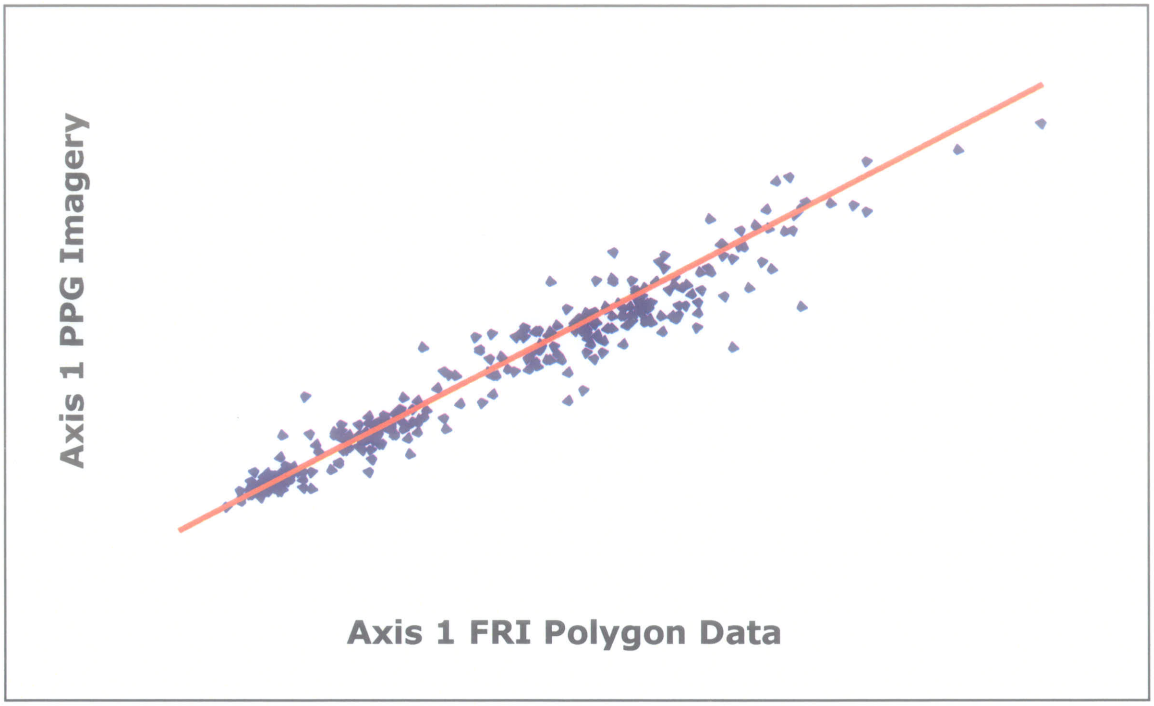

Figure 3.10: CanCor object scores (blue points) for first axes of PPG imagery and FRI polygons with line of best fit (red). X axis contains FRI Polygon data while the Y axis contains PPG Imagery data. The two datasets had a canonical correlation redundancy value 73% and a first canonical variates value of 0.89.

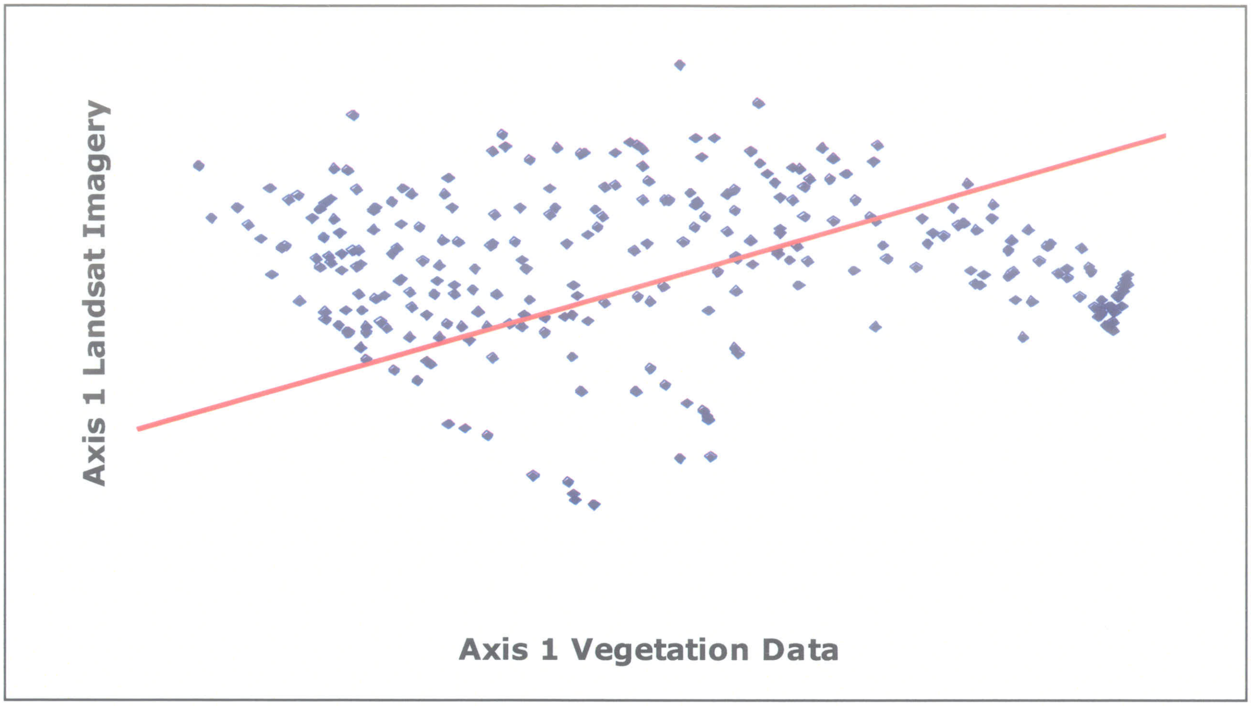

Figure 3.11: CanCor object scores (blue points) for first axes of vegetation data and Landsat imagery polygons with line of best fit (red). X axis contains vegetation data while the Y axis contains Landsat imagery data. The two datasets had a canonical correlation redundancy value 73% and a first canonical variates value of 0.23.

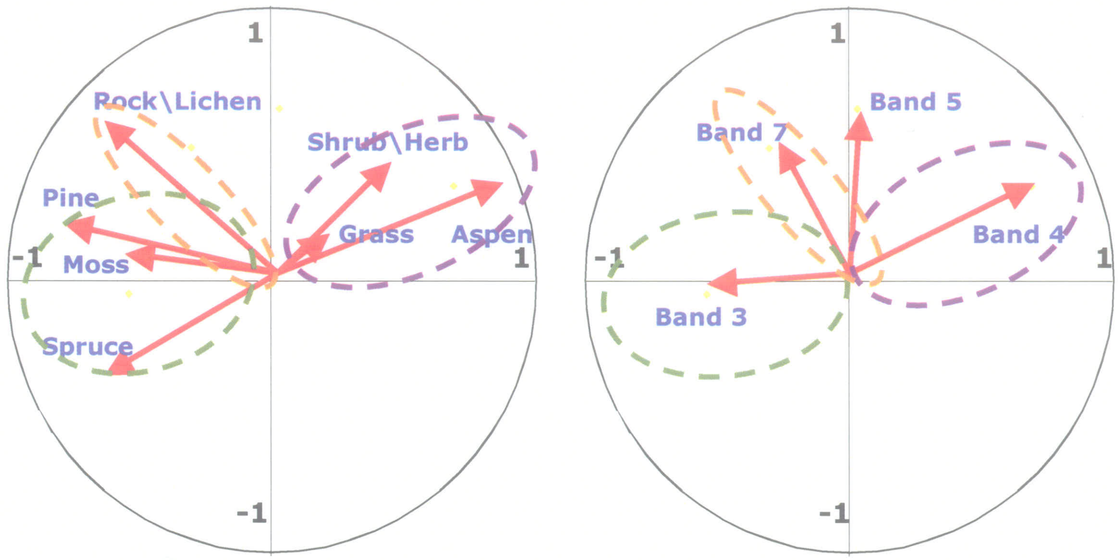

Figure 3.12: CanCor Analysis correlation scores of vegetation data (left) and Landsat data (right). Attribute axes are displayed in red on both figures. Results also show correlation between band 3 and conifer species, spruce and moss (green dashed oval), band 4 and deciduous species, grass and shrub\herb (purple dashed oval) and band 7 and rock/lichen (orange dashed oval).

Chapter 4

Comparison of Boreal Tree Species and Enduring Landform Features using Remote Sensing Technologies

Abstract

A Canonical Correspondence Analysis (CCA) is used to determine relationships between Forest Resource Inventory (FRI) species and landform features generated from a Digital Information Model (DEM). Existing forest inventory GIS layers do not account for landscape variables that are critical to the ecology of the boreal forest and its sustainable management. Utilization of a DEM allows topology measurements to be made for the generation of six enduring landscape features: 1) Peak, 2) Ridge, 3) Pass, 4) Plane, 5) Channel and 6) Pit. Identifying relationships between boreal tree and wetland species to their surrounding landform features enables delineation of forested areas at the ecosite level in a quantifiable and repeatable manner.

4.1 Introduction

The nature of boreal tree species and how they relate to enduring features is critical to ecological theory and sustainable forest management (Zoladeski 1998, Canadian Council of Forest Ministers 2000). It is widely believed vegetation can be predicted by its location in the surrounding micro-landform environment (Canadian Committee on Ecological Land Classification 1997). Smith (1998) explains ecoregions are classified by the intimate relationship between ecoclimate, regional landscape physiography, surface materials and form, soil development and vegetative data. This analysis examines the relationship between landform and vegetation at the ecoelement level (Canadian Committee on Ecological Land Classification 1997). What is unknown is the relationship tree and wetland species have to their surrounding enduring landform features at the ecosite scale (Donnelly 2003). It is believed boreal terrestrial and wetland species are dependent on their enduring feature landscape (Beckingham 1996). Using the existing FRI as a surrogate measure to evaluate how species composition of tree stands compare to their enduring landform feature types derived from a Digital Elevation Model (DEM) is the focus of this chapter.

DEMs have played a vital role in identifying ecological attributes to enduring landform features (Jenson and Domingue 1988). Kenward (2000) used a DEM to model hydrological characteristics of an entire watershed. Manfreda (2006) made use of elevation data to scale spatial patterns of soil moisture. Fox (1985) classified timberland productivity using Landsat, topographic, and ecological data. Lieffers and Larkin-Lieffers (1987) utilized slope, aspect, and slope position as factors controlling grassland communities. Often the position of a feature within a toposequence is equally as important as the landscape feature itself (Zoladeski 1995). Topographic modeling goes beyond individual site identification by incorporating information from neighboring areas. What occurs above or below a location along a slope profile can directly affect the ecoelements at that site. The landscape must be examined as a whole in a continual manner before assumptions about individual areas can be made. Modeling the continuity of topology using DEMs is accomplished using a series of quadratic equations (Wood 1996c).

A quadratic equation is a polynomial equation of the second degree. The general form is given in **Equation 4.1**.

$$ax^2 + bx + c = 0 \qquad \textbf{[Equation 4.1]}$$

Where $\boldsymbol{a}$ is not equal to 0. If $\boldsymbol{a}$ is equal to 0 then the Equation simply becomes a linear Equation.

The letters $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ are coefficients:

$\boldsymbol{a}$ is the quadratic coefficient,

$\boldsymbol{b}$ is the linear coefficient,

$\boldsymbol{c}$ is the constant coefficient, A quadratic equation with real coefficients has two solutions called roots, which may be real or complex as shown in **Equation 4.2**.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$ **[Equation 4.2]**

where the symbol plus or minus "±" indicates that both are solutions shown in **Equations 4.3** and **4.4**.

$$x_+ = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$ **[Equation 4.3]**

$$x_- = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$ **[Equation 4.4]**

This function has been the basis for many DEM analyses (Evans 1980, Zevenbergen and Thorne 1987, Skidmore 1989). Quadratic functions have the advantage of second order properties allowing curvature to be generated directly from the equation (Wood 1996c). An example of the quadratic equation output model is given in **Figure 4.1**. Topographic modeling produces such variables as slope, profile convexity, plan convexity, longitudinal curvature, cross-sectional curvature, minimum curvature and maximum. They are use to generate landform types and are the basis for the enduring features of a landscape. It is these enduring landform features paralleled with boreal tree species data that are critical to ecosite delineation.

4.2 Objective

The objective of this chapter is to identify the relationship between boreal forest communities and surrounding enduring landscape features. Many authors have suggested enduring feature for biodiversity conservation (Pabst and Spies 1998; Vasudevan 2004) and ecological delineation (Smith 1998). Few authors have examined the direct relationship by objectively defined enduring features and species diversity. Four sub-objectives are examined to identify this relationship:

1) Examine trends within boreal species as contained by the FRI to better understand how species interact and relate to one another.

2) Develop an enduring features layer from a DEM.

3) Identify the relationship within enduring landscape features to gain knowledge of how enduring landform features co-occur on the landscape.

4) Determine the relationship between boreal species as coded in FRI and enduring landscape features.

4.3 Study Area

See Chapter 2.1 - Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba

4.4 Methodology

4.4.1 Topographic Modeling Calculations

The Topographic Modeling function produced landform parameters slope, profile convexity, plan convexity, longitudinal curvature, cross-sectional curvature, minimum curvature and maximum curvature (Wood 1996c). These are local calculations generated from neighboring pixels with a defined kernel size. Slope is a simple measure in degrees from the horizontal plane which is equal to 0 degrees to pixel value. It measures the angle at which the pixel exists. Aspect is the direction a pixel is facing. Although aspect values are inherently generated by the topographic modeling function and are used for the calculation of other landform measures, the aspect values were not included as a landform measure in the multivariate analysis. Aspect at the latitude of the study does not influence the vegetative growth of an ecosite. Aspect does however play an important role as how pixels relate to one another and that information is retained by ENVI to determine many of the following landform variables.

For the remaining topographic modeling parameters, a positive value represents a convex surface measurement and a negative value represents a concave surface measurement. Profile convexity is a measure of the rate of change of slope along the vertical profile while plan convexity is a measure of the amount potential gravity influence or concavity along surface profile. The longitudinal curvature value is calculated by intersecting with the plane of the slope normal and aspect direction. The cross-sectional curvature value is calculated by intersecting with the plane of the slope normal and perpendicular aspect direction. These two measures can be interpreted as perpendicular measures of the surface curvature in the down slope and across slope directions, respectfully. Minimum and maximum curvatures are essentially the overall curvature individual pixels with a DEM.

4.4.2 Topographic Feature Calculations

These landform variables are the basis for the enduring features of a landscape. The topographic features produced a thematic map classifying each pixel into one of the following six enduring landform features: 1) Peak, 2) Ridge, 3) Pass, 4) Plane, 5) Channel and 6) Pit. Classes are defined by a tolerances of slope, longitudinal curvature and cross-sectional curvature (**Table 4.1**).

A Peak is a raised area consisting of slope values less than tolerant levels, convex longitudinal curvature and convex cross-sectional curvature. Ridges have significant slope, insignificant longitudinal curvature and convex cross-sectional curvature. A Pass has insignificant slope, with longitudinal and cross-sectional curvatures of concave and convex or convex and concave respectively. Planes have no significant landform values. Channels consist of slope values greater than tolerant levels, longitudinal values less than tolerant levels and concave cross-sectional values. Finally, Pits have insignificant slope, concave longitudinal and cross-sectional curvatures. The topographic feature calculations were generated in raster format and later converted into vector polygons. These landform feature polygons were clipped with the Forest Resource Inventory (FRI) layer.

4.4.3 Forest Resource Inventory

The Forest Land Inventory (FRI) produced by Manitoba Conservation, Forestry Branch is a GIS based vector layer file comprised of polygons that represent tree stands within forested areas of Manitoba. The FRI is produced through human interpretation of aerial photographs to identify individual tree stands and are hand digitized into polygons to model tree stands. Each polygon has several attributes associated with it including species types, landform, stand height, year of origin, vegetation type, area and perimeter. For more information on the FRI please see **Chapter 1.4.4.**

For this analysis each FRI polygon was broken down by the species type string which is recorded as two letters to represent the species type and a number to represent the presence of that species type (**Table 4.2**). For treed FRI polygons there may be one or more tree species occupying that tree stand as shown below:

JP5BS3TA2 = Jack Pine 50%, Black Spruce 30% and Trembling Aspen 20%

In this example the FRI polygon species string is interpreted as a treed stand consisting of Jack Pine 50%, Black Spruce 30% and Trembling Aspen 20%. Each FRI polygon coverage must sum to 10 or 100% to account for all areas within the tree stand. Each polygon is coded to either be a combination of tree species types or some other form of feature such as a treed muskeg, shrub wetland, meadow or rock outcrop. FRI polygons occurring on igneous rock were combined with Jack Pine and Black Spruce in a new code (XR) for the purposes of reducing outliers within the dataset. Jack Pine and Black Spruce where chosen because they most often occur with the presence of igneous rock (Zoladeski 1998). The same procedure applied to muskeg with Black Spruce and Tamarack Larch most frequently occurring (Racey 1996) in the (XM) class also to reduce outlining information. Alder and Willow were combined in the (XX) code and all remaining wetland were combined in the (XM) class for the same purpose as they share similar ecological properties (Racey 1996). (YB) beaver flood is an operational category in the FRI and was not adjusted. All lakes, rivers, roads and human intervention polygons were excluded from the analysis.

The topographic modeling values slope, profile convexity, plane convexity, longitudinal curvature, cross-sectional curvature minimal\maximum convexity and a root mean square (RMS) error value were summarized for each FRI polygon. The mean, minimum, maximum and range values of each topographic modeling attribute were calculated for each FRI polygon. FRI polygons were then intersected by the topographic feature vector file so each FRI polygon had a landform feature variable associated with it. In many cases more than one topographic feature value occurred within a single FRI polygon. A simple area calculation was performed to summarize the amount of each topographic feature present in each FRI polygon. There is a species composition percentage value, a series of summary topographic feature values and a landform feature type amount for each FRI polygon (**Figure 4.2**). The next step is to identify the relationship between boreal forest tree species and landform. Ideally, we would prefer to use an ecosite vector layer to examine ecosite landform but no such GIS layer is in existence. We were forced to the FRI as a surrogate measure of boreal vegetative tree stands.

4.4.4 Multivariate Analysis

Principal Components Analysis (PCA) was used to identify the variance distribution with the boreal species dataset (**Table 4.2**), the topographic modeling parameters (**Table 4.3**) and the enduring landscape feature dataset in three separate PCAs (**Table 4.1**). A correlation cross-product matrix was used for the Principal Components Analysis (PCA) and scores for species were calculated using a distance-based biplot. For details on PCA also please see **Chapter 1.5.1.** For determining the relationship between boreal tree species and enduring landscape features a CCA was used to describe those relationships. Two Canonical Correspondence Analyses (CCA) were performed on the boreal species and topographic modeling parameters datasets as well as boreal species and enduring landform type datasets with species being dependent on landform in both instances using row and column scores standardized by Hill's (1979) method. For further details on CCA please see **Chapter 1.5.4.** A flow chart depicting the workflow from the FRI manipulation to the DEM methodology is shown in **Figure 4.3**.

4.5 Results

4.5.1 Boreal Species Trends

Jack Pine (JP), Trembling Aspen (TA), and Black Spruce (BS) occur in opposite directions from one another while Black Spruce\Tamarack Larch Muskeg (XM) and Willow and Alder (XX) occur in similar directions on the PCA1-2 plot as shown (**Figure 4.4**). All other types are clustered in the centre. The list of percentage of variance for each PCA axis is listed in **Table 4.3**. On ordination plot PCA1-3 (**Figure 4.5**) Beaver Flood (YB) and Marsh (YM) occur in exactly the same direction. Conifer species Balsam Fir (BF), White Spruce (WS) and Jack Pine (JP) all occur in similar directions while deciduous species Trembling Aspen (TA), Balsam Poplar (BA) and White Birch (WB) also occur in a similar direction. Both Black Spruce (BS) and Tamarack Larch (TL) are being grouped out with Black Spruce\Tamarack Larch Muskeg (XM) and Willow and Alder (XX). Very similar trends occur in ordination biplot PCA 2-3 (**Figure 4.6**) as biplot PCA1-3.

4.5.2 Enduring Landform Feature Trends

The PCA of the topographic modeling parameters showed 59.0% variance on PCA1 and 96.3% of all variance on the first three axes (**Table 4.4**). The enduring landform feature area values were log transformed to reduce the influence of very large landform feature types. The list of percentage of variance for each PCA axis is listed in **Table 4.4**. On ordination biplot PCA1-2 (**Figure 4.7**) Ridge and Peak occur in the same direction, Pit, Pass and Channel also occur in the same direction while Plane seems to be the most independent landform type. Pass joins Ridge and Peak as anticipated while Pit and Channel grew closer on PCA1-3 (**Figure 4.8**). The Plane landform type continues to be isolated. Peak and Ridge occur together, Channel and Pit occur in the same direction and Plane and Pass occur in opposite directions on the PCA2-3 biplot (**Figure 4.9**).

4.5.3 Landform and Species Correspondence

The results of the CCA on the Species and Landform correlation scores are compared graphically side by side (**Figure 4.10**). Jack Pine (JP) and Igneous Rock, Jack Pine on rock, Black Spruce on rock (XR) species types showed high correspondence with landform types Peak and Ridge. Beaver Flood (YB), Marsh (YM) and Alder, Willow (XX) species type trends were very similar to the Channel and Pit landform type trends. The Pass landform type showed a similarity to White Birch (WB), Green Ash (AS) and Balsam Fir (BF) while the Plane landform type showed little correlation with any particular species type. Landform and species results are further supported by the CCA object scores of the first two axes for topographic modeling parameters and FRI tree species (**Figure 4.11**). The dominate trend in the topographic parameters on the first axis goes from convex parameter types to concave parameter types while the dominate trend on the FRI species also occurs on the first axis from dry species to wet species.

Discussion 4.6

Several ecoelement variables were excluded from the landform\species correspondence analysis. Climate can be considered constant as the ecosite scale is smaller than any climatic subregion type and therefore neglected from the multivariate analysis (Price 1999). Surface material also does not change dramatically enough within the 10 km by 10 km study area to be utilized in the analysis (Zevenbergen and Thorne 1987). Soil development can be argued as the end product of the landform\vegetative relationship (Manfreda 2006) and therefore dependent and also excluded from the study.

Significant slope and curvature values are determined by the user for topographic modeling calculation. A slope value of 7.5 degrees and a curvature tolerance value of 0.025 were used in the topographic feature analysis based on several summers in the boreal forest collecting landform information for ecosite delineation. Slope and curvature tolerant levels can significantly change the topographic modeling calculations (Wood 1996c). Several slope and curvature tolerant values were inputted but the resulting model characteristics did not correspond to field collected landform data. It was determined a slope of 7.5 degrees and a curvature tolerance of 0.025 were the most appropriate values to use within the study site.

4.6.1 Boreal Species Trends

Information from the species string in the FRI was used in percentage format. Because the FRI species string is only measured in integers that are divisible by 10 there is a lack of detail pattern that is exposed in the PCA output as each biplot appears in linear blocks (**Figures 4.3, 4.4 and 4.5**). When dealing with information in percentages on three axes there is also a minimum value of 0 and maximum value of 100 that can exist creating a bow tie or 3-dimensional triangle effect. If a value is 90 on axis A it can only be 10 on axis B or C. Generally most sites are species poor because only a few tree species occur (Beckingham 1996). 34.5% of the variance was accounted for on the first three axes with 13.7% occurring on PCA1 (**Table 4.3**). This is a result of incorporating 14 species in the analysis with 14 axes trying to account for variance. If no information was retained on PCA1 the percent of variance should have been only 7% (1/14). This was clearly not the case as PCA1 retained nearly double that amount indicating significant structure within the dataset.

Igneous Rock, Jack Pine on rock, Black Spruce on rock (XR) was consistently separating with Jack Pine (JP). This was partially due to the fact both Jack Pine on rock and Black Spruce on rock were grouped with in the XR class but it is also due to the fact mainly Jack Pine (JP) is one of the only boreal tree species that occur on igneous rock (Zoladeski 1998). The Black Spruce\Tamarack Larch Muskeg (XM) and Willow and Alder (XX) types strongly occurred in the same direction. This is due to the fact that both these species types thrive in wet conditions (Racy 1996). Caught in the middle of the dry and wet occurrences is Black Spruce (BS). Black spruce as a species has the ability to survive in both wet and dry conditions (Beckingham 1996). Both of the above findings thus far are occurring with species that thrive in nutrient poor soils. Many of the boreal deciduous species such as Trembling Aspen (TA) and Balsam Poplar (BA) are found in nutrient rich soils and occur in the opposite direction of the wet and dry or nutrient poor species (Zoladeski 1995).

4.6.2 Enduring Landform Feature Trends

The PCA of enduring landform features exposes the Ridge and Peak landscape types occurring together and the Pit and Channel landscape types occurring together in each of the PCA biplots (**Figure 4.6, 4.7 and 4.8**). This is anticipated as both Ridge and Peak can be considered a convex landform type, meaning they repel water and Pit and Channel are considered a concave landform type, meaning they gather water. The Pass landform type can have either a concave or convex longitudinal and\or cross-sectional curvatures with insignificant slope and the Plane type has no significant landform values. This is evident in the PCA biplots as each class occurs around the Ridge and Peak landscape types and the Pit and Channel landscape types. Slope features have less spatial variety in terms of surface complexity. This simple concave and convex landscape feature trend dominates the PCA as much of the landscape feature information can be reduced to 81.8% on the first three PCA axes with 41.8% occurring on the first axis (**Table 4.5**). This would indicate a single dominant trend is occurring within the landscape feature dataset which can be reduced to whether or not a feature is concave or convex.

There is a large degree of overlap within FRI polygons of different land form types mainly because individual tree stands occur on or part of toposequence (**Figure 4.6**). Peak, ridge, pass and plane ecoelements can all occur within one FRI polygon, especially large polygons (Zoladeski 1995). Aerial photo interpretation used to create the FRI cannot use landform values to distinguish polygon boundaries, only visual inspection of tree stands. Many boreal tree species can flourish along a toposequence occurring on different landform types. Ecoelements such as soil moisture, soil texture and understory species can change dramatically from landform to landform (Zoladeski 1998) resulting in multiple ecosites occurring within the same FRI polygon (**Figure 3.5**). The principal components of the enduring landscape features generated from a DEM indicates the FRI is incapable of accurately delineating landform ecoelements for ecosite identification but does correspond to general landscape trends of the boreal forest.

4.6.3 Species and Landform Correspondence

The CCA revealed trends between the boreal species and enduring landform types for the delineation of boreal ecosites. The fact that Jack Pine (JP) and Igneous Rock, Jack Pine on rock, Black Spruce on rock (XR) species types showed high correlation with landform types Peak and Ridge confirms Jack Pine occurs on a convex or Peak or Ridge surface and such a surface is highly likely to be an igneous rock outcrop (Host 1996). Results are further supported the correspondence with convex topographic parameters and (JP) and (XR) (**Figure 4.11**). This is indicative to ecosite E-2, Jack pine-black spruce on very shallow rugged terrain features (**Appendix A**). A typical E-2 ecosite possess jack pine stands mixed with black spruce in depressions, frequent exposures of bedrock and high lichen cover on a generally rough topology. It would seem the JP and XR FRI class types were accurately correlated with the Peak and Ridge landform features. From a sustainable forest management standpoint this has recreational implementations. Campbell (2006) identified ecosite E-2 as an attractive overnight camping destination when situated near lakes or rivers and especially rapids. Special management practices of locations classified as ecosite E-2 may now be employed to ensure continued recreational usage.

Other correspondences include Beaver Flood (YB), Marsh (YM) and Alder\Willow (XX) species types correlated to the Channel and Pit landform types. These FRI types typically occur in depressional areas and this is solidified with the Channel and Pit landform types being of a concave landform type (Racy 1996). Results are further supported the correspondence with concave topographic parameters and (XX), (XM) and (YM) (**Figure 4.11**). The Marsh (YM) FRI type is common in depressional wetland ecosites E-36, Meadow marsh – organic mineral soil to E-40, Open Water Marsh – Submergent on mineral substrate. The Alder\Willow (XX) class matches ecosite E-34, Thicket Swamp - Alder\Willow on organic soil where both alder and willow are both present in a seasonally flooded area. No ecosite can exist for Beaver Flood (YB) because it is not an ecological type but a fluctuating habitat that does occur in wet areas (Jenkins 1979). The convex landform features Channel and Pit capture the typically wet FRI types YB, YM and XX and may be used in a knowledge database when classifying boreal ecosites.

The Plane landform feature shared correlations scores with the Black Spruce (BS) species type. Black spruce can occur in both wet and dry areas (Zoladeski 1995) and a Plane landform feature can also occur in either wet or dry areas (Wood 1996c), hence their correlation. This conclusion is further supported by the fact black spruce is present in a variety of ecosites ranging from E-11, Black spruce-jack pine\Feathermoss on fresh sandy-coarse loamy soil, a drier ecosite to E-31, Treed Bog – Black spruce\Sphagnum on organic soil, a very wet ecosite.

4.6.4 Summary

The comparison of boreal tree species from the FRI and enduring landform features from topographic modeling calculations using remote sensing technologies was successful. The CCA gave strong indication of where boreal species types occur based on their surrounding enduring features and would be very advantageous when delineating boreal ecosites. Landform is a key ecoelement and when combined with other ecoelements the identification of ecosites becomes possible. The next step is to build an ecoelement knowledge database using landform from a DEM, understory characteristics identified by Landsat and any other sources of ecoelement data to develop a logical decision support model to delineate boreal ecosites. Once ecosites can be physically identified, the boreal forest can be managed in a spatial and ecological manner.

Tables

Table 4.1: Landform classification types defined by a topographic modeling tolerances of slope, longitudinal curvature and cross-sectional curvature values.

Slope Significant	Longitudinal Curvature	Cross-sectional Curvature	Landform Classification
No	Convex	Convex	Peak
Yes	-	Convex	Ridge
No	Concave	Convex	Pass
No	Convex	Concave	Pass
No	-	-	Plane
Yes	-	Concave	Channel
No	Concave	Concave	Pit

Table 4.2: FRI tree species codes used in the multivariate analyses.

Code	Species Type	Scientific Names or Description
BA	Balsam Poplar	*Populus balsamifera*
AS	Black Ash	*Fraxinus nigra*
BF	Balsam Fir	*Abies balsamea*
BS	Black Spruce	*Picea mariana*
JP	Jack Pine	*Pinus banksiana*
TA	Trembling Aspen	*Populus tremuloides*
TL	Tamarack Larch	*Larix laricina*
WB	White Birch	*Betula papyrifera*
WS	White Spruce	*Picea glauca*
XM	Black Spruce Muskeg, Tamarack Larch Muskeg	BS & TL in wet areas with Sphagnum
XX	Willow, Alder	*Salix pedicellaris, Alnus crispa*
XR	Igneous Rock, Jack Pine on Rock, Black Spruce on Rock	JP & BS in dry areas with Lichen
YB	Beaver Flood	FRI landcover type
YM	Marsh	Various Wetlands

Table 4.3: PCA eigenvalues, percentage of variance and cumulative variance for FRI species.

PCA - FRI Species			
AXIS	Eigenvalue	% of Variance	Cum.% of Var.
1	1.917	13.689	13.689
2	1.666	11.899	25.588
3	1.241	8.866	34.454

Table 4.4: PCA eigenvalues, percentage of variance and cumulative variance for topographic modeling parameters.

PCA - Topographic Model Parameters			
AXIS	Eigenvalue	% of Variance	Cum.% of Var.
1	4.133	59.037	59.037
2	1.621	23.152	82.19
3	0.801	11.439	93.629

Table 4.5: PCA eigenvalues, percentage of variance and cumulative variance for enduring landform feature types.

PCA - Landform			
AXIS	Eigenvalue	% of Variance	Cum.% of Var.
1	2.687	44.786	44.786
2	1.15	19.167	63.954
3	1.077	17.956	81.909

Figures

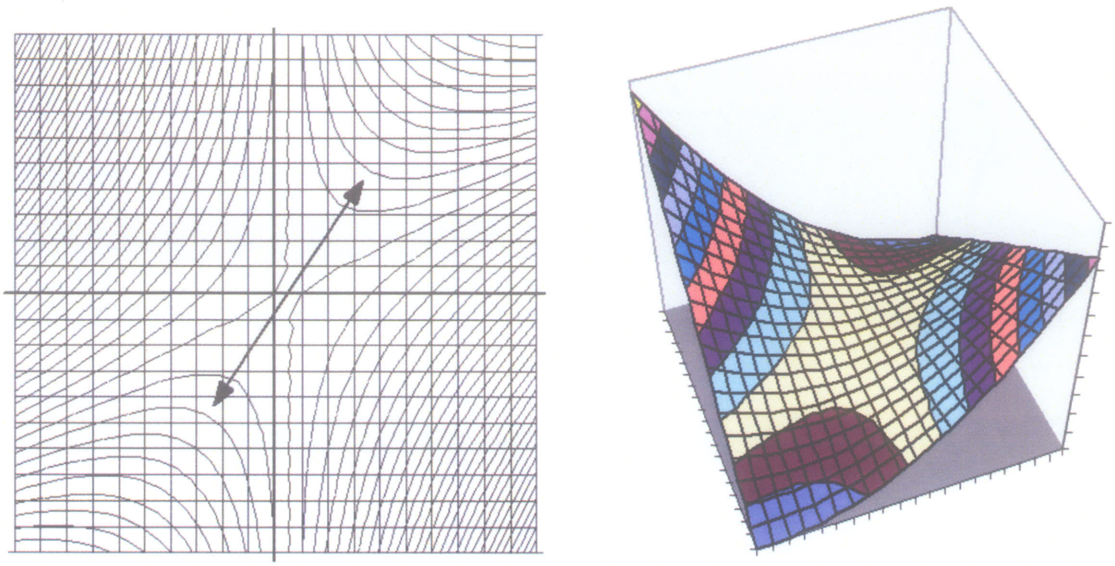

Figure 4.1: An example of the output from a quadratic equation in 2-dimensions (left) 3-dimensions (right). Each pixel with topographic model is rotated on three axes. Bases for enduring landform features creation. Adopted from (Wood, 1996c).

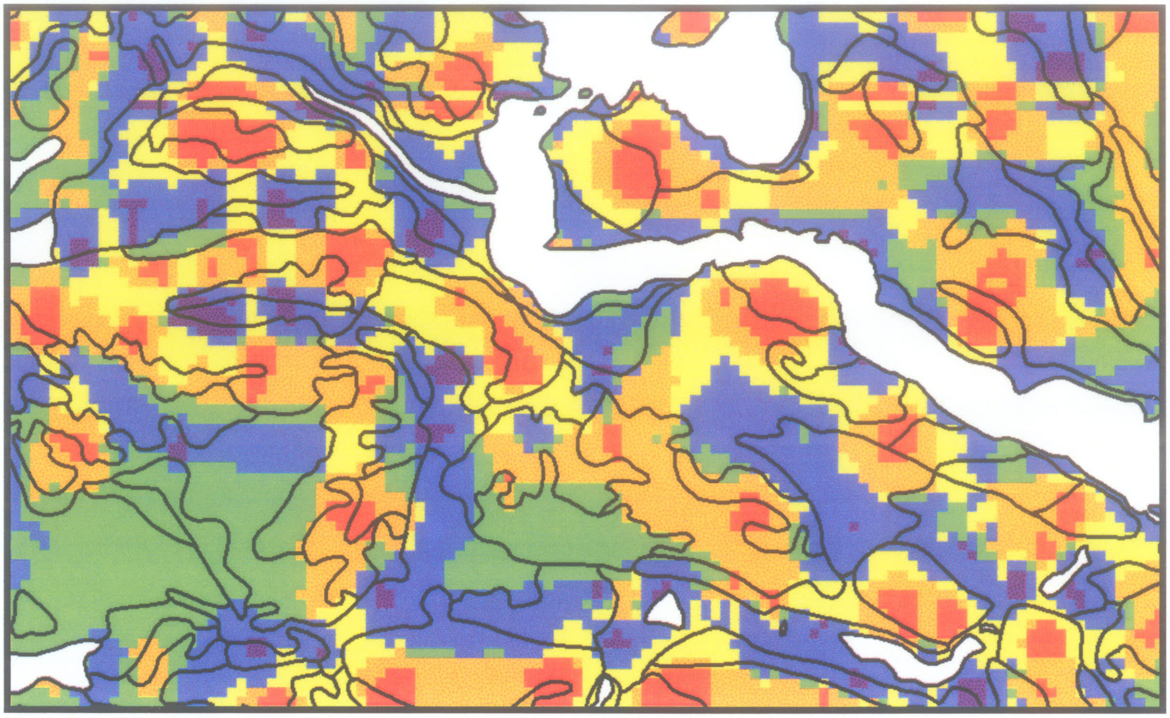

Figure 4.2: An image of the FRI polygon layer (black outlines) draped over the enduring landform features layer (Peak red, Ridge orange, Pass yellow, Plane green, Channel blue and, Pit purple). White spaces represents water bodies and were excluded from the analysis.

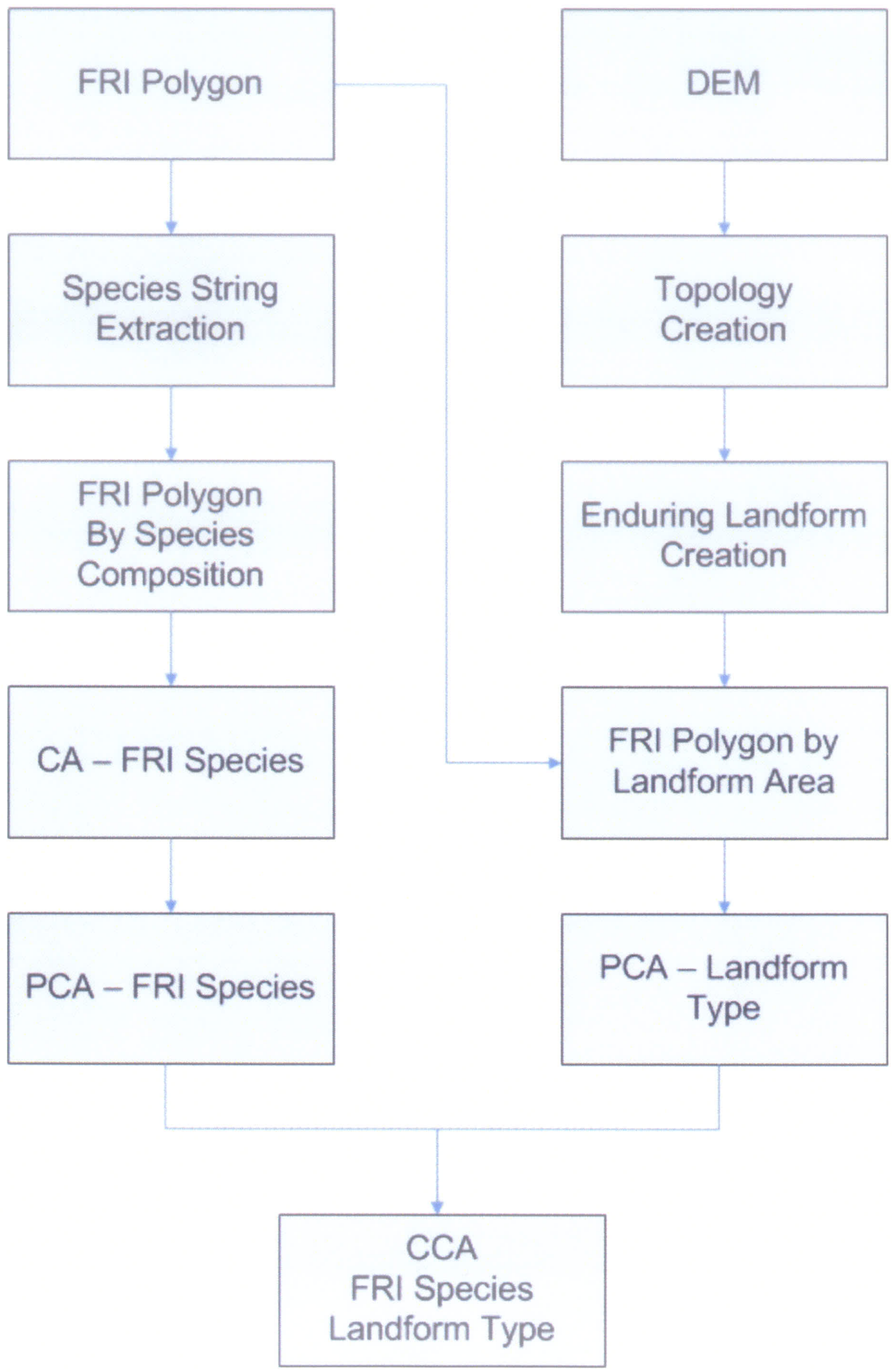

Figure 4.3: Flowchart depicting the workflow of chapter 4. The FRI species string was extracted into individual species composition percentages. From the DEM topographic modeling features generated and the enduring landscape features. FRI polygons used to intersect landform layer. PCAs were performed on FRI species and enduring landscape features. The two datasets were analyzed together in a CCA.

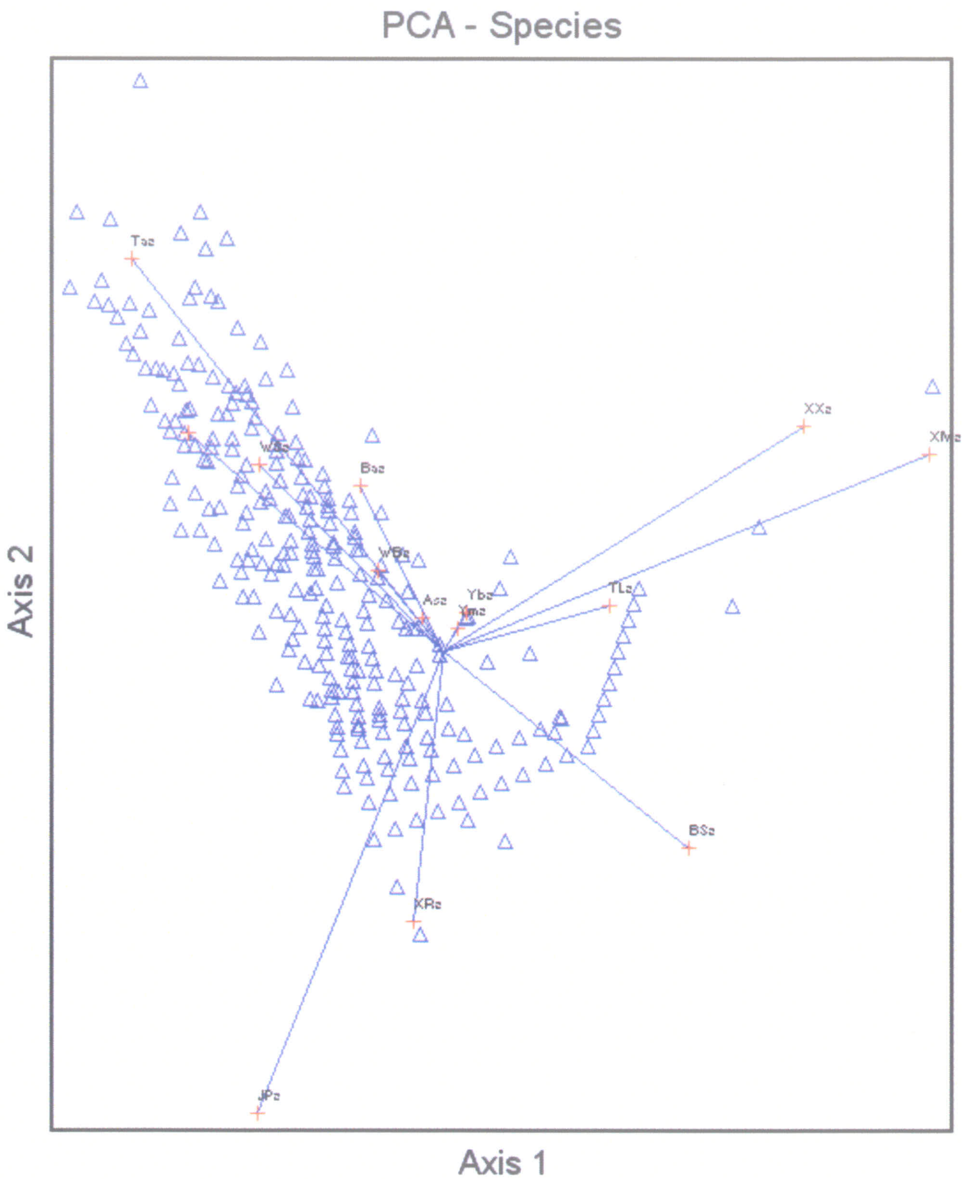

Figure 4.4: PCA of FRI species ordination biplot of PCA1-2

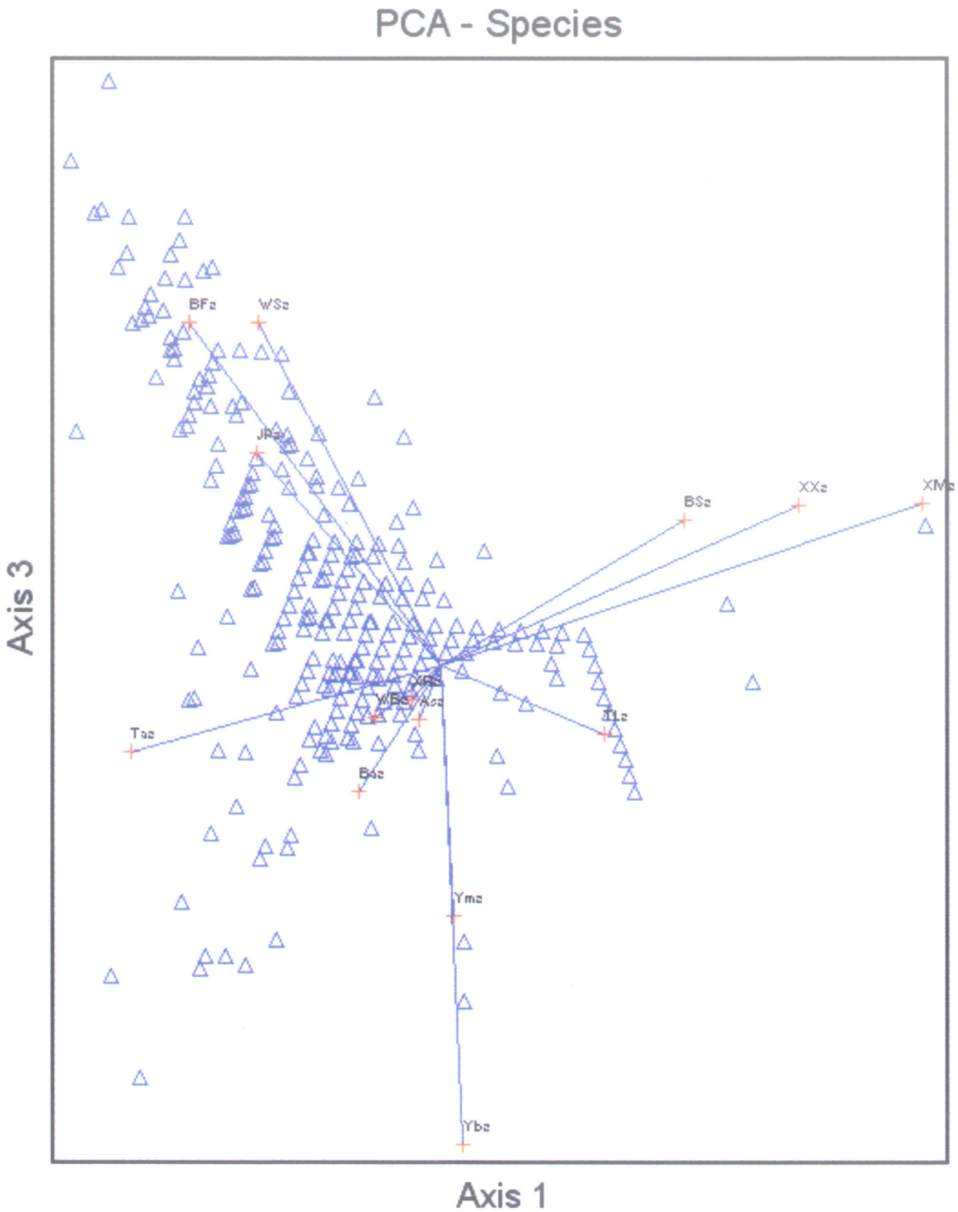

Figure 4.5: PCA of FRI species ordination biplot of PCA1-3

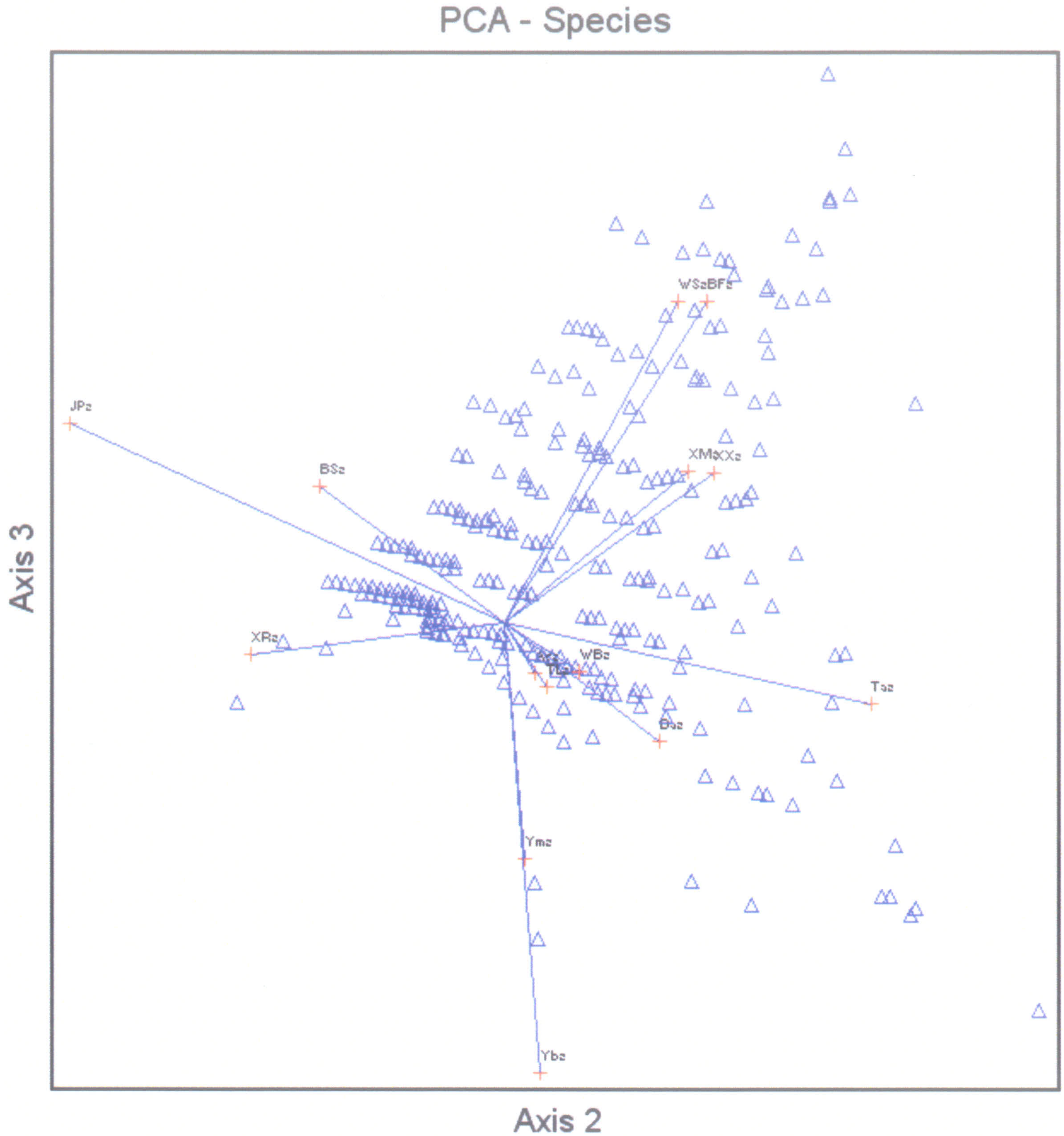

Figure 4.6: PCA of FRI species ordination biplot of PCA2-3

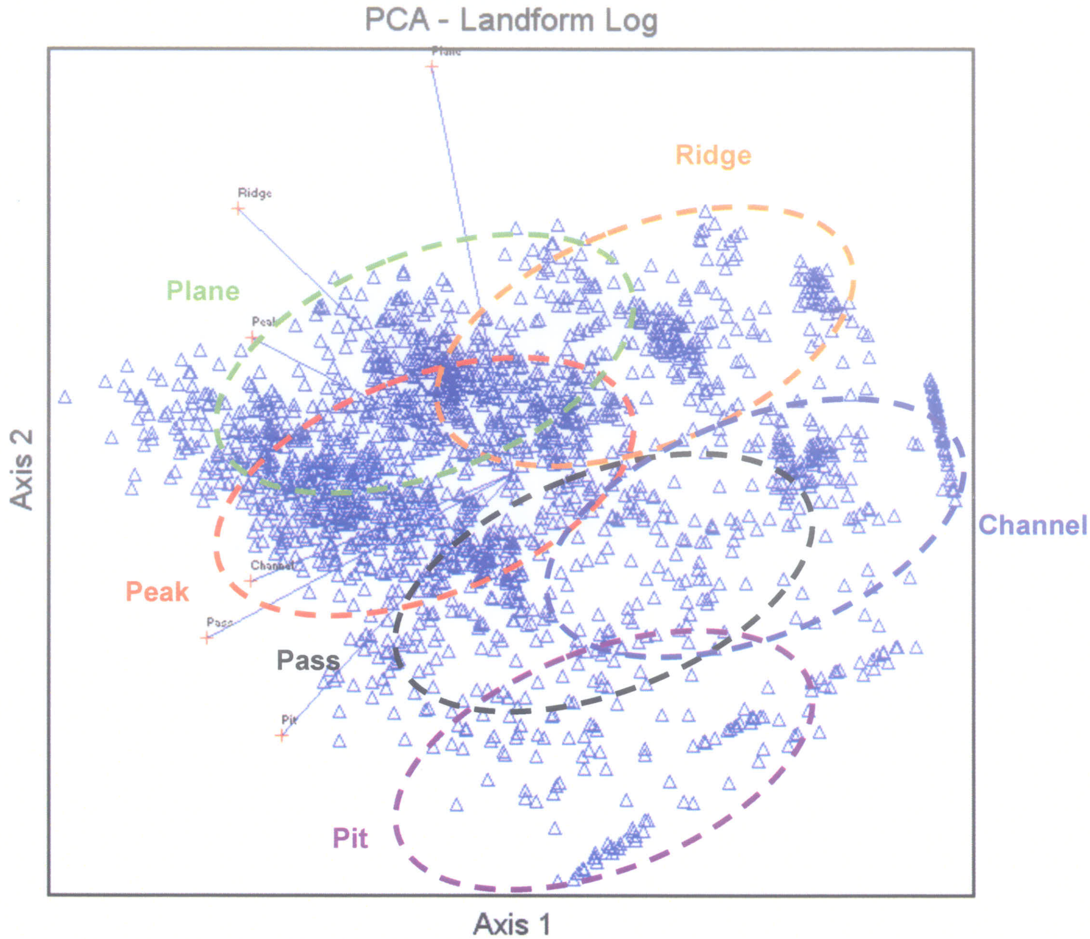

Figure 4.7: PCA of landform ordination biplot of PCA1-2. Landform types are separating out along PCA1: peak (red), ridge (orange), pass (black), plane (green), channel (blue) and pit (purple).

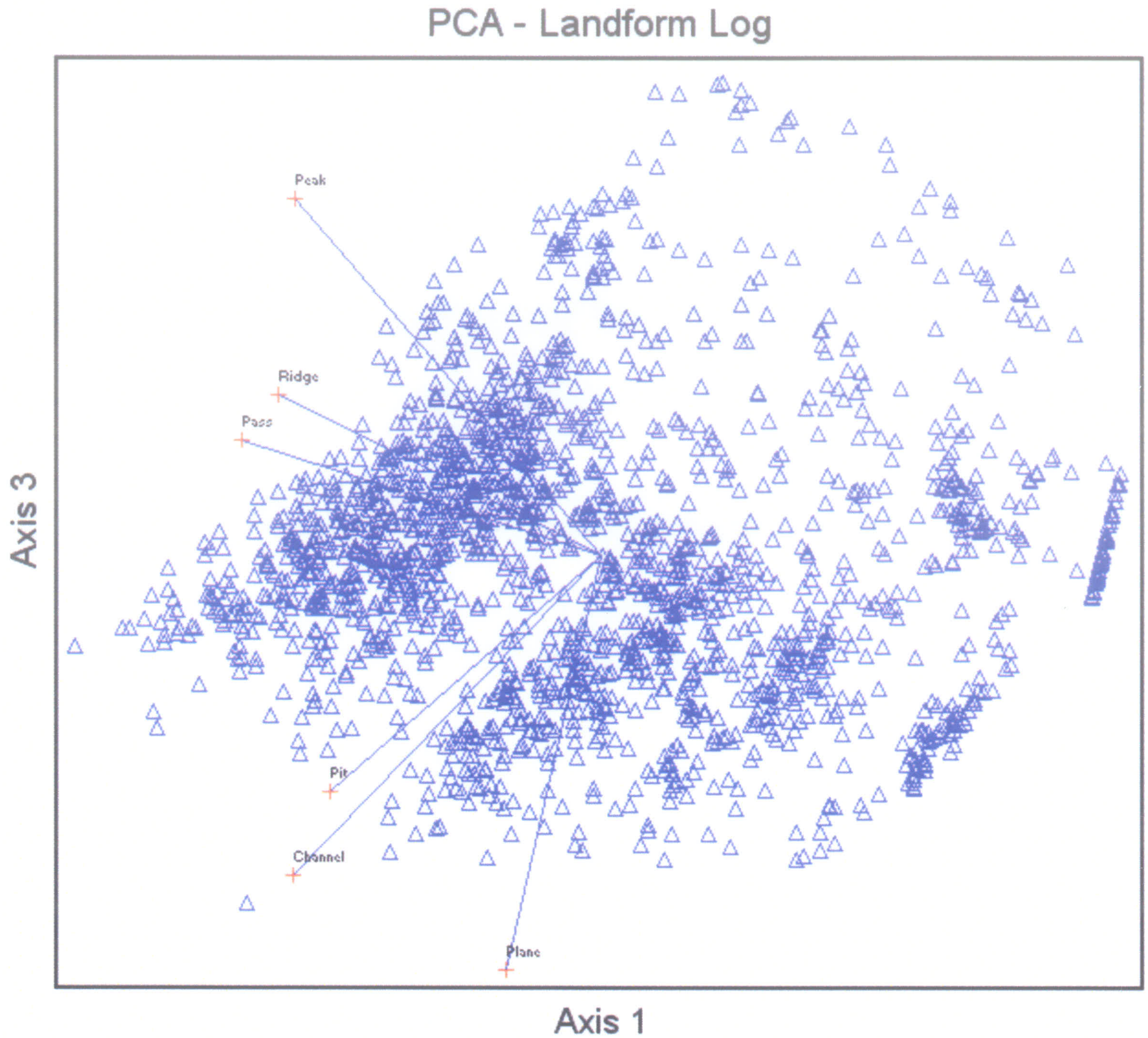

Figure 4.8: PCA of landform types ordination biplot of PCA1-3

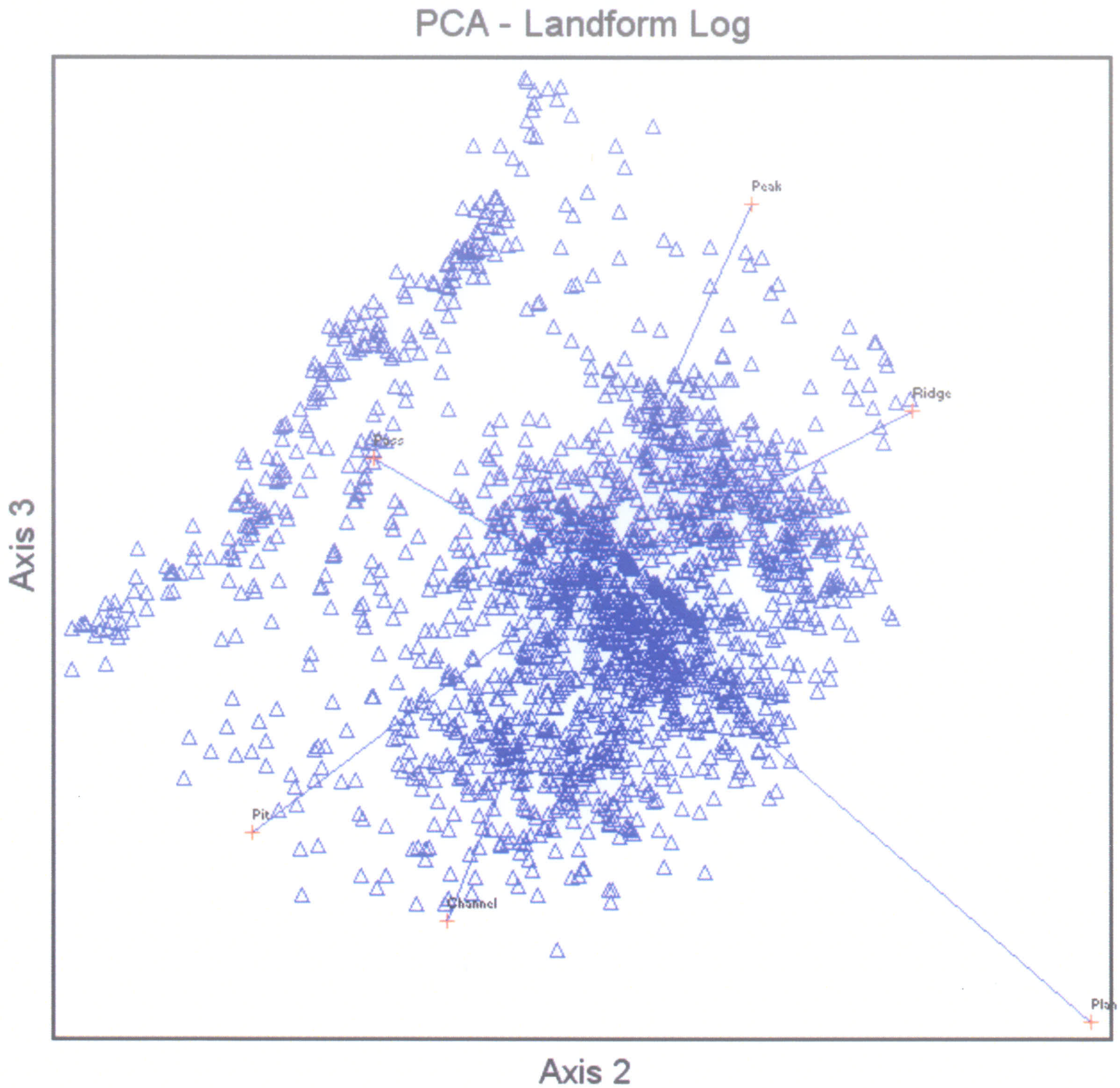

Figure 4.9: PCA of landform types ordination biplot of PCA2-3

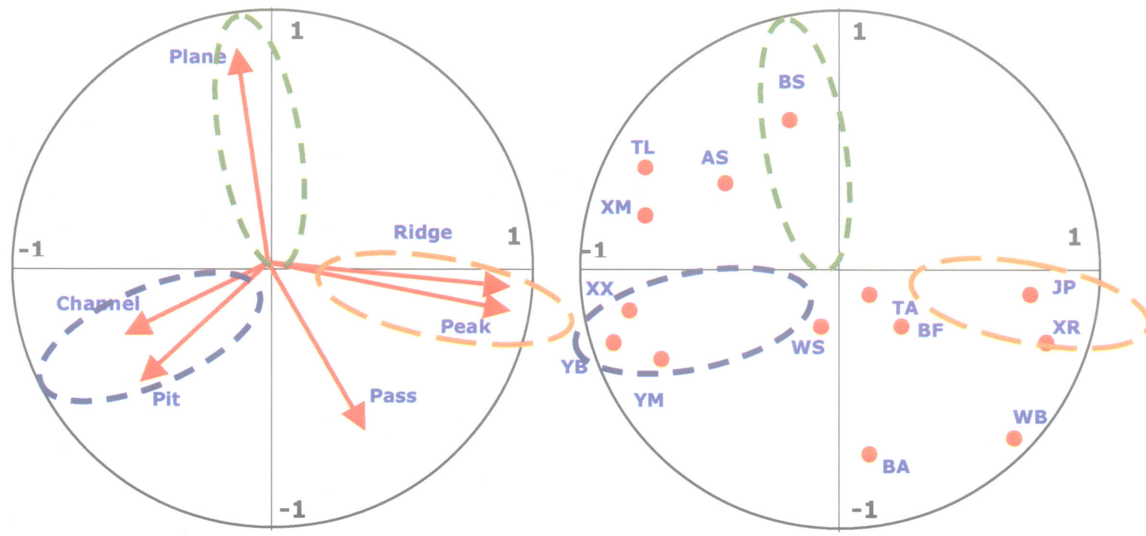

Figure 4.10: Canonical correspondence analysis object scores of the first two axes for Landform types and FRI tree species. Trends begin to emerge between convex land form features and the JP and XR classes (orange dashed oval), concave landform features and XX, YM and YB classes (blue dashed oval) and the Plane landform feature and BS (green dashed oval).

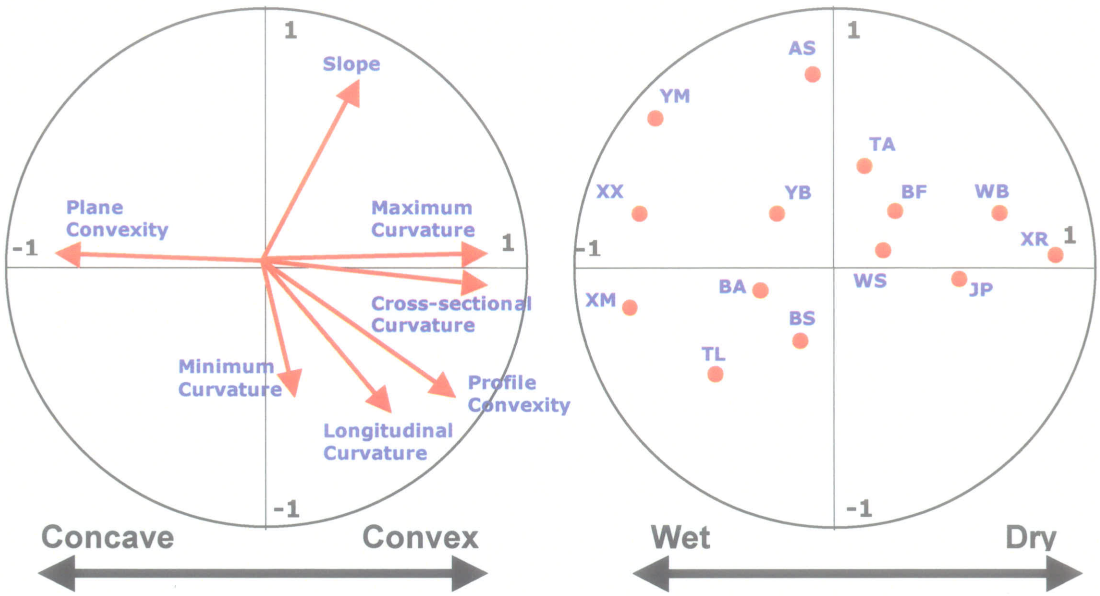

Figure 4.11: Canonical correspondence analysis object scores of the first two axes for topographic modeling parameters and FRI tree species. The dominate trend in the topographic parameters on the first axis goes from convex parameter types to concave parameter types (left black arrow). The dominate trend on the FRI species also occurs on the first axis goes from dry species to wet (right black arrow).

Chapter 5

An Evaluation of Speckle Reduction Filters based on Multivariate Performance Measures of Multitemporal Radarsat imagery

Abstract

Multiple Discriminate Analysis (MDA) and Principal Component Analysis (PCA) are presented as a quantitative evaluation of filter speckle suppression to identify cultural features within Kalimantan Timur, Indonesia. Based on segmentation properties of MDA and data recovery ability of PCA using varying kernel sizes of a multitemporal multi-incident angle Synthetic Aperture Radar (SAR) dataset the most suitable filtering technique was be selected. Continual cloud cover makes it nearly impossible to utilize optical remote sensing in remote tropical regions while low level aerial photo acquisition is prohibitively expensive and also subject to weather conditions. Radarsat-1 imagery possesses cloud penetrating ability as it utilizes microwave radiation and is relatively inexpensive. However, image speckle is inherent in SAR data making it difficult to interpret. Five filtering techniques are evaluated using MDA and PCA at varying kernel sizes to determine which algorithm reduced speckle and maintained spatial properties of cultural features.

5.1 Introduction

The traditional livelihoods of the Dayak tribal people in Kalimantan Timur, Indonesia depend on a diverse income portfolio that includes raw rattan as a significant component (Dewi et al., in press). In May 2004, the government of Indonesia reinstated a ban on the export of raw rattan (*Calamus* spp.) in response to a perceived shortage in supply for the domestic manufacture of furniture (Minister of Trade Decree No. 355/5/04). This policy was not supported by a quantitative analysis of the rattan stock as currently there are no tools to provide accurate estimates (Belcher 2001). An inventory is needed to plan import\export targets that protect domestic processing of rattan and value-added products (Pambudhi 2004). There are efforts to measure rattan stock on the ground by local non-government organizations. The entry point for the rattan economy is dry rice fields called Ladang (Belcher 2001). Rattan is an epiphyte and requires other vegetation to provide structure to grow from (Whitten 1996). Ladang farmers intentionally leave a few trees behind to allow rattan to grow when clearing a hillside for dry rice agriculture (Mayer 1989). Ladang are found sporadically through out the landscape surrounding remote villages on hillsides where soils are ideal for growing upland rice and are typically 125 m by 125 m in size. Land is clear by manual labor leaving only a handful of trees behind. Once ladangs have been cultivated for a number of years they are left to grow a variety of vegetation including bananas, cassava, rubber tree and rattan (Dewi et al., in press).

Since ladang are in such isolated areas and have no recognizable order an identification tool is required to develop an inventory (Asia Forest Network 1993). There have been numerous attempts to study tropical regions using a variety of optical sensors such as Landsat but nearly all are incapable of providing adequate results due to frequent cloud clover (Chou 2002). To compensate for this shortcoming, mosaics are engineered by extracting only cloud free pixels from multiple week or month long repeat cycles (Richards and Jia 1999). However, this method is not practical for planning as mosaics are generally comprised of imagery spanning over many months or even years (Song 2002). To overcome the deficiency of temporal continuity sensors such as NOAAs AVHRR, or other platforms with high frequency coverage period (twice daily), have been used for vegetative mapping but have a very large pixel footprint of 1 km or greater which far exceeds spatial resolution required to identify ladang (Johnson 1989). Low level aerial photo acquisition far exceeds the allotted budgets of government agencies (FAO 2000). Radarsat Synthetic Aperture Radar (SAR) imagery has cloud penetrating ability as it utilizes the microwave portion of the electromagnetic spectrum and is more affordable than aerial reconnaissance (Herold 2005). SAR has shown great potential for use in rain forests but serious research efforts are still required in order to make SAR imagery a viable and operational data resource of small-scale feature identification (Forster 1996).

Active SAR sensors such as Radarsat have been significant in a variety of cloud covered biophysical detection processes including flood mapping (MRSC 1997), sea ice monitoring (Barber 1993), agricultural crop inventory generation (McNairn and Brisco 2004) and soil moisture identification (Sokol 2004). These applications have not come without difficulties as SAR imagery is contaminated by inherent noise resulting from coherent radiation (Kuan 1987). When a radiation pulse illuminates an object at an incident angle the reflection from that surface is contaminated by many independent scattering points (Walessa and Dutcu 2000). Interference from these other coherent waves result in a granular pattern known as speckle (Dachasilaruk 1999). Speckle differs from pattern in that image speckle arises from the fundamental physics of SAR imaging while image texture is caused by heterogeneities of the surface structure on a spatial scale greater than one pixel (Kasischke 1997, Luckman 1998). Due to this phenomenon it is generally desirable to filter Radarsat SAR data scenes prior to image analysis (CCRS 2000, McNairn 2002). In order to understand the potential of SAR in identifying small scale cultural features a proper filtering evaluation must be undertaken, as filtering also results in image simplification.

There are two broad types of filtering available for speckle noise reduction; adaptive and texture filtering. Adaptive filters include the Frost filter (Frost 1982, Zhenghao and Fung 1994), the Kuan filter (Kuan 1985) and the Gamma MAP filter (Lopes 1993). Each is designed to reduce speckle in homogeneous areas, preserve liner features and maintain radiometric values (Oliver and Quegan 1998). For texture filters, more specifically second order texture measures based on grey level co-occurrence matrix (GLCM) (Haralick 1973), many measures exist including contrast and variance. Numerous studies have evaluated the quality of traditional and potential filters based on such criteria as edge detection (Lee 1986, Li 1988, Adair 1989, Yan 2002, Lui 2004, Mastriani and Giraldez 2004) texture preservation (Escalante-Ramirez 1996, Short 2000, Myint 2001, Yan 2002, Herold 2003) and classification accuracy (Durand 1987, Mascarenhas 1991, Chomczimsky 1998, Prasad 1998, Herold 2002). These criterions satisfy specific needs but lack the overall performance measures required to distinguish small scale cultural features in heterogeneous tropical regions.

Segmentation is the process of segregating individual image pixels into like areas with similar spectral characteristics (Pal & Pal 1993). Many types of mapping processes require information to be placed into thematic categories for classification or feature identification. Image segmentation has played a key role in many mapping and identification studies and can be used as a key step when interpreting all types of remote sensing imagery (Tilton 1996, Zhong 2005). Segmentation of a filtered image in combination with verifying kernel sizes is a gage of filtering effectiveness. Tighter segmentation groups represent the ability of a filter to remove noise (speckle) from an image allowing for image interpretation and classification. Data recovery also shows how well a filter preformed based on the amount of information retained on the first principal component. The more information on the first axis implies the image is less complex having less speckle interference.

Principle Component Analysis (PCA) and Multiple Discriminant Analysis (MDA) are multivariate measures of single value decomposition (SVD) which provides a unique quantitative perspective on filter and kernel size speckle suppression performance based on data recovery and segmentation. There are many segmentation processes that exist and the selection of a technique is a challenge onto its own (Pal and Pal, 1993). Baronti (1994) has applied PCA to SAR data to increase the signal to noise ratio of the first component resulting in decreased speckle and increased visual enhancement. MDA is a multivariate method used to measure the between to within group sum of squares. Unlike PCA where groups are formed that are maximally similar reducing variance, MDA attempts to form maximally dissimilar groups increasing variance (Pal and Pal, 1993).

5.2 Objective

This chapter focuses on the analyses of remotely sensed SAR imagery in a tropical environment to determine the most effective filtering technique and optimal kernel size for ladang identification in multitemporal Radarsat data. Although our primary objective is to identify ladang within SAR imagery our methodology is not limited to dry rice fields and can be applied to any spatially distinct small scale anthropogenic tropical features.

5.3 Study Area

Please see Chapter 2.2 - Case Study 2 – Rain Forest: Remote Sensing of Cultural Features in Kalimantan

5.4 Methodology

Figure 5.1 demonstrates the workflow of Landsat and Radarsat imagery, Ladang feature creation and the multivariate analyses.

5.4.1 Field and GIS data

GPS data was collected for 36 ladangs with such ancillary information as age of ladang, vegetative species re-growth, height of vegetative re-growth, perimeter, slope and aspect for each sampled site. A variety of GIS data were provided by CIFOR including a community polygon, road, river and DEM layer which all aided in ladang identification and orientation. Existing thematic land cover maps generated by a previous CIFOR complimentary study were included in data analysis (Dewi et al., in press). These classified Landsat images date from 1987 to 1999 and range in spatial resolution from 30 m to 79 m. Imagery is heavily cloud contaminated with extensive missing data values throughout.

5.4.2 Image sources

After reviewing all possible optical images taken during the period of the field component of the study, we selected a Landsat 7 ETM+ image (Channels 1-5, 7; Path 117, Row 060) from September 25, 1999. Utilizing Band 1 (0.45-0.52 μm), Band 2 (0.52-0.6 μm), Band 3 (0.63-0.69 μm), Band 4 (0.76-0.9 μm), Band 5 (1.55-1.75 μm), and

Band 7 (2.09-2.35 μm). Despite having the lowest cloud contamination, approximately 30% of the image contained cloud or cloud shadow with significant areas of haze. Over the same dry season, but not identical time period, five Radarsat SAR C Band (5.6 cm) standard beam mode descending path images with 12.5 m spatial resolution were acquired creating a multitemporal dataset (Scene ID/Acquisition date: M0198827 /Nov. 4, 1999; M0199437/Nov. 11, 1999; M0200470/Nov. 25, 1999; M0200665/Nov. 28, 1999; M0200535/Dec. 5, 1999).

5.4.3 Image rectification and registration

The Landsat imagery was purchased as a LG1 georectified product in a WGS84 UTM Zone 50 projection. The Landsat imagery was resampled to a spatial resolution of 12.5 m using a nearest neighbor algorithm to match the resolution of SAR images. Resampling the Landsat image allowed us to spatially match pixels between the optical and Radar images without confounding the effects of speckle noise (Siegert and Rücker 2000). Radar speckle noise made it difficult to georectify the SAR imagery to known ground control points (Yan 2002). Instead, we opted to image register the Radar data to the Landsat scene using features such as lakes and rivers that were clearly identified in both datasets. All images were then cropped in order to ensure complete overlap between the Landsat and multiple SAR standard beam mode images.

5.4.4 Landsat Image classification

The Landsat scene was then subject to two unsupervised classifications (Richards and Jia 1999) in order to discriminate landcover types within the radar images. The first classification performed was a K-Means clustering utilizing all six bands, using 20 cluster classes, a 5% change threshold and one iteration. The second classification was an Isodata classifier also using all six bands, 20 clustering classes, a 5% change threshold and one iteration. The Isodata parameters also included a minimum of one pixel per class, a maximum standard deviation of one, a minimum class distance of 5 and a maximum number of merge pairs of two.

5.4.5 SAR Filtering

We compared five filtering techniques in total; three adaptive filters: the Kuan filter (additive measure) and the Gamma and Frost filter (multiplicative); and two grey level co-occurrence matrix (GLCM) texture based filters were examined: the Variance and Contrast filters.

Adaptive filters use the standard deviations of surrounding pixels that meet the specified criteria to self-adjust according to an optimizing algorithm and replace the centre value within the kernel (Lopes 1993, Harteneck and Stewart 1999). The Kuan filter is used to reduce speckle but preserves linear features by transforming the multiplicative noise model into an additive noise model (Zhenghao and Fung 1994). The remaining three filters are multiplicative meaning as pixel values increase their speckle error increases exponentially. Similar to the Kuan filter, the Gamma filter also reduces speckle while maintaining edge features but assumes the data to gamma distributed (Hagg and Sites 1994). The Frost filter also reduces speckle while preserving linear anomalies but does so with a dampening value that is applied to local variance dependent on location within the kernel (Zhenghao and Fung 1994).

For co-occurrence textural filters, a matrix is generated for each individual pixel consisting of grey level frequency values where calculations such as variance and contrast and be compiled (Haralick 1973, Anys 1994, Soh 1996, Tso 2004). Sampling of pixels within the kernel occurs in a set direction (X) and distance (Y). We chose an offset of 0 for X and 4 for Y based on a 11 x 11 kernel to overcome speckle effect inherent with SAR imagery (Luckman 1994).

Traditionally, PCA has been used for the compression and enhancement of multispectral optical imagery. We intend to perform a PCA on filtered images as a means of filter evaluation. After a thorough inspection of the SAR filtering evaluation literature it was evident our approach using data recovery from PCA and segmentation statistics from MDA had never been undertaken before.

5.5 Results

5.5.1 Evaluation of SAR filters

Since the cultural feature we are attempting to identify is 125 m by 125 m we felt the 11x11 kernel size at a 12.5 m resolution would be most capable of doing so. **Table 5.1** shows the mean of the filtered scenes are relatively the same as the unfiltered dataset. Of the adaptive filters the Kuan and Gamma filter means were slightly higher than the raw SAR mean for all five images while the Frost filter is slightly lower for three of the five images. The analysis did not apply to the variance filter.

The next evaluation criteria utilized a Principal Component Analysis (PCA) to identify which filter at the 11 x 11 kernel size was able to best summarize the multitemporal multi-incident angle SAR imagery dataset onto one axis in ordination space. The Gamma filter was able to account for 57.9% of variance within the PCA1 image followed by the Frost, Variance and Contrast respectively (**Table 5.2**). While the Kuan filter was only able to account for 34.3%, only a 9.5% improvement over the unfiltered original data. PCA was also used to summarize landcover areas with Radarsat imagery identified by Landsat unsupervised classifications (**Figure 5.2**). This gives a sense as to how well filtering techniques performed at removing noise from images.

Unlike PCA where the algorithm is trying to account for as much variation as possible Multiple Discriminate Analysis (MDA) attempts to maximally discriminate data into groups (Legendre and Legendre 1998). Here we compared the legacy data from a 1998 Landsat supervised classification map to the five date imagery filtered by the 11 x 11 kernel. The Single Value Decomposition (SVD) value is an indicator of how well the filter is able to segment the data into classes provided by the Landsat thematic map. **Table 5.3** shows the Gamma filter outperformed the filters with a value of 15.42 again followed by the Frost, Variance and Contrast respectively while the Kuan filter had the lowest value of 8.64. A false colour Red, Green and Blue image (RGB) image of

Radarsat standard beam mode 2, 3, and 2 filtered images at the 11 x 11 kernel size provides a visual inspection of how each filtering kernel preformed (**Figure 5.3**).

5.5.2 Evaluation of Kernel Size

The Gamma, Frost, Context and Variance filters all display an increase of information on their first axes as kernel size increased while the Kuan filter shows a modest increase in captured data on the first axes up to the 9x9 kernel size but then gradually declines. **Figure 5.4** compares the primary principal component axis for each filter type and kernel size in a simple scatter plot. The Gamma kernel retains more information on its first principal component than all other filter types at all kernel sizes. The two GLCM filters, Contrast and Variance, showed less information retained on the first axis at the 3x3 kernel than the raw SAR images.

The Gamma filter showed a rapid SVD increase as filter size increased peaking at the 13x13 kernel then gradually tapered off. **Figure 5.5** examines the SVD value of each MDA for all filter types and kernel sizes. The Frost and Contrast filters showed a steady SVD increase and did not plateau until the 19x19 and 23x23 kernel respectively. The Variance SVD statistic also showed a gradual increase but had a small decrease at the 15x15 kernel then continued to increase peaking at the 19x19 kernel size. The Kuan filter peaked the earliest at the 11x11 kernel and showed a long decrease in SVD value as the kernel size increased. A side by comparison of all filters and kernel sizes is illustrated in Figure 3b.

5.6 Discussion

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Novel applications of multivariate analyses were used to examine trends in the multi-incident angle and multitemporal SAR data at the 11 x 11 pixel kernel size. Based on the mean comparison, the PCA from the multitemporal dataset and the MDA to segment images into categories we decided the Gamma filter provided the best solution to inherent SAR speckle while identifying ladang. The Gamma filter either performed the best or close to the best in each of the three analyses. We plot out the image chips for the Gamma filter type illustrating the images progression from unfiltered to filtered gradually increasing kernel size (**Figures 5.6**). The inherent SAR speckle is prominent in the unfiltered image, begins to dissipate using kernels sizes 3x3 to 15x15 and then image chips begin to lose spatial properties for kernel sizes 19x19 and beyond as a result of over sampling. The 11 x11 kernel size proved to remove speckle effectively without losing spatial properties of the image.

5.6.1 Mean Comparison

The first step in evaluating the selected filters is to examine the means of the filtered data compared to the raw unaltered SAR imagery to ensure the quality of the data remains the same (Walessa and Dutcu 2000). For the mean comparison test, a perfect score would be indicated by a filtered mean with the same value as the mean of the unfiltered SAR image indicating the pixel values within the filtered image are not significantly altered (Lopes 1990). When filtering occurs values do change both positively and negatively but should balance each other to have no effect on the mean (Richards and Jia 1999). If a gap either positive or negative is found between filtered means and the original image mean this would indicate the filter caused a shift in the image pixels values in one direction resulting in an altered image. Even though the Gamma filter's mean was slightly higher than the raw SAR images' mean, it was not significantly different with regard to the other filtered image means.

5.6.2 Data Recovery

The PCA was intended to identify which filter was able to recover the most shared information from the multitemporal multi-incident angle imagery dataset. Data recovery represents several good criteria for filtering effectiveness. Luckman (1994) concluded texture measures of C-Band SAR imagery can provide additional information beyond simple backscatter intensity alone for tropical environments. It shows consistency of output when filtered images contain redundant data (Mascarenhas 1991). The images represent the same cultural features and therefore should be similar in their filtered output. The higher the amount of information retained on PCA1 indicates how well the filter performed from a consistency perspective (Lopes 1993). Not only is the consistency important but this allows for a greater volume of data retained on one image resulting in an easier and more meaningful analysis (Hagg and Sites 1994). This data is critical when mapping or identifying features as classification algorithm attempt to cluster data into thematic categories (Durand 1987). The more information within an image the more detailed a classification can be (Mascarenhas 1991).

The Gamma filter retained the highest amount of information on PCA1 at the 11 x 11 kernel size (**Table 5.2**) and most other kernel sizes (**Figure 5.4**). The Gamma filter also categorized unsupervised Landsat landcover areas the most effectively of all techniques examined by separating multitemporal multi-incident angle SAR data into distinct clusters in a PCA1-PCA2 biplots (**Figure 5.2**). Each of these results point to the Gamma filter as the most appropriate filter to remove inherent speckle from SAR imagery in the tropics when identifying small scale cultural features such as landag.

5.6.3 Image Segmentation

The MDA utilized the segmentation measure to identify which filter was able to separate ladang the best. Segmentation plays a key role in many landuse\landcover mapping projects (Richards and Jia 1999). Instead of classifying images based on spectral signature alone and ignoring spatial properties segmentation allows for pixel close in proximity to be grouped as one feature. This is critical in ladang identification as small scale heterogeneous features must be separated from the surrounding homogeneous jungle. Segmentation was our most important filtering evaluation because of the spatial fundamentals that are inherent in the analysis. Segmentation recovers shared information between radar data and by doing so separates images into landcover categories allowing small scale ladang identification. The Gamma filter successfully separated the multitemporal multi-incident angle imagery dataset most effectively at the 11 x 11 kernel size (**Table 5.3**) and most other kernel sizes (**Figure 5.5**). These results further support the Gamma filter as the most appropriate filter to remove inherent speckle from SAR imagery for cultural feature classification.

5.6.4 Summary

Our overall objective is to provide a cost effective geomatic tool that is able to identify ladang and other relevant cultural features within Kalimantan Timur using SAR imagery. The Indonesian government has no way of identifying the amount of ladang within its rural areas. Like many natural resource problems, information is critical to managerial decision making. The delivered methodology quantitatively identified the most effective filtering technique for ladang using PCA and MDA. This process can now be applied as an indirect measure of rattan and other social attributes. Once an inventory of rattan is established, the amount of available rattan will also be known. This information can be used to make sustainable managerial decisions about the amount rattan that should be exported for sale by the Dayak tribal people of Kalimantan Timur. With proper management of this essential resource the rural livelihoods of the Indonesia people should be improved.

Tables

Table 5.1: Mean values of unfiltered and filtered Radarsat ladang pixel values

11x11 Filters	Image Mean				
	M0200665	M020535	M0200470	M0199437	M0198827
Raw SAR	85.2	95.8	93.3	110.2	81.9
Kuan	85.6	96.2	94.2	110.8	82.1
Gamma	86.1	96.6	95.1	111.4	82.5
Frost	84.9	95.2	93.9	110.5	81.0
Variance	38.4	47.8	42.4	29.9	38.1
Contrast	76.8	91.0	81.9	59.3	72.3

Table 5.2: PCA scores of unfiltered and filtered Radarsat ladang pixel values at 11x11 kernel size

11x11 Filters	PCA Scores		
	PCA 1	PCA 2	PCA 3
Raw SAR	24.8%	22.1%	19.2%
Kuan	34.3%	22.1%	15.9%
Gamma	57.9%	19.8%	8.9%
Frost	52.6%	22.1%	9.9%
Variance	42.5%	23.3%	13.9%
Contrast	37.9%	21.7%	17.2%

Table 5.3: MDA scores of unfiltered and filtered Radarsat ladang pixel values at 11x11 kernel size

11x11 Filters	MDA
	SVD
Raw SAR	5.77
Kuan	8.64
Gamma	15.42
Frost	14.00
Variance	11.10
Contrast	9.04

Figures

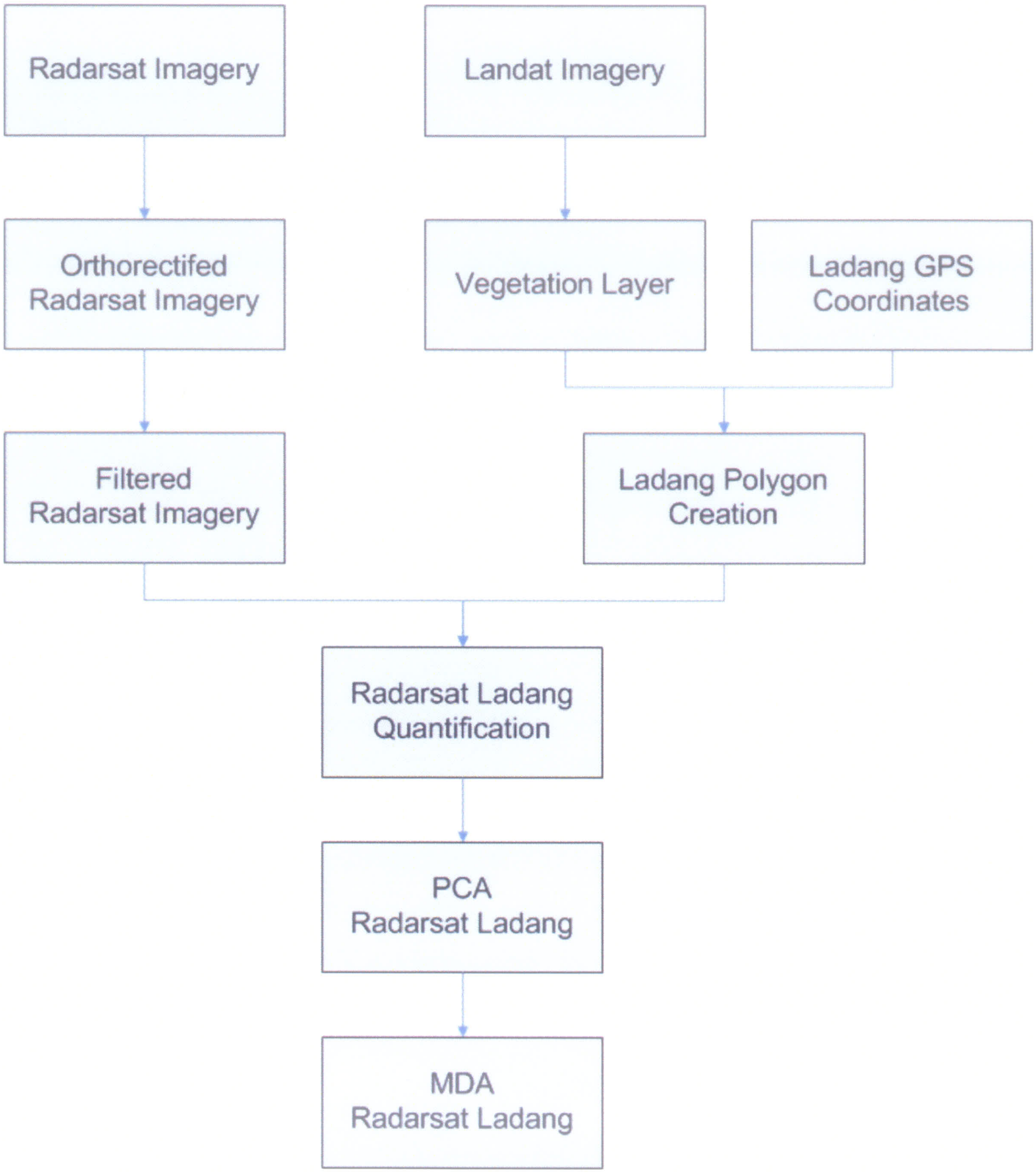


Figure 5.1: Flowchart of Landsat and Radarsat imagery, Ladang feature creation and the multivariate analyses

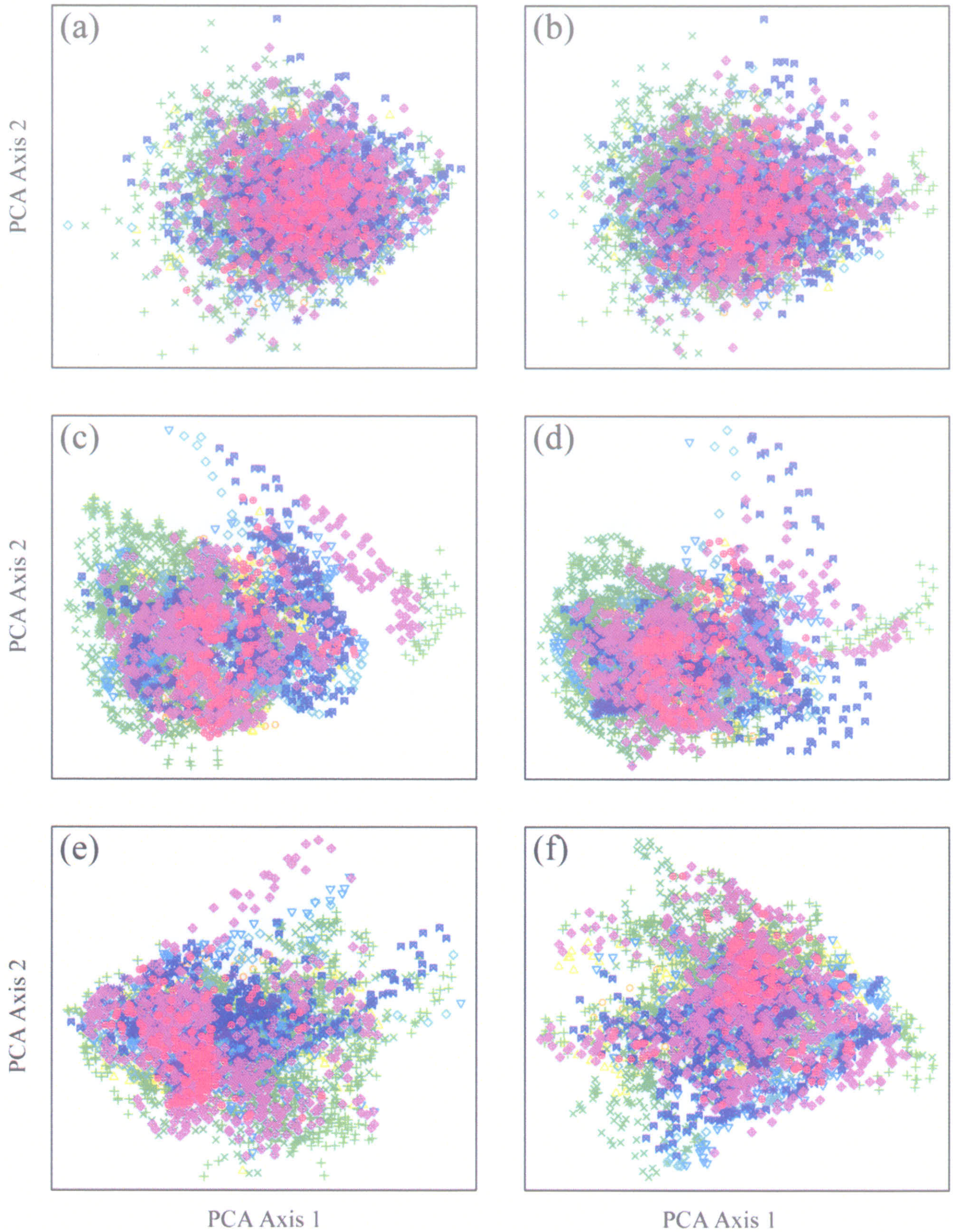


Figure 5.2: Bi-plots of PCA1 (x axis) verses PCA2 (y axis) of landcover areas with Radarsat imagery identified by Landsat unsupervised classifications: (a) Unfiltered; (b) Kuan; (c) Gamma; (d) Frost; (e) GLCM Variance; (f) GLCM Contrast.

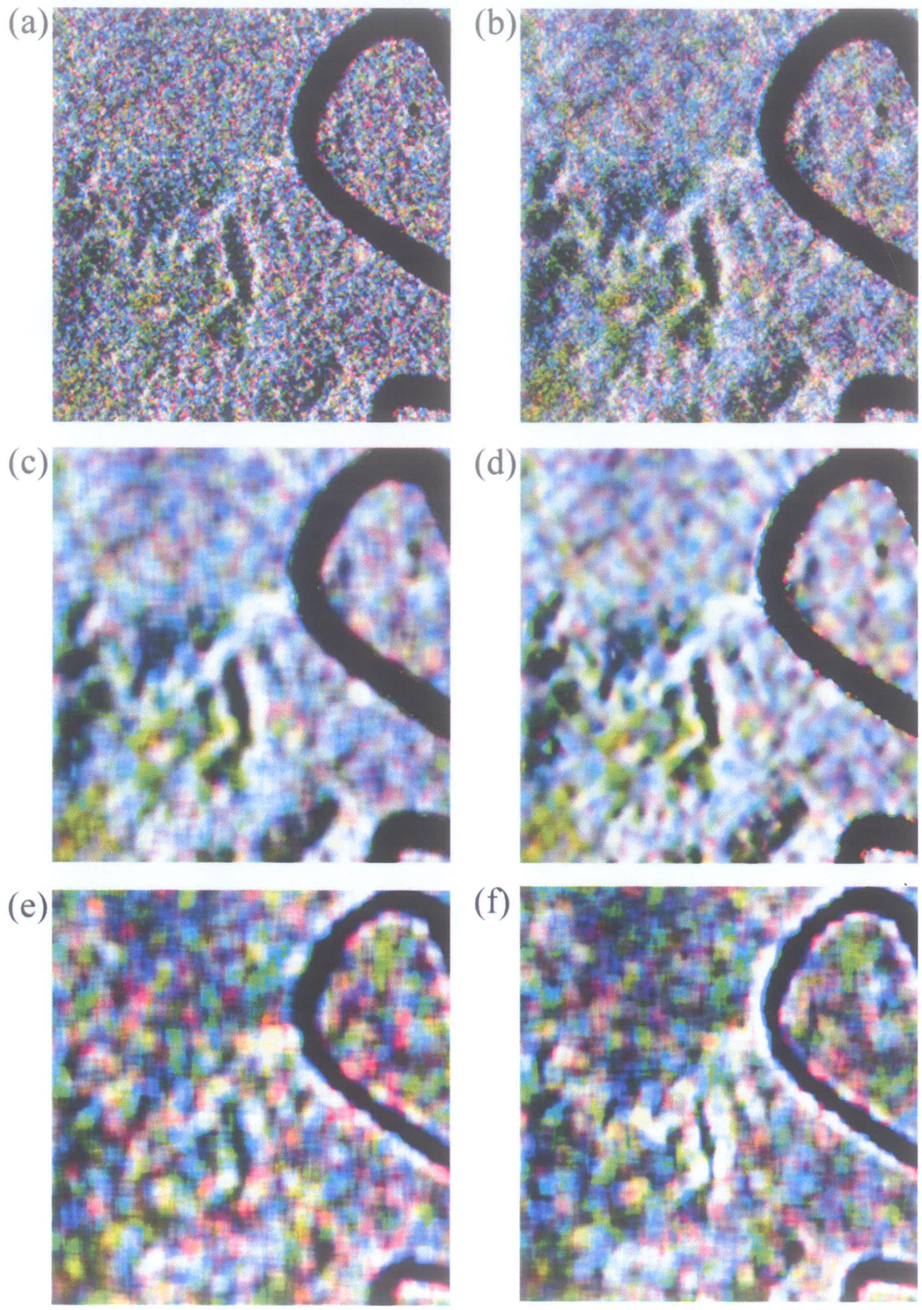
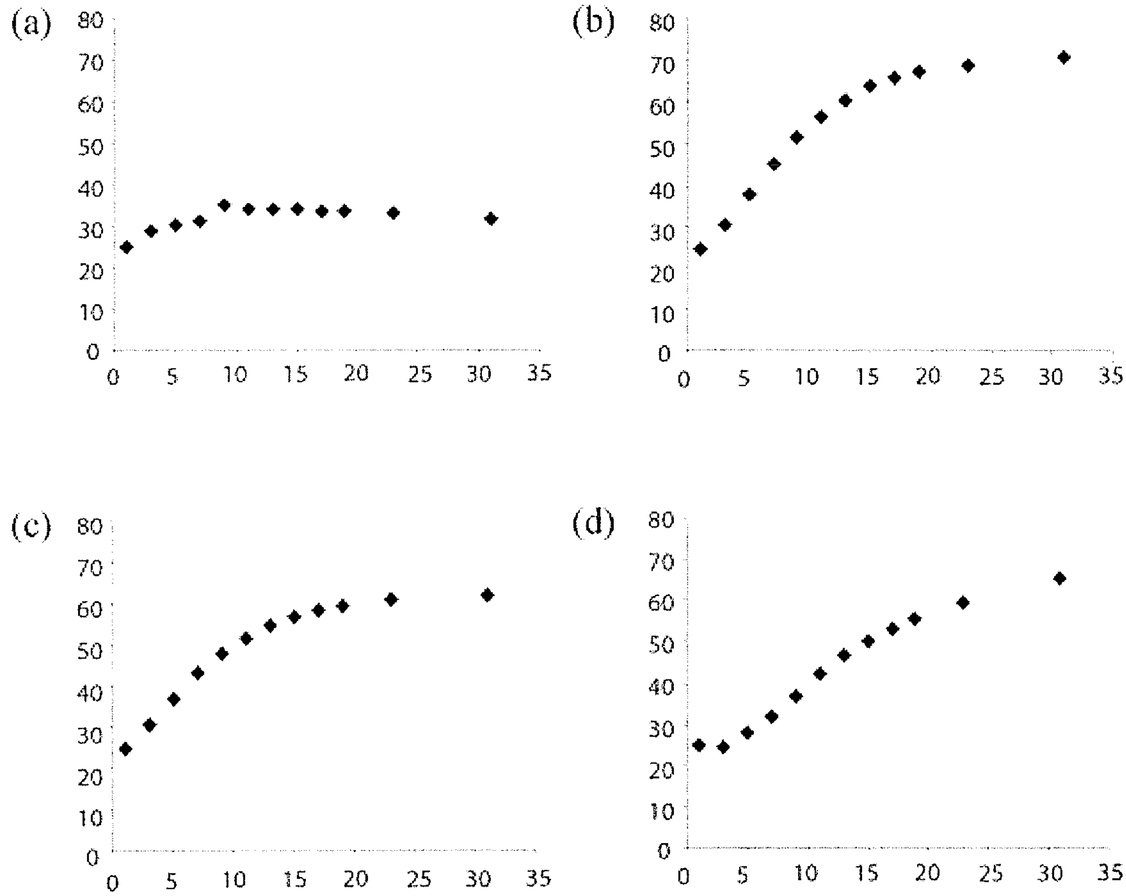


Figure 5.3: A comparison of RGB Radarsat path image standard beam mode 2, 3, and 2 filtered images at the 11 x 11 kernel size: (a) Unfiltered; (b) Kuan; (c) Gamma; (d) Frost; (e) GLCM Variance; (f) GLCM Contrast.



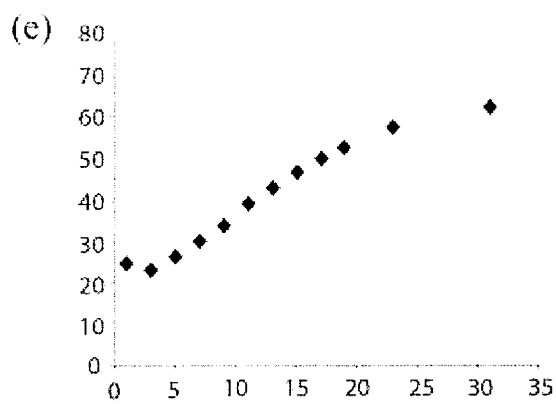


Figure 5.4: : Scatter plots of component scores of PCA of filtered radarsat ladang pixel values at each kernel size. X axis represents PCA1 component score value, Y-axis size of filtering kernel: (a) Kuan; (b) Gamma; (c) Frost (d) GLCM Variance; (e) GLCM Contrast.

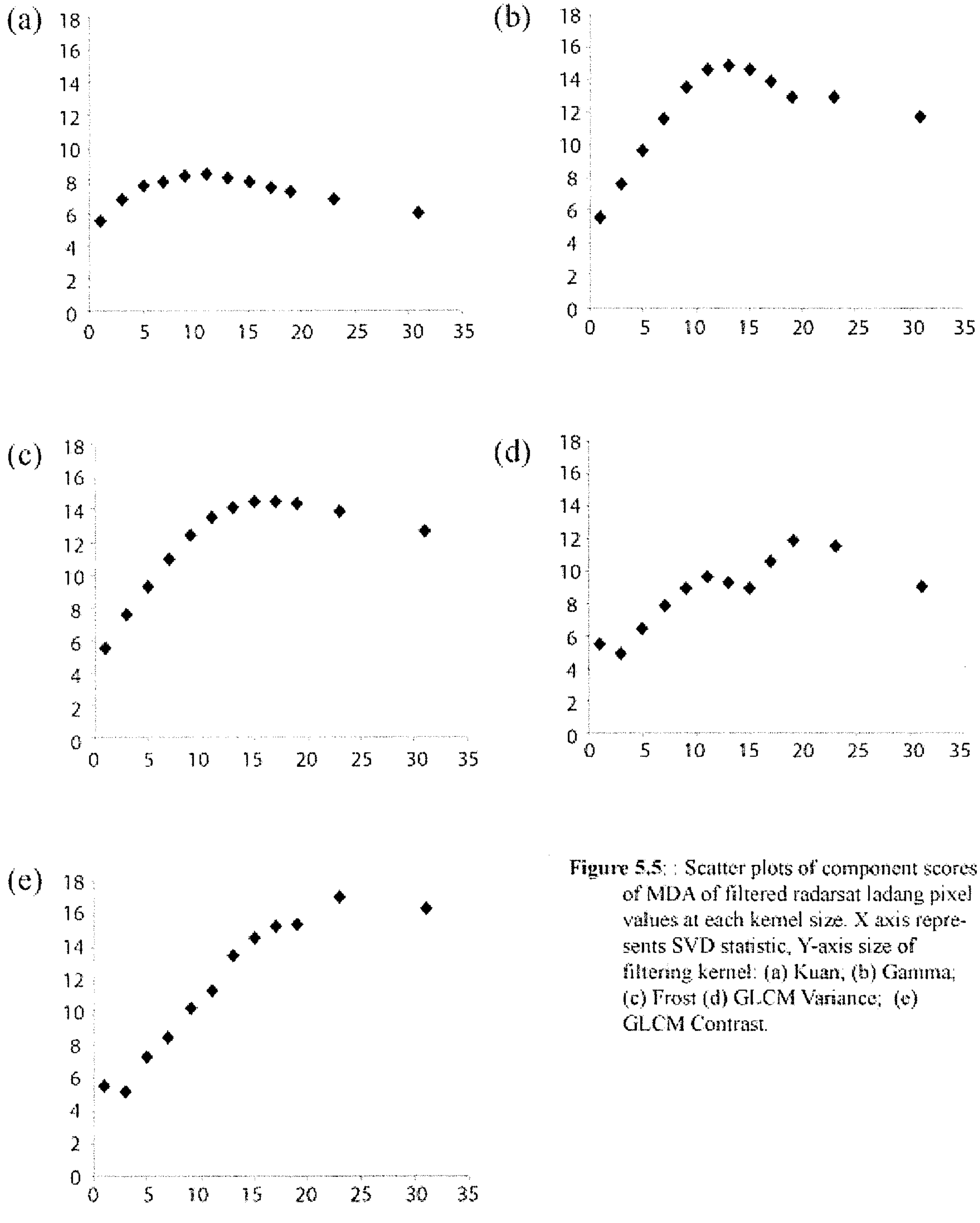


Figure 5.5: : Scatter plots of component scores of MDA of filtered radarsat ladang pixel values at each kernel size. X axis represents SVD statistic, Y-axis size of filtering kernel: (a) Kuan; (b) Gamma; (c) Frost (d) GLCM Variance; (e) GLCM Contrast.

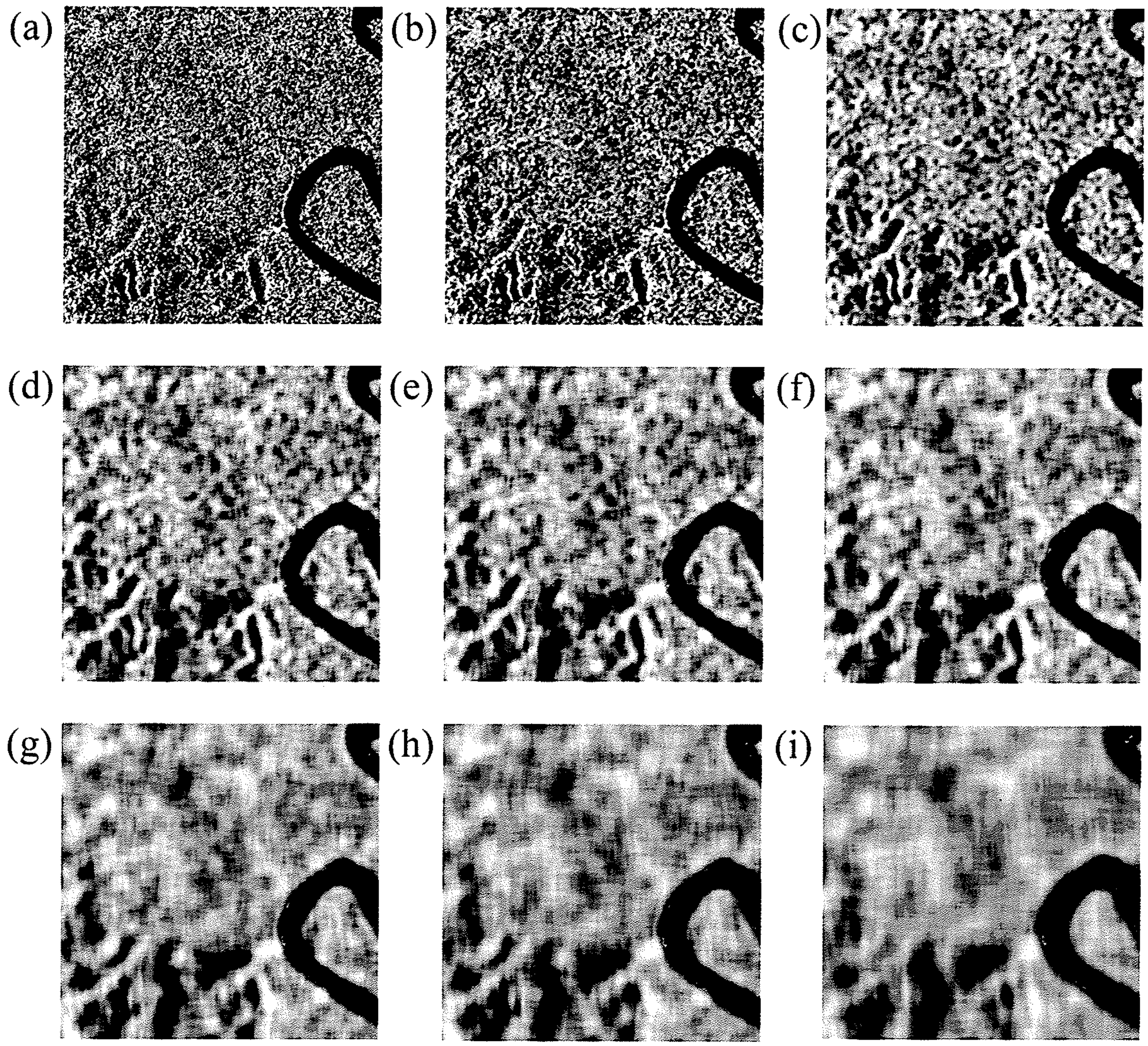


Figure 5.6: A comparison of Gamma filtered images at various kernel sizes: (a) Unfiltered SAR image; (b) 3 x 3 kernel size; (c) 7x7; (d) 11x11; (e) 13x13; (f) 15x15; (g) 19x19; (h) 23x23: (i) 31x31.

Chapter 6

Summary and Knowledge Gained

6.1 General Conclusions

6.1.1 Case Study 1 - Boreal Forest: Ecological Attribute Identification in Manitoba

There are useful similarities between the optically interpreted digital images and the Landsat imagery in the IFOV polygons for ecosite delineation from **Chapter 3**. Delineation of ecoelements showed correlation between band 3 and conifer species and band 4 and deciduous species. More importantly from an ecosite delineation stand point there was high correlation between band 3 and moss, band 4 and shrub\herb and grass and band 7 and rock/lichen (**Figure 3.11**). This information may be used in SFM as a measure of biodiversity (Vasudevan 2004). Understory species are used as biodiversity indicators for a wide variety of ecological attributes such as soil moisture, soil texture, nutrient availability, stand age and stand maturation (Rolstad 2002). Each of these derived pieces of information from understory species may be used for appropriate managerial forestry decisions.

For the purpose of ecosite identification these trends are the building blocks of a knowledge database required to interpret satellite imagery. For example if a portion of a Landsat image over the boreal is showing a high value in band 7 there is a higher probability it likely to be a ecosite with rock\lichen as the understory. Boreal species and the enduring landform features indicate strong trends that may be used for ecosite delineation from **Chapter 4**. There were strong correlations between the convex landform types and typically dry boreal species types as well as concave landform types and wet boreal species types. We can now safely assume wet ecosites to occur in concave landform feature and dry ecosite in convex ecosite features. Species and landform correspondence can be used to formulate a more accurate landscape attribute within the FRI using GIS and remote sensing technologies. The DEM did account for much of the landscape complexity of the boreal forest (**Figure 4.12**) and would be a valuable tool when mapping out boreal ecosites. This is especially true when aerial photography methods (used to generate the FRI) are unable to detect subtle enduring landform features that are critical to the ecology of the boreal forest. The next step is to gather all data gained from these innovative geomatic techniques and integrate them into a decision support model.

Figure 6.1 illustrates a conceptual model of a Decision Support System (DSS) and how valuable information about ecoelements interpreted from spatial data using geomatics such as understory may be used for ecosite delineation. The spatial data we have been interpreting is the Landsat imagery and the DEM. Through the use of the power paraglider imagery we have interpreted how the Landsat signature reacts to understory ecoelements. We have established a new database of understory characteristics related to ecosites interpreted by Landsat. Similarly we have take information from a DEM and interpreted enduring landform features and how they relate to boreal forest species. A new ecoelement landform database related to ecosites has now been created. Both of these databases are comprised of probabilities. Given a certain Landsat reflectance value of an area and a particular landform feature type of that same area in combination with tree stand information from the FRI we can identify with strong probability the area's ecosite type.

For example, if an area had a high reflectance value in Landsat band 3 and 7, the area was occurring on a Peak enduring landform feature and the FRI indicated the area was dominated by Jack Pine, we can safely identify this area as an ecosite E-2, Jack pine-black spruce with lichen on very shallow rugged terrain features. We've established Landsat band 3 has a high correlation conifer species and band 7 has a high correspondence with lichen\igneous rock from our understory ecoelement database. Peaks tend to be highly correlated with igneous rock and Jack Pine from our enduring landform feature ecoelement database. The FRI has confirmed the area has a strong occurrence of Jack Pine. This information matches the ecoelement criteria of an ecosite E-2. Therefore we can classify this area with a high degree of confidence as an E-2. Classification of ecosites is only the first step in sustainable forest management. How this knowledge is used to make ecological and economical decision is what is critical. Campbell (2006) identified ecosite E-2 as an attractive overnight camping destination when situated near lakes or rivers and especially rapids. Perhaps special attention should be paid to areas designated as E-2 near water bodies for continued recreational usages. This example exemplifies how boreal ecosites generated from spatial ecological knowledge can be utilized to make sustainable forest management decisions.

Methods from the case study developed in Boreal Shield Ecozone 90 may be applied throughout the ecozones that is dominated by open canopy tree communities. There are anticipated difficulties in the Mid-Boreal Low Land Ecoregion of the boreal with a high degree of mixedwood stand types where tree canopy is much denser (Smith 1998). During the summer season deciduous tree species dominate the overstory making the understory difficult to identify (Zoldeski 1998). To compensate for this problem a multitemporal approach may be used to observe the understory ecoelements during pre-leaf on and post leaf off seasons (Hall 2000; Townsend 2001).

6.1.2 Case Study 2 – Rain Forest: Remote Sensing of Cultural Features in Kalimantan Timur

There is much preprocessing required to obtain any meaningful information from SAR imagery especially in a complex environment such as a tropical rain forest (Oliver and Quegan 1998; Siegert and Rücker 2000). After testing a series of filtering techniques at varying kernel sizes it was found the Gamma filter performed the best at identifying ladang during the dry season in Kalimantan Timur using Radarsat standard beam mode imagery (**Figures 5.4 and 5.5**). Using the multivariate analyses PCA and MDA was a new and innovative method of testing filtering performance and was a critical initial step if the cloud penetrating ability of radar imagery is to be used in ladang identification. This methodology can now be applied as an indirect measure of rattan and other cultural features. Once a thematic classification of landcover types can be established, including rattan and other cultural features, fair and competitive prices of agro-forestry products can be determined improving rural livelihoods of the people of Kalimantan Timur.

Similar to Case Study 1, the methods investigated in Case Study 2 use various geomatics techniques to interpret spatial information. The result is a database comprised of key information used to identify an object. In this case we were interpreting Radarsat data for the purposes of delineating ladangs for a rattan inventory. The geomatic method was limited to only filtering but through the incorporation of other spatial data and GIS and remote sensing techniques the identification of ladangs could greatly improve. This new data and knowledge could be utilized in a similar DSS. One such spatial data layer is a DEM of Kalimantan Timur. Ladangs occur on hillsides for ideal growing conditions of dry rice production (Belcher 2001). This spatial property of ladangs could aid in their identification. With the proposed launch of Radarsat-2 by the Canadian Space Agency (CSA) comes a variety of new SAR imaging opportunities, many of which may improve the identification of ladang. Radarsat-2 will provide all of the imaging products Radarsat-1 currently provides in the C-Band frequency but will also be equipped with an increased range of incident angles, increased spatial resolution and quad-polarization capabilities. Each new imaging option could potentially aid in the classification of many cultural features including ladang by adding to the knowledge database used to delineate them.

The introduced filtering evaluation technique developed in the case study is applicable to many other small anthropogenic tropical features when dealing with multitemporal multi-incident angle SAR imagery. Many other villages within Indonesia have similar sized ladang and small scale features where case study results may be applied (Pambudhi 2004). Once an inventory of rattan is established, the amount of available rattan will also be known. This information can be used to make sustainable managerial decisions about the amount rattan that should be exported for sale by the Dayak tribal people of Kalimantan Timur. With proper management of this essential resource the rural livelihoods of the Indonesia people should be improved. More case studies will contribute to an improved understanding of our introduced SAR filter evaluation method. It is sincerely hoped the results from this thesis may be applied to and developed further in the sustainable forest management of the tropical rain forests of Indonesia.

6.2 Final Thoughts

It has been proposed in **Case Study 1 and 2** the quality of feature identification can greatly be improved through the use of a Decision Support System (DSS). This type of data integration can be done through a modeling process known as evidential reasoning. (this is the Logic component of **Figure 6.1**). The knowledge-based evidential reasoning analysis has stronger abilities to comprehensively analyze spectral indexes with different knowledge backgrounds and scales of measurement, and is an effective approach of quantifying remote sensing data (Xiaofang 2001). There can be an association drawn between conifer species and broad understory species based on moisture regimes (Bubier 1997; Price 1999). Based on Dempter Saphfer's rule of evidence, evidential reasoning is a form of artificial intelligence that allows for multiple sources of information from different origins, scales and data types used in a classification procedure (Peddle 1999, 2000). Unlike many modeling techniques today, evidential reasoning not only generates a belief indicator which represents a membership value of an item to a class but it also generates a plausibility value (Peddle 1999). Stand alone GIS and remote sensing software packages traditionally used by local governments are not capable of interpreting various type of data into a classification (Wilkinson and Mégier 1990). It is this plausibility value where the true power of evidential reasoning may be used in ecosystem classification (Peddle 1999). Once complete, results can be used for sustainable management of forests in Manitoba, cultural feature identification in Kalimantan Timur and beyond.

In closing, there have been many lessons learned about the role geomatics plays in sustainable forest management and the livelihoods of people from literally around the world. The problems that face Canada and other northern latitude countries that utilize the boreal forest for industry and recreation are very different from the many tropical nations such as Indonesia whose people depend on the rain forest for sustenance and survival. However, the solutions to their natural resource struggles are strikingly similar. There is a delicate balance that exists between economics and ecological integrity. I've discovered one of the keys to this equilibrium is accurate and timely geomatic information. All problems, especially natural resource management, must be solved using sound, dependable data. It is only when a solid foundation is in place can true knowledge of the issue be utilized for managerial decisions. There is no question the need for geomatic data will increase and many new and exciting data interpretation techniques will be required as the demand on the earth's natural resources continues. I am proud to contribute to the solution of this struggle for the betterment of people and our environment.

Figures

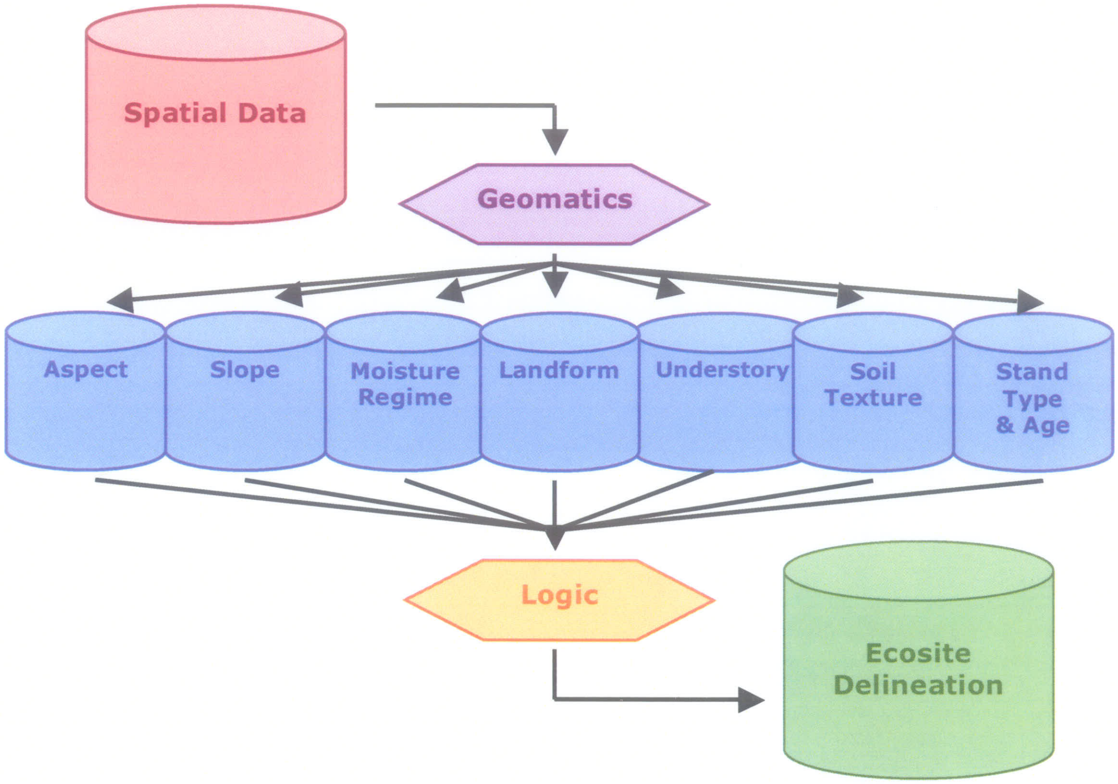


Figure 6.1: A conceptual model of a Decision Support System (DSS) for ecosite delineation. The spatial data database (red) comprises of Landsat imagery and Digital Elevation Model (DEM). Geomatics (purple) represents all of the GIS and remote sensing techniques required to interpret spatial data. Ecoelements databases (blue) consist of probability data relating to ecosite types. Logic (orange) refers to the data integration process Evidential Reasoning. Finally, ecosite (green) represent the 40 terrestrial and wetland ecosites of Manitoba (**Appendix A**). Model can be adopted for ladang identification.

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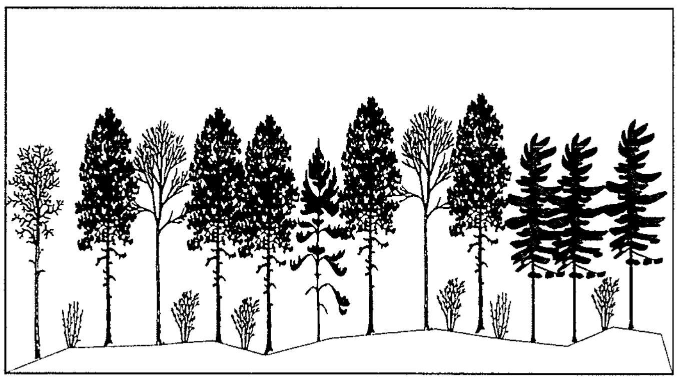
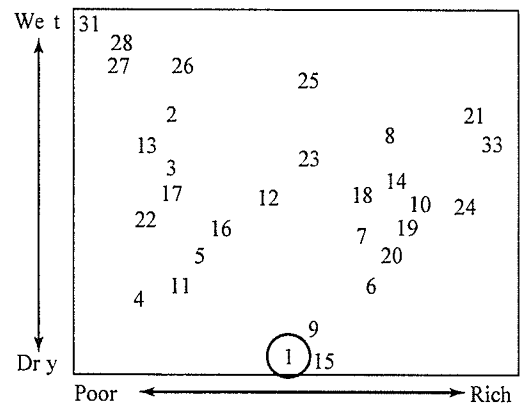
Appendix A

E-1 • Red pine /White pine on very shallow soil

General Description: Canopy usually dominated by red or white pines, and secondary canopy species such as spruce, aspen and jack pine. The understory shrub and herb is typically varied from rich to poor depending largely on soil depth and the amount of needles accumulated on the ground. In red pine stands, feather moss occurs in patches interspersed with extensive needle litter. Characteristic V- types include V-11, V-12, V-22 and V-23. Occasionally jackpine dominated V-26 can be seen. The shrub layer when present consists mainly of mountain maple, bush honeysuckle, hazelnut and occasionally common juniper occurs. This ecosite is limited in its distribution to extreme southeastern Manitoba. Occurs on shallow coarse textured soils associated with precambrian rock outcrops.

Overstory Species Pinus banksiana, Pinus resinosa, Pinus strobus, Picea mariana, Populus tremuloides, Betula papyrifera, Picea glauca.





Common Understory Species:

Shrub layer: Linnaea borealis, Diervilla lonicera, Abies balsamea, Vaccinium angustifolium, Vaccinium myrtilloides, Amelanchier alnifolia, Corylus cornuta, Acer spicatum, Arctostaphylous uva-ursi, Rosa acicularis .

Herbs: Maianthemum canadense, Aralia nudicaulis, Cornus canadensis, Oryzopsis asperifolia, Trientalis borealis, Clintonia borealis, Agrostis hyemalis.

Mosses and Lichens: Mosses: Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens.

Forest Floor Cover: Moss 40%, Broadleaf litter 15%, Conifer litter 38%

FEC Forest Composition: Common: V23, V22, V12, V11; Occasional: V26, V25.

Soil/Site Characteristics

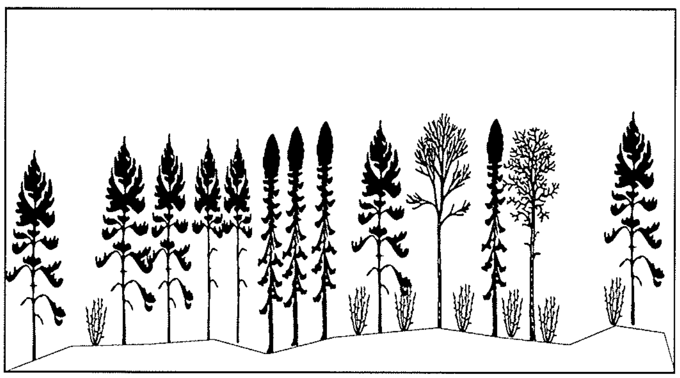
Soil Types: Common: SS1, SS2, SS3, SS4, Occasional: SS5, SS6, SS9.
Organic Layer (LFH) Common: (6-15 cm)
Surface texture c.loamy, c.sandy, f.sandy, silty, No-soil.
C horizon texture c.loamy, f.sandy, clayey, No-soil,
Moisture-Drainage: Moisture: dry, fresh; Drainage: rapid, well.
Deposition and Landform glaciofluvial, morainal, lacustrine. Sites often with exposed bedrock and mineral soils. Topography often rough, rolling.

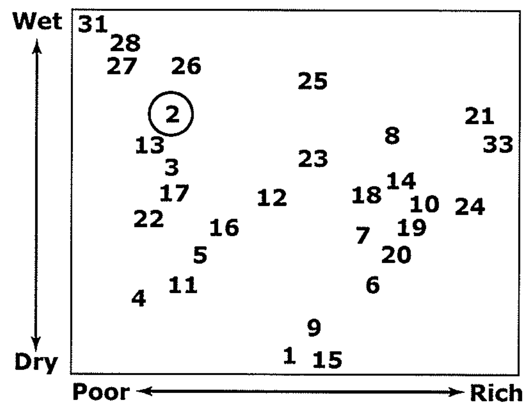
Comments: Both old stands as well as post-fire regenerating stands occur in this ecosite. The distribution is restricted to the southeastern portion of Manitoba. Similar ecosites include E-2 and E-3. This ecosite differs from E-2 because of higher cover of white and red pine (>10%), while E-3 is restricted to limestone outcrops in central Manitoba.

E-2 • Jack pine-black spruce on very shallow soil rugged terrain features

General Description: Canopy dominated by open jack pine stands mixed with black spruce in moist depressions. Soil is very shallow with frequent exposure of bed rock. The shrub and herb layer is typically poorly developed with a high lichen cover. The characteristic V-types of Ecosite 2 are primarily V-26, with occurrences of V-24 and V-25. A transition toV-30 and V-31 occurs in wet depressions in the rock.

Overstory Species: *Pinus banksiana, Picea mariana, Populus tremuloides, Picea glauca, Larix laricina, Thuja occidentalis, Populus balsamifera, Betula papyrifera.*





Common Understory Species:

Shrubs: *Arctostaphylous uva-ursi, Vaccinium angustifolium, Vaccinium myrtilloides, Alnus crispa, Juniperus communis, Vaccinium vitis-idaea, Spiraea alba, Rosa acicularis, Shepherdia canadensis, Rosa acicularis, Ledum groenlandicum, Picea mariana, Vaccinium vitis-idaea, Alnus rugosa.*

Herbs: *Maianthemum canadense, Agrostis hyemalis, Oryzopsis pungens, Oryzopsis asperifolia, Cornus canadensis, Aralia nudicaulis,Smilacina trifolia, Cornus canadensis, Mitella nuda, Calamagrostis canadesis, Equisetum scirpoides.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Dicranum polysetum, Sphagnum spp.;* Lichens: *Cladina rangiferina, Cladina stellaris, Cladina mitis*

Forest Floor Cover: Wood 20%, Moss/Lichen 50%, Conifer litter 5%, Needles 10%, Humus 5%

FEC Forest Composition: Common: V26; Occasional: V30-V33; Rare: V19.

Soil/Site Characteristics

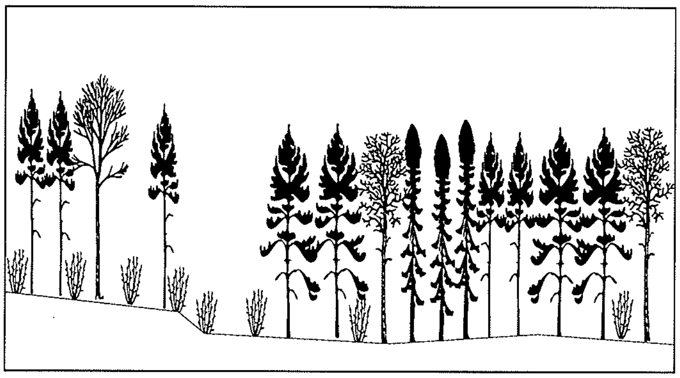
Soil Types: Common: SS1 - SS4; SS5, SS6, SS9.
Organic Layer (LFH): Common: (6-15 cm), (15-26), Occasional: (> 40).
Surface texture: c.sandy, f.sandy, c.loamy, f.loamy, clayey, no-soil, organic.
C Horizon texture: clayey, c.sandy, f.sandy, no-soil, organic
Moisture-Drainage: dry, wet, well, rapid, poor.
Deposition and Landform: lacustrine, glaciofluvial, organic. Generally rough topography with frequent exposure of bedrock.

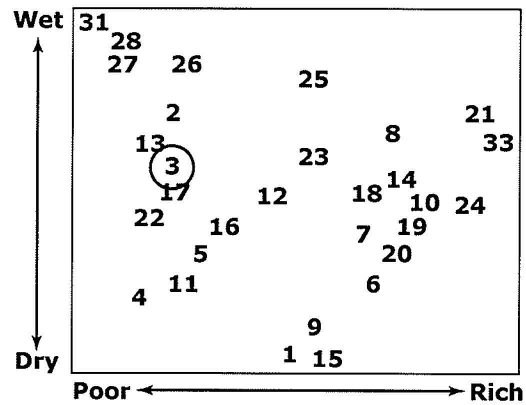
Comments: This ecosite consists of stands that are of fire origin and generally young on a predominantly granitic substrate . However, rough topography results in varied degrees of fire intensity, leaving pockets of vegetation with little combustion loss. Canopy development is therefore fairly heterogeneous with multiple layers in some locations. The lower slope of this toposequence may transition to lowland black spruce with occasional occurrences of tamarack or white cedar.

E-3 • Jack pine-black spruce on very shallow soil flat terrain features

General Description: Open or close canopy jack pine dominated stands with black spruce and trembling aspen often as co-dominants. Bedrock is frequently exposed and/or shallow soils (< 10 cm). The shrub layer is usually poorly developed but often dominated by blueberry. The Ecosite is primarily composed of V-25 and V-26, with the occurrence of V-24, V-31, V-30, and V-29. Feather moss is characteristic of moister sites. These stands are often young even aged and of fire origin, with increased spruce and fir invasion over time. Characterized by rapidly drained, coarse textured shallow soils over a limestone bedrock.

Overstory Species: *Picea mariana, Pinus banksiana, Populus tremuloides, Picea glauca, Betula papyrifera.*





Common Understory Species:

Shrub layer: *Arctostaphylous uva-ursi, Vaccinium angustifolium, Vaccinium myrtilloides, Linnaea borealis, Picea mariana, Juniperus communis, Rosa acicularis, Shepherdia canadensis, Alnus crispa, Rubus pubescens, Diervilla lonicera.*

Herbs: *Cornus canadensis, Maianthemum canadense, Oryzopsis asperifolia, Aralia nudicaulis, Galium boreale, Fragaria virginiana, Trientalis borealis.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Dicranum polysetum (rarely Sphagnum spp.);* Lichens: *Cladonia spps, Cladina mitis, Cladina rangiferina, Cladina stellaris*

Forest Floor Cover: Wood 15%, Moss 55%, Broadleaf litter 5%, Conifer litter 10%, Needles 10%, Humus 5%

FEC Forest Composition: Common: V25,V26; Occasional: V30 - V33, V24; Rare: V19.

Soil/Site Characteristics

Soil Types: Common: SS1, SS2, SS3, SS4; Occasional: SS5, SS6, SS9.
Organic Layer (LFH): Common: (1-5), (5-15); Occasional: (> 40 cm)
Surface texture: c.sandy, c.loamy, f.sandy, silty, no-soil.
C Horizon texture: c.sandy, clayey, f.sandy, f.loamy, no-soil.
Moisture-Drainage: Moisture: dry, fresh; Drainage: well, rapid.
Deposition and Landform:glaciofluvial, morainal, lacustrine, aeolian. Generally flat to slightly rolling topography of sediments of a glaciofluvial or morainal origin, deposited in a thin layer over a limestone bedrock . Periodic bedrock exposure and vertical cliff faces may be encountered.

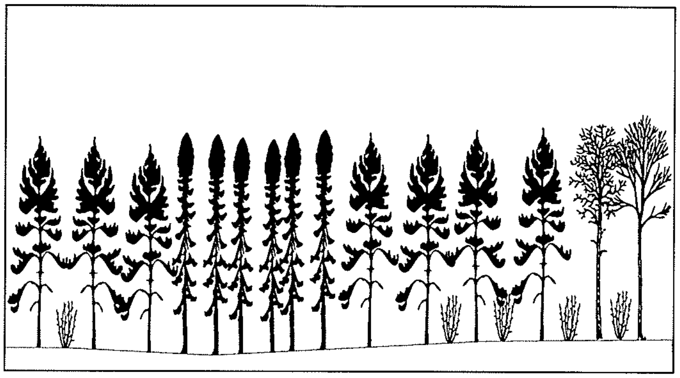
Comments: These sites are characterized by rapid drainage on thin soils overlying a calcareous bedrock. Sites of this type are most common in the northern portion of the interlake by Grand Rapids, Manitoba. Local pockets and sink holes may develop into bog vegetation associations (e.g. *Sphagnum spp.* with *Picea mariana*).

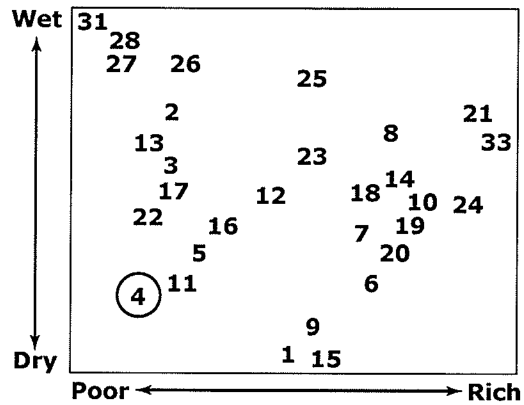
E-4 • Jack pine – conifer on dry to moderately fresh sandy soil

General Description: Canopy predominantly jack pine with occasional mixed woods species such as aspen and birch often codominant with black spruce in wetter areas. The shrub-herb layer varies from rich to poor with green alder and Canada dogwood dominant at the richer sites. Characteristic V-types comprising Ecosite 4 include 15, 16, 24, 26, and occasionally 30 where there is a predominance of black spruce. This ecosite transitions to EC 26 on organic soil. This Ecosite type is characteristic of fire regenerating stands and is generallyyoung. Soils are dry to moderately fresh well-drained and sandy.

Overstory canopy: *Pinus banksiana, Populus tremuloides, Picea mariana, Picea glauca, Betula papyrifera*

Overstory Species:





Common Understory Species:

Shrub Layer: *Vaccinium myrtilloides, Linnaea borealis, Arctostaphylous uva-ursi, Rosa acicularis, Alnus crispa, Vaccinium angustifolium, Vaccinium vitis-idaea, Picea mariana, Viburnum edule, Diervilla lonicera, Juniperus communis, Amelanchier alnifolia, Rubus pubescens.*

Herbs: *Maianthemum canadense, Cornus canadensis, Oryzopsis asperifolia, Aralia nudicaulis, Elymus innovatus, Fragaria virginiana, Petasites palmatus, Agrostis hyemalis*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Dicranum polysetum, Ptilium crista-castrensis;* Lichens: *Cladonia spp., Cladina mitis, Cladina rangiferina, Cladina stellaris.*

Forest Floor Cover: Wood 5%, Moss 70%, Broadleaf litter 5%, Conifer litter 10%.

FEC Forest Composition: Common: V24, V25, V26; Occasional: V28, V29.

Soil/Site Characteristics

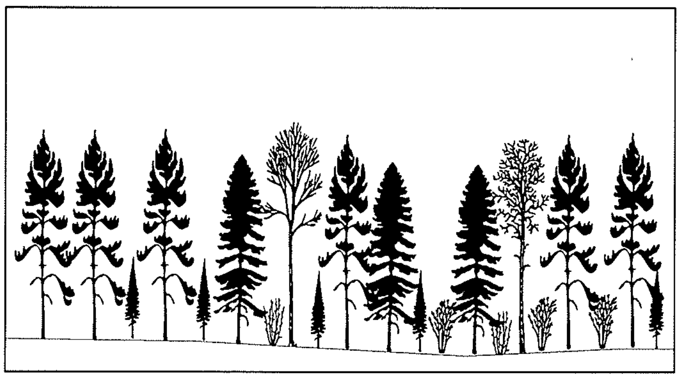
Soil Types: Common: S1, S2; Occasional: SS5
Organic Layer (LFH): Common: (6-15), (16-25).
Surface texture: c.sandy, f.sandy, c.loamy, f.loamy, silty
C Horizon texture: c.sandy, f.loamy, silty, f.sandy, c.loamy
Moisture-Drainage: fresh, dry, moist, rapid, well.
Deposition and Landform: lacustrine, morainal, aeolia. Generally flat to slightly rolling topography of coarse sediments with lacustrine origin.

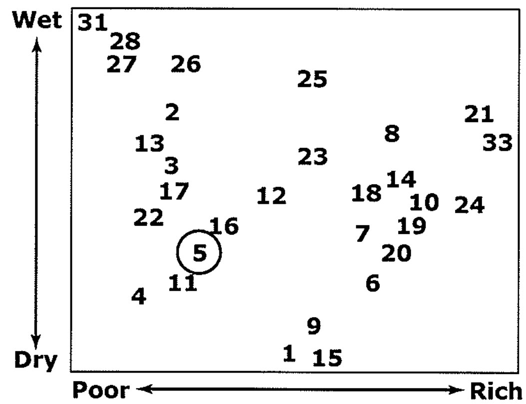
Comments: Jack pine stands with an often single generation between fire intervals. Because of the dry conditions, fuelwood accumulation makes these sites subject ot catastrophic fires.

E-5 • Jack pine –spruce mixed wood on sandy soil

General Description: Jack pine and spruce with mixed woods consisting primarily of aspen, but white birch and balsam fir form a secondary component. Herb and shrub layer is typically rich. The primary V-types are V-15, V-16, V-17 and V-18. In older and moist sites , white spruce replaces jackpine (V-28 and V-29). As these stands mature black spruce may replace most species. This ecosite occurrs on sandy soils.

Overstory Species: *Pinus banksiana, Picea glauca, Populus tremuloides, Betula papyrifera, Picea mariana, Populus balsamifera.*





Common Understory Species:

Shrub layer: *Alnus crispa, Rosa acicularis, Linnaea borealis, Rubus pubescens, Diervilla lonicera, Picea mariana, Viburnum edule, Vaccinium myrtilloides, Ledum groenlandicum, Arctostaphylous uva-ursi, Vaccinium vitis-idaea, Abies balsamea.*

Herbs: *Cornus canadensis, Aralia nudicaulis, Maianthemum canadense, Aster ciliolatus, Petasites palmatus, Fragaria virginiana, Lycopodium annotinum, Epilobium angustifolium, Oryzopsis asperifolia, Geocaulon lividum, Mitella nuda*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum polysetum;* Lichens: *Cladina mitis, Cladina rangiferina, Cladina stellaris.*

Forest Floor Cover: Wood 5%, Moss 65%, Broadleaf litter 15%, Conifer litter 10%, Humus 5%.

FEC Forest Composition: Common: V15-V18; Occasional: V26 -V29; Rare: V10.

Soil/Site Characteristics

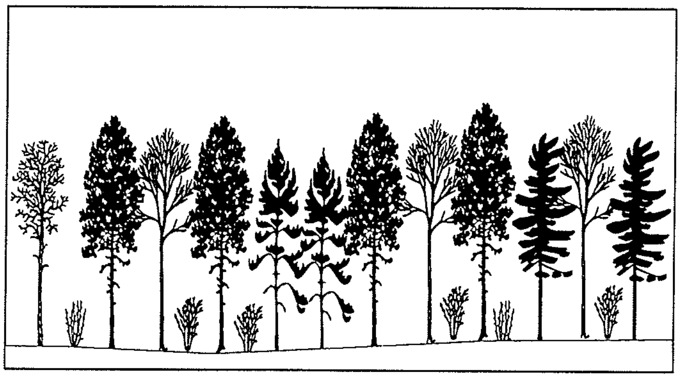
Soil Types: Common: S1, S2; Occasional: SS5.
Organic Layer (LFH): Common: (6-15 cm), (15-26).
Surface texture: c.loamy, f.sandy, c.sandy, f.loamy
C Horizon texture: f.loamy, f.sandy, c.sandy, silty
Moisture-Drainage: Moisture: dry, fresh; Drainage: well, rapid
Deposition and Landform: lacustrine, morainal, glaciofluvial, aeolian, fluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin.

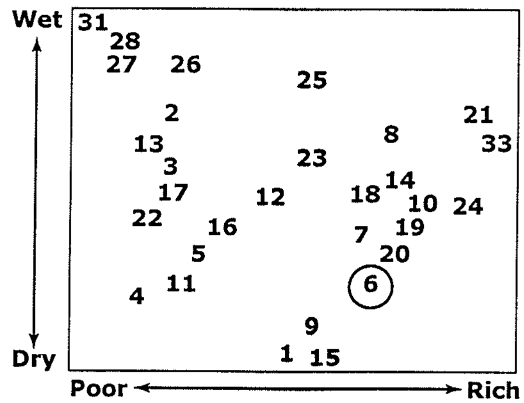
Successional Relations: Black spruce feathermoss communities are relatively stable in the abscence of fire because of continuous recruitment of black spruce into the canopy. In jack pine dominated stands (V28), forest composition is considered to be successionally intermediate between V27 and V29.

E-6 • Red pine/white pine on sandy soil

General Description: Canopy usually dominated by red or white pines, with spruce, aspen and jack pine as secondary canopy constituents. The understory shrub and herb layer typically varies from rich to poor. In poor sites, the forest floor is covered with pine needle litter. Characteristic V types are V-11, V-12, V-22 and V-23. Occasional V-26 with jack pine as canopy dominant. The shrub layer when present consists mainly of mountain maple, bush honeysuckle, and hazelut, on occasion the common juniper may be encountered. This ecosite is limited in its distribution to dry habitats in extreme southeastern Manitoba. In red pine stands feather moss occurs in patches. These sites develop on fine textured sandy soils.

Overstory Species: *Pinus resinosa, Pinus strobus, Picea glauca, Abies balsamea, Betula papyrifera, Populus tremuloides.*





Common Understory Species:

Shrubs: *Linnaea borealis, Corylus cornuta, Diervilla lonicera, Acer spicatum, Amelanchier alnifolia, Vaccinium myrtilloides, Vaccinium angustifolium, Thuja occidentalis, Rosa acicularis, Cornus stolonifera, Rubus pubescens.*

Herbs: *Maianthemum canadense, Cornus canadensis, Aralia nudicaulis, Clintonia borealis, Aster ciliolatus, Aster macrophyllus, Carex spp., Oryzopsis asperifolia, Trientalis borealis, Equisetum scirpoides.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens, Climacium dendroides;* Lichens: *Cladina rangiferina.*

Forest Floor Cover: Moss 15%, Broadleaf litter 20%, Conifer litter 45%, Needles 15%, Humus 5%

FEC Forest Composition: Common: V11, V12, V22, V23; Occasional: V25.

Soil/Site Characteristics

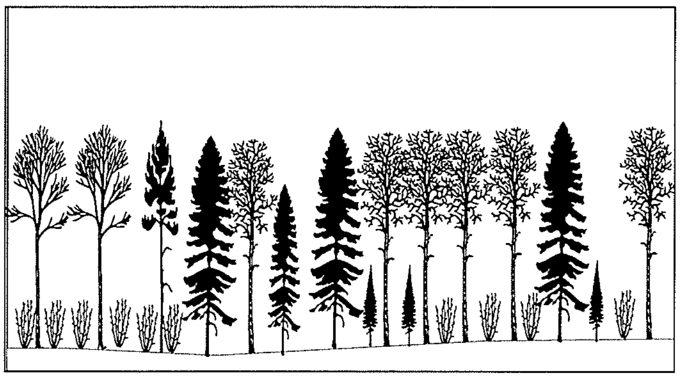
Soil Types: Common: S1, S2; Occasional: SS5
Organic Layer (LFH): Common: (6-15 cm), (1-5).
Surface texture: c.loamy, c.sandy, silty, f.sandy, no-soil.
C Horizon texture: c.sandy, c.loamy, f.sandy
Moisture-Drainage: fresh, dry, rapid, well
Deposition and Landform: glaciofluvial, morainal, lacustrine. Generally flat to slightly rolling topography of sediments of glaciofluvial origin.

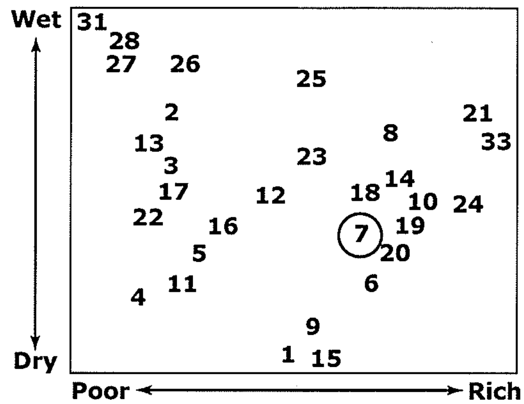
Successional Relations: This is a rare stand type in the Province and is restricted to the extreme south-east. Often successionally young, most stands have been planted.

E-7 • Hardwood – Balsam fir- spruce mixedwood on sandy soil

General Description: Sites dominated by hardwoods species such as aspen, white birch and balsam poplar with occasional occurrences of jack pine and white spruce in the overstory. Herb and shrub layer is variable ranging from dense to sparse. The Primary V-types associated with this Ecosite are V-4 to V-10. Sites that are herb and shrub rich are usually dominated by moutain maple, sarsaparilla and occasionally bush honeysuckle. Poor sites are characterized by dense balsam fir in the understory. These stands are usually successionally young from fire origin and have varied successional pathways. This ecosite occurs onwell drained sandy soils.

Overstory Species: *Populus tremuloides, Picea glauca, Abies balsamea, Betula papyrifera, Pinus banksiana, Populus balsamifera, Picea mariana.*





Common Understory Species:

Shrub layer: *Rubus pubescens, Rosa acicularis, Alnus crispa, Corylus cornuta, Diervilla lonicera, Viburnum edule, Abies balsamea, Linnaea borealis, Populus tremuloides, Acer spicatum, Cornus stolonifera, Amelanchier alnifolia, Viburnum trilobum, Ledum groenlandicum, Arctostaphylous uva-ursi, Vaccinium angustifolium.*

Herbs: *Aralia nudicaulis, Cornus canadensis, Aster ciliolatus, Maianthemum canadense, Fragaria virginiana, Mitella nuda, Viola renifolia, Streptopus roseus, Clintonia borealis, Pyrola asarifolia, Petasites palmatus, Lathyrus ochroleucus, Lycopodium annotinum, Equisetum arvense, Mertensia paniculata, Schizachne purpurascens, Pteridium aquilinum, Oryzopsis asperifolia.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Brachythecium spp., Hylocomium splendens, Drepanocladus uncinatus, Rhytidiadelphus triquetrus.*

Forest Floor Cover: Wood 5%, Moss 25%, Broadleaf litter 60%, Conifer litter 10%.

FEC Forest Composition: Common: V4-V10; Occasional: V15-V17, V21

Soil/Site Characteristics

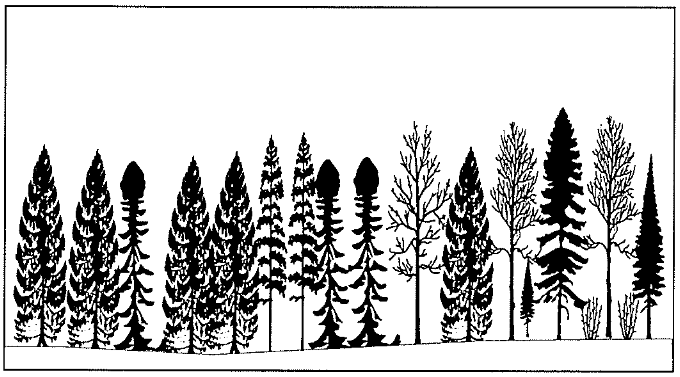
Soil Types: Common: S1, S2; Occasional: SS5.
Organic Layer (LFH): Common: (6-15 cm), (16-25 cm), (1-5 cm).
Surface texture: f.sandy, c.sandy, c.loamy, f.loamy.
C Horizon texture: f.loamy, c.sandy, c.loamy, f.sandy, silty
Moisture-Drainage: Moisture: moist, fresh; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciofluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin. Higher slope positions.

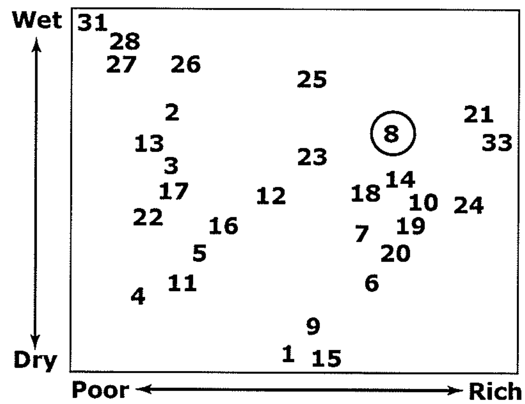
Comments: Hardwood stands generally of fire origin often with a strong recruitment of balsam fir. Softwood composition of the ecosite generally increases with age, developing a similar composition to ecosite 5. These stands are often diverse in species composition over all of the canopy strata.

E-8 • White cedar on fresh to moist, coarse to fine loamy soil

General Description: The canopy is usually dominated with a mixture of eastern white cedar and tamarak with some hardwoods (black ash, balsam poplar). Balsam fir and white spruce dominated sites are occasional. Diversity in the herb layer is usually high except in moss dominated areas. This Ecosite is primarily characterized by V-19 with occasional occurrences of V-types 20 and 21 in areas of poor drainage (tamarack dominated often). Hardwood dominated richer V-2 sites may also occur and are often dominated by Black ash. This Ecosite is successionally mature with a strong regeneration of cedar. Occurring on wet to moist well-drained sandy to loamy soil, with thin organic deposits.

Overstory Species: *Thuja occidentalis, Picea glauca, Populus tremuloides, Populus balsamifera, Abies balsamea, Larix laricina, Picea mariana, Fraxinus nigra.*





Common Understory Species:

Shrubs: *Thuja occidentalis, Abies balsamea, Rosa acicularis, Corylus cornuta, Cornus stolonifera, Linnaea borealis, Rubus pubescens, Alnus rugosa.*

Herbs: *Cornus canadensis, Aster ciliolatus, Petasites palmatus, Maianthemum canadense, Carex spp., Fragaria virginiana, Mitella nuda, Caltha palustris, Calamagrostis canadesis.*

Mosses and Lichens: Mosses: *Hylocomium splendens, Climacium dendroides, Mnium spp, Drepanocladus uncinatus, Sphagnum nemoreum;* Lichens: *Peltigera polydactyla.*

Forest Floor Cover: Wood 5%, Moss 25%, Broadleaf litter 35%, Conifer litter 20%, Needles 10%, Humus 5%, Water 5%.

FEC Forest Composition: Common: V19; Occasional: V1, V2, V13, V20, V21.

Soil/Site Characteristics

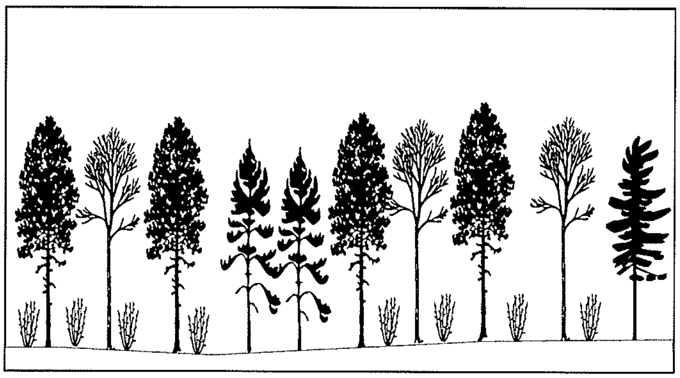
Soil Types: Common: S3, S4, S6, S9, S10; Occasional SS7
Organic Layer (LFH): Common: (6-15 cm), (16-25); Occasional: (> 40 cm).
Surface texture: sandy, f.loamy, clayey, f.sandy, c.sandy
C Horizon texture: f.loamy, c.sandy.
Moisture-Drainage: Moisture: moist, wet; Drainage: poor, v. poor.
Deposition and Landform: lacustrine, organic, glaciofluvial, morainal. Generally flat to slightly rolling topography of sediments with lacustrine origin or from organic accumulation. Usually at a lower slope position and adjacent to morainal deposits where ground water seepage occurs.

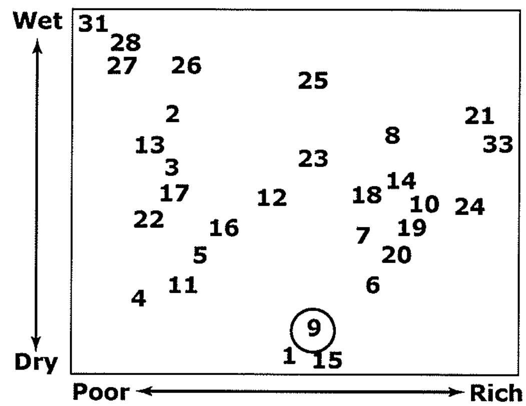
Comments: This ecosite is successional stable because of the high shade tolerance of eastern white cedar, which allows for continuous recruitment in the absence of fire.

E-9 • Red pine/ white pine on fresh coarse loamy soil

General Description: Canopy characteristically dominated by red or white pines, other tree species like spruce, aspen and Jack pine occur in the secondary canopy. The understory shrub and herb is typically varies from rich to poor. Characteristic V types are V-11, V-12, V-22 and V-23. Occasional V-25 with Jack pine dominance is encountered. The shrub layer when present consists mainly of manitoba maple, bush honeysuckle, and hazelnut. In poor sites the forest floor is covered with pine needle litter and extensive patches of feather moss, especially in redpine stands.This ecosite is limited in its distribution to habitats in the extreme southeastern portion of Manitoba. Occurs on fresh coarse loamy soils.

Overstory Species: *Pinus resinosa, Pinus strobus, Betula papyrifera, Pinus banksiana, Populus tremuloides, Picea mariana, Picea glauca.*





Common Understory Species:

Shrubs: *Linnaea borealis, Diervilla lonicera, Abies balsamea, Amelanchier alnifolia, Vaccinium angustifolium, Corylus cornuta, Acer spicatum, Vaccinium myrtilloides, Arctostaphylous uva-ursi.*

Herbs: *Maianthemum canadense, Aralia nudicaulis, Cornus canadensis, Oryzopsis asperifolia, Trientalis borealis, Clintonia borealis, Aster macrophyllus, Anemone quinquefolia, Fragaria virginiana, Streptopus roseus, Polypodium virginianum, Lycopodium complanatum.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens, Dicranum spp.;* Lichens: *Cladina mitis, Cladina rangiferina, Cladonia spp.*

Forest Floor Cover: Moss 30%, Broadleaf litter 20%, Conifer litter 45%

FEC Forest Composition: Common: V11, V12, V22, V23; Occasional: V25.

Soil/Site Characteristics

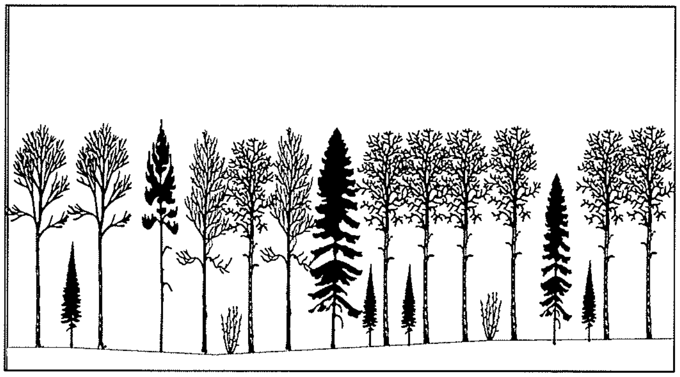
Soil Types: Common: S3; Occasional: SS6.
Organic Layer (LFH): Common: (16-15), (1-5), (Generally 10 cm)
Surface texture: c.loamy, c.sandy, silty, f.sandy. no-soil.
C Horizon texture: c.loamy, c.sandy, f.sandy, no-soil
Moisture-Drainage: Moisture: dry, fresh; Drainage: rapid, well
Deposition and Landform: morainal, glaciofluvial, lacustrine. Generally flat to slightly rolling topography of morainal origin.

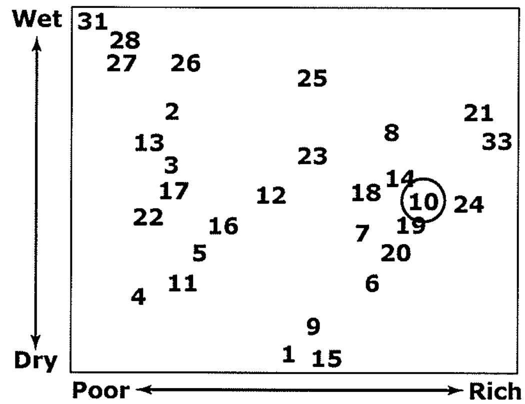
Comments: Pure red and white pine stands are rare in the Province, in many cases, they are mixed hard and softwood communities with a relatively open understory. Careful examination of many candidate sites in this study determined that the forests were likely planted. Naturally occuring stands of these species are located the extreme southeastern portion of the Province.

E-10 • Hardwood – Balsam fir – spruce mixedwood on fresh sandy – coarse loamy soil

General Description: The canopy is characterized by varied hardwoods such as Aspen, White birch and Balsam poplar with occasional occurrences of Jack pine and White spruce in the overstory. The Primary V-types associated with this Ecosite are V-4 to V-10. The understory of rich sites are dominated by Mountain Maple and Sarsaparilla and poorer sites by dense Balsam fir. Occurring on fresh, to moist mineral soils, wet sites with a thickened organic layer occur, mainly consisting of black ash and its associated communities (V-2).

Overstory Species: *Populus tremuloides, Betula papyrifera, Populus balsamifera, Fraxinus nigra, Picea glauca, Abies balsamea, Acer negundo.*





Common Understory Species:

Shrub layer: *Rubus pubescens, Corylus cornuta, Rosa acicularis, Acer spicatum, Viburnum edule, Alnus crispa, Cornus stolonifera, Diervilla lonicera, Prunus virginiana, Abies balsamea, Viburnum trilobum, Linnaea borealis, Amelanchier alnifolia.*

Herbs: *Aralia nudicaulis, Aster ciliolatus, Cornus canadensis, Maianthemum canadense, Fragaria virginiana, Petasites palmatus, Viola renifolia, Clintonia borealis, Mitella nuda, Streptopus roseus, Pyrola asarifolia, Mertensia paniculata.*

Mosses and Lichens: Mosses: *Brachythecium spp., Pleurozium schreberi, Drepanocladus uncinatus, Hylocomium splendens, Mnium spp., Plagiomnium drummondii, Rhytidiadelphus triquetrus;* Lichens: *Peltigera polydactyla*

Forest Floor Cover: Wood 5%, Moss 10%, Broadleaf litter 70%, Conifer litter 10%

FEC Forest Composition: Common: V4 - V10; Occasional: V1, V2, V13, V15.

Soil/Site Characteristics

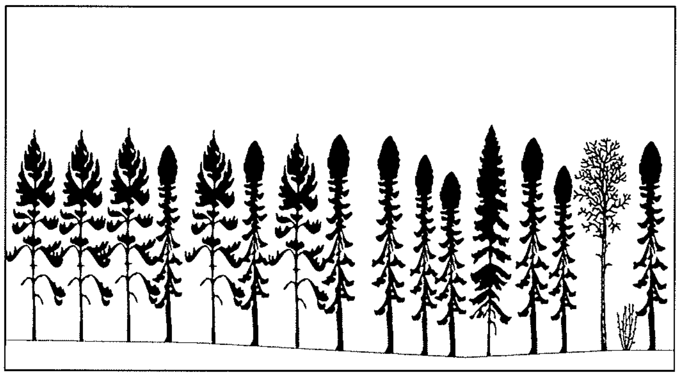
Soil Types: Common S1, S2, S3; Occasional SS5, SS6.
Organic Layer (LFH): Common: (6-15 cm), (1- 5 cm); Occasional (16- 25 cm).
Surface texture: c.loamy, c.sandy, f.loamy, f.sandy, silty,
C Horizon texture: f.loamy, c.sandy, c.loamy, f.sandy, silty
Moisture-Drainage: Moisture: moist, fresh; Drainage: well, rapid.
Deposition and Landform: lacustrine, morainal, glaciofluvial, glaciolacustrine. Generally flat to rolling topography without impeeded drainage.

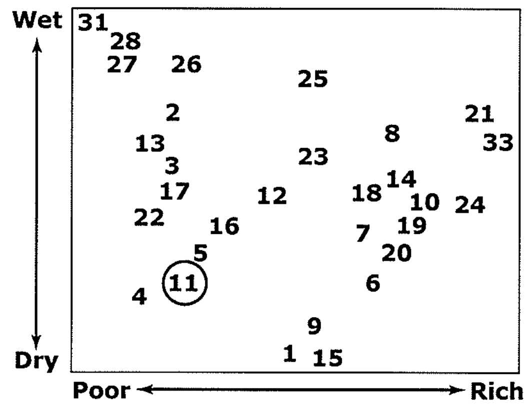
Comments: Often aspen dominated sites that are successionally young. Invasion by softwood species (white spruce, balsam fir) often occurs as sites age. Richer mixed hardwood forests along rivers and streams may also be older and occur in the southern portion of the province.

E-11 • Spruce-jack pine /Feathermoss on fresh sandy-coarse loamy soil

General Description: Canopy characterized by black spruce and jack pine with paper birch as the dominant hardwood (cover < 20%) trembling aspen is occasional. Characteristic V-types include V-24, V-25, V-27, V-28 and V-29 from dry to wet in transition. Drier soils are dominated by stands of jack pine with an understory of bearberry, blueberry and lichen. On moister soils a continuous cover of feathermoss may develop. V-24 and V-25 are relatively younger age stands dominated by Jack pine, while V-28 and V-29 are generally older and have a greater proportion of black spruce. As these stands mature, black spruce and balsam fir tend to dominate, while Jack pine declines. Found on fresh sandy to coarse loamy soil and/or rocky outcrops.

Overstory Species: *Picea mariana, Pinus banksiana, Betula papyrifera, Populus tremuloides, Picea glauca.*





Common Understory Species:

Shrub layer: *Alnus crispa, Linnaea borealis, Arctostaphylous uva-ursi, Rosa acicularis, Vaccinium myrtilloides, Picea mariana, Vaccinium vitis-idaea, Diervilla lonicera, Rubus pubescens, Viburnum edule, Vaccinium angustifolium.*

Herbs: *Cornus canadensis, Maianthemum canadense, Aralia nudicaulis, Fragaria virginiana, Oryzopsis asperifolia, Petasites palmatus, Lycopodium annotinum, Aster ciliolatus, Elymus innovatus, Lathyrus ochroleucus, Lycopodium complanatum.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum polysetum.*

Forest Floor Cover: Wood 5%, Moss 65%, Broadleaf litter 10%, Conifer litter 15%, Humus 5%

FEC Forest Composition: Common: V24, V25, V26, V27, V28, V29; Occasional: V15, V16, V18.

Soil/Site Characteristics

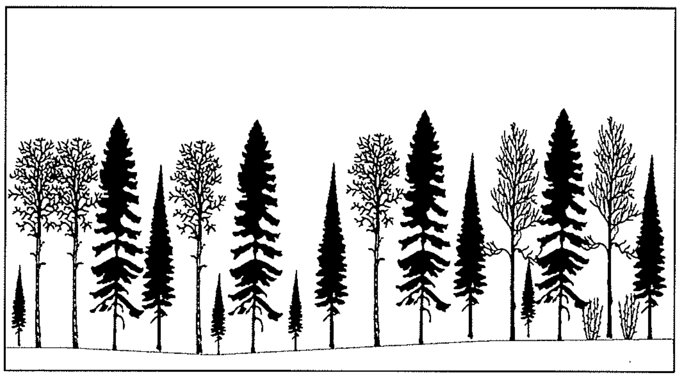
Soil Types: Common: S1, S2, S3; Occasional: SS5, SS6.
Organic Layer (LFH): Common: (6-15 cm), (1- 5 cm).
Surface texture: c.loamy, f.sandy, f.loamy, c.sandy, silty.
C Horizion texture: c.sandy, f.loamy, f.sandy, silty
Moisture-Drainage: Moisture: fresh, dry, Drainage: well, rapid. Drainage is rapid on thin soils in V25, V26.
Deposition and Landform: lacustrine, glaciofluvial, morainal. Generally flat to slightly rolling topography of sediments with lacustrine origin. This ecosite is found at mid-slope locations.

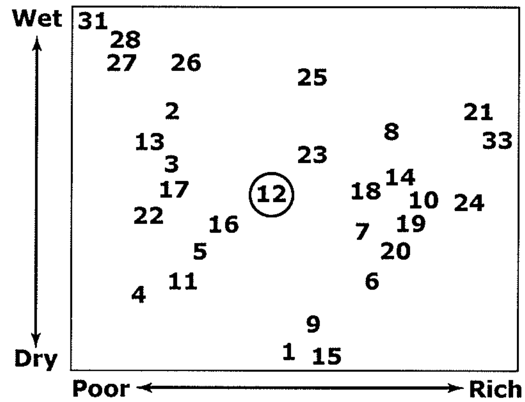
Successional Relations: Black spruce feathermoss communities are relatively stable in the abscence of fire. In jack pine dominated stands (V28), forest composition is considered to be successionally intermediate between V27 and V29.

E-12 • Balsam fir – spruce mixedwood on fresh coarse loamy soil

General Description: Successionally mature forests characterized by white spruce mixedwoods often with balsam fir in the understory. Canopy codominants include a mixture of hardwood species, typically aspen and birch. Balsam fir can form an extensive secondary canopy, especially in eastern Manitoba. The shrub and herb layer composition varies from rich to poor, and often discontinuous. Feather moss when present forms a discontinuous mat. Characteristic V-types include V-13 and V-14 and occasionally V-17 and V-21. This Ecosite is characterized by an uneven age structure and canopy closure that varies from open and discontinuous to closed. Occurring on fresh to moist coarse loamy mineral soils.

Overstory Species: *Picea glauca, Populus tremuloides, Picea mariana, Betula papyrifera, Pinus banksiana, Populus balsamifera, Abies balsamea.*





Common Understory Species:

Shrub layer: *Abies balsamea, Rubus pubescens, Linnaea borealis, Viburnum edule, Cornus stolonifera, Rosa acicularis, Populus tremuloides, Alnus crispa, Vaccinium myrtilloides, Acer spicatum, Rubus idaeus.*

Herbs: *Cornus canadensis, Aster ciliolatus, Mitella nuda, Maianthemum canadense, Mertensia paniculata, Fragaria virginiana, Petasites palmatus, Lycopodium annotinum, Geocaulon lividum, Equisetum arvense, Calamagrostis canadesis, Pyrola asarifolia.*

Mosses and Lichens: Mosses: *Hylocomium splendens, Pleurozium schreberi, Brachythecium spp.* Lichens: *Peltigera polydactyla*

Forest Floor Cover: Wood 5%, Moss 35%, Broadleaf litter 25%, Conifer litter 40%.

FEC Forest Composition: Common: V13, V14, V17; Occasional: V21

Soil/Site Characteristics

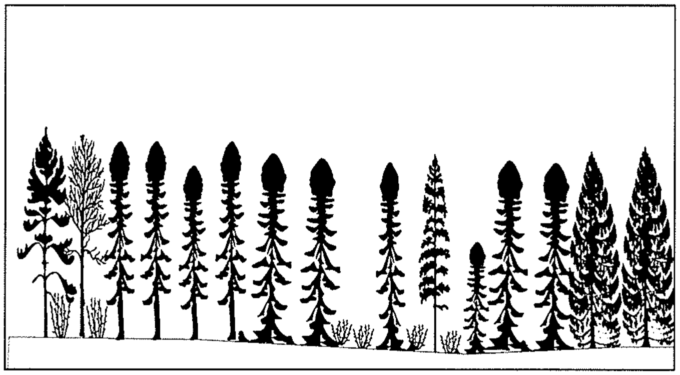
Soil Types: Common: S3; Occasional: S2, SS5, SS6; Rare S1.
Organic Layer (LFH): (6-15 cm), (16-25 cm), (generally 14 cm).
Surface texture: c. loamy, f. loamy, silty, clayey
C horizon texture: f.loamy, clayey, silty.
Moisture-Drainage: Moisture: moist, fresh, dry; Drainage: well, rapid
Deposition and Landform: glaciolacustrine, lacustrine, glaciofluvial, morainal. This ecosite forms on lacustrine deposits on gently rolling to flat topography.

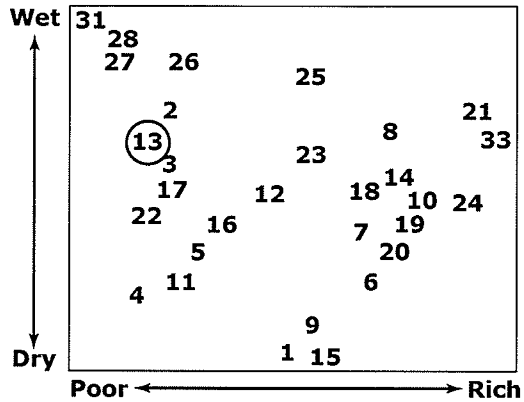
Comments: Mixedwood stands that are generally late successional and uneven aged. Balsam fir often forms a significant understory component that increases over time.

E-13 • Spruce – jack pine/ledum/feathermoss on moist sandy to coarse loamy soil

General Description: Mature forest with a canopy dominated by black spruce and jack pine, cedar or tamarack. Hardwood species (aspen, birch and balsam poplar) occur less frequently, but increase in abundance on sites with improved drainage. Labrador tea is often the primary understory shrub often associated with a layer of continuous Feather Moss and/or Sphagnum. The primary V-types observed are V-29 in upland sites and in V-30 and V-31 in lowland sites. V- 17 or V-18 may also occur occasionally in better drained sites. Occurring on moist to wet loamy soils. Organic component in the top layer of the soil seen in typically wet areas.

Overstory Species: *Picea mariana, Pinus banksiana, Populus balsamifera, Larix laricina.*





Common Understory Species:

Shrubs: *Picea mariana, Ledum groenlandicum, Linnaea borealis, Vaccinium vitis-idaea, Alnus crispa, Vaccinium myrtilloides, Viburnum edule.*

Herbs: *Cornus canadensis, Mitella nuda, Smilacina trifolia, Aralia nudicaulis, Petasites palmatus, Maianthemum canadense, Lycopodium annotinum, Fragaria virginiana, Aster ciliolatus, Calamagrostis canadesis.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Dicranum polysetum, Ptilium crista-castrensis, Sphagnum spp., Sphagnum magellanicum, Sphagnum fuscum.*

Forest Floor Cover: Wood 15%, Moss 65%, Broadleaf litter 5%, Conifer litter 10%.

FEC Forest Composition: Common: V29, V30; Occasional: V17, V18, V28, V31; Rare: V32

Soil/Site Characteristics

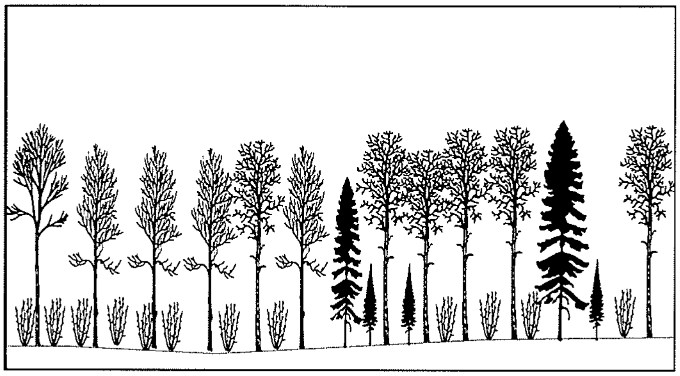
Soil Types: Common: S7, S8; Occasional: SS8.
Organic Layer (LFH): Generally: (6-15), (16-25); Occasional: (> 40 cm)
Surface texture: sandy, f. sandy, c. loamy. organic.
C-horizon texture: f. sandy, loamy, clayey.
Moisture-Drainage: Mosture: fresh, wet; Drainage: well, poor.
Deposition and Landform: lacustrine, organic, morainal. Generally flat to slightly rolling topography of sediments with lacustrine origin. This ecosite develops on lower slope positions and in catchment basins.

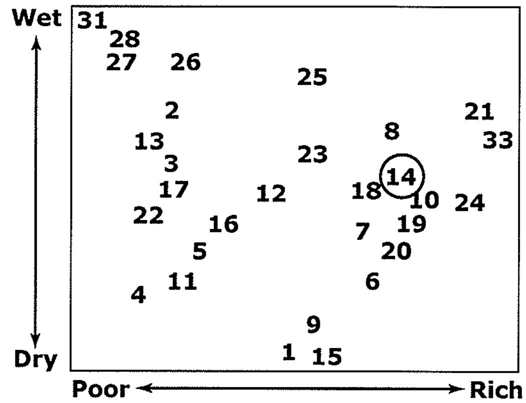
Successional Relations: Black spruce feathermoss communities are relatively stable in the abscence of fire because of continuous recruitment of black spruce into the canopy. In the absence of fire jack pine will be replaced by black spruce.

E-14 • Hardwood – balsam fir – spruce mixedwood on moist sandy to coarse loamy soil

General Description: Hardwoods stands dominated by aspen and balsam poplar and softwood species including balsam fir and white spruce. Balsam fir when present, forms a dense secondary canopy, while white spruce is more occasional in the canopy. The understory is generally shrub and herb rich. The characteristic V-types include V-1, V-5 to V-9 and occasionally V-17 where white spruce represents a larger component. The understory characterized by mountain maple, hazelnut and sarsaparilla. Aspen dominated sites are usually of fire origin, while presence of a significant conifer component is generally associated with older sites. This ecosite occurs on deep, fresh to moist sandy to coarse loamy soil.

Overstory Species: *Populus tremuloides, Betula papyrifera, Picea glauca, Populus balsamifera, Pinus banksiana, Abies balsamea, Picea mariana.*





Common Understory Species:

Shrubs: *Rubus pubescens, Acer spicatum, Corylus cornuta, Rosa acicularis, Viburnum edule, Abies balsamea, Cornus stolonifera, Alnus crispa, Populus tremuloides, Linnaea borealis, Diervilla lonicera.*

Herbs: *Aralia nudicaulis, Cornus canadensis, Aster ciliolatus, Maianthemum canadense, Mitella nuda, Fragaria virginiana, Petasites palmatus, Viola renifolia, Pyrola asarifolia, Clintonia borealis.*

Mosses and Lichens: Mosses: *Brachythecium spp., Pleurozium schreberi, Drepanocladus uncinatus, Hylocomium splendens, Plagiomnium drummondii, Rhytidiadelphus triquetrus.*

Forest Floor Cover: Wood 5%, Moss 5%, Broadleaf litter 75%, Conifer litter 10%, Needles 5%

FEC Forest Composition: Common: V1, V5, V6, V7, V8, V9; Occasional: V13, V17.

Soil/Site Characteristics

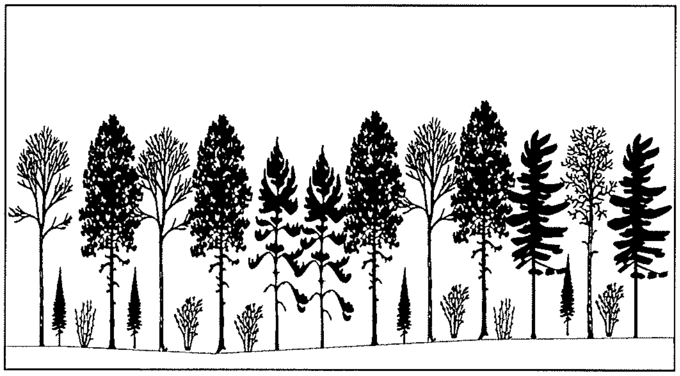
Soil Types: Common: S7, S8; Occasional: SS8
Organic Layer (LFH): Common: (6-15 cm), (1-5 cm); Occasional: (16-25 cm)
Surface texture: f. sandy, c. sandy, c. loamy.
C-horizon texture: f.loamy, c.loamy, c.sandy.
Moisture-Drainage: Moisture: moist, fresh; Drainage: well.
Deposition and Landform: lacustrine, morainal. Generally flat to slightly rolling topography of sediments with lacustrine origin. This ecosite develops on lower slope positions and in catchment basins.

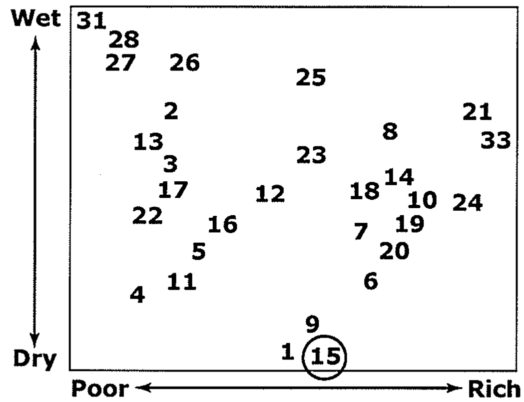
Comments: Aspen dominated hardwood stands are often of fire origin, the presence of increased softwood in the canopy and sub-canopy are often indicative of increased site age. Stands dominated by balsam poplar may be relatively successionally stable because of increased soil moisture. High cover of hardwoods separates this ecosite from E-13.

E-15 • Red pine/ white pine on fresh fine sandy to loamy soil

General Description: Canopy characteristically dominated by red or white pines, often including jack pine and aspen. The understory shrub and herb layer typically varies from rich to poor. On poor drier sites, the forest floor is covered with pine needle litter, while extensive patches of feather mosses occur with increased soil moisture. Characteristic V types are V-11, V-12, V-22 and V-23. At sites where jack pine is dominated V-25 will be encountered occasionally. The Shrub layer when present consists mainly of mountain maple, bush honeysuckle and hazelnut. This ecosite is limited in its distribution to habitats in the extreme southeastern portion of Manitoba. Occurs on fresh fine sandy to loamy soil.

Overstory Species:*Pinus resinosa, Pinus strobus, Betula papyrifera, Abies balsamea, Pinus banksiana, Populus tremuloides, Picea mariana.*





Common Understory Species:

Shrubs: *Linnaea borealis, Diervilla lonicera, Abies balsamea, Amelanchier alnifolia, Vaccinium angustifolium, Corylus cornuta, Acer spicatum, Vaccinium myrtilloides, Arctostaphylous uva-ursi.*

Herbs: *Maianthemum canadense, Aralia nudicaulis, Cornus canadensis, Oryzopsis asperifolia, Trientalis borealis, Clintonia borealis.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens, Dicranum spp.*; Lichens: *Cladina mitis, Cladina rangiferina, Cladonia spp.*

Forest Floor Cover:Moss 30%, Broadleaf litter 20%, Conifer litter 45%

FEC Forest Composition: Common: V11, V12, V22, V23; Occasional: V25.

Soil/Site Characteristics

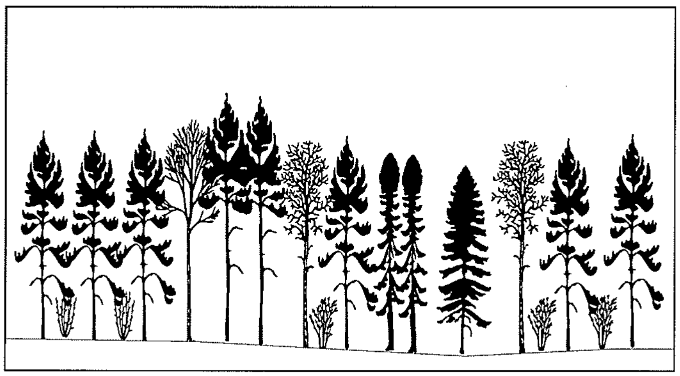
Soil types: Common: S4, S5; Occasional: SS7.
Organic Layer (LFH): Common: (6-15 cm), (1-5 cm); Occasional: (16-25cm).
Surface texture: f. sandy, c. sandy, c. loamy.
C-horizon texture: c. loamy, c.sandy, f.sandy.
Moisture-Drainage: Moisture: fresh, dry; Drainage: well, rapid .
Deposition and Landform: morainal, glaciofluvial, lacustrine. Generally flat to slightly rolling topography of sediments with lacustrine origin. Located on sand-rich deposits in the southeastern portion of the Province.

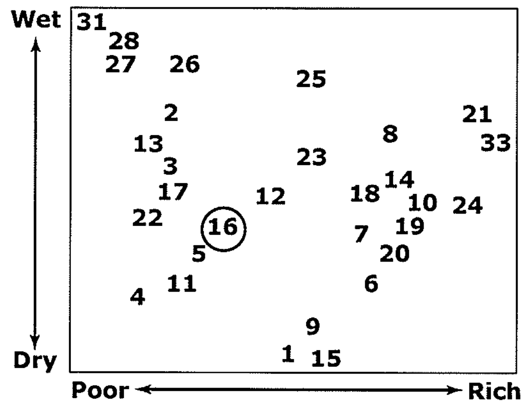
Comments: This ecosite is rare in the Province restricted to the extreme southeast. Evidence of planting was found in many of the red pine stands sampled, often associated with high accumulation of undecomposed needls on the forest floor. White pine is rarely found growing in large numbers in the Province, occuring on refugia around lakes or isolated rock outcrops. Better drained sandy sites often have relatively open canopy and a discontinuous understory cover of herbs and small shrubs.

E-16 • Jack pine – Spruce/Feathermoss on fresh silty soil

General Description: Canopy dominated by Jack pine and black spruce with scattered occurrences of trembling aspen and white birch. Patches of white spruce and balsam fir may also occur, particularly in conjunction with depressions and adjacent to wet areas. Typically shrub- and herb-poor in younger fire origin stands, and also under dense crown closure. Characteristic V-types includeV-types 27 and 28. This ecosite tends to be fairly homogenous but can also include areas of V-10 associated with trembling aspen pockets, V13 (white spruce), transitioning to V-15 (jack pine dominated) and V- 18 and V- 29 (increased black spruce). Without a disturbance the jack pine will eventually decrease as a result of black spruce recruitment over time. Soils are fresh to moist, fine textured mineral, occuring on well to moderately drained sites. Terrain is generally rolling, with Jack pine dominating on upper slopes and ridges and denser spruce occurring on lower slopes. Transitioning to ecosite 22 in low level areas and depressions.

Overstory Species: *Pinus banksiana, Picea mariana, Populus tremuloides, Picea glauca, Betula papyrifera, Populus balsamifera.*





Common Understory Species:

Shrubs: *Rosa acicularis, Linnaea borealis, Alnus crispa, Rubus pubescens, Viburnum edule, Picea mariana, Ledum groenlandicum, Vaccinium myrtilloides, Vaccinium vitis-idaea*

Herbs: *Cornus canadensis, Petasites palmatus, Aralia nudicaulis, Aster ciliolatus, Fragaria virginiana, Maianthemum canadense, Epilobium angustifolium, Equisetum arvense, Mitella nuda.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum polysetum*; Lichens: *Cladina mitis, Peltigera polydactyla.*

Forest Floor Cover: Wood 5%, Moss 50%, Broadleaf litter 20%, Conifer litter 20%, Humus 5%, LFH(cm) 11.85714286

FEC Forest Composition: Common: V27, V28; Occasional: V10, V13, V15, V18, V29.

Soil/Site Characteristics

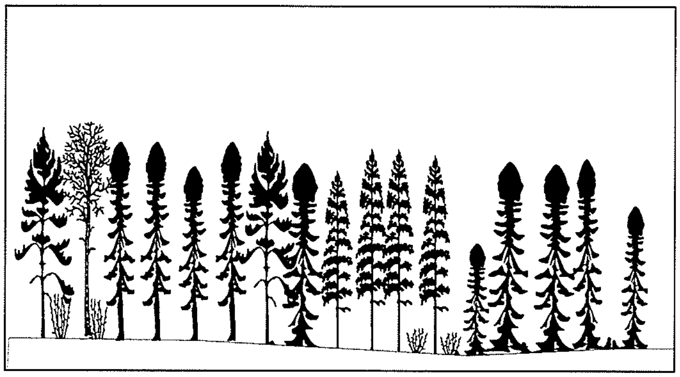
Soil types: Common: S4; Occasional: SS7.
Organic Layer (LFH): Common: (6-15 cm), (1-5 cm); Occasional: (16-25 cm).
Surface texture: silty, f.loamy.
C-horizon texture: f. loamy, silty.
Moisture-Drainage: Moisture: fresh, moist; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciolacustrine. Generally flat to slightly rolling topography of sediments with lacustrine origin.

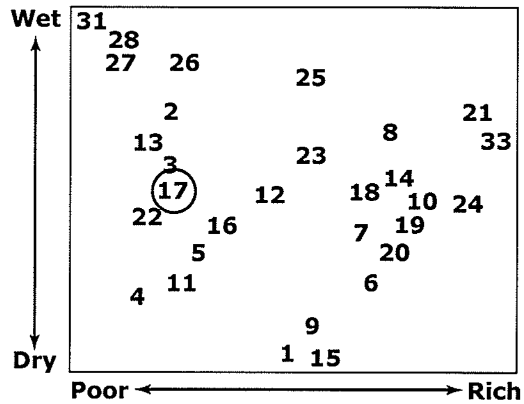
Comments: Black spruce feathermoss communities are relatively stable in the abscence of fire because of continuous recruitment of black spruce into the canopy. In jack pine dominated stands (V28), forest composition is considered to be successionally intermediate between V27 and V29. This ecosite separates from E-17 because of higher abundance of jack pine.

E-17 • Spruce – Jack pine/Feathermoss on fresh fine loamy to clayey soil

General Description: Canopy dominated by black spruce and jack pine with scattered occurrences of trembling aspen. Occasional birch and white spruce may also occur. The shrub-and herb-layer is typically sparse with continuous feather moss mat. Ecosite 17 is primarily dominated by V-17, and from V-27 to V-29. Occasional occurrences of V-15 and V-17 with increased Jack pine and rich understory may be observed. In wetter areas, V-30 and V-32 with small pockets of tamarack and cedar may occur. Black spruce dominated sites are successionally stable. The soil is well drained to wet and fine textured loamy to clayey.

Overstory Species: *Picea mariana, Pinus banksiana, Populus tremuloides, Betula papyrifera, Populus balsamifera, Larix laricina*





Common Understory Species:

Shrubs: *Linnaea borealis, Picea mariana, Rosa acicularis, Alnus crispa, Ledum groenlandicum, Rubus pubescens, Vaccinium myrtilloides, Vaccinium vitis-idaea, Viburnum edule.*

Herbs: *Cornus canadensis, Aralia nudicaulis, Petasites palmatus, Fragaria virginiana, Aster ciliolatus, Mitella nuda, Lycopodium annotinum, Maianthemum canadense, Smilacina trifolia, Geocaulon lividum, Equisetum arvense, Carex disperma.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum polysetum, Sphagnum magellanicum, Sphagnum fuscum.*

Forest Floor Cover: Wood 5%, Moss 65%, Broadleaf litter 10%, Conifer litter 15%, Humus 5%.

FEC Forest Composition: V18, V27, V28, V29; Occasional: V15, V17, V30, V32

Soil/Site Characteristics

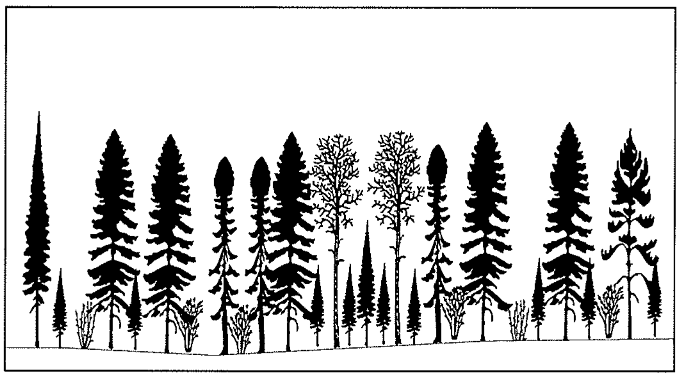
Soil types: Common: S5, S6; Occasional: SS7, SS9.
Organic Layer (LFH): Common: (6-15 cm), (1-5); Occasional: (16-25 cm), (26-35 cm)
Surface texture: f. loamy, c. loamy, silty.
C-horizon texture: clayey, f.sandy, f.loamy.
Moisture-Drainage: Moisture: fresh, moist; Drainage: well.
Deposition and Landform: lacustrine, morainal, organic. Generally flat to slightly rolling topography of sediments with lacustrine origin.

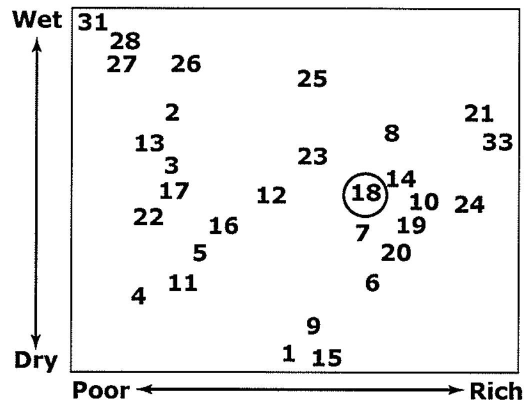
Comments: Upland black spruce feathermoss communities are relatively stable in the abscence of fire because of continuous recruitment of black spruce into the canopy. In northern Manitoba, this ecosite replaces jack pine on well-drained upland sites. In jack pine dominated stands (V28), forest composition is considered to be successionally intermediate between V27 and V29.

E-18 • Balsam fir – spruce mixedwood on fresh silty to fine loamy soil

General Description: Canopy dominated by a mixture of white spruce, black spruce and jack pine, with varied hardwoods. Fir can form a significant dense secondary canopy layer. The understory is typically varied with shrub-herb from poor to rich, dominated by feathermoss in a fairly continuous mat on poorer sites. The characteristic V-types are V-13 and V-14, however occasional scattered pockets of trembling aspen with other hardwoods do occur (associated with V-7, V-8, and V-9). This is a fairly homogenous successionaly mature ecosite with white spruce as a canopy dominant. Usually on deep mineral soil, fresh silty to fine loamy.

Overstory Species: *Picea glauca, Picea mariana, Abies balsamea, Populus tremuloides, Betula papyrifera, Pinus banksiana.*





Common Understory Species:

Shrubs: *Rubus pubescens, Abies balsamea, Rosa acicularis, Linnaea borealis, Acer spicatum, Cornus stolonifera, Viburnum edule, Viburnum trilobum, Rubus idaeus.*

Herbs: *Aralia nudicaulis, Cornus canadensis, Aster ciliolatus, Mitella nuda, Maianthemum canadense, Mertensia paniculata, Petasites palmatus, Equisetum arvense, Viola renifolia, Fragaria virginiana*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Brachythecium spp., Drepanocladus uncinatus, Rhytidiadelphus triquetrus*; Lichens: *Peltigera polydactyla.*

Forest Floor Cover: Wood 5%, Moss 20%, Broadleaf litter 50%, Conifer litter 25%

FEC Forest Composition: Common: V13, V14; Occasional: V7, V8, V9, V21

Soil/Site Characteristics

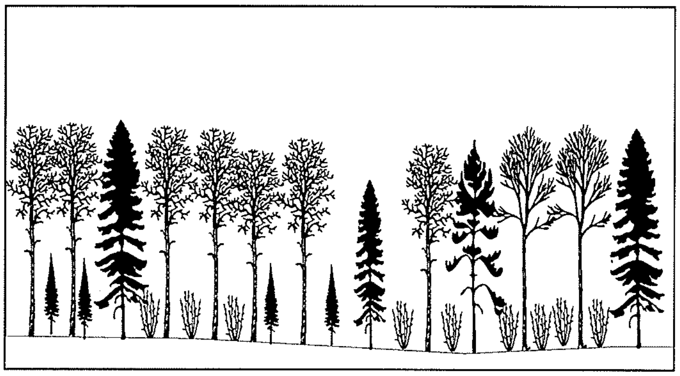
Soil types: Common: S4, S5; Occasional: SS7.
Organic Layer (LFH): Common: (6-15 cm); Occasional: (26 -35 cm).
Surface texture:silty, f. loamy, clayey.
C-horizon texture: loamy, silty, clayey.
Moisture-Drainage: Moisture: moist, fresh; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciofluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin.

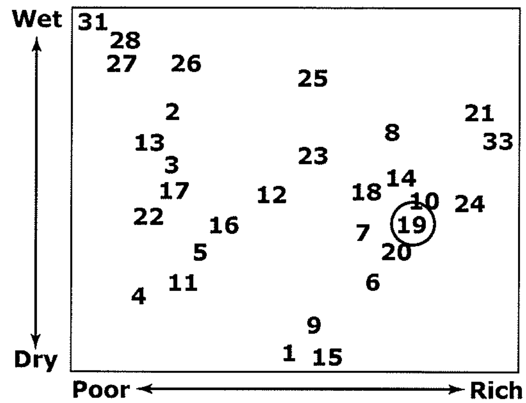
Comments: White spruce rarely occurs in pure stands and is almost always in mixture with hardwood species such as trembling aspen. This ecosite is generally successionally late and often has an uneven, discontinuous canopy.

E-19 • Hardwood – balsam fir – spruce mixedwood on fresh silty soil

General Description: Canopy dominated by hardwoods, mainly trembling aspen often with white spruce as a co-dominant (rarely jackpine in dry sites). Other hardwoods include birch and balsam poplar. The shrub and herb is usually rich, but sparse sites may also be observed dominated by dense balsam fir. The primary V-types include V-5, V-6, V-7, V-8 and V-9 where the dominant hardwood is trembling aspen. The shrub layer when rich, is characterized by mountain maple and other tall shrubs. Feather moss and balsam fir occur in mature stands. The successional trajectory for this ecosite are from hardwood dominated fire origin stands to an increase in conifers as the stands age. The ecosite occurs on deep fresh well drained silty soils developed on a flat terrain.

Overstory Species: *Populus tremuloides, Betula papyrifera, Picea glauca, Picea mariana, Pinus banksiana, Abies balsamea, Populus balsamifera, Larix laricina*





Common Understory Species:

Shrubs: *Rubus pubescens, Corylus cornuta, Rosa acicularis, Acer spicatum, Alnus crispa, Viburnum edule, Cornus stolonifera, Abies balsamea, Diervilla lonicera, Linnaea borealis, Prunus virginiana, Populus tremuloides, Amelanchier alnifolia, Vaccinium angustifolium.*

Herbs: *Aralia nudicaulis, Aster ciliolatus, Cornus canadensis, Maianthemum canadense, Viola renifolia, Petasites palmatus, Mitella nuda, Streptopus roseus, Fragaria virginiana, Clintonia borealis, Pyrola asarifolia.*

Mosses and Lichens: Mosses: *Brachythecium spp., Pleurozium schreberi, Drepanocladus uncinatus, Hylocomium splendens, Rhytidiadelphus triquetrus, Mnium spp,*

Forest Floor Cover: Wood 5%, Moss 10%, Broadleaf litter 70%, Conifer litter 10%, Needles 5% .

FEC Forest Composition: Common: V4, V5, V6, V7, V8, V9, V10, V13; Rare: V3

Soil/Site Characteristics

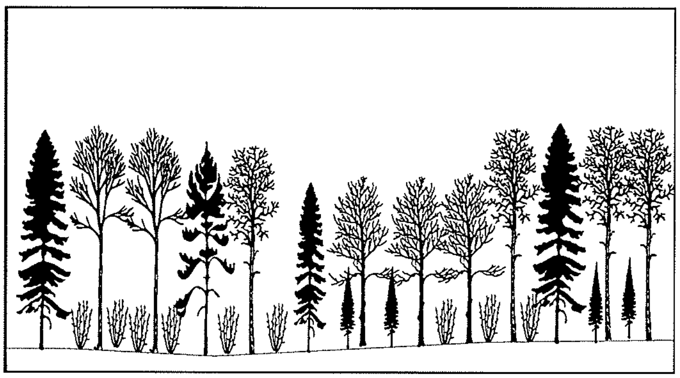
Soil types: Common: S4; Occasional: SS7.
Organic Layer (LFH): Common: (6-15 cm), (1-5 cm); Occasional: (16-25 cm)
Surface texture:silty, f. loamy.
C-horizon texture: loamy, silty.
Moisture-Drainage: Moisture: moist, fresh; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciofluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin.

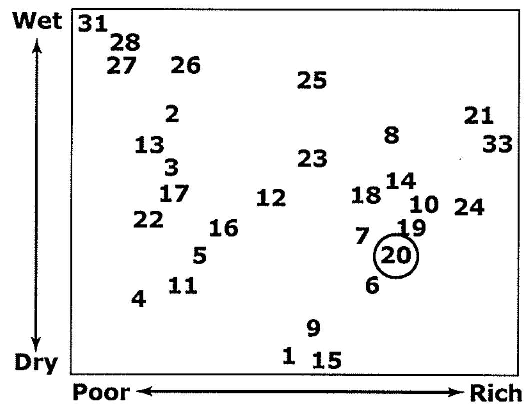
Comments: Hardwood stands are successionally young, often tending to increase in softwood abundance with site age.

E- 20 • Hardwood – balsam fir – spruce mixedwood on fresh fine loamy to clayey soil

General Description: Canopy is dominated by predominantly hardwoods like trembling aspen, birch and balsam poplar with a scattered occurrence of softwood species. A rich shrub and herb layer characterizes the understory. The primary V-types associated with ecosite areV-4, V-5, V-6, V-7, V-8 and V-9, where hardwoods form the canopy. Occasional V-13 and V-14 also occur with white spruce pockets in the canopy and/or balsam fir in the sub-canopy. The shrub layer is mostly tall shrub such as mountain maple, hazelnut and green alder. Softwood form a larger constitutent in mature stands. The soil is well drained moist fine loamy to clayey.

Overstory Species: *Populus tremuloides, Betula papyrifera, Populus balsamifera, Picea glauca, Picea mariana, Pinus banksiana, Abies balsamea.*





Common Understory Species:

Shrubs:*Rubus pubescens, Corylus cornuta, Acer spicatum, Rosa acicularis, Abies balsamea, Viburnum edule, Linnaea borealis, Diervilla lonicera, Alnus crispa, Cornus stolonifera, Amelanchier alnifolia, Vaccinium angustifolium.*

Herbs: *Cornus canadensis, Maianthemum canadense, Aster ciliolatus, Petasites palmatus, Clintonia borealis, Streptopus roseus, Viola renifolia, Fragaria virginiana, Pyrola asarifolia, Mitella nuda, Mertensia paniculata, Schizachne purpurascens.*

Mosses and Lichens: *Pleurozium schreberi, Brachythecium spp., Hylocomium splendens, Drepanocladus uncinatus, Plagiomnium drummondii, Rhytidiadelphus triquetrus, Dicranum polysetum*

Forest Floor Cover: Wood 5%, Moss 10%, Broadleaf litter 65%, Conifer litter 20%, Needles 5%,

FEC Forest Composition: Common: V4, V5, V6, V7, V8, V9; Occasional: V10, V13, V14; Rare: V1, V3, V11, V12.

Soil/Site Characteristics

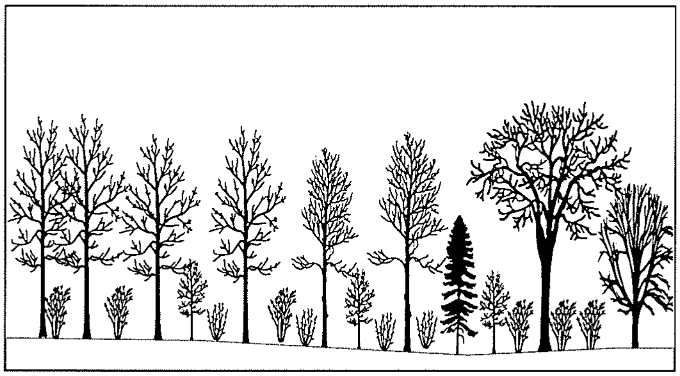
Soil Types: Common: S5, S6; Occassional: SS1, SS2, SS7.
Organic Layer (LFH): Common: (6-15 cm), (1 -5); Occasional: (16-25 cm).
Surface texture: loamy, f. loamy, silty, f.sandy, clayey.
C-horizon texture: c. loamy, c. sandy, f. loamy, clayey, f.sandy.
Moisture-Drainage:Moisture: fresh, moist; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciofluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin.

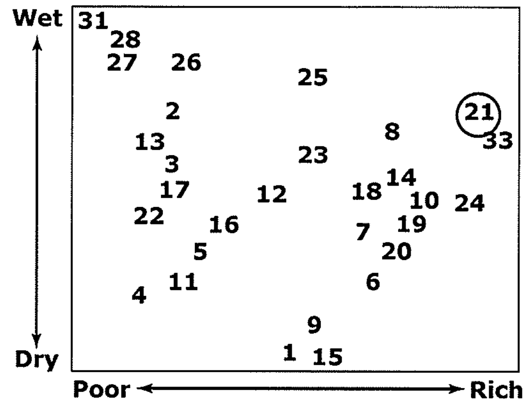
Comments: Generally successionally young sites with a large hardwood component in the canopy. Increasing abudance of softwoods is associated with increasing site age. Predominantly birch dominated stands occur on south facing slopes of the Duck Mt. and may be assigned to this ecosite.

E-21 • Black ash hardwood on fresh silty to clayey soil

General Description: Canopy dominated by black ash, elm, manitoba maple and occasionally trembling aspen. The shrub and herb layer is typically rich to poor., with rich sites developing a 'gallery forest' physiognomy. Ecosite 21 is characterized primarily by V-2, with occasional occurrences of cedar dominated V-19. In drier areas, V-1 may occur, and is associated with balsam poplar and trembling aspen in the canopy. The soil silty to clayey characterized by wet to saturated flood plains along watercourses, often with an accumulation of organic matter in the upper soil layers.

Overstory Species: *Fraxinus nigra, Acer negundo, Ulmus americana, Populus balsamifera, Fraxinus pennsylvanica, Populus tremuloides, Betula papyrifera, Thuja occidentalis, Picea glauca, Picea mariana.*





Common Understory Species:

Shrubs: *Corylus cornuta, Rubus pubescens, Rosa acicularis, Cornus stolonifera, Acer spicatum, Ribes triste, Prunus virginiana, Fraxinus nigra, Thuja occidentalis.*

Herbs: *Aster ciliolatus, Cornus canadensis, Carex spp., Fragaria virginiana, Petasites palmatus, Aralia nudicaulis, Carex Intumescens, Calamagrostis canadesis, Caltha palustris, Mertensia paniculata.*

Mosses and Lichens: Mosses: *Brachythecium spp., Mnium spp, Hylocomium splendens, Climacium dendroides, Plagiomnium drummondii*

Forest Floor Cover: Wood 5%, Moss 5%, Broadleaf litter 50%, Needles 25%, Humus 10%, Water 5%.

FEC Forest Composition: Common: V2; Occasional: V1, V19

Soil/Site Characteristics

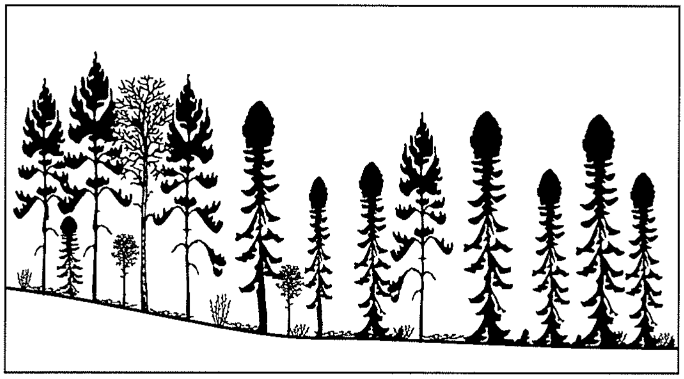
Soil Types: Common: S4, S5, S6, S10; Occasional: S11, SS9.
Organic Layer (LFH): Common: (6-15), (1-5).
Surface texture: clayey, f. loamy, silty.
C Horizon texture: clayey
Moisture-Drainage: Moisture: moist, wet; Drainage: poor, v.poor
Deposition and Landform: lacustrine, organic, glaciofluvial, morainal. Generally flat to slightly rolling topography of sediments with lacustrine origin. Located on flood plains subject to seasonal ponding and saturated soils.

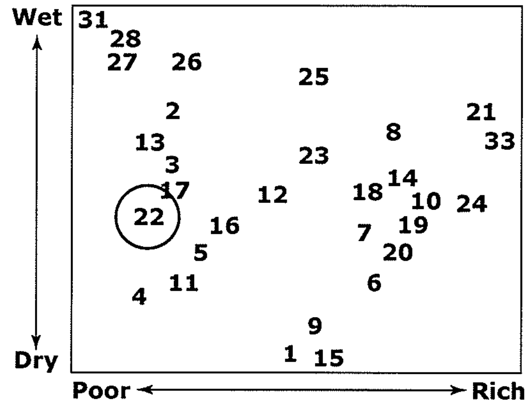
Comments: Generally a successionally stable ecosite because of the recruitment of black ash in the understory of most sites. This ecosite develops on very rich soils and is often found in riparian areas. The canopy often has good vertical development and displays a 'gallery forest' physiognomy.

E-22 • Spruce – jack pine/feathermoss on moist silty to clayey soil

General Description: Black spruce or jack pine dominated sites with poorly developed herb and dwarf shrub layers. Feathermoss cover is well-developed and forms the dominant understory component. Canopy cover is intermediate (spruce dominated) to open (jack pine dominated stands). Occurs on fresh to moist fine textured soils (V27, V28) and fresh to wet sites (V29).

Overstory Species: *Picea mariana, Pinus banksiana, Populus tremuloides, Betula papyrifera, Populus balsamifera, Larix laricina, Picea glauca.*





Common Understory Species:

Shrub layer: *Linnaea borealis, Picea mariana, Rosa acicularis, Alnus crispa, Vaccinium myrtilloides, Rubus pubescens, Ledum groenlandicum, Abies balsamea, Viburnum edule, Vaccinium vitis-idaea, Populus tremuloides, Gaultheria hispidula, Corylus cornuta.*

Herbs: *Cornus canadensis, Aralia nudicaulis, Lycopodium annotinum, Petasites palmatus, Mitella nuda, Aster ciliolatus, Geocaulon lividum, Fragaria virginiana, Maianthemum canadense, Equisetum scirpoides, Pyrola secunda, Smilacina trifolia, Elymus innovatus, Epilobium angustifolium.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum polysetum*; Lichens: *Cladina mitis.*

Forest Floor Cover: Moss 70%, Wood 8, Conifer litter 10%, Humus 40%.

FEC Forest Composition: Common: V27, V28, V29; Occasional: V17, V18, V30.

Soil/Site Characteristics:

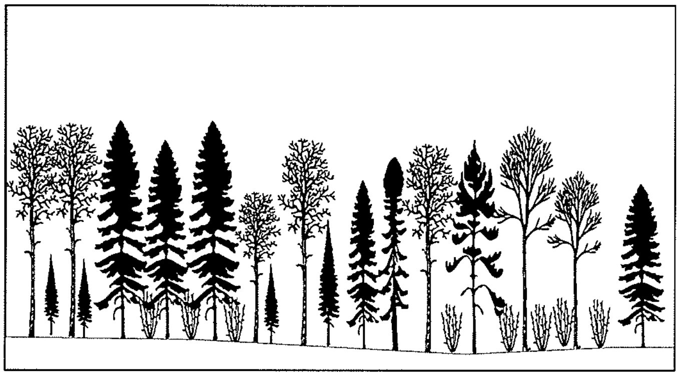
Soil Types: Common: S9, S10; Occasional: S11, SS7, SS9.
Organic Layer (LFH): Common: (6-15 cm), (15-26); Occasional (> 40 cm).
Surface texture: clayey, f.loamy, c.loamy, f.sandy, c.sandy.
C horizon texture: clayey, f. loamy, silty.
Moisture-Drainage: Moisture: fresh, moist; Drainage: well.
Deposition and Landform: lacustrine, morainal, glaciofluvial. Generally flat to slightly rolling topography of sediments with lacustrine origin. This ecosite occurs at lower slope positions and in catchment basins.

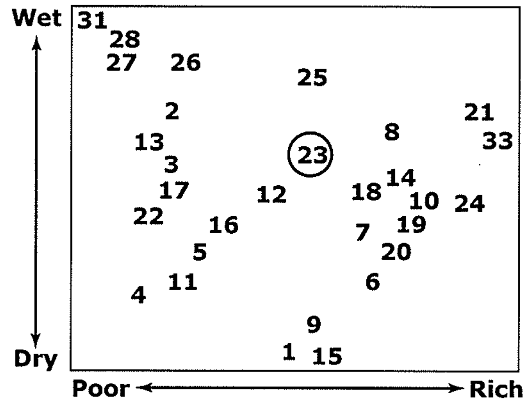
Comments: Black spruce feathermoss communities are relatively stable in the abscence of fire because of continuous recruitment of black spruce into the canopy. In jack pine dominated stands (V28), forest composition is considered to be successionally intermediate between V27 and V29. This ecosite separates from E-23 and E-24 because the canopy composition is almost exclusively softwood.

E-23 • Balsam fir – spruce mixedwood on moist silty to clayey soil

General Description: Canopy dominated by mixed hardwood and softwoods, mainly trembling aspen and white spruce. Other hardwoods such as paper birch can be mixed with jack pine on areas of improved drainage. The shrub and herb is usually rich but sparse sites dominated by dense balsam fir patches may be observed. The primary V-types are V-5, V-6, V-7, V-8 and V-9 dominated by trembling aspen, and occasionally V-4 (paper birch dominated sites). The shrub layer, when rich is characterized by tall shrubs such as mountain maple. Feather moss and balsam fir occur in mature stands. The terrain is usually flat on a deep, fresh, well drained silty to clayey soil.

Overstory Species: *Picea glauca, Populus tremuloides, Abies balsamea, Picea mariana, Populus balsamifera, Betula papyrifera, Pinus banksiana, Thuja occidentalis.*





Common Understory Species:

Shrub layer: *Abies balsamea, Rubus pubescens, Linnaea borealis, Cornus stolonifera, Rosa acicularis, Acer spicatum, Corylus cornuta, Viburnum edule, Alnus crispa, Thuja occidentalis.*

Herbs: *Cornus canadensis, Aralia nudicaulis, Aster ciliolatus, Mitella nuda, Maianthemum canadense, Fragaria virginiana, Petasites palmatus, Lycopodium annotinum, Geocaulon lividum, Carex spp., Equisetum arvense.*

Mosses and Lichens: Mosses: *Hylocomium splendens, Pleurozium schreberi, Brachythecium spp., Drepanocladus uncinatus, Climacium dendroides*; Lichens: *Peltigera polydactyla.*

Forest Floor Cover: Wood 5%, Moss 30%, Broadleaf litter 20%, Conifer litter 25%, Needles 20%, Humus 10%.

FEC Forest Composition: Common: V13, V17, V21; Occasional: V19.

Soil/Site Characteristics

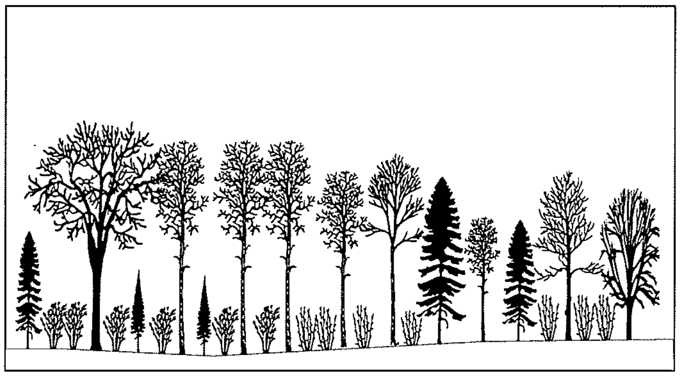
Soil Types: Common: S9, S10; Occasional: S11, SS8, SS9.
Organic Layer (LFH): Common: (6 - 15 cm), (16 -25 cm) (26 - 35 cm).
Surface texture: f.loamy, silty, clayey.
C Horizon texture: clayey.
Moisture-Drainage: Moisture: moist, wet; Drainage: well, poor
Deposition and Landform: lacustrine, glaciofluvial, organic, glaciolacustrine. Generally flat to slightly rolling topography of sediments with lacustrine origin: This ecosite occurs at lower slope positions and in catchment basins.

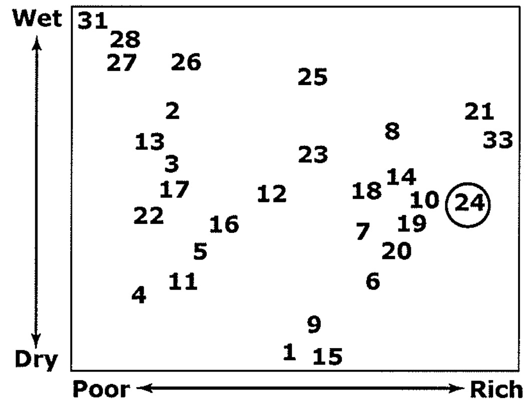
Comments: Successionally mature mixedwood forest of an uneven age structure. The occurence of black spruce in the canopy is associated with increased soil moisture and organic accumulation. This site separates from E-24 because of higher softwood abundance.

E-24 • Hardwood – balsam fir – spruce mixedwood on moist silty to clayey soil

General Description: Canopy dominated by trembling aspen, white spruce, jackpine, balsam fir and birch, wet areas characterized by cedar. The understory is typically shrub – herb rich to poor. The primary V-types associated with ecosite 24 is V-5, V-6, V-7, V-8, with V-9. & V-8 occasional as conifer abundance increases. Hardwood stands dominated with V-1, V-4 (with birch) and V-2 (with black ash as co-dominant) occur occasionally. When the shrub layer is present it is characterized by mountain maple and sarsaparilla. The terrain is flat to rolling moist silty to clayey soil. This ecosite is successionally young usually fire origin.

Overstory Species: *Populus tremuloides, Betula papyrifera, Populus balsamifera, Picea glauca, Pinus banksiana, Abies balsamea, Acer negundo, Ulmus americana, Fraxinus pennsylvanica.*





Common Understory Species:

Shrubs: *Acer spicatum, Corylus cornuta, Rubus pubescens, Rosa acicularis, Cornus stolonifera, Prunus virginiana, Viburnum edule, Diervilla lonicera.*

Herbs: *Aralia nudicaulis, Aster ciliolatus, Maianthemum canadense, Cornus canadensis, Fragaria virginiana, Viola renifolia, Streptopus roseus, Clintonia borealis, Pyrola asarifolia, Petasites palmatus, Mitella nuda, Mertensia paniculata, Schizachne purpurascens, Lathyrus ochroleucus.*

Mosses and Lichens: Mosses: *Brachythecium spp.,Pleurozium schreberi, Mnium spp, Plagiomnium drummondii, Drepanocladus uncinatus, Rhytidiadelphus triquetrus.*

Forest Floor Cover: Wood 5%, Moss 5%, Broadleaf litter 80%, Conifer litter 5%, Needles 5%

FEC Forest Composition: Common: V5, V6, V7, V8,V9; Occassional: V1, V2, V4; Rare: V3

Soil/Site Characteristics

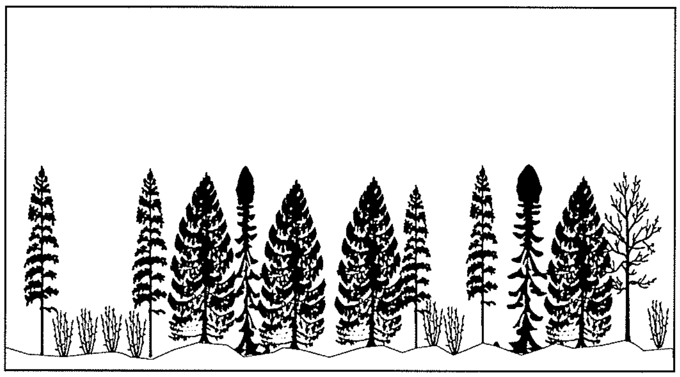
Soil Types: Common: S9, S10; Occassional: SS8.
Organic Layer (LFH): Common: (6-15 cm), (1 - 5 cm).
Surface texture: silty, f. loamy, clayey
C Horizon texture: clayey, silty
Moisture-Drainage: Moisture: moist, fresh; Drainage: well
Deposition and Landform: lacustrine, morainal, glaciofluvial, glaciolacustrine. Generally flat to slightly rolling topography of sediments with lacustrine origin. Ecosite is at lower slope position or in a catchment basin.

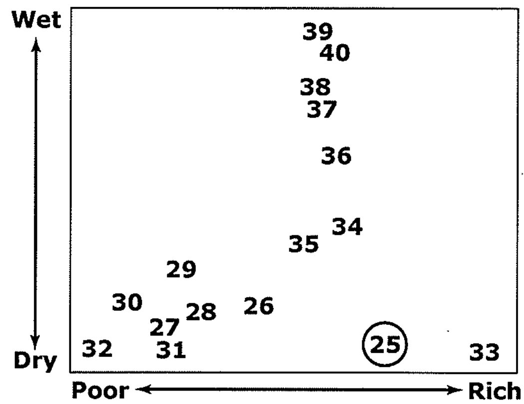
Successional Relations: This ecosite is generally aspen dominated and likely successionally young. Presence of softwoods, particularly balsam fir indicate increasing site age. A tall shrub component is often present consisting of mountain maple in richer soils in the southern area of the Province and hazelnut elsewhere. Increased diversity of shrubs and herbs is associated with decreasing abundance of tall shrubs. This site separates from E-23 because of greater hardwood abundance.

E-25 • Rich swamp - eastern white cedar, tamarack, black spruce on organic soil

General Description: Ecosite 25 is characterized by white cedar, tamarack and scattered black spruce dominant canopy; the shrub layer is usually composed of cedar and balsam fir. The herb layer is usually diverse. The water is at or near the surface. Soil characterized by organic peat accumulation. Characteristic V- types include predominantly V-19, V-20, however scattered black spruce dominated V-30 and V-31 will occur. In more nutrient rich sites, occasional black ash dominated V-2 may be encountered.

Overstory Species: *Thuja occidentalis, Larix laricina, Picea mariana, Populus tremuloides, Populus balsamifera, Fraxinus nigra*





Common Understory Species:

Shrubs: *Alnus rugosa, Rubus pubescens, Ledum groenlandicum, Picea mariana, Linnaea borealis, Cornus stolonifera, Chamaedaphne calyculata, Betula pumila, Corylus cornuta, Vaccinium vitis-idaea, Rosa acicularis, Gaultheria hispidula, Fraxinus nigra, Thuja occidentalis.*

Herbs: *Cornus canadensis, Maianthemum trifolium, Mitella nuda, Carex spp., Caltha palustris, Calamagrostis canadensis, Equisetum scirpoides, Aster ciliolatus, Carex trisperma, Petasites palmatus, Carex Intumescens, Carex aquatilis, Fragaria virginiana, Impatiens capensis, Matteuccia struthiopteris, Carex leptalea, Urtica dioica, Galium triflorum, Equisetum fluviatile.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Hylocomium splendens, Sphagnum spp., Dicranum polysetum, Mnium spp, Sphagnum nemoreum, Sphagnum magellanicum, Brachythecium spp.*

Forest Floor Cover: Wood 20%, Moss 30%, Broadleaf litter 10%, Conifer litter 10%, Needles 15%, Humus 5%, Water 5%.

FEC Forest Composition: Common: V2, V19, V20; Occasional: V30, V31.

Soil/Site Characteristics

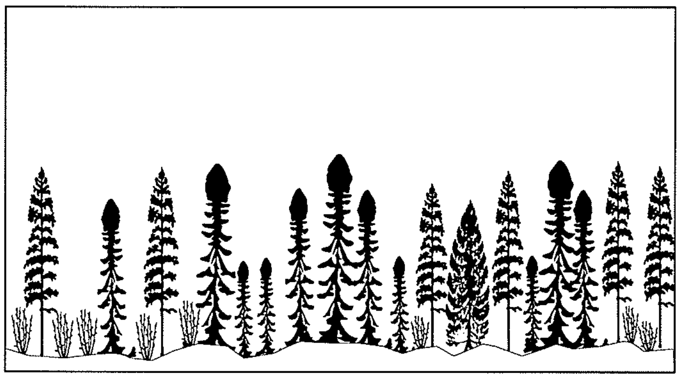
Soil Types: Common: S11, S12F, S12S; Ocassional: SS9.
Organic Layer (LFH): Generally > 40 cm.
Surface texture: organic, clayey, f.loamy
C Horizon texture: clayey, f.loamy, Organic c.loamy,
Moisture-Drainage: Moisture: wet, moist; Drainage: poor, v. poor.
Deposition and Landform: organic, lacustrine, glaciofluvial. Ecosite development on lower slope positions. Where eastern cedar is abundant, sites are typically along the edge of seepage slopes (e.g. morainal deposits). This system is raised relative to surrounding landform.

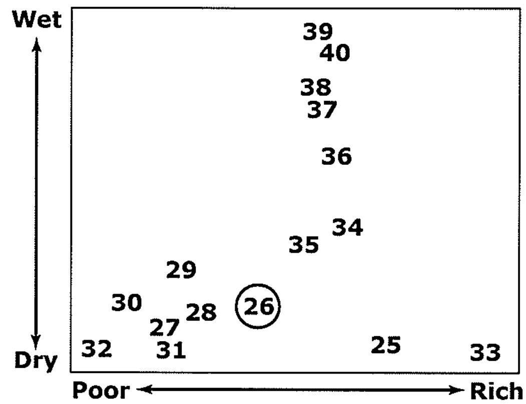
Comments: These stands are generally successionally stable as eastern white cedar, black spruce and black ash are capable of regeneration in closed canopy conditions. Stands with a higher proprotion of tamarack will often transition towards greater dominance of black spruce over time. This ecosite can be separated from E26 by the dominance of eastern white cedar. The distribution of the ecosite is primarily restricted to the south eastern portion of the Province. A disjunct population occurs along the Grand Point moraine as far north as The Pas.

E-26 • Intermediate swamp - black spruce, tamarack on organic soil

General Description: Ecosite 26 is codominated by black spruce and tamarack in the canopy. The Shrub-Herb layer is typically rich to poor. Labrador tea and a fairly continuous mats of feather moss are characteristic of this Ecosite. The V-types observed are V-20 with tamarack dominant, and V-31, V-32 dominated by black spruce.

Overstory Species: *Picea mariana, Larix laricina, Thuja occidentalis, Populus balsamifera.*





Common Understory Species:

Shrubs: *Ledum groenlandicum, Picea mariana, Alnus rugosa, Chamaedaphne calyculata, Rubus pubescens, Vaccinium vitis-idaea, Linnaea borealis, Betula pumila, Rubus chamaemorus, Gaultheria hispidula, Vaccinium oxycoccos, Larix laricina, Salix pedicellaris, Andromeda glaucophylla.*

Herbs: *Cornus canadensis, Maianthemum trifolium, Mitella nuda, Calamagrostis canadensis, Carex trisperma, Carex disperma, Carex aquatilis, Equisetum scirpoides, Caltha palustris, Carex leptalea, Equisetum fluviatile, Petasites palmatus.*

Mosses and Lichens: Mosses: *Pleurozium schreberi, Sphagnum magellanicum, Sphagnum nemoreum, Hylocomium splendens, Sphagnum spp., Dicranum polysetum, Sphagnum fuscum, Ptilium crista-castrensis, Sphagnum girgensohnii.*

Forest Floor Cover: Wood 25%, Moss 55%, Conifer litter 10%.

FEC Forest Composition: Common: V20, V31, V32; Occassional: V30.

Soil/Site Characteristics

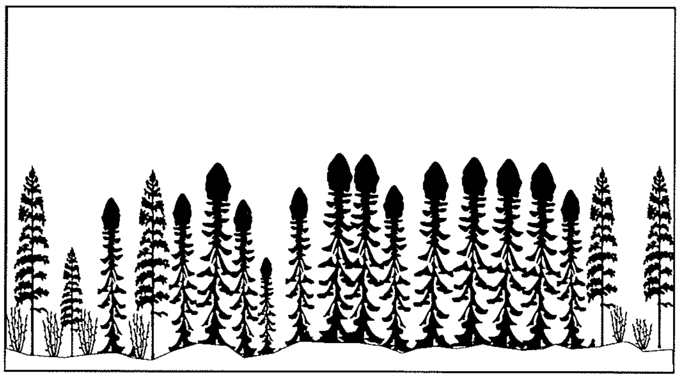
Soil Types: S11, S12F, S12S; Occassional: SS9.
Organic Layer (LFH): Generally > 40 cm.
Surface texture: organic, clayey.
C Horizon texture: clayey, organic.
Moisture-Drainage: Moisture: wet; Drainage: poor, v. poor.
Deposition and Landform: organic, lacustrine. This ecosite develops on peatlands in lower slope positions and catchments, it is unraised.

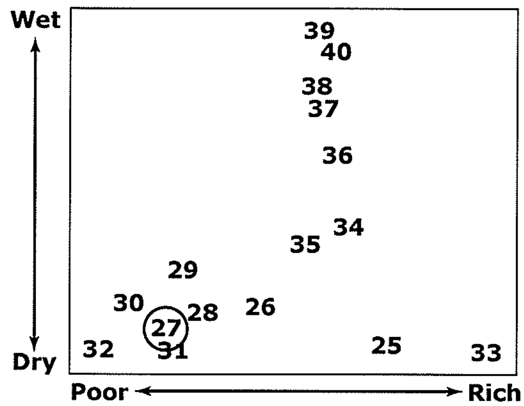
Comments: These stands are generally successionally stable, although tamarack may be replaced by black spruce over time. Presence of tamarack is often indicative of moving water and higher nutrient inputs. This ecosite can be separated from E25 by the lower abundance of eastern white cedar and increased cover of black spruce and tamarack and because the peatland is unraised relative to surrounding landform.

E-27 • Poor swamp - black spruce on organic soil

General Description: Continuous canopy of black spruce stands with occasional larch on an organic soil. Trees greater than 2 m tall provide a high crown closure. Labrador tea is the principal shrub species in the understory and a continuous cover of sphagnum mosses are present. Soils are primarily thick organics derived from sphagnum moss and carex decomposition. Open pools of water are absent.

Overstory Species: *Picea mariana, Larix laricina.*





Common Understory Species:

Shrubs: *Ledum groenlandicum, Picea mariana, Vaccinium oxycoccos, Chamaedaphne calyculata , Vaccinium vitis-idaea, Andromeda glaucophylla, Rubus chamaemorus, Kalmia polifolia, Betula pumila, Alnus rugosa.*

Herbs: *Maianthemum trifolium, Calamagrostis canadensis, Carex trisperma, Carex disperma, Sarracenia purpurea, Cornus canadensis, Eriophorum spissum.*

Mosses and Lichens: Mosses: *Sphagnum fuscum, Sphagnum magellanicum, Sphagnum nemoreum, Pleurozium schreberi*

Forest Floor Cover: Moss 100%

FEC Forest Composition: Common: V32, V33.

Soil/Site Characteristics

Soil Types:

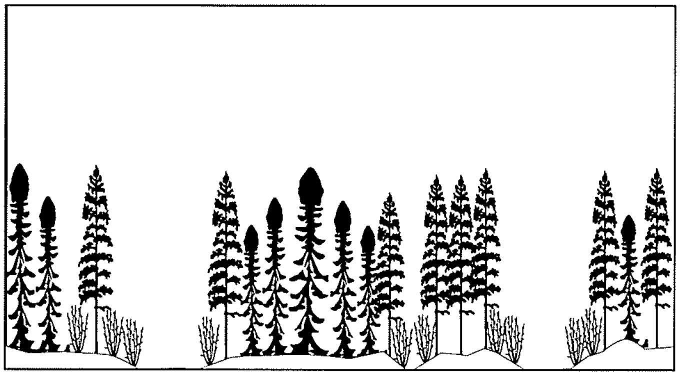
Soil Types: Common: S11, S12S, S12F; Occasional: SS9.
Organic Layer (LFH): Generally > 100 cm
Surface texture: organic
C Horizon texture: Variable very deep, often clays and silts.
Moisture-Drainage: Moisture: v. wet; Drainage: v. poor
Deposition and Landform: Organic, Lacustrine. This ecosite develops on hummocky organic soils.

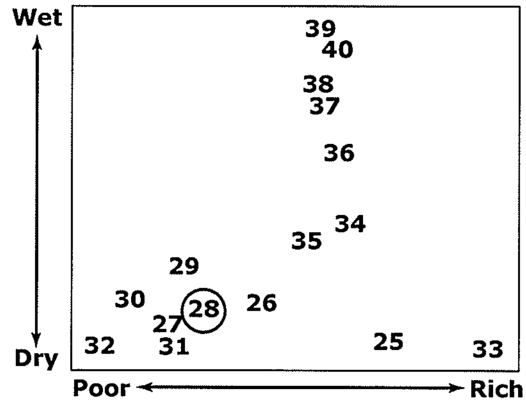
Comments: These stands are successionally stable, black spruce regeneration occurs from both seed and by layering. This ecosite is separated from E28 and E31 by having a relatively continuous canopy. This ecosite lacks moving water like E28 but is slightly drier than E31 allowing for greater decompositional turnover of nutrients in addition to those provided by rainfall.

E-28 • Treed Fen - Tammarack black spruce/sphagnum on organic soil

General Description: Scattered or clumped tammarack and black spruce stands on an organic soil. Trees greater than 2 m tall provide a crown closure greater than 10%. Labrador tea is the principal shrub species in the understory and a discontinuous cover of sphagnum mosses and carices are present. Soils are primarily thick organics derived from sphagnum moss and carex decomposition. Open pools of water are frequent.

Overstory Species: *Picea mariana, Larix laricina.*





Common Understory Species:

Shrubs: *Ledum groenlandicum, Picea mariana, Vaccinium oxycoccos, Chamaedaphne calyculata , Vaccinium vitis-idaea, Andromeda glaucophylla, Rubus chamaemorus, Kalmia polifolia, Betula pumila, Alnus rugosa.*

Herbs: *Maianthemum trifolium, Calamagrostis canadensis, Carex trisperma, Carex disperma, Sarracenia purpurea, Cornus canadensis, Eriophorum spissum.*

Mosses and Lichens: Mosses: *Sphagnum fuscum, Sphagnum magellanicum, Sphagnum nemoreum, Pleurozium schreberi*

Forest Floor Cover: Moss 100%

FEC Forest Composition: Common: V32, V33.

Soil/Site Characteristics

Soil Types:

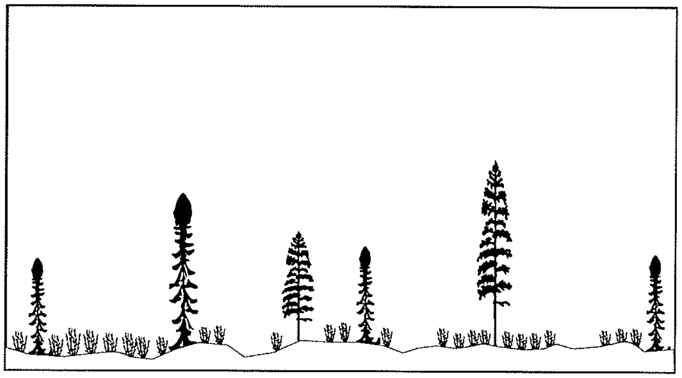
Soil Types: Common: S12F, S12S; Occasional: SS9.
Organic Layer (LFH): Generally > 100 cm
Surface texture: organic
C Horizon texture: Variable very deep, often clays and silts.
Moisture-Drainage: Moisture: v. wet; Drainage: v. poor
Deposition and Landform: organic, lacustrine. Fens form in depressions where some water movement occurs.

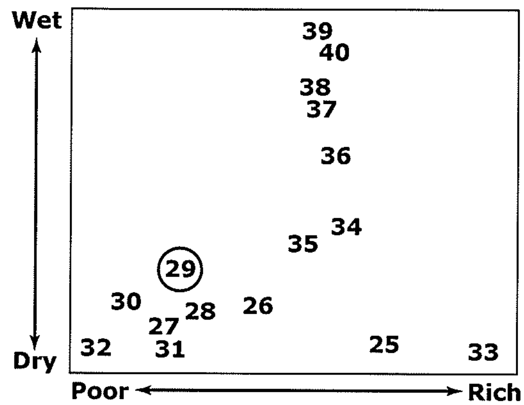
Comments: Black spruce stands are successionally stable, as regeneration occurs from both seed and by layering. Presence of tammarack is often indicative of younger stand age, succeeding into black spruce over time. This ecosite is separated from E27 by having a discontinuous canopy of scattered and clumped individuals and separates from E31 because of the presence of open pools of water. Nutrient availability is often higher at these sites compared with E31 because of water movement.

E-29 • Open poor fen - Ericaceous shrub/sedge/sphagnum on organic soil

General Description: Ecosite29 consists mainly of very open stands of scattered individuals of black spruce and tamarack greater than two meters in height. Black spruce and tamarack typically forming less than ten percent cover in the polygon. Hummocky microtopography characterizes ecosite 29. Ericaceous shrubs and *Betula pumila* (dwarf birch) and Sphagnum are found in the ground cover. Wire sedge could dominate occasionally with occurrences of willow. Water regime is well saturated; peatlands however have less exposure to mineral- rich ground water. This ecosite is similar to treed bog communities, except that minerotrophic indicators like dwarf birch are present.

Overstory Species: *Picea mariana, Larix laricina.*





Common Understory Species:

Shrubs: *Chamaedaphne calyculata* (leather leaf), *Andromeda polifolia* (bog rosemary), *Betula pumila* (dwarf birch), *Kalmia polifolia* (bog laurel), *Vaccinium oxycoccos* (small cranberry), *Ledum groenlandicum* (labrador tea), *Salix pedicellaris* (bog willow), *and Salix discolor* (pussy willow).

Herbs: *Sarracenia purpurea* (pitcher plant), *Menyanthes trifoliata* (buckbean), *Equisetum fluviatile* (water horsetail), *Maianthemum trifolium* (three-leaved Solomon's seal), *Scheuchzeria palustris* (pod grass), *Drosera rotundifolia (round leaved sundew)*.

Graminoids: *Carex limosa* (candle lantern sedge), *Carex oligosperma* (few-seeded sedge), *Carex chordorrhiza* (creeping sedge), *Carex lasiocarpa* (wire sedge).

Mosses: *Sphagnum magellanicum, Sphagnum fuscum Sphagnum capillifolium, Sphagnum angustifolium, Pleurozium schreberi* (Schreber's moss).

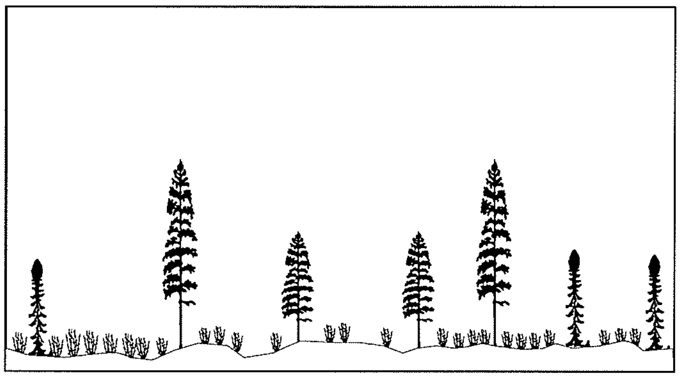
WEC Composition: W20, W21, W22.

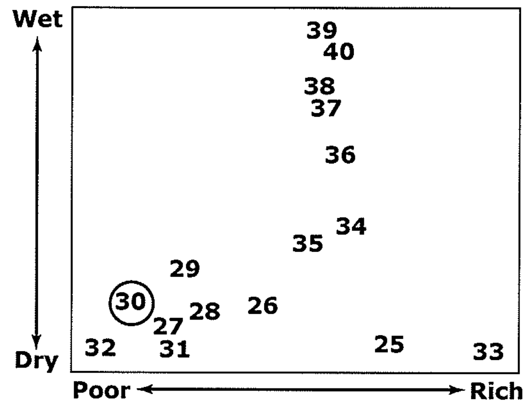
Soil/Site Characteristics: Organic substrate.

E-30 • Open rich fen - Ericaceous shrub/sedge/brown moss on organic soil

General Description: Ecosite 30 primarily consists of very open stands of scattered individuals of black spruce and tamarack greater than two meters in height. Black spruce and tamarack typically forming less than ten percent cover in the polygon. Hummocky micro-topography the ground cover is characterized by brown moss with patches of sphagnum. May sometime consist of raised "strings" typically perpendicular to the water flow. Usually associated with calcium rich ground water. Water regime is usually semi-permanently flooded to saturated.

Overstory Species: *Larix laricina, Picea mariana.*





Common Understory Species:

Shrubs: *Betula pumila* (dwarf birch), *Andromeda polifolia* (bog rosemary), *Vaccinium oxycoccos* (small cranberry), *Larix laricina* (tamarack), *Lonicera villosa* (mountain fly honeysuckle), *Picea mariana* (black spruce), *Potentilla fruticosa* (shrubby cinquefoil), *Rhamnus alnifolia* (alder-leaved buckthorn), *Rubus acaulis* (artic raspberry), *Chamaedaphne calyculata* (leatherleaf), *Juniperus horizontalis* (creeping juniper), *Ledum groenlandicum* (labrador tea), *Salix pedicellaris* (bog willow), *Rubus pubescens* (dwarf raspberry), *Linnaea borealis* (twinflower).

Herbs: *Menyanthes trifoliata* (buckbean), *Maianthemum trifolium* (three-leaved Solomon's seal), *Equisetum fluviatile* (water horsetail), *Sarracenia purpurea* (pitcher plant), *Tofieldia glutinosa* (sticky asphodel), *Triglochin maritimum* (greater arrowgrass), *Galium labradoricum* (labrador bedstraw), *Solidago uliginosa* (northern bog goldenrod), *Drosera rotundifolia* (round-leaved sundew), *Scheuchzeria palustris* (pod grass), *Selaginella selaginoides* (spikemoss), *Mitella nuda* (naked mitrewort), *Epilobium palustre* (marsh willow-herb).

Graminoids: *Carex lasiocarpa* (wire sedge), *Carex livida* (livid sedge), *Muhlenbergia glomerata* (marsh timothy), *Scirpus cespitosus* (tufted clubrush), *Scirpus hudsonianus* (Hudson Bay clubrush), *Carex interior* (inland sedge), *Carex limosa* (candle lantern sedge).

Mosses: *Camylium stellatum* (starry campylium), *Tomenthypnum nitens* (fuzzy brown moss), *Drepanocladus revolvens* (red hook moss), *Scorpidium scorpioides* (Scorpion tail moss), *Pleurozium schreberi* (Schreber's moss), *Aulacomnium palustre* (ribbed bog moss).

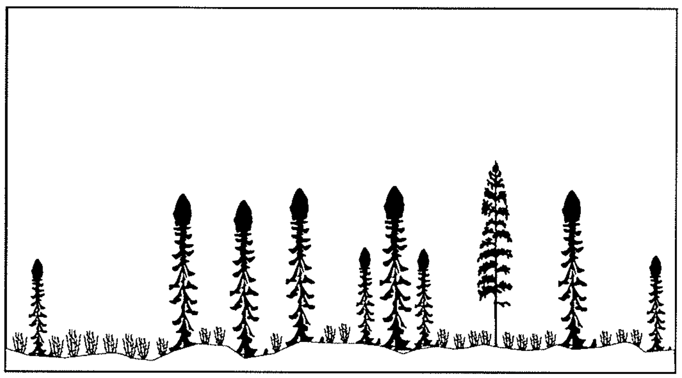
WEC Composition: W17, W18, W19.

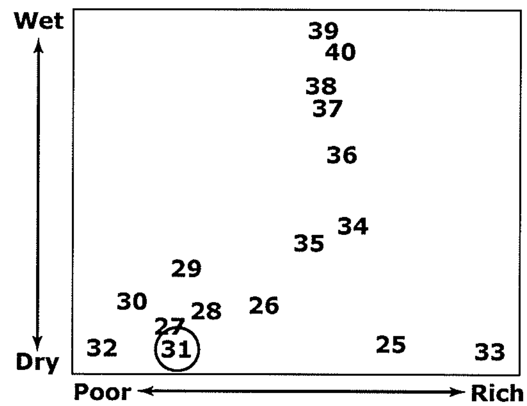
Soil/Site Characteristics: Organic substrate.

E-31 • Treed Bog - Black Spruce/Sphagnum on organic soil

General Description: Scattered or clumped black spruce stands with occasional larch on an organic soil. Trees greater than 2 m tall provide a crown closure greater than 10%. Labrador tea is the principal shrub species in the understory and a continuous cover of Sphagnum mosses are present. Soils are primarily thick organics derived from Sphagnum moss and Carex decomposition. Open pools of water are absent.

Overstory Species: *Picea mariana, Larix laricina.*





Common Understory Species:

Shrubs: *Ledum groenlandicum, Picea mariana, Vaccinium oxycoccos, Chamaedaphne calyculata , Vaccinium vitis-idaea, Andromeda glaucophylla, Rubus chamaemorus, Kalmia polifolia, Betula pumila, Alnus rugosa.*

Herbs: *Maianthemum trifolium, Calamagrostis canadensis, Carex trisperma, Carex disperma, Sarracenia purpurea, Cornus canadensis, Eriophorum spissum.*

Mosses and Lichens: Mosses: *Sphagnum fuscum, Sphagnum magellanicum, Sphagnum nemoreum, Pleurozium schreberi*

Forest Floor Cover: Moss 100%

FEC Forest Composition: Common: V32, V33.

Soil/Site Characteristics

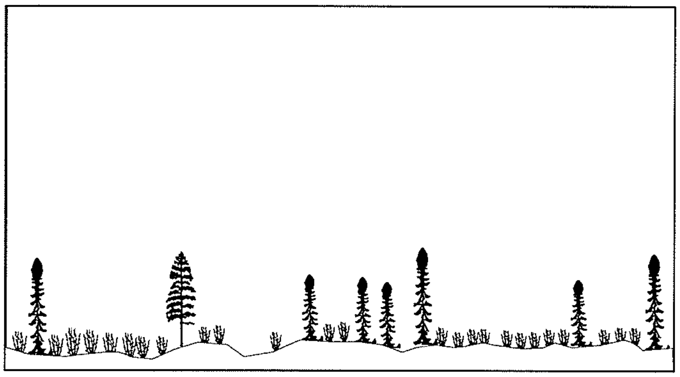
Soil Types: Common: S12F, S12S; Occasional: SS9.
Organic Layer (LFH): Generally > 100 cm
Surface texture: organic
C Horizon texture: Variable very deep, often clays and silts.
Moisture-Drainage: Moisture: v. wet; Drainage: v. poor
Deposition and Landform: organic, lacustrine. Bogs often form in depressions. but after sufficient organic accumulation they become raised relative to adjacent communities.

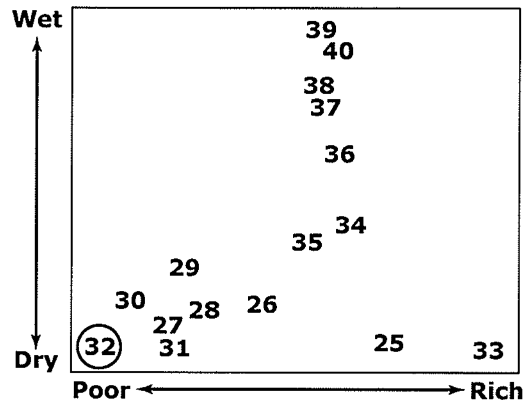
Comments: These stands are successionally stable, black spruce regeneration occurs from both seed and by layering. This ecosite is separated from E27 by having a discontinuous canopy, and separates from E28 because of continuous cover of Sphagnum mosses without open pools of water.

E-32 • Open Bog - Ericaceous shrub/sedge/sphagnum on organic soil

General Description: Ecosite 32 primarily consists of stunted shrubby looking black spruce/tamarack forming less than ten percent of tree cover. Ericaceous shrubs and sedge species characterize the shrub layer. Herb layer is sparse. Ground cover is continuous with sphagnum and occasional feathermoss carpet. Substrate is fibric peat. The water regime is saturated.

Overstory Species: *Picea mariana, Larix laricina.*





Common Understory Species:

Shrubs: *Chamaedaphne calyculata* (leatherleaf), *Kalmia polifolia* (bog laurel), *Vaccinium oxycoccos* (small cranberry), *Ledum groenlandicum* (labrador tea), *Andromeda polifolia* (bog rosemary), *Picea mariana* (black spruce).

Herbs: *Sarracenia purpurea* (pitcher plant), *Scheuchzeria palustris* (pod grass).

Graminoids: *Carex oligosperma* (few-seeded sedge), *Eriophorum vaginatum* (dense cotton grass), *Carex pauciflora* (few-flowered sedge).

Mosses: *Sphagnum magellanicum, Sphagnum fuscum, Sphagnum angustifolium.*

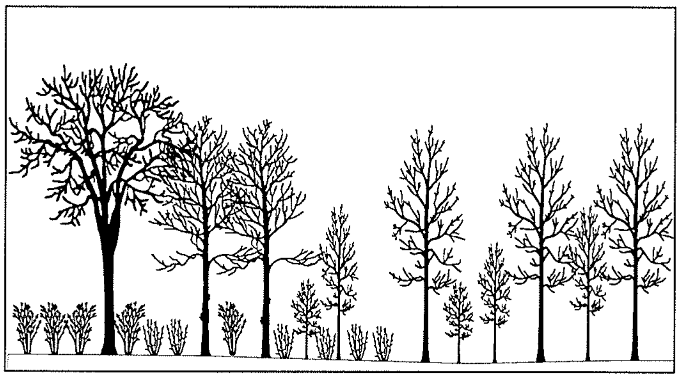
EC Forest Composition: Common: W23, W24.

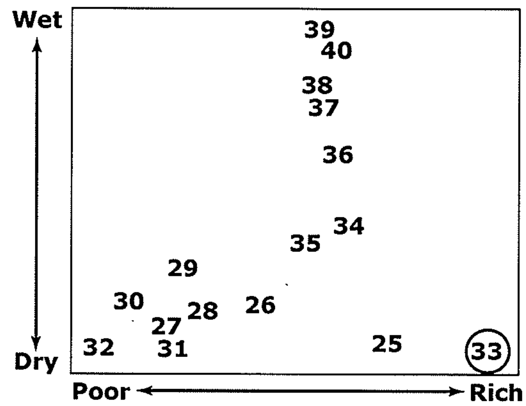
Soil/Site Characteristics: Organic.

E-33 • Rich Swamp - black ash - other hardwoods on seasonally flooded organic soil

General Description: Seasonally flooded hardwood stands dominated by black ash but often with an admixture of american white elm and balsam poplar in fresh sites. This ecosite is often associated with water courses and riparian areas occuring in relatively small stands in the south eastern portion of the Province. Soils are well decomposed organics derived from accumulated broadleaf litter, the subsoil is often clays or silts.

Overstory Species: *Fraxinus nigra, Populus balsamifera, Populus tremuloides, Acer negundo, Ulmus americana, Picea mariana, Betula papyrifera, Picea glauca.*





Common Understory Species:

Shrubs: *Rubus pubescens, Corylus cornuta, Acer spicatum, Ribes triste, Prunus virginiana, Fraxinus nigra, Ulmus americana, Cornus stolonifera, Populus balsamifera, Ribes hudsonianum, Rosa acicularis, Alnus rugosa, Viburnum edule, Ribes glandulosum, Rhamnus alnifolia, Rubus idaeus, Viburnum trilobum.*

Herbs: *Carex spp., Carex Intumescens, Fragaria virginiana, Calamagrostis canadensis, Cornus canadensis, Caltha palustris, Aster ciliolatus, Aralia nudicaulis, Mertensia paniculata, Petasites palmatus, Impatiens capensis, Matteuccia struthiopteris, Urtica dioica, Maianthemum canadense, Galium triflorum, Clintonia borealis, Pyrola asarifolia, Athyrium filix-femina.*

Mosses and Lichens: Mosses: *Brachythecium spp., Mnium spp., Plagiomnium drummondii.*

Forest Floor Cover: Wood 5%, Moss 10%, Broadleaf litter 75%, Humus 5%, Water 10%.

FEC Forest Composition: Common: V2; Occasional: V1

Soil/Site Characteristics

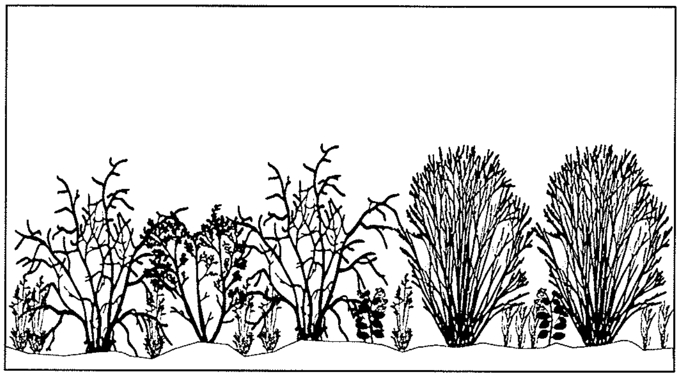
Soil Types: S8, S10
Organic Layer (LFH): Common: (6 - 15 cm), (16-25 cm).
Surface texture: f. loamy, clayey.
C Horizon texture: f. loamy, clayey.
Moisture-Drainage: Moisture: moist, wet; Drainage: poor, v. poor.
Deposition and Landform: Lacustrine, Organic. This ecosite is associated with lower slope positions in imperfectly drained sites.

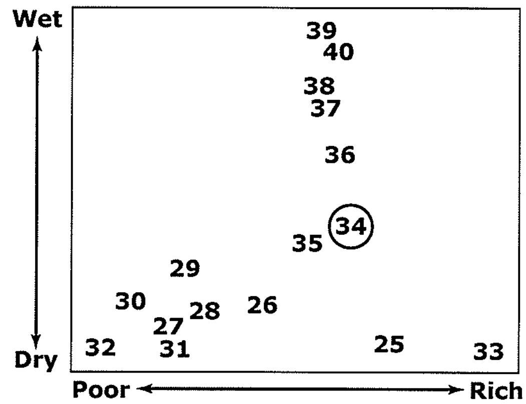
Comments: This vegetation type develops on rich organic deposits derived from decomposed broadleaf litter overlying a mineral C horizon soil. It is successionally stable as black ash is able to regenerate under an existing canopy. This ecosite is primarily restricted to south eastern Manitoba, the western most recorded stand of black ash occurs between Winnipeg and Portage La Prairie in a roadside rest-stop along the Assiniboine river. This ecosite is separated from E-34 because of high cover of hardwood tree species (E-34 is alder dominated).

E-34 • Thicket Swamp - alder/willow on organic soil

General Description: Thicket swamp is characterized by Alnus incana (speckled alder) and bluejoint grass. Swamps with tall willow species like *Salix petiolaris* (slender willow), *S. discolor* (pussy willow), *S.planifolia* (flat-leaved willow) also occur. Sites with high canopy are herb and moss rich. Canopy cover declines with increased flooding frequency. Open sites have usually more graminoid cover. Microtopography is flat. Substrate is well-decomposed peat or organic mineral soil. The water regime is seasonally flooded.

Overstory Species: *Alnus incana* (speckled alder), *Salix petiolaris* (slender willow).





Common Understory Species:

Shrubs: *Cornus stolonifera* (red osier dogwood), *Rubus idaeus* (red raspberry), *Rubus pubescens* (dwarf raspberry).

Herbs: *Impatiens capensis* (jewelweed), *Campanula aparinoides* (marsh bellflower), *Lycopus asper* (rough bugleweed), *Equisetum sylvaticum* (wood horsetail), *Scutellaria galericulata* (common skullcap).

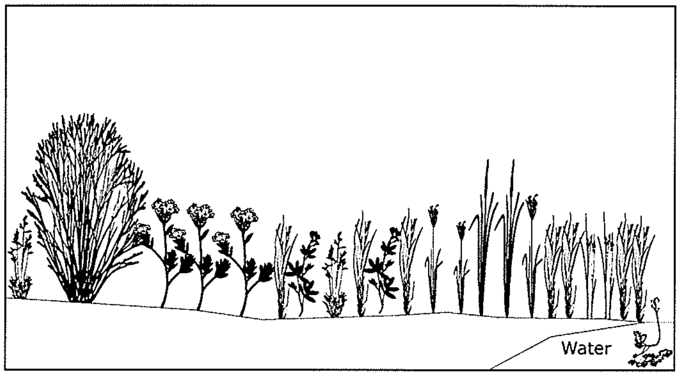
Graminoids: *Calamagrostis canadensis* (bluejoint grass)

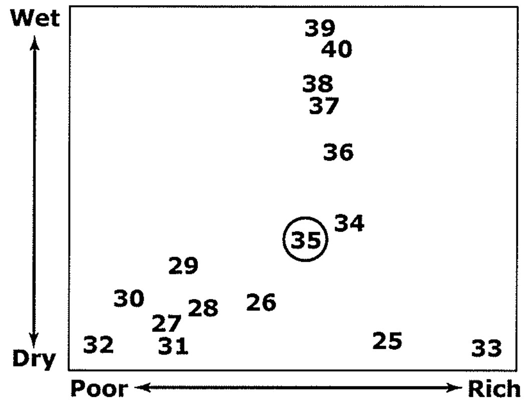
WEC Composition: W35, W36.

Soil/Site Characteristics: Organic substrate.

E-35 • Shore Fen - organic mineral soil

General Description: Ecosite 35 is characterized by typically floating mat substrate with emergents. Usually dominated by wire sedge, ericaceous shrub species to occasional tall shrub mainly speckled alder or willows. Permanent shallow surface pools may persist through out the growing season. Ground cover is characterized by sedge litter, water, peat or patches of sphagnum may also occur. Soil is organic fibric to mesic peat usually held together by roots and rhizomes. Found along edges of lakes. Water regime is seasonally to permanently flooded.





Common Species:

Shrubs: *Chamaedaphne calyculata* (leather leaf), *Alnus incana* (speckled alder), *Betula pumila* (dwarf birch), *Myrica gale* (sweet gale), *Salix pedicellaris* (bog willow), *Cornus stolonifera,* (red osier dogwood), *Ledum groenlandicum* (Labrador tea), *Rubus idaeus* (red raspberry), *Rubus acaulis* (artic raspberry), *Rubus pubescens* (dwarf raspberry), *Salix discolor* (pussy willow), *Salix planifolia* (flat leaved willow), *Rhamnus alnifolia* (alder –leaved buckthorn).

Herbs: *Potentilla palustris* (marsh cinquefoil), *Aster borealis* (slender white aster), *Athyrium filix-femina* (lady fern), *Equisetum fluviatile* (water horsetail), *Triandenum fraseri* (marsh St. John's wort), *Iris versicolor* (northern blue iris), *Maianthemum trifolium* (three leaved solomon's seal), *Viola spps* (violets).

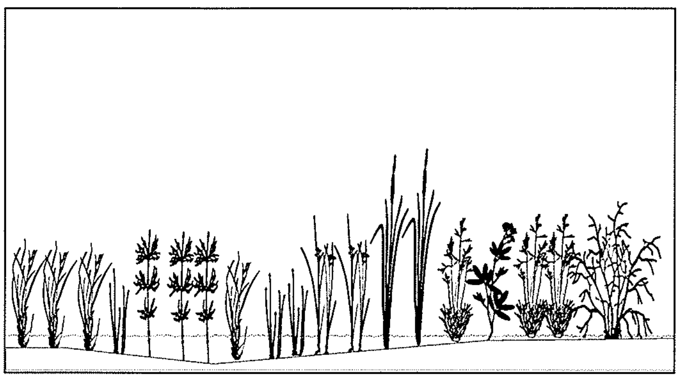
Graminoids: *Carex lasiocarpa* (wire sedge), *Calamagrostis canadensis* (bluejoint grass), *Carex rostra* (beaked sedge), *Carex aquatilis* (water sedge), *Carex leptalea* (bristle-stalked sedge), *Typha spp.* (cattail), *Phragmites australis* (common reed).

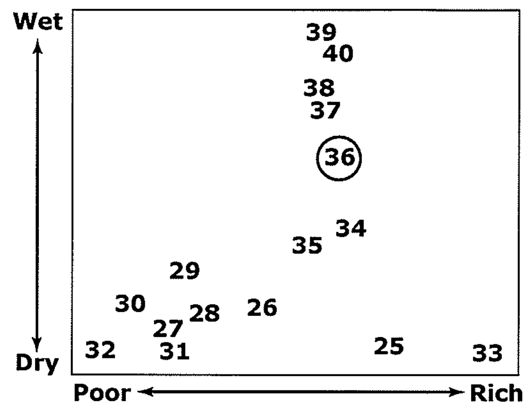
WEC Composition: W14, W16, W17.

Soil/Site Characteristics: Organic substrate.

E-36 • Meadow Marsh - organic mineral soil

General Description: Ecosite 36 is characterized by fixed bottom substrate of vegetation, usually dominated by tall sedges or *Calamogrostis canadensis* (bluejoint grass) ground cover is a mat of sedge stems and leaves. Floating leaved and submergents like *Utricularia* also do occur. The substratum is usually fine mineral soil or well decomposed peat. Marsh has characteristic zonal or mosaic surface patterns composed of pools or channels interspersed with clumps of emergent vegetation, along side grassy meadows. Found along flood plains of small streams, and lakeshores. Water regime may be semi-permanently flooded to seasonally flooded.





Common Species:

Shrubs: *Alnus incana* (speckled alder), *Spiraea alba* (narrow-leaved meadowsweet).

Herbs: *Equisetum fluviatile* (water horsetail), *Sium suave* (water parsnip), *Potentilla palustris* (marsh cinquefoil), *Campanula aparinoides* (marsh bellflower), *Lysimachia thyrsiflora* (tufted loosestrife), *Acorus calamus* (sweetflag), *Polygonum amphibium* (water smartweed), *Typha latifolia* (common cattail), *Scutellaria galericulata* (common skull cap), *Epilobium leptophyllum* (narrow-leaved willow- herb), *Iris versicolor* (northern blue iris).

Graminoids: *Calamagrostis canadensis* (bluejoint grass), *Carex rostra* (beaked sedge), *Carex lasiocarpa* (wire sedge), *Carex aquatilis* (water sedge), *Carex lacustris* (lake sedge), *Scirpus cyperinus* (woolgrass), *Eleocharis smallii* (marsh spikerush), *Typha spp.* (cattail).

Mosses: *Drepanocladus aduncus* (common hook moss)

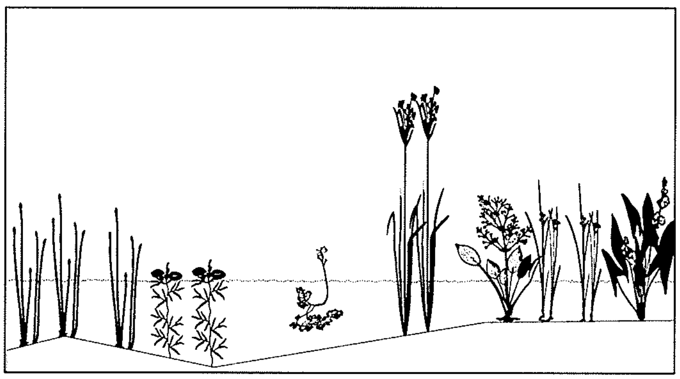
Floating-leaved and submergents: *Urticularia intermedia* (flat-leaved bladderwort), *Utricularia vulgaris* (common bladderwort).

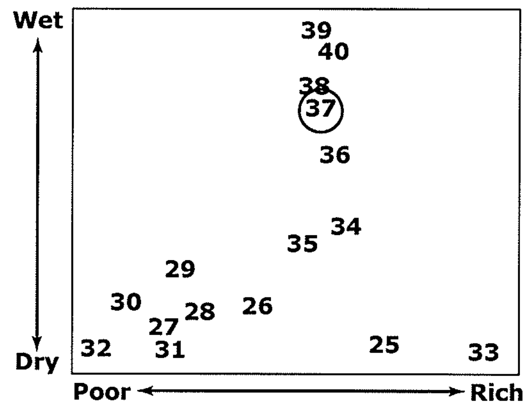
WEC Composition: W12, W13.

Soil/Site Characteristics: Organic mineral substrate.

E-37 • Sheltered Marsh - sedimentary peat substrate.

General Description: Ecosite 37 Has a polygon cover with greater than twenty five percent emergents, Species composition is highly variable, however emergent species occur as single dominant species in dense stands with pools of water in between, floating and submergent vegetation is also high, Water depth usually above 50 cm. Thick mat of vegetation covers the bottom, found along sheltered bays and have deep slow moving water. Substrate is of rich sedimentary peat. Water regime is from permanently flooded to semi – permanently flooded.





Common Species:

Herbs:*Sium suave* (water parsnip), *Equisetum fluviatile* (water horsetail), *Acorus calamus* (sweetflag), *Sagittaria latifolia* (broad-leaved arrowhead), *Sagittaria rigida* (stiff arrowhead), *Sparganium eurycarpum* (large-fruited burreed).

Graminoids: *Eleocharis smallii* (marsh spike rush), *Zizania palustris* (wild rice), *Scirpus acutus* (hard stem bulrush), *Carex rostra* (beaked sedge), *Typha spp.* (cattail).

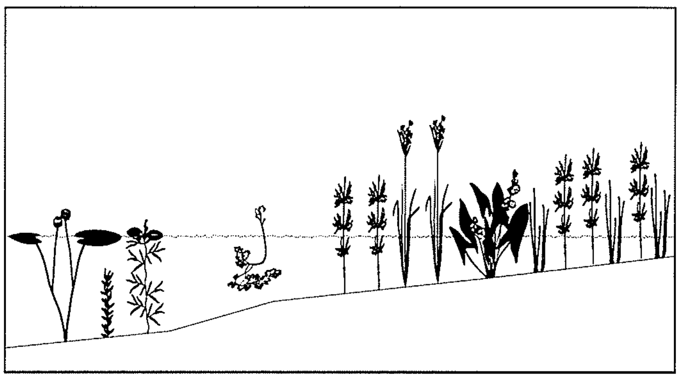
Floating-leaved and submergents: *Utricularia vulgaris* (common bladderwort), *Nuphar variegatum* (yellow pond lily), *Potamogeton natans* (floating leaved pondweed), *Potamogeton gramineus* (variable-leaved pondweed), *Spirodela polyrhiza* (greater duck weed), *Ceratophyllum demersum* (coontail), *Lemna trisulca* (star duckweed), *Potamogeton zosteriformis* (flat-stemmed pondweed), *Megalodonta beckii* (water marigold), *Nymphaea ododrata* (fragrant white water lily), *Potamogeton richardsonii* (Richardson's pondweed).

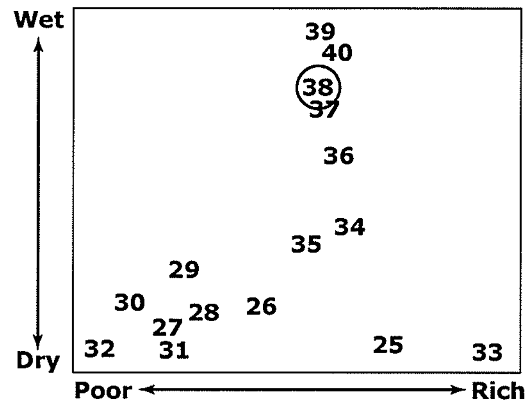
WEC Composition: W9, W10.

Soil/Site Characteristics: Sedimentary peat substrate.

E-38 • Exposed Marsh - emergent on mineral substrate

General Description: General Description: Ecosite 38 has greater than 25 percent emergents, with variable species composition, domination by a single species often occurs, emergents occurr in dense stands, water depth variable but usually less than one metre. Substrate is usually sandy mineral soil. Found along wave washed exposed shores, and streams. Water regime is permanently flooded to intermittently flooded.





Common Species:

Herbs: *Sium suave* (water parsnip), *Equisetum fluviatile* (water horsetail), *Sagittaria rigida* (stiff arrowhead), *Acorus calamus* (sweet-flag), *Sagittaria latifolia* (broad-leaved arrowhead), *Sparganium eurycarpum* (large-fruited burreed).

Graminoids: *Eleocharis smallii* (marsh spikerush), *Glyceria borealis* (northern manna grass), *Typha spp.* (cattail), *Scirpus acutus* (hard-stem bulrush).

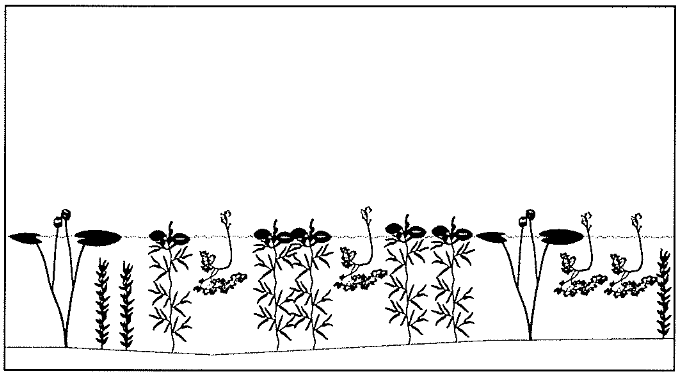
Floating-leaved and submergents: *Utricularia vulgaris* (common bladderwort), *Spirodela polyrhiza* (greater duckweed), *Ceratophyllum demersum* (coontail), *Lemna minor* (lesser duckweed), *Potamogeton zosteriformis* (flat stemmed pondweed), *Elodea canadensis* (common waterweed), *Lemna trisulca* (star duckweed), *Polygonum amphibium* (water smartweed), *Potamogeton gramineus* (variable-leaved pondweed), *Isoetes echinospora* (spiny-spored quillwort), *Potamogeton richardsonii* (Richardson's pondweed).

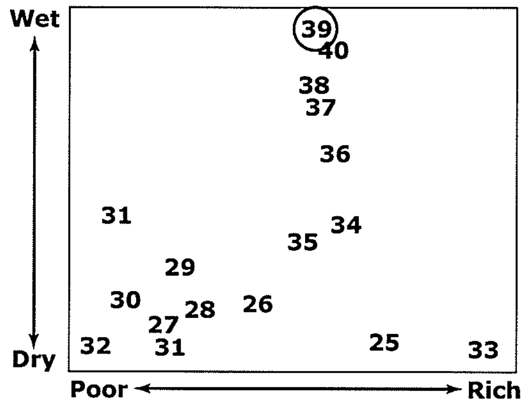
WEC Composition: W5, W6.

Soil/Site Characteristics: Mineral substrate.

E-39 • Open Water Marsh - submergent/floating leaved on sedimentary peat substrate

General Description: Ecosite 39 has less than twenty five percent emergent cover, open water with depth greater than 50 cm. Submergent cover often variable, floating leaved cover more than 50 percent of the ecosite. Substrate is typically well decomposed peat. Found along sheltered bays of slow moving streams and lakes. Water regime is permanently flooded.





Common Species:

Graminoids: *Eleocharis spp., Zizania palustris* (Wild rice)

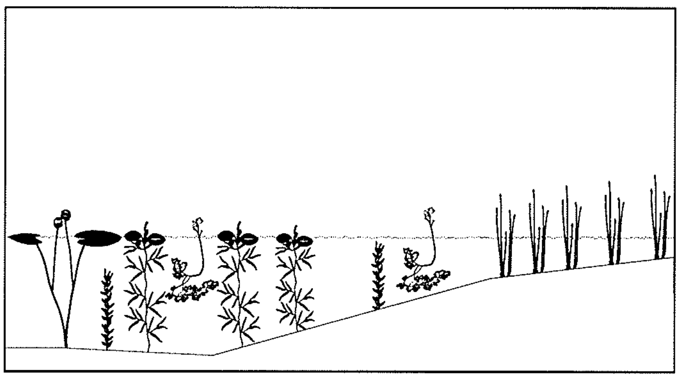
Floating-leaved and submergents: *Potamogeton zosteriformis* (flat-stemmed pondweed), *Utricularia vulgaris* (common bladderwort), *Sparganium fluctuans* (floating-leaved burreed), *Ceratophyllum demersum* (coontail), *Nuphar variegatum* (yellow pond lily), *Potamogeton natans* (floating-leaved pondweed), *Ranunculus longirostris* (curly white water crowfoot), *Lemna trisulca* (Star duckweed), *Myriophyllum verticillatum* (bracted water milfoil), *Potamogeton richardsonii* (Richardson's pondweed), *Spirodela polyrhiza* (greater duckweed), *Megalodonta beckii* (water marigold).

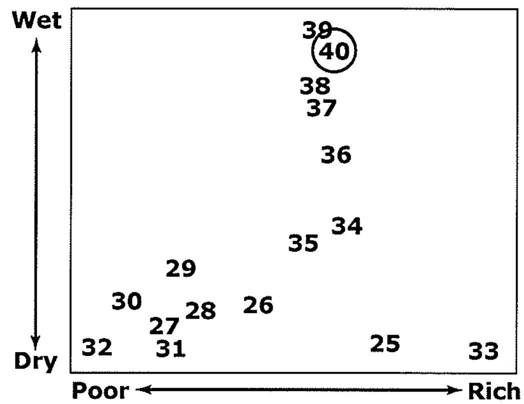
WEC Composition: W4, W3.

Soil/Site Characteristics: Sedimentary peat substrate.

E-40 • Open Water Marsh - Submergent on mineral substrate

General Description: Ecosite 40 Consists of less than twenty five percent emergent cover, vegetation may vary from sparse to low submergent cover, generally found with a single dominant species. Water depth is greater than fifty centimeter. Substrate varies from sandy mineral soil to rocky substrate. Water regime is permanently flooded. This ecosite is found along lake shores.





Common Species:

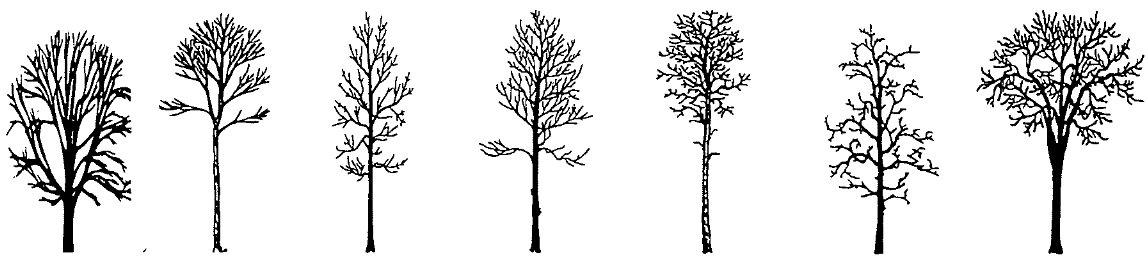
Floating-leaved and submergents: *Potamogeton gramineus* (variable-leaved pondweed), *Nuphar variegatum* (yellow pond lily), *Eleocharis acicularis* (needle spikerush), *Eriocaulon aquaticum (pipewort), Lobelia dortmanna* (water lobelia), *Isoetes echinospora* (spiny-spored quillwort), *Potamogeton richardsonii* (Richardson's pondweed), *Potamogeton zosteriformis* (flat stemmed pondweed), *Sparganium fluctuans* (floating-leaved burreed), *Utricularia vulgaris* (common bladderwort), *Ceratophyllum demersum* (coontail), *Elodea canadensis* (common waterweed).

WEC Composition: W1, W2.

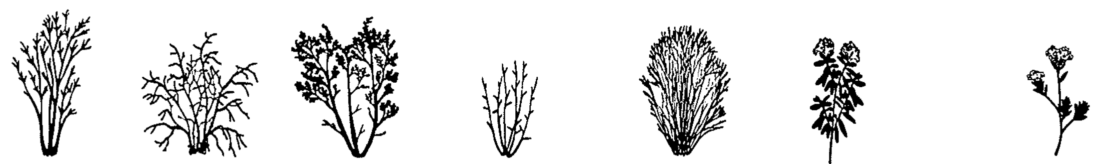
Soil/Site Characteristics: Mineral substrate.

Plant Silouettes for Ecosystem Profiles

Abies balsamea · *Larix laricina* · *Picea glauca* · *Picea mariana* · *Pinus banksiana* · *Pinus resinosa* · *Pinus strobus* · *Thuja occidentalis*



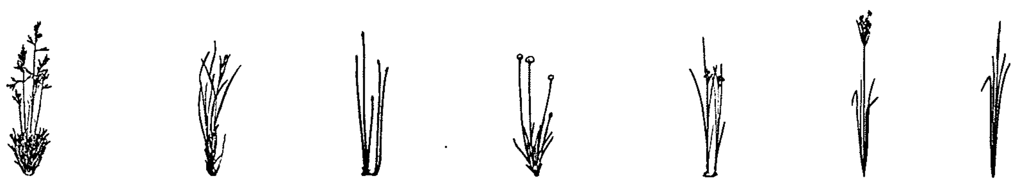
Acer negundo · *Betula papyrifera* · *Fraxinus nigra* · *Populus balsamifera* · *Populus tremuloides* · *Quercus macrocarpa* · *Ulmnus americana*



Acer spicatum · *Alnus rugosa* · *Betula glandulosa* · *Corylus cornuta* · *Salix spp.* · *Ledum groenlandicum* · *Chamaedaphne calyculata*

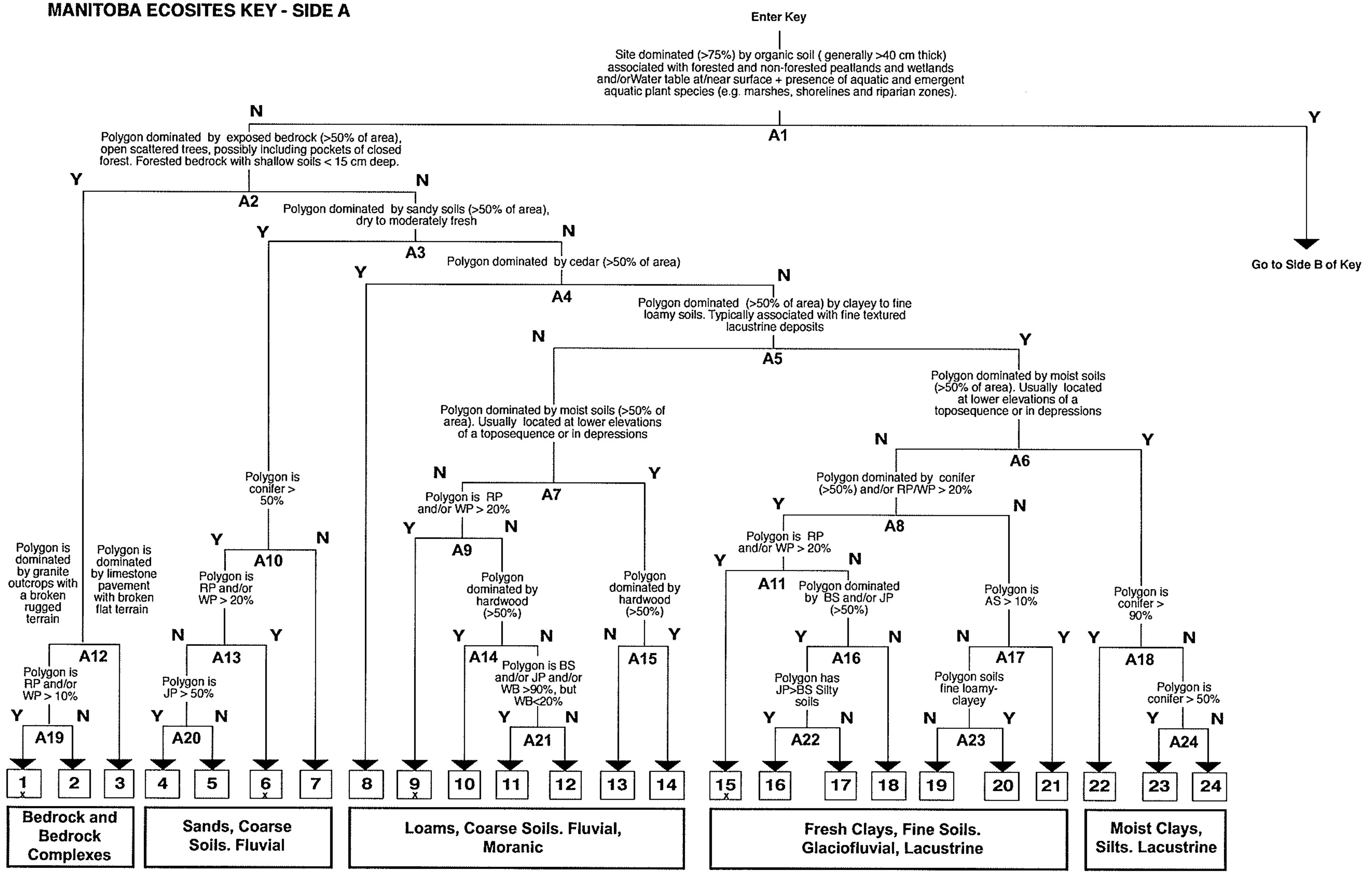
Alisma plantago-aquatica · *Athyrium filix-femina* · *Equisetum spp.* · *Impatiens biflora* · *Nuphar spp.* · *Potamogeton gramineus* · *Potamogeton richardsonii*

Potentilla palustris · *Sagittaria spp.* · *Smilacina trifoliata* · *Utricularia vulgaris*



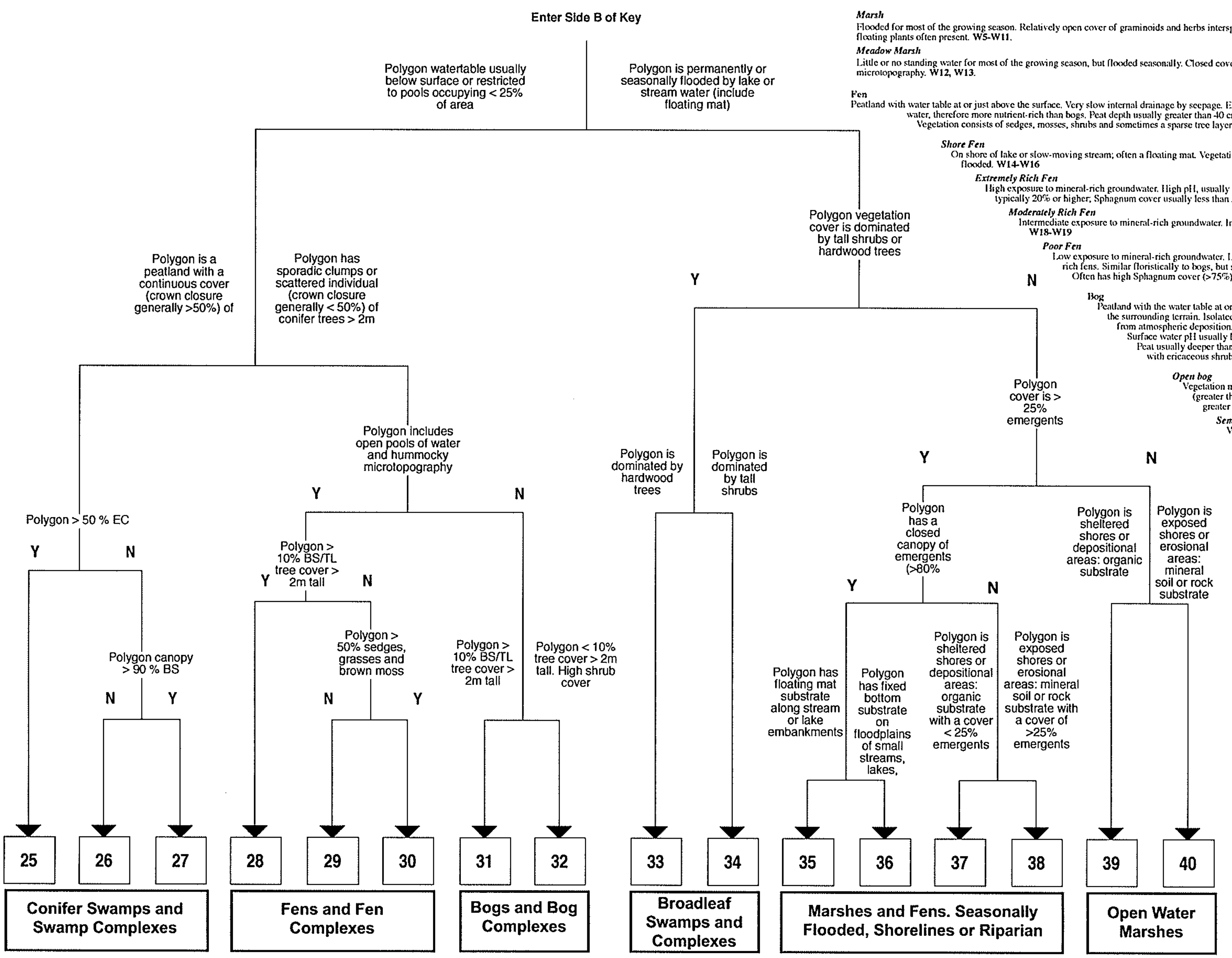
Calamagrostis canadensis · *Carex spp.* · *Eleocharis spp.* · *Eriophorum spp.* · *Juncus/Scirpus spp.* · *Scirpus spp.* · *Typha spp.*

MANITOBA ECOSITES KEY - SIDE A



MB Ecosite Key 1: Side A - Terrestrial

MANITOBA ECOSITES KEY - SIDE B



MB Ecosite Key 2: Side B - Wetland

Definitions of Terms and Links with WEC Key (modified from Harris et al. 1996)

Open Water Marsh
Standing or flowing water with emergent plant cover less than 25%. Submergent and/or floating-leaved plant cover normally greater than 25%, but including sites with lower submergent cover and sparse emergents. Permanently flooded or intermittently exposed. Includes shallow lakeshores, ponds, pools, oxbows and channels. Distinguished from deep water aquatic systems by midsummer water depths of less than 2 m. **W1-W4**

Marsh
Standing or slow-moving water with emergent plant cover greater than 25%. Permanently flooded, intermittently exposed or seasonally flooded. Nutrient-rich water generally remains within the rooting zone for most of growing season. Substrate is mineral soil, sedimentary peat or peat, often held together by a root mat.

Marsh
Flooded for most of the growing season. Relatively open cover of graminoids and herbs interspersed with pools or channels. Submerged and floating plants often present. **W5-W11.**

Meadow Marsh
Little or no standing water for most of the growing season, but flooded seasonally. Closed cover of graminoids. Often tussocky or hummocky microtopography. **W12, W13.**

Fen
Peatland with water table at or just above the surface. Very slow internal drainage by seepage. Enriched by nutrients from upslope mineral water, therefore more nutrient-rich than bogs. Peat depth usually greater than 40 cm. Sometimes occurs as a floating mat. Vegetation consists of sedges, mosses, shrubs and sometimes a sparse tree layer.

Shore Fen
On shore of lake or slow-moving stream; often a floating mat. Vegetation usually sedges and/or shrubs. Seasonally flooded. **W14-W16**

Extremely Rich Fen
High exposure to mineral-rich groundwater. High pH, usually 5.8-7.5. Species rich. Brown moss cover typically 20% or higher; Sphagnum cover usually less than 50%. **W17**

Moderately Rich Fen
Intermediate exposure to mineral-rich groundwater. Intermediate pH, usually 5.0-6.0. Species-rich.. **W18-W19**

Poor Fen
Low exposure to mineral-rich groundwater. Low pH, usually 4.7-5.5. Fewer species than rich fens. Similar floristically to bogs, but some minerotrophic indicator species present. Often has high Sphagnum cover (>75%). **W20-W22**

Bog
Peatland with the water table at or near the surface. Surface often raised above the surrounding terrain. Isolated from mineral-rich soil waters; nutrient input from atmospheric deposition. Strongly acidic and extremely nutrient-poor. Surface water pH usually less than 4.7. Minerotrophic indicators absent. Peat usually deeper than 40 cm. Ground cover of Sphagnum, usually with ericaceous shrubs. May be open to treed.

Open bog
Vegetation mainly Sphagnum, sedges or low shrubs. Trees (greater than 2 m) at less than 10% cover. Lacks trees greater than 10 m. **W23, W24**

Semi-treed Bog
Vegetation mainly Sphagnum, sedges and/or low shrubs with scattered (10-25% cover), small black spruce (rarely tamarack). Lacks trees greater than 10 m. **W25**

Treed Bog
Vegetation mainly Sphagnum, sedges and/or low shrubs. Trees greater than 10 m present or trees greater than 2 m at greater than 25% cover. **W26**

Swamp
Wooded mineral wetland or peatland. Internal flow of water from margins or other mineral sources. Standing or gently flowing water in pools or channels; or subsurface flow. Water table may drop below the rooting zone of vegetation, creating aerated conditions at the surface. Substrate often woody, well decomposed peat, or a mixture of mineral and organic material. Vegetation consists of deciduous or coniferous trees or shrubs, graminoids, herbs and mosses.

Conifer Swamp
Coniferous trees dominant. Trees greater than 10 m tall present, or trees greater than 2 m tall at greater than 25% cover. Conditions range from poor to rich. Poor conditions similar to treed bog, but swamp indicators present. **W27-W32**

Hardwood Swamp
Hardwood trees, usually greater than 10 m tall, dominant. **W33, W34**

Thicket Swamp
Tall shrubs (greater than 2 m) dominant; cover greater than 25%. **W35, W36**

DS6 - Ecosite and Remote Sensing Integrated Datasheet

Team Names:	Plot Number:	MBEC:	Date:
Northings:	Eastings:	FRI adjust:	Gap Modifier: None/S/G
V-type:	W-Type:	Sask EC	Gap % (from paces):
Prob/Altern/Comments:		Other Data Sheets Used?:	

Tree Species	Canopy Layer Cover % + #/layer								
	L1-Ht:		L2-Ht:		L3-Ht:		L4-Ht:		L5 %
	%	#	%	#	%	#	%	#	
Tot. %,Av. DBH	%	DBH	%	DBH	%	DBH	%	DBH	

L1= C+3 m L2=C, av. Ht. L3=C-3 (3-10m) L4=C-6 (3m) L5 < .5 m

Downed Woody Debris		
DBH cm	Line 1	Line 2
1-4		
5-9		
10-18		
19-35		
36+		

Decay Class
D1-bark, twigs, hard
D2-bark, n/twigs, hard
D3-s/bark, hard dry, bleach
D4-n/bark, soft, bleach
D5-crumbs, peaty

Tree Ages		
Core	Sp. Abbr.	age
1		
2		

Main Plot Understory Components and Recreation

Tall Shrub Tot%:		Low Shrub Tot%:		Herb Tot%:		Moss Tot%:	
						Lichen Tot%:	

Herbals	%	Berries	%
Roses		Blueberry	
Wintergreen		Chokechy	
Seneca		L. Cranbry	
Labrador Tea		Raspberry	
Mint species		Saskatoon	
Yarrow		Strawberry	

Attribute	Comments/UTM Coor
Trail (tire, foot)	
Tree stand/bait	
Litter	
Fire pit	
Campsite	
Tree cut/delib	

Main Plot Soil and Ecosite Landform

Sf.Text/Org: Effective (circle)		Lwr Text/Org: Effective (circle)	
Mottles Gley: Y / N Depth:		Rock%:	B.Leaf%:
Depth:	Pit Depth cm:	Bare S%:	N.Leaf%:
Abund: few/com /mny	C. Frag.%:	Wood%:	Water%:
Size: fine/med/cors	Bould.#:	L/[Of]:	F/[Om] H/[Oh]:
Cont: Fnt/Dist/Prom			

Topo. Position	Crest	U Slope	M Slope	L Slope	Toe	Depress	Level
Landsc. Param	Seepage Slope		Slope %:		Aspect:		
Topo. Form	Planar	Concave	Convex	Ridge	Trough	Hummock	Cmplx
Parent Mat.	Moraine	Gl Flu	Fluv	E	GL	Or	R
Soil Moisture	V.Xeric-Xeric	Submesic		Mesic	Subhygric	V.Hyg-Hygric	
Drainage	V.R-Rapid	Rapid		Mod.W-Well	Imperfect	V.P-Poor	
Nutrient Status	Poor	Med.		Rich	V. Rich	V. Poor	
Humus Form	Mull	Moder		Raw Moder	Mor	Peaty Mor	

Ecoelement V & W-type Plot: a

N:	E:	V/W:

Sf.Text/Org: Effective (circle)		Lwr Text/Org: Effective (circle)	
Mottles Gley: Y / N Depth:		Rock%:	B.Leaf%:
Depth:	Pit Depth cm:	Bare S%:	N.Leaf%:
Abund: few/com /mny	C. Frag.%:	Wood%:	Water%:
Size: fine/med/cors	Bould.#:	L/[Of]:	F/[Om] H/[Oh]:
Cont: Fnt/Dist/Prom			

Describe Polygon or give other V or W-types:

Tr.-L1%:	L1Ht:	L1#:	Spp.:		
Tr.-L2%:	L2Ht:	L2#:	FRI(L1,2):		
Tr.-L3%:	L3 FRI:	L4-%:	L4 FRI:	L5-SW%	HW%

Most Common spp.	
Shrub%:	
Herb%:	
Moss%:	
Lichen%:	