Environment Canada Environnement Canada

National Agri-Environmental Standards Initiative (NAESI)

Report No. 2-29

NAESI Biodiversity Standards - Assessment of Information - Pre-Settlement Conditions of Terrestrial and Aquatic Ecosystems in Agricultural Regions of Canada

Technical Series 2006

Photos:
Bottom Left- clockwise

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Prepared and published by
Environment Canada
Gatineau, QC

December 2006

NATIONAL AGRI-ENVIRONMENTAL STANDARDS INITIATIVE TECHNICAL SERIES

NAESI BIODIVERSITY STANDARDS - ASSESSMENT OF INFORMATION - PRE-SETTLEMENT CONDITIONS OF TERRESTRIAL AND AQUATIC ECOSYSTEMS IN AGRICULTURAL REGIONS OF CANADA

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NOTE TO READERS

The National Agri-Environmental Standards Initiative (NAESI) is a four-year (2004-2008) project between Environment Canada (EC) and Agriculture and Agri-Food Canada (AAFC) and is one of many initiatives under AAFC's Agriculture Policy Framework (APF). The goals of the National Agri-Environmental Standards Initiative include:

- Establishing non-regulatory national environmental performance standards (with regional application) that support common EC and AAFC goals for the environment
- Evaluating standards attainable by environmentally-beneficial agricultural production and management practices; and
- Increasing understanding of relationships between agriculture and the environment.

Under NAESI, agri-environmental performance standards (i.e., outcome-based standards) will be established that identify both desired levels of environmental condition and levels considered achievable based on available technology and practice. These standards will be integrated by AAFC into beneficial agricultural management systems and practices to help reduce environmental risks. Additionally, these will provide benefits to the health and supply of water, health of soils, health of air and the atmosphere; and ensure compatibility between biodiversity and agriculture. Standards are being developed in four thematic areas: Air, Biodiversity, Pesticides, and Water. Outcomes from NAESI will contribute to the APF goals of improved stewardship by agricultural producers of land, water, air and biodiversity and increased Canadian and international confidence that food from the Canadian agriculture and food sector is being produced in a safe and environmentally sound manner.

The development of agri-environmental performance standards involves science-based assessments of relative risk and the determination of desired environmental quality. As such, the National Agri-Environmental Standards Initiative (NAESI) Technical Series is dedicated to the consolidation and dissemination of the scientific knowledge, information, and tools produced through this program that will be used by Environment Canada as the scientific basis for the development and delivery of environmental performance standards. Reports in the Technical Series are available in the language (English or French) in which they were originally prepared and represent theme-specific deliverables. As the intention of this series is to provide an easily navigable and consolidated means of reporting on NAESI's yearly activities and progress, the detailed findings summarized in this series may, in fact, be published elsewhere, for example, as scientific papers in peer-reviewed journals.

This report provides scientific information to partially fulfill deliverables under the Biodiversity Theme of NAESI. This report was written by CANTOX Environmental Inc. The report was edited and formatted by Denise Davy to meet the criteria of the NAESI Technical Series. The information in this document is current as of when the document was originally prepared. For additional information regarding this publication, please contact:

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NOTE À L'INTENTION DES LECTEURS

L'Initiative nationale d'élaboration de normes agroenvironnementales (INENA) est un projet de quatre ans (2004-2008) mené conjointement par Environnement Canada (EC) et Agriculture et Agroalimentaire Canada (AAC) et l'une des nombreuses initiatives qui s'inscrit dans le Cadre stratégique pour l'agriculture (CSA) d'AAC. Elle a notamment comme objectifs :

- d'établir des normes nationales de rendement environnemental non réglementaires (applicables dans les régions) qui soutiennent les objectifs communs d'EC et d'AAC en ce qui concerne l'environnement;
- d'évaluer des normes qui sont réalisables par des pratiques de production et de gestion agricoles avantageuses pour l'environnement;
- de faire mieux comprendre les liens entre l'agriculture et l'environnement.

Dans le cadre de l'INENA, des normes de rendement agroenvironnementales (c.-à-d. des normes axées sur les résultats) seront établies pour déterminer les niveaux de qualité environnementale souhaités et les niveaux considérés comme réalisables au moyen des meilleures technologies et pratiques disponibles. AAC intégrera ces normes dans des systèmes et pratiques de gestion bénéfiques en agriculture afin d'aider à réduire les risques pour l'environnement. De plus, elles amélioreront l'approvisionnement en eau et la qualité de celle-ci, la qualité des sols et celle de l'air et de l'atmosphère, et assureront la compatibilité entre la biodiversité et l'agriculture. Des normes sont en voie d'être élaborées dans quatre domaines thématiques : l'air, la biodiversité, les pesticides et l'eau. Les résultats de l'INENA contribueront aux objectifs du CSA, soit d'améliorer la gérance des terres, de l'eau, de l'air et de la biodiversité par les producteurs agricoles et d'accroître la confiance du Canada et d'autres pays dans le fait que les aliments produits par les agriculteurs et le secteur de l'alimentation du Canada le sont d'une manière sécuritaire et soucieuse de l'environnement.

L'élaboration de normes de rendement agroenvironnementales comporte des évaluations scientifiques des risques relatifs et la détermination de la qualité environnementale souhaitée. Comme telle, la Série technique de l'INENA vise à regrouper et diffuser les connaissances, les informations et les outils scientifiques qui sont produits grâce à ce programme et dont Environnement Canada se servira comme fondement scientifique afin d'élaborer et de transmettre des normes de rendement environnemental. Les rapports compris dans la Série technique sont disponibles dans la langue (français ou anglais) dans laquelle ils ont été rédigés au départ et constituent des réalisations attendues propres à un thème en particulier. Comme cette série a pour objectif de fournir un moyen intégré et facile à consulter de faire rapport sur les activités et les progrès réalisés durant l'année dans le cadre de l'INENA, les conclusions détaillées qui sont résumées dans la série peuvent, en fait, être publiées ailleurs comme sous forme d'articles scientifiques de journaux soumis à l'évaluation par les pairs.

Le présent rapport fournit des données scientifiques afin de produire en partie les réalisations attendues pour le thème la biodiversité dans le cadre de l'INENA. Ce rapport a été rédigé par CANTOX Environmental Inc. De plus, il a été révisé et formaté par Denise Davy selon les critères établis pour la Série technique de l'INENA. L'information contenue dans ce document était à jour au moment de sa rédaction. Pour plus de renseignements sur cette publication, veuillez communiquer avec l'organisme suivant :

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1 INTRODUCTION

The Agricultural Policy Framework (APF) is an integrated policy structure supported by the federal, provincial, and territorial governments. Its primary purpose is to enhance the profitability of the agriculture and agri-foods sector by making Canada a world leader in food safety, *innovation and environmentally responsible agricultural production.* The goals of the Environment Chapter of the APF are to reduce agricultural risks and provide benefits to the health of soil, water and atmosphere; and to ensure compatibility between biodiversity and agriculture. Under the APF, governments have agreed to research and develop agri-environmental standards that support these goals. The National Agri-environmental Standards Initiative (NAESI) is part of a federal government initiative in support of this agreement. Environment Canada has the lead in the APF to establish performance standards in agriculture that attend to each of the APFs environmental themes (soil, pesticides, water, air and biodiversity). The NAESI Biodiversity Thematic Group is responsible for the development of biodiversity standards for use in Canadian agriculture that recognizes the importance of biodiversity in ecosystem function and integrity. Information on ecological processes and structures prior to human impact can be a useful tool to assist in the study and management of present ecosystems. This project provides an assessment of information concerning pre-settlement conditions of terrestrial and aquatic ecosystems in agricultural regions of Canada. We evaluate the utility of this information for the development of biodiversity standards for Canadian agriculture regions.

An ecosystem is an interacting complex of organisms and the abiotic environment with which they form a functional ecological unit (Tansley, 1935; Bergon et al., 1990). The re-construction of past terrestrial and aquatic ecosystems involves investigation of biological and physical-chemical evidence to determine species groups present during the time frame under investigation. The nature of the intricate relationships between organisms and their surroundings within that period may also be elucidated. Numerous techniques have been applied to ecosystem re-construction. These techniques can be grouped into four broad categories: (1) historical documentation or measurements recorded during or near the time period in question (2) space-for-time substitution/gradient analyses (3) computer simulation/modelling, and (4) analysis of physical evidence that has endured the environment to present day (palaeoecological re-construction). Historical documentation or measurements can be invaluable in ecosystem reconstruction as they are direct records of the past state of the ecosystem. The detail and completeness of the historical records will determine their value to a reconstruction. Examples of historical records include maps, land surveys, written accounts (e.g., journals books, reports papers, etc.) and photographs. Space-for-time substitution and gradient analysis (e.g., Burel et al., 1998) seek to determine the state of an ecosystem that may have been impacted by human activities using representative landscapes that have not been impacted, or by examining the gradient of change between impacted and non-impacted landscapes. Computer simulations and modelling include population and habitat supply models that have been used to predict the presence and abundance of species based on life-cycle and habitat requirements. Such models may be executed in a geographical information system (GIS) environment to provide georeferenced output (Rosenfeld, 2003). Palaeoecological re-constructions involve biological indicators such as pollen, fossil pigments, diatoms, seeds, macrofossils, fish scales, eggshells and tree rings. These have been used to analyse ecosystem features such as the presence of particular species, historic plant communities, as well as environmental conditions such as water body pH and salinity, soil quality, climate and prevalence of fire (Gorham et al., 2001). Examples of chemical indicators include isotopes (both radioactive and stable), phosphorus, iron, manganese and calcium carbonate in lake sediment. Sediment influx rates and sediment grain size are two examples of physical indicators. Chemical and physical palaeoindicators are used for temporal analysis, as well as the establishment of environmental conditions, such as temperature, the nature of surrounding soils, turbidity in water bodies, and climatic change. The scale and limitations of these indicators have been reviewed by Gorham et al. (2001), for example.

Anthropogenic influences on the environment are of great interest and importance, particularly with regards to pollution and changes in landuse. Over the past 500 years, Canada has changed from a nation without agriculture to one of the world's primary sources of agricultural products. Today, Canadian farms occupy over 67.5 million hectares (Statistics Canada, 2001). Although this land base is limited relative to the size of Canada, agriculture is intensive in particular ecoregions. This kind of dramatic change in some of the landscapes of our nation gives rise to questions about the influence of agricultural practices on local ecosystems. There are two major considerations in evaluating biodiversity in agroecosystems: (i) nature conservation and (ii) biological control against agricultural pests (Duelli, 1997). Agriculture may also affect biodiversity (e.g., species richness) either through habitat deterioration or the side effects of inputs (e.g., pesticides, nutrients) (Burel and Baudry, 1997).

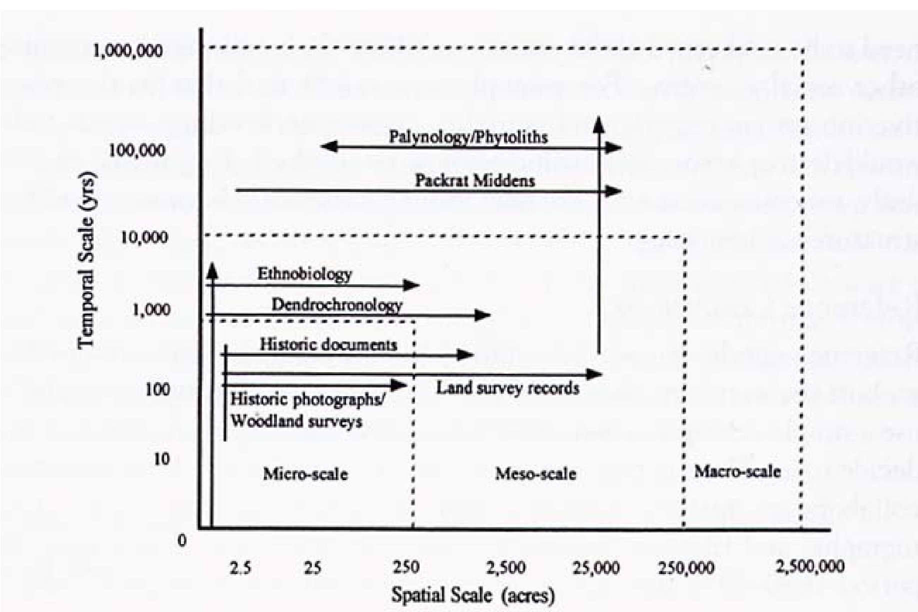
One way of gauging the impact of agriculture on ecosystems is to compare historic and present biodiversity. Biodiversity has ecological, economic and cultural value, and is a feature of all levels of biotic organization, from genes to biomes, and beyond. Biodiversity is a measure of biological variety that at the scale of ecosystems comprises species richness and relative abundance (or evenness). The development of a biodiversity standard implies a scale against which current levels of biodiversity can be compared. Several biodiversity indices have been constructed that mathematically merge richness and evenness (e.g., the Shannon-Wiener Diversity Index). If data from complete ecosystem re-constructions are fed into a biodiversity index, it may be possible to compare the diversity of pre-settlement ecosystems to those of today. However, given the difficulty of acquiring information on today's ecosystems (due to the high number of species in any given system), it may be necessary to find alternative ways of assessing biodiversity. For instance it may be more practical to substitute higher taxon richness for species richness (Williams and Gaston, 1994). Other surrogate measures for biodiversity include environmental factors (such as temperature ranges and precipitation) and presence of indicator species.

This report provides an overview of the various methods used in ecosystem reconstruction with particular emphasis on what is currently the state of the art in reconstructing ecosystems impacted by agriculture. Examples of reconstructions from around the world as well as a review of reconstructions undertaken in Canada are provided. Methods for the measurement of biodiversity are also reviewed, to determine the use of these methods in ecosystem re-constructions and the development of biodiversity standards in agricultural areas. Finally, recommendations are made on how reconstruction methods and measures of biodiversity can be used to generate biodiversity standards for Canadian agriculture. An associated MS-Access database application provides a complete bibliography of scientific literature on reconstruction and biodiversity methods, along with contact information for persons that are involved in or have performed Canadian reconstructions.

2 HISTORICAL ECOLOGY - METHODS OF ECOSYSTEM RECONSTRUCTION

Historical ecology is a branch of ecology that investigates historic populations, communities and species-environment interactions. It encompasses a wide variety of reconstructive data, methods, and perspectives, including but not limited to compilation and analysis of historic documents and images, palaeoecology, space-for-time substitutions and modeling (Swetnam *et al.*, 1999). Each method of ecosystem reconstruction is operational at its own specific temporal and spatial scales (see Figure 1), which makes it more or less appropriate to use, depending upon the scientific enquiry. The current project is focussed on pre-settlement conditions (~1600 to 1900), and thus requires methods that are effective at the relatively finer temporal scale of decades and centuries. Spatially, the project is restricted to agricultural regions of Canada; this is unlikely to rule out any reconstructive techniques, though some may have yet to be applied in these regions. What follows is a brief review of some pertinent methods used to reconstruct ecosystems.

Figure 1: Spatial and Temporal Scales of Historical Ecology Techniques (from Egan and Howell, 2001)



2.1 Historic Accounts and Measurements

Reconstruction of ecosystems using historic records and measurements is an important method for relatively recent time scales. Because narratives, journals and surveys tend to be structured around specific regions, researchers in this area tend to investigate locales as opposed to specific taxa (Edmonds, 2001).

Elements of past ecosystems have been reconstructed in North America using pre-settlement surveys (Cogbill *et al*., 2002), traveller accounts (MacDougall *et al.*, 2004), land surveys, forest inventory data (Bragg, 2003; Whitney and DeCant, 2003), historic air quality data (Egerton-Warburton *et al*., 2001), records of fire and pathogen outbreaks, records of logging (McLachlan *et al*., 2000), municipal land records (Brugam, 1978), notary deeds, nominative censuses (Bouchard and Domon, 1997) and aerial photographs (Waldhardt and Otte, 2003). Historic mammalian species richness has also been reconstructed from historic range maps (Wiersma and Nudds, 2001).

Reconstructions using historic documents and images in agricultural regions are relatively common because of the availability of records in some settled areas. Whitney and Decant (2003) studied changes in an agricultural region of northwestern Pennsylvania using land surveys and forest inventory data from the U.S. Forest Service. Their study area, which was composed of four counties, had been 80% cleared for agriculture after European settlement. Marginal sites were abandoned after World War II, and today 40 to 70% of the study area is wooded. They used witness tree (*i.e.*, trees used historically as land reference markers) and current tree composition to infer changes in composition from pre-European settlement to present. A similar reconstruction was performed by Taft and Haig (2003) in Oregon's Willamette Valley, where a former wetland had been converted to agriculture. Hessburg *et al*. (1999) used aerial photographs from 1938 to 1993 to quantify changes in vegetation cover at the sub-watershed scale in an agricultural region of the U.S. northwestern interior.

Documentation about the state of the landscape exists for most parts of the continent; the sheer number of documents and images makes it hard to establish exactly what was recorded about a given place at any given time. Documents may be located in any of thousands of archives and libraries across the continent, and beyond. Also, texts may be difficult to decipher, in terms of language, biases, and retrieving pertinent ecological information (Edmonds, 2001). Thus, reconstructions through historic records can be exceptionally time and resource consuming.

To locate general data of this kind for Canada, contact was made with over one hundred archives and libraries across Canada (see Appendix A). Many recommendations and suggestions have been made by local librarians and archivists. Through this effort, some locally significant documents were acquired. Moreover, the nature, relative number and distribution of documents across agricultural regions of Canada was ascertained.

2.2 Space for Time Substitution and Gradient Analysis

Space-for-time substitution involves inferring a history of a particular area by investigating areas assumed to have been like the area under investigation during the time period of interest. For instance, remnant old-growth forests can be used to infer the history, via dendroecological techniques of an agricultural region that has been cleared of forest. This is an example of a space-for-time substitution (i.e., an adjacent area is being used to infer the past of the study area). Another potential space-for-time substitution method is gradient analysis; where a transect along a gradient is studied to infer impacts of the factor under investigation. It is supposed that the gradient factor is the cause of change. For example, Burel et al. (1998) investigated changes in biodiversity along an agricultural gradient in western France, and were able to correlate intensification of agriculture with several functional responses including loss of species and stability by replacement.

Space-for-time substitution may be a useful means of investigating past ecosystems where anthropogenic disturbances have made palaeoecological reconstruction alone, too arduous of a task (e.g., where large expanses have been drained, cleared and tilled).

2.3 Modelling

There are no general models relating overall species diversity to landscape diversity. The relationship between biodiversity and landscape diversity strongly depends upon the taxon under investigation (Jeanneret et al., 2003). However, models have been developed to simulate historic fire regimes (Wimberly, 2002), to infer past vegetation distributions based on climate and other abiotic environmental variables (Hilbert and Ostendorf, 2001; Bickford and Mackey, 2004). These models examine the effects of landscape patterns on species richness. Although such models are not necessarily reconstructive they may be useful in linking historic landscape patterns with levels of biological diversity (Steiner and Kohler, 2003), to infer historic vegetation distributions on a finer scale in relation to geomorphology and land use history (de Blois et al., 2001) and to predict species composition based on fossil records, food webs and energy flow (Matsukawa et al., 2006). To identify the dominant predictors of vegetation patterns, researchers often use a partial regression approach to eliminate the least significant variables and build an explanation with the most significant predictors (Taverna et al., 2004). This approach can lead to inappropriate explanatory variables, particularly when linear models are used on ecological data that is non-linear and frequently contains high-order interactions (Draper, 1995)

Taverna et al. (2005) used a classification tree model to test specific hypotheses of environmental variables effecting dominant vegetation patterns in the North Carolina Piedmont. Hardwood and pine vegetation was modeled using explanatory topographic and edaphic variables selected based on historic reconstructions of patterns of land use. These included soil quality, potential soil moisture, topographic position, and slope angle. This model type emphasized alternative environmental settings for each vegetation type. For instance, relic hardwood stands could be found on steep slopes, highly plastic soils or hydric bottomlands – alternatives not well captured by a homogeneous generalized linear model. Although this model was not used to predict historic vegetation patterns, it may be modified to do so.

A Canadian modeling example is provided by De Blois et al. (2001) from an agricultural region of Haut Saint-Laurent, Quebec. Though the study was not reconstructive, the authors employed many techniques that could be used to predict historic vegetation patterns. A model was developed to test the characterization of vegetation (tree and shrub) composition based on land use history; spatial context; environmental variables including soil type, soil drainage, surface deposits, elevation and slope and landscape identification. Results confirmed the dominant effect of historical factors, in the Haut Saint-Laurent study area, on vegetation patterns. Land-use history overrides environmental and contextual control for tree species, while herbaceous and shrub species are more sensitive to environmental conditions. Context (i.e., the configuration and composition of the surrounding landscape) is determinant only for understory species in older, less-disturbed plots.

Bickford and Mackey (2004) reconstructed presettlement vegetation cover in modified Australian landscapes using environmental modelling, historical surveys and remnant vegetation data. Records of presettlement vegetation distribution made in surveyors' notebooks were recorded into a GIS. Maps of remnant vegetation distribution were attained. Analysis was carried out to quantify the environmental domains of historical survey record and remnant vegetation data to selected meso-scaled climatic parameters and topo-scaled terrain-related indices at a 20 m resolution. An investigative analytical procedure was used to quantify the probability of occurrence of types in environmental domains. The procedure uses spatial distribution data of a target vegetation type to empirically identify the environmental domain in which the vegetation type occurs and is dominant. Individual probability maps were combined to produce a presettlement vegetation map of the study region.

Matsukawa et al. (2006) reconstructed early Cretaceous terrestrial ecosystems in East Asia using fossils, food web and energy-flow models. The approach applies methods of modern ecosystem analysis and may be applicable to the reconstruction of presettlement ecosystems in agricultural regions of Canada. Food web models were restored based on taxa that occurred in the study region. This is essentially the general energy pyramid of a typical ecosystem. Counts of small numbers of confirmed species and estimates of maximum numbers of species present in the study area (based on resource availability and metabolism) were used for the analysis and estimation of energy flow.

Modeling is cost effective relative to more intensive methods of ecosystem reconstruction. It may also be possible to effectively model past biodiversity through parameters measured through other reconstructive techniques (e.g., using diatoms and modeling in a multi-technique approach).

2.4 Palaeoecological Reconstruction

Palaeoecology is a broadly defined branch of ecology that studies preserved physical evidence of past ecosystems. Palaeoecology sheds light on past species assemblages, inter-specific, intra-specific and biotic-abiotic interactions, as well as variations in these relationships over time. Thus, palaeoecology includes all disciplines of the natural sciences that use preserved physical evidence to reconstruct the composition, configuration and processes of past environments. This includes but is not limited to palynology, climatology, dendrochronology, midden analysis, palaeobotany and limnology. Palaeoecological studies can provide insight into the nature of succession, evolutionary changes, anthropogenic effects, historic species assemblages and historic ranges of variability in climate, natural disturbances and of communities themselves. These insights can be used to inform land management decisions that will affect these variables in the future. Descriptions of some of the methods used in palaeoecology are presented below.

2.4.1 Biological Evidence

2.4.1.1 Dendroecology

Dendrochronology is the study of tree ring chronologies. The field was founded in 1920 by A.E. Douglass as a way of investigating past climates. Douglass was able to show that annual tree ring widths could be correlated with climatic history (Kipmueller and Swetnam, 2001). Since its inception, many techniques and applications have come from the early and basic study of tree rings. Tree ring characteristics are directly related to the environmental conditions of a tree, and thus its growth over a given season. Ring characteristics can shed light on climate, injury, disturbance, light, water and nutrient availability. Dendroecology is an application of dendrochronology that applies such information to the long-term ecological history of tree communities. For instance, an opening in a forest canopy might result in extreme growth for an opportunistic individual within that gap, or a scar might be evident in a tree ring chronology – indicating the timing and perhaps the intensity of fire disturbance. Dendroecology has been used extensively over the past half-century in North America to reconstruct past forest communities and to investigate changes in communities over time (Stokes and Smiley, 1968; Henry and Swan, 1974; Abrams et al., 1995; Abrams and Orwig, 1996; Bergeron, 2000). Some of the highly studied areas in North America include the northeastern United States and the province of Quebec.

Dendroecological techniques have been used to determine canopy recruitment in relation to disturbance histories. Abrams and Orwig (1996) determined the three hundred year history of white pine and hemlock in a mixed-wood forest in Pennsylvania. They reconstructed community composition and age-class structure over the three hundred year period. From the data they collected they were able to correlate changes in growth patterns with the occurrence of a catastrophic tornado in 1690, and were able to deduce that periodic fires had taken place. Abrams and Orwig (1996) observed differences in growth due to microtopography and soil type, and correlated early hemlock decline and later lack of recruitment in all species with intense deer browsing. They were also able demonstrate a relationship between increased hardwood recruitment and fire suppression after 1900. Numerous similar studies have been done throughout the world over the past 50 years. Some of them are cited later in this section.

Old growth-forests are thought to represent our best prospect for understanding pre-settlement forest conditions (Abrams et al., 1995). Dendroecology is well suited to historical ecological research because trees tend to live for a relatively long time, and because their chronologies not only supply a record of their lives, but of the environment in which they developed (Kipmueller and Swetnam, 2001).

Dozens of articles cite dendroecology as part of their reconstructive method. These include Whipple and Dix (1979), Whitney (1984), Bergeron and Charron (1994), Abrams et al. (1997) and McLachlan et al. (2000). These articles investigated the succession of forests through time using tree-ring chronologies and, in some cases, additional data sources. Remnants of forests may provide the best clues available to investigating the past of some agricultural areas.

2.4.1.2 Palynology

Palynology is the study of preserved pollen, spores, algae, charcoal (and other microscopic plant remains resistant to chemical extraction processes used to free 'palynomorphs' from their substrate), to better understand the nature of the historic plant communities they once represented. Palynomorphs are often found in sediment layers and sedimentary rocks and require chemical extraction to free them from the substrate. The science originated with Paulus Reinsch and Lenart von Post at the turn of the last century. The former being the first to extract pollen from rock; the later being the first to reconstruct pollen based floral history using quantitative techniques. Palynology is among the strongest tools for studying past ecosystems because pollen and associated microfossils are plentiful and well preserved in many sediment types (Davis, 2001).

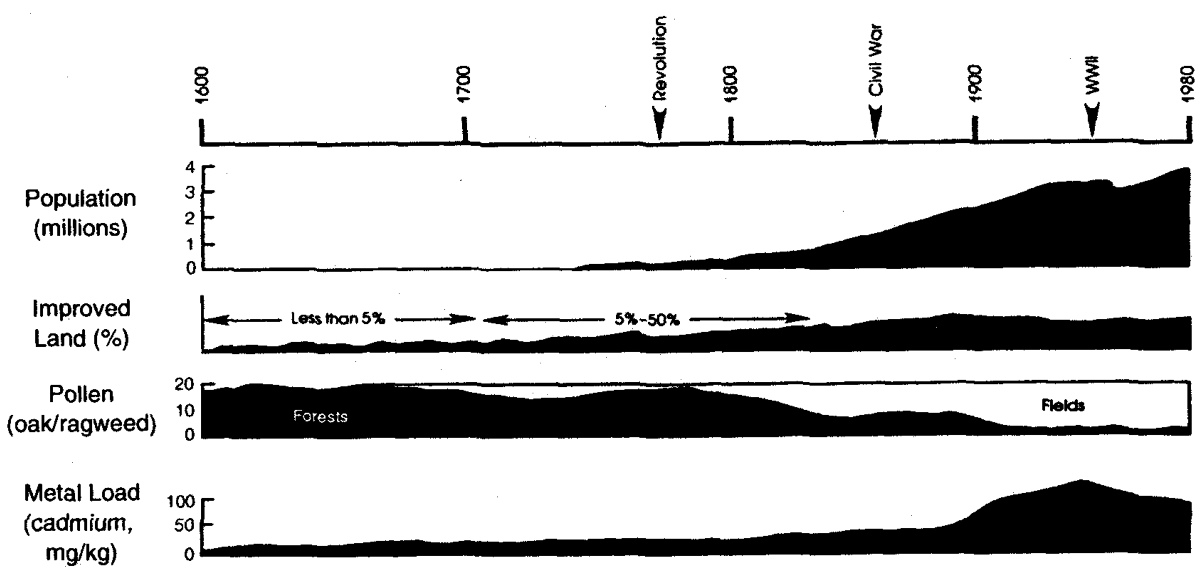
The temporal resolution of pollen records depends upon the nature of the sedimentation process. The best records are extracted from areas of high deposition, such as from varved (i.e., layered) sediments in lakes, marshes or upper estuaries where each varve represents one year. Records from these locales have temporal resolutions of quality equivalent to that of tree ring chronologies. Other potentially fruitful coring sites include peat deposits and forest hollows, which often allow for smaller-scale analyses (Calcote, 1998). The geographic scale of study is determined by life history and taphonomy, which will dictate the distances travelled by palynomorphs. Distances can range from a few meters to hundreds of kilometres (Gorham et al., 2001; Davis, 2001).

The most difficult task in palynological analyses is the identification of specimens. Pollen and spore cataloguing is executed by comparison of size, structure and sculpture. Routinely, palynomorphs are recognized at the genus level. Identification to the species level is much more time consuming, and requires the expertise of a specialist.

Palynological results are often expressed as percentages of a pollen sum, as this representation requires the fewest assumptions. Interpretation of such results must account for production, dispersal and preservation of palynomorphs, as there is no simple relationship between their abundance and the composition of plants in the landscape (Davis, 2001). Generally speaking, differences in flowering plant pollen production and dispersal correspond with pollination tactics; the two major strategies being wind and animal pollination. Wind pollinators tend to produce more, while animal pollinators produce less. There are exceptions, of course, and currently the only reliable way of establishing the relationship between vegetation and the palynological record is through comparison with contemporary patterns. This is accomplished through the study of surface samples (i.e., pollen samples and other remains taken from the upper most sedimentary layers). Surface samples are related to current vegetation composition and distribution to establish palynomorph-landscape relationships, and in turn, inductively establish historic patterns (Davis, 2001).

Palynology has been used to reconstruct past ecosystems in agricultural regions. A common trend across the continent in these, and surrounding areas, is the abrupt increase in ragweed, and decrease in other pollen types associated with land clearing and the introduction of European agricultural practices. The United States Environmental Protection Agency (U.S. EPA) is one of several sources that have demonstrated this relationship (see Figure 2). A Canadian palynological example was done by Campbell and Campbell (2000), who reconstructed the vegetation history of aspen parkland that forms the southern tree-line in the western interior. Through pollen and charcoal analysis collected from pond sediment cores from three sites in Elk Island National Park, they were able to reconstruct pre-settlement floral composition. They also established a relationship between an overall decline in charcoal abundance in the 19th century and fire suppression due to agricultural activity around the park. Other larger scale examples include Watts (1971), Thompson and Anderson (2000) and Williams et al. (2000).

Figure 2: Relative changes in population, land use, and metal load in the northern Chesapeake Bay area since 400 BP. Taken from Cooper (1995), source data is from United States Environmental Protection Agency (1983)



Palynology is important for aquatic ecosystems as well as terrestrial. Microscopic evidence of aquatic life is often abundant in lake and estuary core samples. Cores from aquatic sediment usually contain remains of aquatic algae. Although their ecology is not well understood, evidence of the common genera *Pediastrum* and *Botryococcus* is indication of year-round standing water of moderate temperature (Davis, 2001). This kind of information could be quite beneficial to aquatic ecosystem reconstruction. For additional data methodologies related to reconstruction of aquatic ecosystems see the section entitled 'Other Biological Evidence'.

2.4.1.3 Middens

Middens are refuse deposits (Merriam-Webster Online Dictionary, 2005). Many species of mammals and birds build up large quantities of biological remains in nests or waste heaps (e.g., rats, porcupines, owls and other raptors). Under favourable conditions these middens can be preserved for thousands of years, providing a detailed fossil record of past environmental conditions. Packrat (Neotoma spp.) middens are probably the best known within the field of palaeoecology for several reasons, and will thus be the focus of this section. Packrats are noted for their tendency to build large dens from a variety of materials they gather from within 30 to 50 metres, including such thing as sticks, dung, grasses, conifer needles, cactus pads and animal parts (Thompson and Anderson, 2000). They heap their findings around their usually rocky and cavernous dens to protect themselves from predators and the elements. Packrat debris piles can decompose over time, but quite often, the materials are preserved in the packrat's sticky urine, known as amberat. Amberat dries as hard as rock, and can prevent microbial decay and insect foraging, so long as it is not wetted. Wetting and intense humidity causes amberat to liquefy and seep out of middens (Rhode, 2001).

The palaeoecological value of packrat middens was first recognized in the 1960s by Wells and

Jorgense (1964). Middens can last for decades, and have been known to last as long as millennia in arid regions. They often contain exceptionally well-preserved plant and animal remains. They can be dated using radiocarbon dating techniques, and can reveal details about past spatial distributions of particular taxa and ecosystems (Rhode, 2001).

A midden analysis requires special expertise and training. Identification of plant and animal macrofossils requires strong knowledge of the regional flora and fauna, a good reference collection or herbarium, and the ability to recognize taxa from a few minute samples (Rhode, 2001).

Burel et al. (1998) examined biodiversity along a gradient of agricultural landscapes in a small region of western France. One of the methods used to determine the diversity in the small mammal population in the study regions was the examination of barn owl (Tyto alba) middens. The barn owl was chosen because it is a generalist, selecting prey species that are commonly available rather than specific prey species (Burel et al. 1998).

Plant macrofossils in middens are often so well preserved that stomatal density can be measured, and used to infer information about ecophysiological functioning. Stable isotopes of elements such as carbon, hydrogen, oxygen and sulfur found in cellulose and other tissues provide information about temperature, precipitation, plant water use and stress. Also, pollen is common in packrat middens. Analysis of pollen can support plant macrofossil findings, and fill out knowledge about past community composition. Middens may also contain preserved faunal evidence such as bones, hair, feathers, scales, faecal pellets and insect or arthropod parts; these are indications of past faunal assemblages. Insect species in particular, have narrow climatic and habitat requirements, and can be useful in establishing past climatic conditions. Faunal remains can also provide physiological and genetic information about past animal populations. For instance, faecal pellets can provide evidence of diet, parasite load, and changing body size due to shifts in climate. Because preserved packrat middens are abundant in rocky areas of drylands, they are often present where other records (such as varved sedimentary pollen deposits) are not (Rhode, 2001).

Limitations of using middens, and in particular packrat middens, include the lack of correspondence with relative abundance of species gathered, reflecting biases in collection behaviour. Also, they provide little direct evidence of biotic structure or function. For instance, pine needles in a midden could be from a shrub, a single tree or a stand of trees; from the physical evidence it is difficult to tell. In addition, there is a bias towards those plant and animal communities that inhabit areas surrounding rocky outcrops and mountainous regions where packrats prefer to make their dens. Like most other palaeoecological techniques, there is always the problem of degradation over time, thus younger middens are more common than older ones. Finally, radiocarbon dating is less precise at finer scales, and especially within the past four hundred years or so. It cannot be used reliably at the scale of decades (the scale of the majority of middens). Thus, packrat middens are often a coarse-grained data source (Rhode, 2001).

2.4.1.4 Other Biological Evidence

There are other sources of biological evidence that have been used to a lesser extent than those already discussed. Many of these additional reconstructive methods are applied in aquatic ecosystems. For instance, diatoms have been extracted from sediment cores in aquatic environments and have been used to reconstruct past community structure and aquatic chemistry (Brugham, 1978; Brugam et al., 1988; Cooper, 1995). Diatoms are particularly sensitive to aquatic chemistry and water depth, with each taxa having a specific range of conditions within which they can thrive. Cooper (1995) investigated past diatom assemblages in an agricultural region of Marylandto determine water quality changes in Chesapeake Bay. She found that diversity of diatoms has decreased since the time of European settlement, and that this change in diversity may be because of reduced benthic and epiphytic habitat due to increased turbidity (because of increased sedimentation), eutrophication and increased occurrence of anoxia and pollution. Other biological indicators of past water quality include biogenic silica, fish scales, fossil pigments and total organic carbon levels in sediment cores.

Herbarium specimens were used to recreate the invasive paths of some exotic floral species in the St. Lawrence watershed (Lavoie et al., 2003). This type of record has the limitation, like historic documents, of being fragmentary, and therefore difficult to extrapolate from. Other possible sources of biological evidence include collected faunal specimens, phytoliths (Fredland, 2001) and bacterial endospores (Gorham et al., 2001).

2.4.2 Abiotic Evidence

To a lesser extent, abiotic evidence has been used to infer fine-scale changes in biological assemblages over time. Cooper (1995) investigated total sulphur, acid-soluble iron and its degree of pyritization (an indicator of hypoxia and anoxia) within sediment cores taken from Chesapeake Bay. She found that hypoxia and anoxia were likely most severe over the past fifty years, and that sulphur levels have been highest in this time period. These findings were correlated with changes in diatom communities over the time frame of the study. Thus, abiotic indicators can be used to infer changes in biotic communities.

Other abiotic indicators of past ecosystems include sediment influx rates and grain size, which were investigated in an Albertan agro-forest ecozone by Strong (1991), and which has been shown to be correlated with changes in diatom communities by Cooper (1995). Other indicators include calcium (as an indicator of surrounding soil and bedrock composition) and stable isotopes, like those mentioned in the section on middens.

2.5 Multi-technique Approaches

Rarely are reconstructions performed using only one reconstructive method. More often than not a suite of reconstructive techniques are applied (e.g., Wilkins et al. 1991; Bouchard and Domon, 1997; Thompson and Anderson, 2000; Fensham and Fairfax, 2003; Bickford and Mackey, 2004). Also, because the study, spatial and temporal, scale is restricted to the scale of the methods, researchers will often use multiple methods to obtain data within the complete range of interest. Often times, historic records will be used with palaeoecological data (e.g., Bouchard and Domon, 1997; Pellerin and Lavoie, 2003). Other combinations include palaeoecology and space-for-time analysis, and palaeoecology with modeling (e.g., Matsukawa et al., 2006). Modelling may be a particularly useful addition to a suite of tools, in that it can reduce costs, and allow for the investigation of larger study areas.

3 MEASURES OF BIODIVERSITY

Biodiversity can be difficult to measure directly given the large number of potentially measurable parameters that define individual species and communities. Typically, three elements are considered in the measurement of biodiversity: 1) scale; 2) component, and 3) viewpoint (OECD, 2005). Scale is comprised of alpha, beta, and gamma diversity. Alpha diversity represents species richness within a local ecosystem. Beta diversity reflects the change in alpha diversity observed in the movement from one ecosystem to another across a landscape (i.e., landscape gradients). Gamma diversity pertains to species richness at a regional or geographical level. Gamma diversity is a more global concept and a measure that is much more dependant on large-scale shocks rather than the local ones (e.g., forest fires) that affect alpha and beta diversity. The component facet of biodiversity measurement addresses the concept of 'safe' species abundance (e.g., minimum viable populations). The viewpoint aspect recognizes that many often-conflicting viewpoints (e.g., scientific, legal, moral, etc.) exist on what constitutes biodiversity and how it should be measured. The remainder of this section will focus on the scale aspects of current biodiversity. Methods for measuring biodiversity in the past (e.g., palaeoecology) have already been discussed in previous sections.

Indices

Species richness in a community is often perceived as the most important measure of biodiversity (Bergon et al., 1990). However, species richness does not take into account that within a community, some species are more rare than others. Several biodiversity indices have been constructed that mathematically merge the concepts of richness and evenness (e.g., Simpson Index; Shannon-Wiener Index). These indices do not necessarily account for differences in the species present, as assemblages differing in their species composition may have the same index values. Similarity indices (e.g., Sorensen's community index; Squires overlapping index) are often used to account for these variations. Taken together these indices are the tools used in the measurement of biodiversity, although the strengths and weaknesses of their application are widely debated in the literature (e.g., Lande, 1996). A description of two widely used indices is presented below.

Simpson Index - A measurement that accounts for the richness and the percent of each species from a sample within a local community. The index assumes that the proportion of individuals in an area indicate their importance to diversity.

$$Simpson\ Index(D) = \frac{1}{\sum_{i=1}^{S} P_i^2}$$

where,

S = total number of species in the community (*i.e*., richness)
P = species proportion
i = number of species

Shannon-Wiener Index - Similar to the Simpson's index, this measurement takes into account species richness and proportion of each species within the local community. The index comes from information science. It has also been called the Shannon index and the Shannon-Weaver index in the ecological literature.

$$diversity\ H = -\sum_{i=1}^{S} P_i \ln P_i$$

where,

S = total number of species in the community (*i.e*., richness)
P = species proportion
i = number of species

There are numerous studies available in the literature where indices have been applied to measure biodiversity. Fewer studies are available on the measure of biodiversity in agricultural areas. Burel *et al*. (1998) compared biodiversity in contrasted land units in a small region in western France. In particular, the study examined the impact to biodiversity from agriculture along a gradient of agricultural landscapes. To measure biodiversity, Burel *et al*. (1998) used a number of methods including species richness, Shannon's diversity, equitability, and similarity indices. Small mammals, carabids, and diptera were sampled in the landscape units designated for the study. Based on the analysis of collected data and application of the selected indices, Burel *et al*.

(1998) concluded that there was no linear relationship between agricultural activities and loss of species.

Indices of Biotic Integrity (IBIs) - Used to evaluate the integrity of a resource (*e.g.*, freshwater ecosystems), are generally applied to freshwater ecosystems, and to determine the impact of human activities on aquatic biota such as fish communities. Although not used as a measurement of biodiversity, IBIs use a large set of ecosystem metrics to evaluate overall biological integrity and ecosystem health. Each metric is evaluated and a score is assigned. Generally, low scores indicate a highly disturbed state and higher scores indicate little human influence. Examples of metrics for an IBI designed to evaluate the ability of a freshwater ecosystem to support a warm-water fish community include: fish species richness, abundance, fish condition, trophic organization and function, number and abundance of indicator species, and reproductive behaviour. Different metrics are used to construct an IBI depending upon the resource being evaluated. IBIs therefore can be a useful tool in the creation of a biodiversity standard, as one of the aims of the standard is to conserve biodiversity critical to maintaining and restoring ecosystem function and integrity at multiple scales.

Indicators/Surrogates

Paoletti (1999) suggested that bioindicator-based studies can have a major impact on the optimization of farming practices and political policies governing landscape management. The numerous aspects of biodiversity, from intraspecific genetic variability up to the complexity of trophic interactions and landscape variability, require any quantification of biodiversity to be based upon relative measures. These may include surrogate species (*e.g.*, carabid beetles as representatives of terrestrial insects) (Duelli, 1997) and/or landscape and environmental factors used to estimate species that should be present (Harper and Hawksworth, 1994). Duelli and Obrist (2003) suggested that an ideal indicator for biodiversity has a linear correlation to the entity or aspect of biodiversity under evaluation. The difficulty is in finding that ideal correlation for the aspect of biodiversity being measured.

Büchs *et al*. (2003) examined the potential and limitations to the application of biodiversity indicators in agroecosystems. The authors defined biodiversity as species richness for the purposes of their study. Büchs *et al.* (2003) suggested that indicators in agricultural systems should do more than provide a measure of species richness. They should also take into account sustainability and long-term stability, and reproductive potential of species in agricultural landscapes.

There are numerous studies that report the use of indicator species for the measure of particular aspects of biodiversity. Burel and Baudry (1995) used spiders, carabid beetles and specific plant species as measures of species biodiversity in the agricultural landscapes of France. In an evaluation of biodiversity in agricultural landscapes in Switzerland, Duelli (1997) proposed a multifaceted approach. The author recognized that the concept of biodiversity could not be reduced to a single quantifiable entity. He proposed the use of a number of surrogates for biodiversity measures. For example, given that greater than 90% of genetic variability is accounted for by invertebrates, Duelli (1997) used them as a standard measure of genetic biodiversity. Duelli (1997) also proposed the use of landscape mosaic patterns (*i.e.*, variations in habitat composition and configuration within landscapes) as a surrogate for regional biodiversity. He identified a number of factors that can be used to predict and evaluate biodiversity in an agricultural mosaic including: habitat variability, habitat heterogeneity and the surface proportions of natural, semi-natural, and intensively cultivated areas. Ekschmitt *et al*. (2003) examined the effectiveness of various soil fauna richness indicators at different spatial scales. They found that climatic and soil parameters were significantly correlated with soil faunal biodiversity in all of the datasets examined. Ekschmitt *et al*. (2003) found that environmental parameters could provide a rough approximation of soil faunal diversity with minimum cost, while for a more robust estimate, indicators such as higher taxon richness are required.

4 REVIEW OF CANADIAN PALAEOECOLOGICAL RECONSTRUCTIONS

4.1 Methods

A collection of information on palaeoecological reconstructions in Canada was undertaken in support of this project. It involved several initiatives including:

1. Keyword search of web-based sources;
2. Keyword search of commercial databases;
3. Survey of provincial and municipal archives and libraries; and,
4. Interview and written survey of Canadian experts.

The keyword search of web-based sources included a number of publicly available bibliographic databases (Table 1) and other sources located during the search. Bibliographic information was collected, or research articles downloaded for content review. Reference sections from relevant articles were used to further direct the search. Based on the results of this initial bibliographic search, a keyword strategy was developed and refined (Table 2). The keyword search strategy was then used in a search of bibliographic databases available commercially through the

DIALOG service (Table 3).

Table 1: Bibliographic Databases Recommended For Initial Scoping Literature Search

Database	Internet Address
National Library of Medicine – PubMed	http://www.ncbi.nlm.nih.gov/entrez/query.fcgi
National Library of Medicine – TOXNET	http://toxnet.nlm.nih.gov/
USDA – National Agricultural Library	http://agricola.nal.usda.gov/
Oak Ridge National Laboratory – Research Library	http://www.ornl.gov/info/library/library-home.shtml
Science Direct	http://www.sciencedirect.com/
Scirus	http://www.scirus.com/srsapp/
National Biological Information Infrastructure (NBII)	http://www.nbii.gov/index.html
International Information System for the Agricultural Sciences and Technology	http://www.fao.org/agris/
Canadian Biodiversity Information Network	http://www.cbin.ec.gc.ca/index.cfm?lang=e
Canadian Wildlife Service	http://www.cws-scf.ec.gc.ca/index_e.cfm
U.S. EPA Publications Database	http://www.epa.gov/epahome/pubsearch.html

Table 2: Initial Keyword Search Strategy For Electronic Literature Search

Primary Keywords			Secondary Keywords
Theme	**Time Frame**	**Methods**	
biodivers*	past	palaeo / paleoecolog*	Canada/Canadian, Ontario, Quebec, Nova Scotia, PEI/Prince Edward Island, BC/British Columbia, Quebec, Manitoba, Saskatchewan, Alberta, New Brunswick, Yukon, NWT/North West Territories, Nunavut, prairie*, grassland*, mixed-wood, plain*
heterogen*	pre-settlement/pre-settlement	palaeo / paleoenvironment*	
vari*	holocene	re-construct*/reconstruct*	
ecological integrity	quaternary	account*	
ecosystem health	historic*	survey*	
terrestrial		record*	

Table 2: Initial Keyword Search Strategy For Electronic Literature Search

Primary Keywords			Secondary Keywords
Theme	**Time Frame**	**Methods**	
aquatic		diary/diaries	
agricultur*		model*	
landscape		simulat*	
restoration		palaeo / paleobotany	
indicator*		archaeology*	
		gradient analy*	
		space-for-time	
		phytogeograph*	
		supply analy*	
		palaeo / paleolimnolog*	
		restor*	
		measure	
		index	

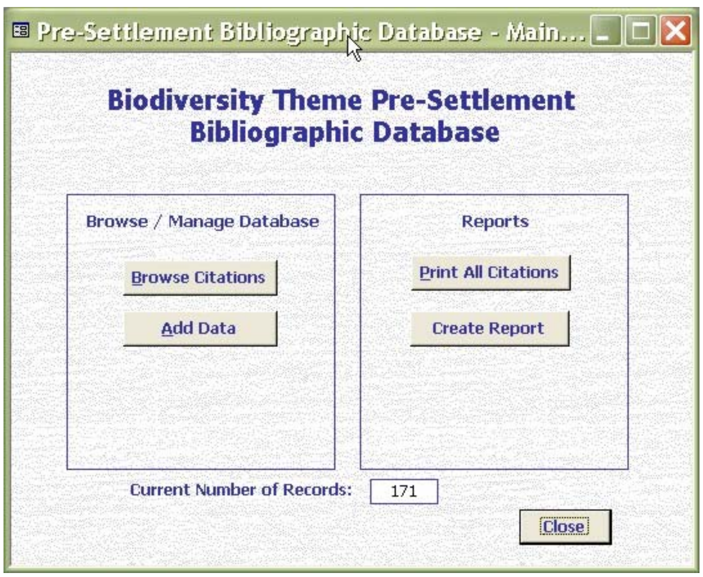
Table 3: Commercial Databases Searched

Database	Coverage
Biosis	1969 +
NTIS	1964 +
EI Compendex	1970 +
AGRICOLA	1970 +
SciSearch	1989 +
Enviroline	1975 +
CAB Abstracts	1972 +
Elsevier Biobase	1994 +
Wilson Applied Science and Technology Abstracts	1983 +
Wilson Biological and Agricultural Index	1983 +

Some of the most potentially valuable sources of information for palaeoecological reconstructions at the pre-settlement time scale come from historic documents including maps, surveys and other items. For this reason, Provincial and Municipal archives across the country were contacted to determine whether relevant information was available in their regions. The complete list of archives and libraries contacted is provided in Appendix A. The results of this library and archive survey are provided in Appendix B.

Finally, Canadian experts in palaeoecological science were contacted and asked to participate in an interview/survey. The survey was intended to identify Canadian reconstructions as well as elicit opinions on issues such as the appropriate spatial scale to conduct a palaeoecological reconstruction to measure past biodiversity in an agricultural context. The results of the expert survey are provided below. The list of experts contacted in provided in Table 4.

Figure 3: Pre-settlement Bibliographic Database



This section along with the accompanying MS-Access™ bibliographic database, presents the results of the information and data gathering process. The state of the science on ecosystem reconstruction in Canada is presented and the applicability of the reconstructions in Canadian agricultural areas to the development of a biodiversity standard is presented.

4.2 Biodiversity Theme Pre-Settlement Bibliographic Application

The literature searches conducted using online sources and commercial databases resulted in a large number of references being identified. To facilitate searching through the collected references and printing bibliographic reports, a MS-Access database application was constructed (Figure 3). The database application is composed of several tables for data storage and user-friendly forms and controls to facilitate data entry and report preparation. It currently contains approximately 171 records. Only data and information that were identified as being relevant to the subject of palaeoecological reconstructions and biodiversity were added to the database. The database is considered an integral part of this report, and the authors encourage the reader to investigate this resource. MS-Access 2000 or greater is required to view the database application.

4.3 Consolidated Summary of Canadian Expert Survey Results

Experts in the field of palaeoecological reconstructions (Table 4) were contacted by telephone and e-mail and asked to participate in a short survey on reconstruction initiatives in Canada. An attempt was made to include experts from across Canada to help ensure that work done in all areas of Canada was captured.

Table 4: List of Canadian Palaeoecological Reconstruction Experts Contacted

Expert	Expertise	Affiliation
John Smol, Ph.D.	Limnology and paleolimnology	Queen's University, Department of Biology, Journal of Paleolimnology, Co-Editor In Chief Environmental Reviews, Editor in Chief
Robert Steedman, Ph.D.	Long term, catchment-scale monitoring of boreal shield lakes; managing human impacts on lakes and streams.	Research Scientist and Project Leader, Coldwater Lakes Experimental Watersheds, Ontario Ministry of Natural Resources
Dion Wiseman, Ph.D.	Applications of GIS for reconstructing Holocene landscapes; statistical modelling techniques for reconstructing pre-settlement	Brandon University, Department of Geography

Table 4: List of Canadian Palaeoecological Reconstruction Experts Contacted

Expert	Expertise	Affiliation
	landcover conditions.	
Alwynne Beaudoin, Ph.D.	Palaeoenvironmental science	University of Alberta, Department of Earth and Atmospheric Sciences, Alberta Provincial Museum
Dan Johnson, Ph.D.	Post-glacial grassland, foothills, montane and alpine ecology and biodiversity; food relationships, biodiversity and ecological integrity; environmentally sustainable methods of crop protection	University of Lethbridge, Department of Geography Canada Research Chair in Sustainable Grassland Ecosystems
David Patriquin, Ph.D.	Agroecosystems and urban ecology	Dalhousie University
Ian Walker, Ph.D.	Palaeoecology; freshwater ecology and climatic change research	Okanagan University College, Faculty of Science, Palaeoecology Laboratory
Claude Lavoie, Ph.D	Canadian wetlands research	École supérieure d'aménagement du territoire et du développement régional Pavillon Félix-Antoine-Savard, Université Laval
Jeremy Kerr, Ph.D.	The influence of human activities on spatial patterns of biodiversity and ecosystem function	University of Ottawa, Department of Biology

Not all of the experts contacted were available to participate. The survey contained questions specific to the project goal of determining the utility of palaeoecological reconstructions in the development of biodiversity standards for agriculture in Canada. The survey questions were:

1 Have you participated in or are you aware of any research efforts that involve the determination of pre-settlement ecological conditions, ecosystem health or biodiversity in agricultural regions? If possible, please provide information on these efforts (*e.g.*, project name, location, contact person, organization involved, short description of the initiative).

2 Are you aware of any research efforts that have involved an attempt to determine or

have given insight to pre-settlement biodiversity (where biodiversity is taken in its broadest sense to mean the diversity of life at all scales, not just species richness)? If so, please provide information on these initiatives?

3 In considering research initiatives with which you are familiar, involving some determination of pre-settlement conditions, what has been the overriding intention of these investigations? What methods were used, and why were these methods appropriate for answering the research question(s)?

4 What measures, surrogate measures, or indicators of biodiversity would you recommend or consider for comparing existing ecosystem integrity/health and associated biodiversity with those of the past?

5 At what spatial scales do you think it is most important to consider differences in ecosystem integrity/health and associated biodiversity?

6 Are you willing to participate in a follow-up interview *via* telephone?

7 Are you aware of any additional experts that may be able to provide insight into reconstruction efforts undertaken in Canada? Please provide contact information.

General themes and ideas in the responses received from the survey participants for each of the questions are presented below.

The contributions of the experts in response to Question 1 were invaluable in isolating reconstruction research performed in Canada. Several citations were provided (e.g., Archibold and Wilson, 1980; Tracie, 1992; Hanuta, 1999; Wiseman et al., 2001) as well as indications of research currently being conducted (e.g., reconstruction of pre-settlement vegetation in wetlands, Haut-Saint-Laurent region, southeastern Quebec). Many of the experts also knew of research currently being performed in Canada on pre-settlement biodiversity (Question 2).

Recommended research included a project on the measurement of ecological diversity and uniqueness of landscapes across the Canadian prairie ecozone using the National Ecological Framework (ESWG, 1995). Research where the reconstruction of pre-settlement forests in Quebec is on-going was also mentioned.

The participating experts indicated that much of the pre-settlement reconstruction research they were familiar with (Question 3) was undertaken to describe natural land cover in Canada prior to European influence. A secondary research theme was the determination of pre-settlement ecological diversity/uniqueness. Some of the most commonly used tools for this research included historical records (e.g., Dominion Land Surveys), palynology, and dendrochronology. Within the specific context of agricultural biodiversity, one participant mentioned the efforts of the European Conservation Institute Research Network (www.nmw.ac.uk/ite/econet/bio.html). This network provides a guide to using landscape ecology to assess and improve the quality of northern European farmed landscapes for biodiversity. The associated research is published in an on-line publication called LANDECONET.

For comparison to present day biodiversity, the experts recommended several measures, surrogate measures, or indicators while at the same time indicating that the question is 'enormous' in scope. Typical palaeoecological methods were recommended including plant macro- and microfossils, pollen analysis, faunal remains, soil development, physiographic/geomorphic reconstructions, climatic indicators and others. One expert indicated that in some ecosystems (e.g., peatlands), measures of species diversity are too difficult to reconstruct. To address this challenge, indicator species critical to the proper structure and function of the ecosystem are chosen. In the case of peatlands for example, Sphagnum mosses could be used, as they are key species for maintaining ecological function in that system. The disruption of plant-soil nutrient cycling was also recognized as a fundamental disturbance caused by agriculture. A surrogate measure of this disturbance is soil conductivity. Comparison of soil conductivity measurements from agricultural areas to undisturbed ‘reference’ areas (if available) can provide an indication of present to past ecosystem function (e.g., Patriquin et al., 1993).

The question of appropriate spatial scale (Question 5) brought several suggestions, with all of the experts agreeing that scale depends upon the objective of the study and the ecosystem of interest. For example, biodiversity can be measured on scales ranging from transcontinental biomes (e.g., O’Connor et al., 1996; Miller et al., 2004) to micro scales of less than 1 hectare (e.g., peatlands). One expert suggested that if the intent was the reconstruction of pre-settlement conditions for the purposes of agricultural land reclamation, it might be most appropriate to proceed at the scale of an ecodistrict. Ecodistricts are characterized by distinctive assemblages of landform, relief, surficial geologic material, soil, water bodies, vegetation, and land uses (ESWG, 1995). The Nation Ecological Framework for Canada (ESWG, 1995) was developed by Environment Canada and Agriculture and Agri-Food Canada and creates eco-regions, ecodistricts and, ecozones within Canada based on numerous data sources. These data sources include the Soil Landscapes of Canada digital map series among other federal and external databases. The National Ecological Framework provides a consistent, national spatial context within which ecosystems at various levels of generalization can be described, monitored, and reported on. More information on the framework can be found at http://sis.agr.gc.ca/cansis/nsdb/ecostrat/index.html.

The expert knowledge captured through the survey provides a summary of the current state of the art in reconstructing Canadian ecosystems. The previous sections provide an overview the science including measurements of biodiversity and descriptions of ecosystem reconstruction methods. The remaining sections explore the use of these methods in ecosystem re-constructions and the development of biodiversity standards in Canadian agricultural areas.

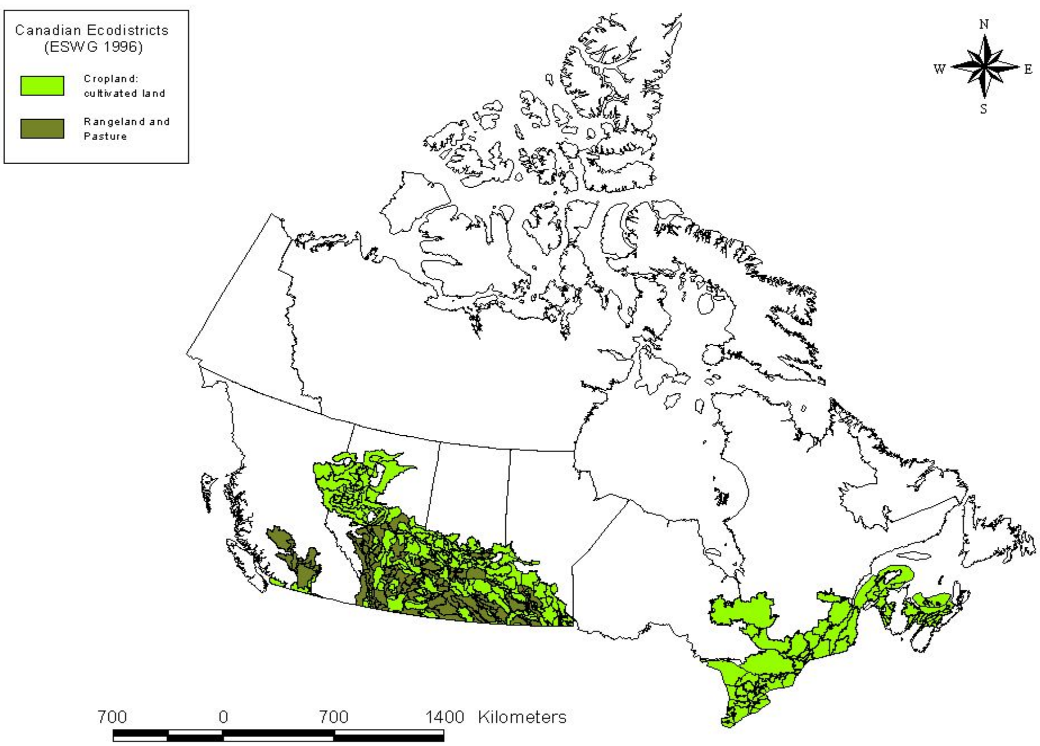
5 RECONSTRUCTIONS AS A TOOL IN THE DEVELOPMENT OF CANADIAN BIODIVERSITY STANDARDS

The impact of human activities on arable lands in Canada has, perhaps irrevocably, altered species richness and abundance of organisms in these landscapes from their pre-settlement state. Although this report focuses on determining pre-settlement conditions in agricultural regions of Canada, pre-settlement conditions are not necessarily the target. The goal of the NAESI biodiversity standard is to conserve biodiversity critical to maintaining and restoring ecosystem function and integrity at multiple scales. Bηchs et al. (2003) similarly describe this goal for agricultural landscapes, where the target is not to maximize biodiversity, but rather, to maintaining the structural and functional qualities of biocenosis consistent with the hierarchical components (i.e., structure, function and composition).

Human land use, particularly from agriculture, can have greater local impacts upon landscapes (e.g., sustained changes in communities and ecosystems) than climatic change (Gorham et al. 2001). According to the 1996 agricultural census conducted by Statistics Canada, 167,936,279 acres of land in Canada were considered agricultural (Statistics Canada 1996) (Figure 4). The

five major crops in terms of area seeded were spring wheat, total hay and fodder crops, barley, canola, and durum wheat. The agricultural census also indicated that the trend in Canadian agricultural landscapes is towards larger farms with less crop diversity. As crop diversity is reduced and farm size increases, habitat heterogeneity also decreases due to loss of hedgerows, woodlots, and wetlands in agricultural landscapes. Agricultural chemical use (e.g., pesticides, fertilizers), increased mechanization, earlier planting and harvesting, and loss of crop rotations also contribute to both aquatic and terrestrial species population declines (Freemark and Kirk, 2001). Information about pre-settlement conditions in agricultural areas can be used to inform the process of evaluating relative past and present biodiversity. This section examines the relationship between reconstruction methods and what they can contribute to our knowledge of pre-settlement biodiversity.

Figure 4: Agricultural areas of Canada based on Cropland and Rangeland/Pasture Ecodistrict, National Ecological Framework of Canada (ESWG, 1996)



The majority of the palaeoecological research in Canada has focused on small spatial scales (e.g., ecosystem, watershed, county). For example, in terrestrial systems, most of the research is focused on changes in plant assemblages (i.e., forest species) at small scales (e.g., Bergeron and Charron, 1994; Jackson et al. 2000; Suffling et al., 2003). In aquatic ecosystems, research has been focused on specific questions relating to the response of species richness or diversity to changes in environmental parameters (e.g., pH) in small local ecosystems (e.g., lakes, ponds) (e.g., Paterson et al., 2001; Uutala et al., 1994).

Canadian pre-settlement conditions are assumed to have existed 500-100 years ago depending upon when local settlement began (roughly east to west). To discern details of the ecosystems in existence in this time period, methods that are effective at the relatively finer temporal scale of decades and centuries are required. These methods include, but are not necessarily limited to: historic documents, palaeolimnology, and palynology (Figure 1). Spatially, nearly all of the reconstruction methods previously reviewed can be applied. Each reconstruction method can provide insight into various aspects of the landscape under study and hence the biodiversity of historic ecosystems; however a weight of evidence approach is recommended. The use of multiple methods can reduce uncertainty about our knowledge of historic ecosystems (Pellerin and Lavoie, 2003). Though valuable, tools for examining and providing insight into historical environmental and landscape trends and conditions, reconstruction methods cannot be used to generate a comprehensive and detailed view of past biodiversity. For example, Tracie (1992) noted that evidence of historic vegetation is lacking in the regions where it is of greatest consequence, in settled and developed areas.

In Canada, the most common form of ecosystem reconstruction reported in the literature involves the use of dendroecological methods (e.g., Begin and Filion, 1985; Gagnon and Payette, 1985;

Delwaide and Filion, 1987, 1988; Begin, 1991; Bergeron and Charron, 1994; McCarthy and Luckman, 1993). This is no surprise, given that there are over 900 million hectares of forested land in Canada (NRCan, 2005). In comparison, farmland occupies less than 1/13th of the area that forests do (Statistics Canada, 2001). Dendroecology is considered a useful tool for the reconstruction of tree stand history and species dynamics (Bergeron and Charron, 1994). A limitation in the application of dendroecology common to most historic research is that less information is available with increasing time before present. Some tree species also degrade faster than others. As tree material decays, it is lost from the record, and thus historic compositions may be skewed by the complete absence of some individuals. Tree rings are a proxy record, and act as a complex filter through which environmental variation is roughly logged. Our ability to understand the historic environmental processes affecting tree ring growth depends on our ability to decipher that filter (Kipmueller and Swetnam, 2001). In some parts of Canada (e.g., Martimes, Southern Ontario) there are few if any examples of old-growth forest, or trees dating from before European settlement (Suffling et al., 2003). Given the lack of suitable pre-settlement dendrological material, dendroecological methods are generally unsuitable to reconstructing pre-settlement ecosystems in most Canadian agricultural areas.

Government Specification for Land Survey Records circ. 1780 **(Pile, 1969)**

- Major changes in vegetation cover and chainage (1 chain = 66 feet)
- All rivers, creeks and smaller streams of water including width and course where survey lines intersect
- All lakes and ponds and their width at survey point of intersection
- All prairies, swamps, and marshes and their chainage

- All precipices, ravines and caves
- All tornado and ‘strong wind’ tracts through forested areas
- The distance at which any ascent or descent begins or ends with the course, estimated height above or below surrounding lands
- Indications of the nature of the soil at given intervals.

Historical documents such as land surveys, photographs, fonds, books, reports, species range maps, etc. are the most commonly used tools in the reconstruction of landscapes of the recent past (Tracie, 1992). Numerous authors have applied this particular method to reconstruct plant diversity in agricultural regions of Canada (e.g., Habib et al., 2003; Lavoie et al., 2003; Wiersma and Nudds, 2001; Wiseman and Joss, 2001; Jackson et al., 2000; Hanuta, 1999; Boyle et al., 1997; Tracie, 1992; Archibold and Wilson, 1980; Pile, 1969). This method has the advantage of first hand accounts of landscape condition and species encountered and locations can usually be related to modern maps. Some of the most relevant sources of historical documentation describing large portions of the Canadian landscape include the Dominion Land Survey (Wiseman and Joss 2001), Canadian censuses (Paquette and Domon, 1997), and species range maps (e.g., Habib et al., 2003). Dominion Land Survey (DLS) township diagrams and surveyor notebooks represent the most comprehensive documentation of pre-European settlement land cover for much of western Canada (Wiseman, Dr. Dion, Brandon University, Manitoba, April 2005, personal communication; McGregor, 1981). Early Canadian censuses contain useful information on the land parcel spatial scale, characteristics of farm holdings, and other data and information at the township scale (Quebec) (Paquette and Domon, 1997). Range maps delineate the range of animal and plant species generally based on historical observation. In Canada, there are numerous sources of relevant historical documents including National and Provincial archives (e.g., CIHM, 2005), libraries, and other collections (Appendix A).

The interpretation of data and information in historic documents can be challenging. Issues such as legibility, condition of the document, identifying abbreviations (e.g., for species names), translating common names into specific species, and bias, selectivity, and inconsistency of surveyor observations can hinder palaeontologists and palaeocologists in piecing together pre-settlement biodiversity and ecosystem condition. Pile (1969), for example, noted that Ontario surveyors only recorded changes in tree cover as they followed concession lines, and only named the trees used to identify lot corners. Therefore, Pile (1969) was only able to determine the relative frequency of a tree species (relative to all other tree species reported). Habib et al. (2003) noted that range maps show the extent of occurrence of species and not necessarily the range of occupancy. Therefore, range maps can misrepresent the range of species on a landscape. However, given information on habitat preferences, pre-settlement landscape condition, and other factors, range maps can be useful in inferring that certain species may have been present prior to conversion of the pre-settlement landscapes to agriculture.

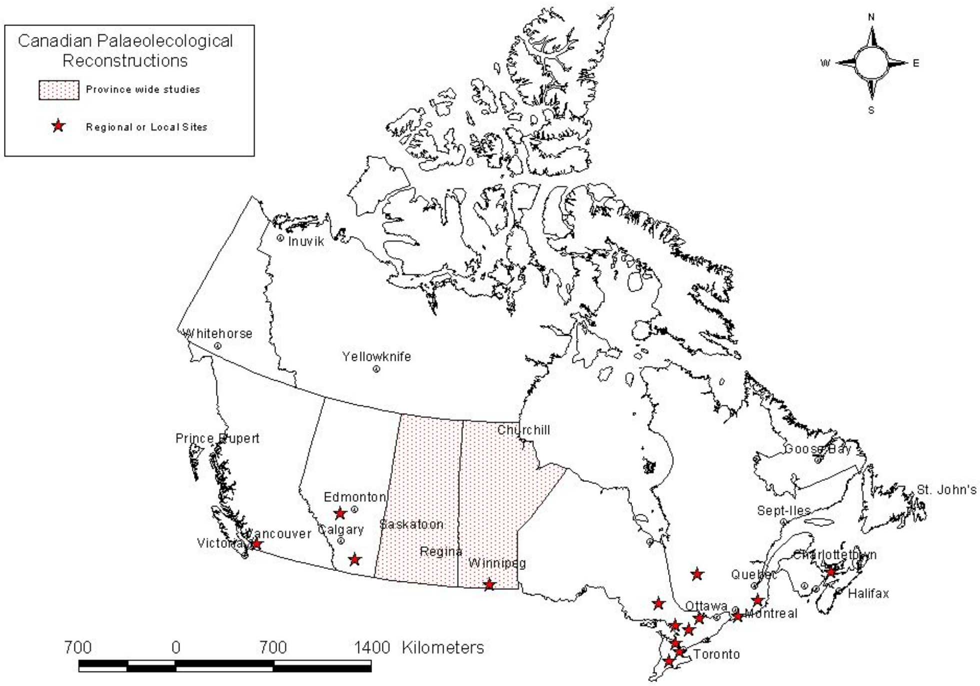
Generally, palynological methods are suited to large temporal (e.g., century to millennium) and spatial scales (Figure 1). Pollen diagrams from lake sediments can represent an area extending one to several kilometres from the coring site (Gorham et al., 2001). Davis and Goodlet (1960) suggested that regional pollen originates within 50 to 100 km of its deposition site. The vegetation history of many parts of North America has been reconstructed from pollen profiles for the last 40,000 to 10,000 years in much of North America (COHMAP Members, 1988). This can provide long-term views of vegetation change due to climate change and the response of vegetation to soil weathering and acidification, nutrient cycling, and other slow processes for which there are few data (i.e., ecological dynamics over time) (Suffling et al., 2003). There are limitations to the use of palynology over long time periods. For example, pollen grains are difficult to identify to the species level, particularly the farther back in time one goes. The plant species assemblages may simply not be representative of modern species, making identification of pollen difficult (Gorham et al., 2001). Palynological methods have been used within the decades to multiple century time scale that corresponds with European pre-settlement (McAndrews and Boyko-Diakonow, 1989). Spatially, palynology is most appropriate for discerning terrestrial and aquatic plant community composition at the region (e.g., Love, 1959) or watershed scale rather than at specific locations (Suffling et al., 2003). Several authors have used pollen analysis to examine trends in changing land use around lakes (e.g., Crawford Lake, Ontario — McAndrews and Boyko-Diakonow, 1989; Lily Lake, Minnesota — Brugam et al., 1988; Lake Washington, U.S. — Davis, 1973). These land use changes primarily involved conversion of pre-settlement landscapes to European agriculture. Pollen assemblages in lake sediments were used to catalogue changes in plant species observed and therefore determine the diversity of terrestrial plant species surrounding the lakes. In each case it was possible for the authors to determine when agriculture began in the study areas from changes in pollen species distribution and the sudden introduction of certain indicator plant species (e.g., dandelion and ragweed).

Palaeolimnological methods allow for calculations of the degree of change over baseline conditions, thereby providing an estimate of the historic configurations of aquatic and terrestrial ecosystems. Having an understanding of these historical conditions allows for determination of long-term trends; an important requirement for measurements of biodiversity (Cottingham et al., 2000). There are numerous examples of the use of palaeolimnological methods to assess the past status and composition of fish and diatom communities and the impacts of human disturbance on local ecosystems (e.g., Uutala et al., 1994; Strong, 1991; Engstrom et al., 1985; Brugam, 1978; Soutar and Isaacs, 1973). One limitation to the use of palaeolimnological methods to determine species diversity is the dependence of the method on sediment depositional rates. The time interval represented by equally-sized sections of a sediment core can vary (Smol, 1981). Therefore, it is important to know and account for changes in sedimentation rate in any analysis of species diversity using palaeolimnological methods.

5.1 Description of Canadian Pre-Settlement Ecosystems in Canadian Agricultural Areas

This section provides insights on the status of the pre-settlement ecosystems examined in Canadian agricultural areas from East to West. Figure 5 presents the approximate spatial locations of the Canadian reconstructions reviewed for this project.

Figure 5: Approximate locations of identified ecosystem reconstructions conducted in Canada



Martimes (Prince Edward Island, Nova Scotia, New Brunswick)

Loo and Ives (2003) examined the change in pre-settlement (~1600's) conditions of forest-dominated landscapes in the Maritime Provinces using historical documents. At the time of settlement the Acadian forest region contained pine, hemlock, cedar, spruce, fir and some tolerant hardwood species. Since settlement a shift has occurred to younger, more even aged stands. The abundance of early successional species such as balsam fir (Abies balsamea), white spruce (Picea glauca), red maple (Acer rubrum), white birch (Betula papyrifera) and trembling aspen (Populus tremuloides) has increased. Late successional species such as sugar maple (Acer saccharum), red spruce (Picea rubens), eastern hemlock (Tsunga canadensis), yellow birch (Betula alleghaniensis), cedar (Thuja occulentalis) and beech (Fagus grandifolia) have declined in both abundance and age.

Quebec

Numerous authors have studied pre-settlement conditions in agricultural areas of Quebec (southern Quebec) using different reconstructive techniques and in different landscapes. Brisson and Bouchard (2003) reported on the status of pre-settlement forests in the Haut-Saint-Laurent region in the 1880's. The authors used old notary deeds containing wood sales reports to reconstruct the tree species composition of the forest now cleared for agriculture. Current forests are young, and show signs of management and grazing with maple currently dominant followed by the pioneer species, trembling aspen, red ash and gray birch. Currently tree species richness is relatively high, with 31 species found in the study area. Tree species eliminated from the study area include: paper birch (Betula papyrifera) and red maple/silver maple. The pre-settlement forest was predominantly a maple-beech-birch mix while American beech and yellow birch have also declined since settlement.

Paquette and Domon (1997) used the Canadian censuses from 1842 to 1993 to examine the change in landscape type over this period in the Haut-Saint-Laurent region of Quebec. In 1842 16.35% of the study area had been 'improved' (i.e., settled and cultivated) with the 'improved' area reached a maximum in 1881 at 83.15%. From 1881 the percent of 'improved' land declined to 53.86% in 1993. From 1958 to 1993 trends have shown an increase in forested land, and declines in cultivated fields and pasture. This study did not look at habitat composition.

Lavoie et al. (2003) examined the spread of invasive plant species in the St. Lawrence River wetlands from the late 19th century to present. Between 1926 and 1950, flowering-rush and purple loosestrife spread rapidly along the St. Lawrence River. Purple loosestrife has continued its expansion, while the spatial distribution of flowering-rush has not changed much since 1950. Common reed expanded its range after 1950. There is a weak linear relationship between exotic species cover and species richness, which may reflect the impact of exotic plants on native species. There is no relationship between the relative exotic cover and the diversity of wetland plants. Low diversity sites can be dominated by either an exotic species or a native plant species. In other sites, exotic species seem to have had little impact on plant communities and can even contribute to increased diversity. In the study area, agriculture was considered an important disturbance factor encouraging the spread of exotic species.

Lavoie and St. Louis (1999) examined the spread of gray birch through the Bas-Saint-Laurent region of Southern Quebec from the late 19th century to present. Herbarium specimens, historic botanical surveys, aerial photographs, company records and dendrochronological methods were used.The authors determined that gray birch is spreading eastward through the region, and that this migration is being facilitated by the presence of large abandoned peat mines. Pellerin and Lavoie (2003) used dendrochronological techniques, analysis of plant macrofossis and pollen, and the examination of aerial photographs to examine vegetation changes in mires in Bas-Saint-Laurent. Prior to European settlement, mires were open and dominated by Sphagnum mosses. Many sites presently have become forested and aerial photographs between 1948 and 1995 have indicated forest cover in mires has increased 22.5 and 56.5%. Lachance and Lavoie (2004) used gradient analysis techniques (from open and undisturbed bogs to forested and highly disturbed sites) to examine changes in bogs in the Bas-Saint-Laurent region. A clear segregation of species assemblages was observed. Tree basal area, water table level and peat thickness had significant effects on plant species composition. Disturbance level, area loss and fire were the most influential spatio-historical factors in determining plant species distribution. Spatio-historic factors had a major influence on peatlands (22% of variation observed in plant species composition) while abiotic factors represented 17% of the variation. Peatlands, and peatland species composition were found susceptible to agricultural activity, particularly associated land clearance and use of fire. Bryophytes and liverwort gradually disappear in more disturbed sites, tree cover expands, and forest bryophytes gain dominance. Ericaceous shrubs usually become more dominant. Chamaedaphne calyculata is replaced by Rhododendron canadense. Disturbance in the peatlands has led to a diversification of tree species with the appearance of Betula papyrifera, Betula populifolia, Larix laricina and Thuja occidentalis. Nearby agriculture favours the introduction of herbaceous species, including Cornus canadensis and sedge. Fire and drainage were found to favour Pinus banksiana, ericaceous shrubs and Cladina rangiferina.

Ontario

Pile (1969) examined the composition of the pre-settlement forest in Tuscarora Township, southern Ontario in 1780 using Upper Canada land survey records. Eleven (11) tree species were commonly identified by the surveyor: sugar maple (Acer saccharum); american beech (Fagus grandifolia); oak (Quercus alba and Quercus ruba); white pine (Pinus strobus); basswood (Tilia americana); ironwood (Ostrya virginiana); elm (Ulmus americana); hickory (Carya ovata); trembling aspen (Populus tremuloides); black ash (Fraximus nigra); and tamarack (Larix laricina). Generally, there was a widespread occurrence of maple, beech and pine with pine clustered, particularly in the northeastern section of the township. Basswood and ironwood were scattered throughout the study area. Nowhere in the area did they have the ecological status of the dominant maple, beech and pine.

Suffling et al. (2003) used surveyor's notes from the mid-1800s to examine changes in forest composition. The results showed increases in deciduous forest, decreases in mixed forest, and an overall increase in non-forested land. Significant declines in hemlock (Tsunga sp.), spruce (Picea sp.), white ash (Fraximus sp.), elm (Ulma sp.), fir, pine (Pinus sp.) and tamarack (Larix sp.) were observed. Beech (Fagus sp.) stands were lost under the pressures of agriculture and grazing. Birch (Betula sp.), poplar (Populus sp.) and maple (Acer sp.) are succeeding in abandoned fields. White cedar (Thuja occulentalis) has replaced logged and burned pine (Pinus sp.) stands. By 1978, 24% of the study area had been cleared.

In central Ontario, Jackson et al. (2000) examined forest composition over the last 140 years (from 1857) using Ontario land survey notes. Large-scale changes in forest composition where found to have taken place in the forests of central Ontario over the past 140 years. Initially, boreal conifers dominated the eastern townships, whereas the western townships supported mixed stands typical of the Great lakes-St. Lawrence region. In the eastern townships a significant increase in shade intolerant hardwoods at the expense of conifers has occurred, and has been attributed to clear-cutting over the past 50 years. Significant reductions in yellow birch (Betula alleghaniensis), balsam fir (Abies balsamea) and eastern white cedar (Thuja occidentalis) and increases in poplar and white birch were observed in the eastern townships. In the western townships an increase in maple (Acer sp.) was observed, as well as the continued dominance of yellow birch (Betula alleghaniensis). A significant decline in eastern white cedar (Thuja occulentalis) was also observed. Small-scale land clearing and clearing for agriculture was attributed to an increase in poplar (Populus sp.).

Reavie et al. (2002) examined sediment cores in 50 lakes in southeastern Ontario to determine the impact of increased nutrient availability in the lakes from 1850 to present using diatom and mass-balance models. The authors found that 29% of 50 lakes, have experienced a significant increase in total phosphorous since pre-settlement while 8% have experienced a decline. Similar results were reported by Cottingham et al. (2000) in an experimental lake in Ontario. Sediment cores were used to determine the presents of fossil pigments in the temporal range from 1940 to 1990. Nutrients were deliberately added to the lake during this period. The authors found that anthropogenic eutrophication can destabilize aquatic ecosystems (increase variability) and obscure impacts of global climate change. Increased community and ecosystem variability often diminished biodiversity.

McAndrews and Boyko-Diakonow (1989) used pollen analysis from sediment cores to discern periods of agricultural development in the area surrounding Crawford Lake, Ontario 1000 to 1970 AD. The results indicated two periods of agricultural development. The first was of native Canadian origin, and was marked by the appearance of corn (Zea mays), weedy grasses and purslane (Portulaca oleracea) in the pollen record. The second agricultural period was that of European settlement. The appearance of, or increase in sorel (Rumex acetosella), grass and ragweed (Ambrosia sp.) was indicative of land clearing between 1820 and 1840. With the expansion of weed and cultivated plant pollen, most tree pollen declined, including: ironwood (Ostrya Carpinus), basswood (Tilia sp.), hickory (Carya sp.), butternut (Juglans sp.), beech (Fagus sp.), pine (Pinus sp.) and hemlock (Tsunga sp.) However, some tree species appear to have carried on strongly through settlement in the area (either holding their own or expanding), such as elm (Ulmus sp.), poplar (Populus sp.), birch (Betula sp.) and cedar (Thuga sp.).

Manitoba

Hanuta (1999) examined the area in and around the Red River Valley, Manitoba during the period of 1872 to 1877, using historic township maps (constructed from land surveys). Information extracted from township plans included amounts of prairie land, wooded area, wetlands, scrub vegetation and water bodies. The purpose of the study was to obtain detailed classification of the state of the landscape prior to mass settlement.

Saskatchewan

Archibold and Wilson (1980) used township plats compiled from Dominion Land Surveys to reconstruct vegetation in southern Saskatchewan in 1880. The North Saskatchewan River valley was determined to be a scrub-grassland zone with <30% tree cover. Northern part of the study area (in the vicinity of Prince Albert) contained a major woodland with tree cover commonly >75%. Scrub was common between the North and South Saskatchewan rivers. The east-central part of the province, as well as further south along the Qu'Appelle Valley and at Moose Mountain and the Cypress Hills was also heavily wooded. Forests of the north and east were denser than those of the southwest. Marshland was most common in the hummocky moraine in the east and southeast. Grass cover dominated the study area, with a mean grass cover of 65%

Only 1% of the study area was densely wooded, 71% of the study area had woodland cover of <10%. Marshland, open water and recently burned forest were negligible in the study area. Apart from the creation of Lake Diefenbaker in 1966, the distribution of open water has not changed. Spruce, aspen and willow were mentioned on the plats; willow often being associated with scrub. All types of natural vegetation cover, with the exception of grass, has been reduced to <5% in most of the study area between 1880s and 1970s. Grovelands have expanded southward.

Alberta

Surveyors' notebooks from 1904 to 1910 on the Peace River District in Alberta were used by Tracie (1992) to create a vegetation map. The map shows the spatial extent and configuration of eight categories of land cover: grassland, groveland, transitional groveland, scrubland, forestland, poorly drained (open), poor drained (treed) and areas with no information. In this region forest and grassland landscapes were dominant. Strong (1977) used sediment cores from 9 lakes in southern Alberta. Modern vegetation formations in southern Alberta were identified from the percentage of pollen species in the first 0 to 1 cm of core. The location of pre-and post-settlement vegetation boundaries was based on changes in the pollen percentages that coincided with changes in the texture of clastic sediments, and carbonate and organic content. Common dandelion (Taraxacum officinale) native to Europe and Russia, and introduced into North America during European settlement was also used as an indicator of the pre- and post settlement boundary. The presence of Chenopodiaceae/Amaranthaceae pollen was also used as an indicator of settlement and land-use change. The author suggested that prior to settlement, the vegetation in southern Alberta consisted of four vegetation formations 1) short grass prairie, 2) mixed grass prairie, 3) fescue grassland, and 4) groveland belt of the aspen parkland. The land area of these formations was determined to be somewhat different relative to their present day ranges. For example, short grass prairie was thought to have expanded, possibly due to the impact of grazing on the mixed grass prairie. The mixed grass prairie had a reduced aerial extent, haven given way to the short grass prairie. Strong (1977) suggested that European settlement appears to have had major effect on the vegetation in southern Alberta. Fire control, elimination of the bison, grazing, and agriculture are the major factors that led to this modification.

Sediment cores taken from three lakes spread out across Elk Island National Park, Alberta were analysed for pollen and charcoal content over a time span of 1500 to 1990 (Campbell and Campbell, 2000). The separation of lakes and the sediment core results indicated that the cores were closely representative of the area immediately surrounding them than of the park in general. Time-averaged results showed a decline in pine (Pinus sp.) from north to south. All sites showed an increase in poplar and a decrease in charcoal that corresponds with periods of active fire suppression due to agricultural activities around the park. Strong (1991) used palaeolimnological methods in an abiotic investigation of limnic sediments with a temporal range between 1754 to 1910. Changes in sedimentation varied with location, degree and type of disturbance in the vicinity of the collection basin. Several lakes had increased concentrations of organic matter suggesting they received greater quantities of nutrients than during the pre-settlement period. A major increase in silt content in the cores also indicated the principal method of erosion changed, and wind erosion became dominant after settlement. Prior to settlement, poorly sorted sediments indicative of short-distance water transport dominated most of the lake sediments analysed.

British Columbia

Hall et al. (1997) compared diatoms, fossil pigments and historical records as measures of lake eutrophication in central British Columbia. This paper had several objectives, the first being to document the trophic history of Lake William through the analysis of diatoms and algal pigments in a sediment core. The second was to make quantitative estimates of past total phosphorus (TP), based on published weighted-averaging transfer functions from modern diatom data in surrounding lakes, and to compare these inferences with 20 years of recorded TP measurements from the lake. Fossil pigments were analyzed for the purpose of investigating historical changes in algal biomass and community composition, and potential relationships with TP. Results showed that Lake William had been productive throughout the last 200 years. Diatoms typical of alkaline, eutrophic conditions were continuously present between ~1765 to 1990 AD (before the advent of settlement and ranching in the area in ~1860). Fossil pigments indicated the presence and importance of filamentous cyanobacteria, cryptophytes, diatoms, chlorophytes, and siliceous algae or dinoflagellates in past algal communities. Comparison of the diatom-TP weighted average model predictions with measured TP in the lake showed that hindcasts were similar to average summer TP measurements. In contrast, there was no significant relationship between TP and past algal abundance.

6 SUMMARY AND CONCLUSION

Information from historical and palaeological reconstructions in agricultural areas of Canada can provide a gauge of the impact of agriculture to these ecosystems, and provide insight on the change from historic to present biodiversity. This is important in the development of a biodiversity standard for agriculture as an understanding of historic biodiversity in specific locales provides a scale against which current levels of biodiversity can be compared. There are numerous methods available to assist in the reconstruction of ecosystems presently impacted by agricultural activities. Each of the methods is considered effective at particular spatial and temporal scales (Figure 1). However, methods tend to be complementary, with the most informative reconstructions using more than one reconstructive technique. Agricultural areas are some of the most difficult to reconstruct due to intense and prolonged disturbance from clearance, drainage and tillage. The most promising reconstruction techniques in these areas include historical records because they are often abundant in settled locales. There are numerous sources of historical records in Canada (Appendix A), and they provide a firsthand account of conditions at the time of writing. However, historical accounts may or may not have sufficient detail to describe biodiversity at even a small spatial scale (e.g., sub-watershed). Palynological and palaeolimnological studies can provide more quantitative information on terrestrial and aquatic communities in pre-settlement times. A number of indicators of landscape change due to agricultural practices are recognized using these methods. For example, the presence of dandelion and ragweed pollen and increasing proportion of silt in sediment cores often indicate the initiation of European agricultural practices. Remnant forests, if available, (via space-for-time analysis) could be used to reinforce palynological findings and fill in gaps where records are sparse. However, the availability of suitable dendrological specimens is generally a major challenge in agricultural areas. Abiotic evidence may be used to buttress biological findings, but on their own, there is no robust way they could be used to infer biodiversity over the time period under consideration. Modeling is not currently at a state where it could be reliably applied for the task of reconstructing the range of historic ecosystems in agricultural regions of Canada, though it may be worth investigating as a future possibility. The most difficult aspect of reconstructing past ecosystems is determining past terrestrial faunal assemblages. Range maps are available for some species, specimen collections, and other historic documents may be of use, but in situ physical evidence of historic faunal assemblages is difficult to find.

It is very difficult to reconstruct pre-settlement aquatic and terrestrial ecosystem biodiversity with any degree of accuracy, particularly in agricultural regions. Palaeoecological reconstructions can provide information and data that researchers can use to infer past species assemblages, but to reconstruct biodiversity accurately even at relatively small scale is difficult. With maps indicating habitat borders, such as those from surveyor’s notes in central Canada, changes in diversity at a multiple-habitat scale (e.g., a colloquial landscape) can be evaluated. For instance, species diversity can be evaluated within a spatial unit (e.g., watershed) as a function of component habitat composition and configuration, or through relative changes in species numbers between habitats over the watershed (i.e., beta diversity, differentiation diversity). These measures do not necessarily require exact numbers of species present in all habitats or taxons and thus represent a practical method to evaluate biodiversity in agricultural regions given a limited understanding of historic ecosystems. Much of the recent work conducted on the measurement of biodiversity has focussed on the search for organism and landscape indicators (e.g., Waldhardt and Otte, 2003; Duelli and Obrist, 1998). Recognizing biodiversity variability in the natural landscape prior to human settlement can aid in the recognition of suitable indicators and provide information on suitable goals for biodiversity standards. Over time changes in climate, local changes due to natural disturbance (e.g., forest fires) and other factors can impact biodiversity and are part of the natural variability of the system. The smaller the spatial scale, the greater the potential for disturbance and the larger the variability in biodiversity measures. For the purposes of standard development, the recommended spatial scale is at the ecodistrict scale (Figure 4). Ecodistricts are characterized by distinctive assemblages of landform, relief, surficial geologic material, soil, water bodies, vegetation, and land uses (ESWG, 1995). Ecodistricts therefore provide a consistent, well-characterized spatial unit for standard development. Recommended future research initiatives include determining which of the agricultural ecodistricts require consideration for biodiversity standard development and why (e.g., loss of unique Canadian habitat and associated species); what indicators would be most appropriate to assist in developing a biodiversity standard; and appropriate locations and methods for palaeological reconstructions in identified ecodistricts to aid biodiversity development.

There are several problems with using presettlement reconstructions in the development of biodiversity standards. First, ecosystems are not static, and with or without human intervention, they are in a constant state of flux due to natural abiotic and biotic shifts (e.g., in climate, in resource availability, in population persistence and size, etc.). Further, reconstructions are like snap-shots, and data gathered may or may not reflect a healthy and sustainable system. Thus, it may be inappropriate to quantitatively compare biodiversity in a present day agroecosystem to that of a presettlement system in the same location. Secondly, biodiversity is not defined by the nature of the species present, but by the numbers (i.e., numbers of species, and number of individuals within a species). However, a healthy ecosystem is defined by its relative resilience, vigour and organization – characteristics that are predominantly a function of the life histories of, and relationships between, the species that play intrinsic roles in the system. Since presettlement in Canada, numerous species have been extirpated from agricultural areas, while hundreds of non-native species have been introduced. Overall biodiversity may have remained somewhat constant in some agroecosystems. This may, however, not be an indication of comparable health and sustainability within the system.

At a coarser scale, if only classifications of habitat are considered (e.g., wetlands, bogs, mixed forest, etc.), habitat based standards may be developed in some regions based, in part, on presettlement reconstructions. However, such standards would include several assumptions: (1) that restoring or introducing these habitats, where deemed appropriate and possible, will lead to improved biodiversity (2) that the presettlement conditions, on which the appropriateness of the restoration is based, are not unsustainable or ill balanced (3) that the environmental conditions of the site continue to be conducive to the habitat type in question (e.g., climate and landscape structure has not changed in such a way that wetlands will no longer be able to thrive in an area they once did). Clearly, not all agricultural lands can be converted to enhance biodiversity. Thus, presettlement conditions cannot represent achievable standards. Consideration of ecological change as a continuum from presettlement to the present may aid in the development of standards. With the necessary data, it may be possible to pinpoint ranges in time over which the most severe ecological damage occurred in association with habitat loss and fragmentation due to agricultural expansion, and these periods may be used to establish habitat based standards. However, no reconstructive studies have looked at the continuum of land use change, and biodiversity change from presettlement to present.

What may be another appropriate approach is assessing the current environmental conditions of agroecosystems (e.g., soil types, soil moisture, temperature ranges, elevation, precipitation, etc.), and using environmental models (such as that described in Bickford and Makey, 2004) and energy flow models (such as that described in Matsukawa et al., 2006) to predict what native, natural communities of species, presumably of greater biological diversity than an average farm field (particularly monocultures, and/or crops treated with pesticides), could be reintroduced, or allowed to regenerate to enhance the resilience and complexity of the agroecosystem, and the productivity within the non-agricultural elements of the system. Unfortunately, invasive species, as well as the considerable habitat requirements of some desirable species, climate change and anthropogenic land use needs may limit the efficacy of these, and other approaches to improving the health of agroecosystems in Canada.

7 ACKNOWLEDGEMENTS

Cantox Environmental Inc. would like to thank Drs. Dion Wiseman, John Smol, Claude Lavoie, David Patriquin, and Alwynne Beaudoin for providing their knowledge and expertise in response to our survey of the state of pre-settlement reconstruction science in Canada. We would also like to thank Cathy Nielsen, Canadian Wildlife Service, Environment Canada, for her assistance on this project.

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9 APPENDICES

APPENDIX A: Canadian Historic Documents Containing Information About Past Ecosystems: Some Provincial Sources and Recommendations

Manitoba

- University of Manitoba Libraries Archives and Special Collections
- The Sam Waller Museum
- Carberry Plains Archives
- Boissevain Community Archives
- Archives of Manitoba
- McKee Archives, Brandon University
- City of Winnipeg Archives
- Magnacca Research Centre - Brandon Museum
- Heritage North Museum

Saskatchewan

- Northern Saskatchewan Archives
- City of Regina Archives
- Moosejaw Public Library
- Saskatchewan Archives Board
- Rosetown and District Archives
- University of Regina Archives and Special Collections
- University of Saskatchewan Archives
- Melfort and District Museum
- Saskatoon Public Library
- City of Saskatoon Archives
- Saskatoon Archives Board

Alberta

- Sir Alexander Galt Museum
- Athabasca University
- University of Calgary Library
- City of Edmonton Archives
- City of Wetaskiwin Archives
- Glenbow Library and Archives
- Millet and District Museum and Archives
- Provincial Archives of Alberta
- Red Deer and District Archives
- Banff Centre Archives
- University of Calgary Archives
- University of Lethbridge Archives
- Whyte Museum of the Canadian Rockies

Prince Edward Island

- University of P.E.I.
- Community Museums Association of P.E.I.
- P.E.I. Archives

Nova Scotia

- Nova Scotia Provincial Library
- Mahone Bay Settlers Museum and Cultural Centre
- Admiral Digby Museum
- Living History Museum and Gaelic Culture Centre
- Eastern Counties Regional Library
- Cumberland County Museum and Archives
- Dalhousie University
- Dartmouth Heritage Museum
- Annapolis Valley MacDonald Museum
- Halifax Regional Municipality
- Yarmouth County Archives
- Colchester Historical Museum Archives

Newfoundland

- Centre for Newfoundland Studies
- Provincial Archives of Newfoundland and Labrador

New Brunswick

- Provincial Archives of New Brunswick
- New Brunswick Museum
- University of New Brunswick
- Mount Allison University Archives

Quebec

- Eastern Township Research Centre
- Bishop's University

Ontario

- Town of Whitby Archives
- Algonquin College
- Region of Peel Archives
- Queen's University Archives
- Sir Adam Beck Archives
- Simcoe County Archives
- Glengarry Historical Society
- Carleton University Archives
- Esqueing Historical Society Archives
- St. Catherines Public Library
- Sault Ste. Marie Public Library
- Arnprior and District Archives
- Wilfrid Laurier University Archives and Special Collections
- Muskoka Heritage Place
- Perth Museum
- Oshawa Community Archives

Ontario (cont'd)

- Wellington County Museum and Archives
- London Public Library
- York University Archives and Special Collections
- Tweed and Area Heritage Centre
- Upper Canada College Archives
- St. Catherines Museum
- Grenville County Historical Society
- Thunder Bay Historical Museum Society
- Brant Museum and Archives
- Bruce County Museum and Archives
- Kitchener Public Library
- Stratford-Perth Archives
- Laurentian University
- Dufferin County Museum and Archives
- Windsor Public Library and Municipal Archives
- Jordan Historical Museum
- Scarborough Archives
- Eva Brook Donly Museum

Ontario (cont'd)

- County of Grey - Owen Sound Museum
- Ryerson Polytechnical University Archives
- Markham Museum and Historic Village
- University of Waterloo Archives
- Grimsby Archives
- University of Ottawa
- Brock University Archives
- Canadian Council of Archives
- Guelph Public Archives
- Osgoode Township Historical Society and Museum
- Heritage Renfrew

British Columbia

- Oliver and District Heritage Society Museum and Archives
- Cowichan Historical Society
- Matsqui - Suma - Abbotsford Museum Society
- Greater Vernon Museum and Archives
- Fort St. John - North Peace Museum
- Bulkley Valley Historical and Museum Society
- City of Surrey Archives
- Kelowna Museum Archives
- Summerland Museum and Heritage Society
- Delta Museum and Archives
- South Perace Historical Society
- Quesnet and District Museum and Archives
- Pitt Meadows Museum and Archives
- Simon Fraser University Archives
- University of Victoria Archives
- Northern British Columbia Archives
- British Columbia Archives Library

Appendix B: Results of Provincial Sources Survey for Canadian Historic Documents Containing Information About Past Ecosystems

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Nova Scotia					
Bedford Institute of Oceanography	none	(1) The last billion years: a geological history of the maritime provinces of Canada. Atlantic Geoscience Society, 2001. (2) The Natural History of Nova Scotia: Vol 1. Topics and habitats, Vol 2 Theme Regions. The Nova Scotia Museum, 1996.	Museum of Natural History	none	Recommended reading located at Carleton University in Ottawa
Admiral Digby Museum	none	none	none	none	none
MacDonald Museum	Museum of Natural History	none	none	none	none
Dartmouth Heritage Museum	(1) Museum of Natural History, 902-424-7370 (2) Nova Scotia Archives and Records Management 902-424-6055	(1) Schubenacadie Canal plans and related maps 1820 to 1870.	none	The central core of what is modern day Dartmouth was a salt water marsh area fed by a series of lakes and streams prior to the construction of the Schubenacadie canal system. The marsh was effectively drained, new waterways constructed, small ponds in filled and so forth as part of the construction process.	Investigated recommended readings and found them to be extraneous. Contact has yet to be made with Nova Scotia Archives and Records Management.

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Cumberland County Museum and Archives	Nappan Experimental Farm	none	none	…we do charge a research fee. We probably have information on salt marshes that might be valuable to you….typically an inquiry takes two hours plus photocopies and postage. We require your mailing address, phone number and the maximum you are willing to pay. You can pay by cheque or money order.	Contact has yet to be made with Nappan Experimental Farm.
Nova Scotia Museum Library	Killam Library at Dalhousie	http://museum.gov.ns.ca/mnh/nature/umbrella2.htm	none	none	Recommended readings have been downloaded and read.
Colchester Historical Archives	none	(1) Andrew Hill Clark. Acadia: The geography of early Nova Scotia to 1760. University of Wisconsin Press, 1968. (2) Philip A. Buckner and John G. Reid (eds.), The Atlantic Region to Confederation: a history. University of Toronto Press, 1994. (3) The reports of surveyor Charles Morris (see Dictionary of Canadian Biography, www.collectionscanada.ca)	none	none	Located recommended reading (1) and (2) at Carleton University Library. Located recommended reading (3) at National Archives

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Map Collection Killam Library, Dalhousie University	(1) Nova Scotia Museum of Natural History, http://museum.gov.ns.ca/mnh/collections.htm (2) Land Information Centre (Service Nova Scotia and Municipal Relations) (3) http://www.gov.ns.ca/natr/library/OLDMAPS.html (4) http://www.gov.ns.ca/nsarm/databases/land/ (5) the National Library and Archives	(1) Davis, Derek S. The Natural History of Nova Scotia, 1996 (2) Haliburton, Thomas Chandler, 1796 to 1865. General description of Nova Scotia 1819.	none	none	Located all recommended readings at Carleton University Library.
New Brunswick					
University of New Brunswick	none	Edward Winslow papers	none	none	Located recommended reading at National Archives
Provincial Archives of New Brunswick	none	none	none	none	none
New Brunswick Museum	none	none	to the Curator of Botany	none	none

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
New Brunswick Museum	(1) Dr. Les Cwynar, a palaeoecologist, Dept. Biology, University of New Brunswick (cwynar@unb.ca) (2) Dr. Judy Loo, tree geneticist, Canadian Forest Service Maritimes (jloo@fcmr.forestry.ca) Her graduate student is presently working on vegetation history of Kouchibouguac National Park, NB	(1) Flora of New Brunswick (2) Lutz, S.G. 1997. Pre-European settlement and present forest composition in Kings County, NB. Graduate thesis, Faculty of Forestry and Environmental Studies, University of New Brunswick.	none	I will be sending you a reprint of the introductory chapter of the book Flora of New Brunswick titled 'History, physical setting, and regional variation of the flora' by New Brunswick Museum curator of botany Stephen Clayden which summarizes the available literature relating to "historic terrestrial and aquatic ecosystems"	Located recommended reading (1) at Carleton University Library. (2) Have yet to locate recommended reading (2).
Prince Edward Island					
none	University of Prince Edward Island	none	yes (unknown)	none	none
Ontario					
Laurentian University	none	none	(1) Lise Doucette, librarian	provided a summary of the aspects of the collection she thought would be of use (attached to email)	References supplied were scanned, and found to be extraneous.
Brock University	(1) Guelph University (2) Guelph Public Library (3) Vineland Research Station (4) Niagara Parks School of Horticulture (www.niagaraparks.com/nature/school.php (5) archeion-aao.fis.utoronto.ca	none	none	none	Yet to contact Vineland Research Station. Other suggested contacts deemed extraneous to the current project.

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Simcoe County Archives	none	none	none	stated that the County Archive has a great deal of information that would be pertinent, but that someone would have to visit the archives in order to sort through available information.	none
Upper Canada College	none	none	Helen Mills and Peter Hare	none	none
St. Catherines Public Library	Vineland Research Station (now in Guelph)	none	none	none	Vineland Research Station has yet to be contacted.
Thunder Bay Museum	none	Hudson's Bay Company journals	none	none	Recommended reading available at National Archives.
Queen's University	Queen's Department of Biology	none	none	seeking input from other staff members	none
Oshawa Museum	Tammy Robinson (trobinson@oshawalibrary.on.ca), local history librarian	none	none	archives closed due to fire	Yet to make contact with Tammy Robinson.
Kitchener Public Library	Mennonote Archives of Ontario (Sam Steiner, steiner@library.uwaterloo.ca) and The Doris Lewis Rare Book Room (Susan Saunders Bellingham, sbelling@library.uwaterloo.ca)	none	none	none	Yet to contact the Mennonite Archives of Ontario

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Huntsville Public Library	none	(1) Muskoka and Haliburton 1616-1875 (2) Report of the Master Plan of Heritage Resources of District Municipality of Muskoka and the Wahta Mohawks (3) Algonquins of Golden Lake Claim (4) A pre-settlement fire history in an oak pine forest near Basin Lake Algonquin Park	Joan Hyslop	none	Recommended readings (1), (3) and (4) available at the National Library. Recommended reading (2) yet to be located.
Osgoode Township Historical Society and Museum	National Archives	(1) Military surveys for the rideau Canal (2) settlement surveys made for the Government Land Grants	none	none	Yet to locate recommended readings.
University of Waterloo Library	none	none	none	none	none
Grimsby Archives	none	none	none	none	none
Arnprior and District Archives	none	none	none	"We have some records which may be of value to your study from the scientific observations of Charles MacNamara, a field naturalist, photographer and entomologist who wrote extensively about the natural phenomena of the area around Arnprior from approx. 1900 to 1940s"	Yet to follow up on the documents of Charles MacNamara

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Muskoka Heritage Place	none	none	(1) Sarah White, Museum Assistant (2) The local library	Requires $25/hr for ~4hr search of holdings	Yet to locate recommended reading (1). Recommended reading (2) located at National Library.
Brock University	none	(1) www.statcan.ca/english/freepub/98-187-XIE/index.htm (2) www.statcan.ca/english/freepub/11-516-XIE/sectiona/toc.htm	none	"Official census records for Canada started in 1871"	none
Manitoba					
Carberry Plains Archives	(1) Manitoba Department of Natural Resources (2) the Archives of Manitoba	none	none	none	none
City of Winnipeg Archives	(1) Archives of Manitoba (www.gov.mb.ca/chc/archives) (2) Hudson Bay Company Archives (www.gov.mb.ca/archives/hbca/index.html)	none	none	none	none
Boissevain and Morton Regional Library	none	none	none	none	none
University of Manitoba	none	none	none	none	none
Daly House Museum	none	none	none	none	none
Sam Waller Museum	(1) Provincial Archives (2) University of Manitoba	none	none	none	none

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Brandon University		www.brandonu.ca/library/archives/PrivateMan/Wallace_%20fonds.htm	none	none	none
Saskatchewan					
Saskatoon Archives	Provincial Archives	Hinde and Palliser expeditions	none	none	Recommended readings located at National Archives.
Saskatchewan Provincial Archives	none	none	reference programme	none	none
University of Saskatchewan	Provincial Archives (www.saskarchives.com)	(1) The Kelsey Papers (2) The Matador Project	none	none	Recommended reading (1) located at National Archives. Recommended reading (2) deemed extraneous based on internet search.
University of Regina	none	Exploration-British North America: papers relative to the exploration by Captain Palliser of that portion of British North America which lies between the northern branch of the River Saskatchewan and the frontier of the United States; and between the Red River and Rocky Mountains	none	none	Recommended readings located at National Archives.
Saskatchewan Archives Board	info.regina@archives.gov.sk.ca, Hudson's Bay Company Archives (www.gov.mb.ca/chc/archives/hbca/index.html)	none	none	Ask about Dominion surveyors	Have yet to receive reply to inquiry to Provincial Archives at Regina

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
	Hudson's Bay Company and Archives Canada	The publications of the Hudson's Bay Record Society: Moose Fort journals 1783-85. -- London: HBRS, 1954.	none	none	Recommended readings located at National Archives.
Alberta					
The Banff Centre	none	none	none	none	none
University of Calgary	[Archives Society of Alberta website](http://www.archivesalberta.org/) http://www.archivesalberta.org/	none	none	none	Archives Society of Alberta has yet to be contacted
Glenbow Archives	University of Calgary Maps (for old aerial photos)	none	none	none	aerial photos deemed extraneous to the current project.
British Columbia					
City of Surrey Hertitage Collections	(1) Provincial Archives (2) Vancouver City Archives (3) Richmond City Archives (4) Fort Langley (5) Gulf of Georgia Cannery (5) New Westminster Public Library (6) UBC (7) Simon Fraser University (8) BCAUL site (BC Archival Union List), aabc.bc.ca/aabc/bcaul.html	none	none	none	none
Royal British Columbia Museum	none	none	none	none	none
Simon Fraser University	British Columbia Archival Union, aabc.ca/aabc/bcaul.html	none	none	none	British Columbia Archival Union has yet to be contacted

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Peace River	www.calverly.ca	(1) Daniel Williams Harmon (1810-13) (2) Charles Horetzky (1872-73) (3) John Macoun (1873) (4) ARC Selwyn (1875) (5) Gerorge Mercer Dawson (1879) (6) James Macoun (1903) (7) J.A. Macdonell (1905-06) (8) A.M. Bezanson (1906)		none	Recommended readings (1)-(3) and (7) located at National Archives, the rest have yet to be located.
Quesnel City	none	none	none	none	none
University of Victoria	(1) BC Archives, www.bcarchives.gov.bc.ca/index.htm (2) Marine Environmental Science Archive, gateway.uvic.ca/archives/featured_collections/esa/default.html	Carnation Creek History Project Fonds	Ophelia Ma, Biology subject Specialist	none	Recommended reading located at the National Library.
Oliver and District Heritage Society	(1) BC Ministry of Sustainable Resource Management Web Site, srmwww.gov.bc.ca/tib/ (2) South Okanagan-Similkameen Conservation Program Species and Habitat Info, www.soscp.org/species (3) The Osoyoos Desert Centre, mail@desert.org (1-877-899-0897) (4) www.nkmipdesert.com	(1) Okanagan Historical Society Report No. 1 (1926) "A Unique Faunal Area in Southern BC" (2) Webber, Jean "Recent Modifications to the Landscape" in "A Rich and Fruitful Land: The History of the Valleys of the Okanagan Similkameen and Shuswap"	none	none	Yet to locate recommended reading (1). Recommended reading (2) located at National Library.
University of Northern British Columbia	BC Provincial Archives	none	Gail Curry, Data Librarian	none	none
University of Northern British Columbia	(1) Susanne Barker, www.for.gov.bc.ca/hfd/library/ (2) Atlas of Canada (3) Stats Canada (4) MapPlace .ca	none	none	none	Suggested links pursued, and found to be extraneous to the current project.

Association	Suggested Contacts	Recommended Reading	Forwarded request	Other Info	Follow-up
Cowichan Valley Museum and Archives	BC Provincial Archives, www.bcarchives.bc.ca	none	none	none	none
Bulkley Valley Smithers Museum		none	none	none	none
Quebec					
Bishops University	(1) www.ubishops.ca/library_info/old-library.htm (2) www.ubishops.ca/library_info/timeline.htm	none	none	none	none
Bishops University	Library and Archives Canada	none	none	none	none
Newfoundland and Labrador					
Memorial University of Newfoundland	www.library.mun.ca/qeii/cns/	none	none	none	none

APPENDIX C: Short Summaries of Reconstructions in Agricultural Regions of Canada

Terrestrial

Historic Records

Pile (1969)

Pile (1969) studied the vegetation cover present prior to European settlement of Tuscarora township in Southern Ontario. Government land survey records from 1780 (Government of Upper Canada) contained information on changes in vegetation cover along concession lines, locations of water bodies and courses, land cover and distance, soil type and other parameters. The survey records indicated that there were 11 tree types commonly identified by the surveyor. These species included sugar maple (*Acer saccharum*); american beech (*Fagus grandifolia*); oak (*Quercus alba* and *Quercus ruba*); white pine (*Pinus strobus*); basswood (*Tilia americana*); ironwood (*Ostrya virginiana*); elm (*Ulmus americana*); hickory (*Carya ovata*); trembling aspen (*Populus tremuloides*); black ash (*Fraximus nigra*); and tamarack (*Larix laricina*). Based on the data on tree types presented in the survey records, Pile (1969) created trend surfaces to determine the likely distribution of each tree species throughout the study area. Pile (1969) performed a second investigation using association analysis, based upon the degree of relationship between major or minor hardwoods and coniferous species and hardwood types on each lot in the study area. Finally, the author examined the role of cultural and physical environmental influences upon forest cover. Based on these analyses, Pile (1969) concluded that although the likely tree species composition can be reconstructed from information in the land survey records, they do not provide sufficient data and information to present a complete picture of the vegetation cover. Cultural and physical environmental influences and the existence of a relationship to vegetation cover can be discerned from the survey records. However, the relative influence of these factors cannot be determined. Pile (1969) reported that the major data limitations encountered in the survey records included the lack of detail on vegetation, including measurements of tree diameters, soils and the exact extent and nature of clearing.

Archibold and Wilson (1980)

Archibold and Wilson (1980) reconstructed the historic natural vegetation of southern Saskatchewan using all of the 2,500 township plats (*i.e.*, maps) that were compiled during the Dominion Lands Survey of the late 19th century within the Province. Plats were obtained from the Saskatchewan Provincial Archives. They contain symbols identifying land cover along section lines that were one and two miles apart running north-south and east-west, respectively (Tracie, 1997). Only north-south section lines were used to estimate percent cover. A digital map was created that was broken down into six categories: grassland, woodland, scrub, brule (fire scarred), marsh and open water. The final map covers approximately 250, 000 km^2 at a scale of 1: 5,000,000. Though the purpose of the study was only to provide a baseline of comparison for natural vegetation distribution, Archibold and Wilson (1980) were able to conclude that groveland and woodland has increased over the past century in the study area. This conclusion was supported by the palynological evidence of Mott (1973). No direct influence of agriculture was reported; this was only a reconstructive exercise.

Tracie (1992)

Tracie (1992) conducted a reconstruction of pre-settlement vegetation in the Peace River District of Alberta. Surveyors' notebooks from 1904 to 1910 (obtained from the Ontario Provincial Archives) were used to reconstruct the vegetation structure of a 6,000 km^2 study area on a quarter section (*i.e.*, approximately 65 hectares) basis. The resulting map illustrated the spatial extent and configuration of eight categories of land cover: grassland, groveland, transitional groveland, scrubland, forestland, poorly drained (open), poorly drained (treed) and no information. Each of these classifications were made on the basis of relative coverage of grass and trees, and drainage, based on notes made along section lines at regular intervals (one or two miles depending on the orientation of the line). No direct influence of agriculture was reported, this was only a reconstructive exercise.

Brisson and Bouchard (2003), Paquette and Domon (1997)

Records less commonly used in reconstructions of agricultural areas in Canada include notary deeds that often document wood sales, and census data. In Quebec, notary deeds have been used to document changes in tree taxa composition and configuration. Brisson and Bouchard (2003) were able to document losses of American beech, yellow birch, tamarack and black spruce from the Haut-St-Laurent region through an analysis of wood sales records within notary deeds. Through the examination of present day lots, they were able to determine that maple and ash had increased in abundance since settlement. Paquette and Domon (1997), also working in the Haut-St-Laurent region of Quebec, used census data to document changes in land cover over the course of land settlement. Their results do not document vegetation cover type, but conversion to agriculture and amount of wooded land, as was reported in censuses in the late 19th century in Quebec.

Hanuta (1999)

Hanuta (1999) executed a reconstruction in Manitoba comparable to that of Archibold and Wilson in Saskatchewan. Historical township maps (constructed from land surveys from ~1872 to 1877) held by the Provincial Archives of Manitoba were used to reconstruct vegetation patterns for parts of southern Manitoba. The purpose of the study was to obtain detailed classification of the state of the landscape prior to mass settlement. The study area was approximately 10,000 km^2. Information extracted from township plans included amounts of prairie land, wooded area, wetlands, scrub vegetation and water bodies. The primary landscape categories were previously determined through the process of *content analysis*, a method to extract quantitative information from textual material. Root words and phrases were identified and assigned for each of the four landscape target areas. Other land cover descriptors were grouped into one of the four target categories. For instance Woodland areas included 'timber',' woods', and specific species, such as 'poplar', 'oak' and 'elm'. Original township maps were digitised and georeferenced. The result is a 1: 250,000 scale map comprised of 134 individual township maps. There were cases in which no data is reported, for instance, where data were only recorded along survey transect lines.

Jackson et al. (2000)

In central Ontario, Jackson *et al.* (2000) performed a reconstruction along a 278 km transect that bisects the current transitional boundary between the Great Lakes-St. Lawrence forest along the shores of Lake Superior and the boreal zone. Ontario land survey notes of 1857 (archived at the Crown Land Surveys, Natural Resources Information Branch of the Ontario Ministry of Natural Resources located in Peterborough, Ontario) were used. The purpose of the study was to assess the change in forest composition by comparing survey notes with current Forest Resource Inventory (FRI) data recorded between 1981 and 1995. The original survey notes contained reports of vegetation cover for 30 township boundaries, including: descriptions of each forest stand on e transect, corresponding township names, locations of stands within townships (starting point), the cross-sectional extent of the stands in chains (0.0201 km) along the township boundary line, and a list of tree taxa present in each stand. Stands were defined by changes in taxa composition, or changes in the order of taxa listing. A total of 338 individual stands were present in the survey notes. FRI data were modified for comparison with 1857 data. Two detrended correspondence analyses were carried out to establish changes in composition over time. In the first, for each data set, the length of each township boundary occupied by the various dominant species was expressed as a percentage of the total length of forest cover along the township boundary. In the second, instead of using only the dominant species of a stand, all species mentioned within the stand were given equal rank. Results of the two ordinations were similar. Univariate statistics were used to test for changes in dominant species composition for the distinct east and west township groups. The ordination indicated a change in ecosystem type at the approximate mid-point of the study transect. The study showed that large-scale changes in forest composition have taken place in the forests of central Ontario over the past 140 years. In the eastern townships a significant increase in shade intolerant hardwoods at the expense of conifers has occurred, and has been attributed to clear-cutting over the past 50 years. In the western townships an increase in maple was observed, as well as the continued dominance of yellow birch. A noted increase in poplar along the transect was attributed to small-scale land clearing, and clearing for agriculture.

Loo and Ives (2003)

Loo and Ives (2003) examined the Acadian Forest Region in three Maritime Provinces of Canada to characterize the forest species that existed prior to European settlement in the 1600's. The authors used historic records and past research in the area (*e.g.*, palynology – Strang, 1970) to conduct their research. The general findings suggest that the Acadian forest has been substantially altered by human activities. There are now larger numbers of balsam fir, red maple, white spruce, white birch and trembling aspen. Abandonment of farmland has aided in an increase of white spruce. Fire suppression has increased over the last 50 years reducing the habitat for fire-adapted species. The authors also examined the impact of the changing forest since pre-settlement time on species of mammals in the Acadian forest. Substantial change has occurred with many of the large mammals (e.g., eastern cougar, gray wolf, deer, moose, caribou). The extreme habitat loss from clear cutting of the forests for agriculture, ship building and other uses has resulted in many of these species being extirpated from the region.

Suffling et al. (2003)

In a 2003 report by Suffling *et al*. (2003) two southern Ontario case studies were conducted, to determine pre-settlement forest composition and broad scale compositional changes since settlement. Both involved the use of 19th century survey data. The first was a study conducted in Darling Township that employed land survey data collected in 1822. The notebooks of William Kilbourn (surveyor) were transcribed and digitized in a GIS. 1960 FRI data were similarly digitized as a ‘current’ comparison. An algorithm was applied to both sets of data in order to classify forest communities based on ranked species present. The results showed increases in deciduous forest, decreases in mixed forest, and an overall increase in non-forested land. Hemlock dominated half the township before settlement, but dominated none of the township in 1960. Similarly, domination of spruce and tamarack in 10% of the township each in 1822, was entirely lost by 1960.

The second study reported in Suffling *et al*. (2003) was conducted in Bruce Peninsula National Park (Lindsay and St. Edmunds Townships). Methods were identical to that of the Darling Township study, only land surveys occurred in 1855, and suitable current FRI data were available for 1978. In 1855, surveys show that the entire study area was forested. Results show hemlock that formerly dominated in 41% of the study area has been virtually eliminated. Similarly, beech stands have been lost due to the presumed influences of agriculture and grazing. Tamarack, white ash, elm, fir and pine have also been drastically reduced or eliminated as dominant species within the study area. Birch, poplar and maple are succeeding in abandoned fields, and white cedar has replaced logged and burned pine stands. By 1978, 24% of the study area had been cleared. Evidence complimentary to these results came from logging production statistics for St. Edmunds Township.

Palynology

McAndrews and Boyko-Diakonow (1989)

Crawford Lake, Ontario, was the site of a palynological investigation of agricultural settlement by McAndrews and Boyko-Diakonow (1989). A sediment core collected from the lake bottom in 1971 was used in the study. Varves were sampled in 5 to 10 year increments from 1970 to 1000 AD. Pollen was concentrated by digestion with acid, and 400 to 1,000 grains were identified in each sample. Results indicated two periods of agricultural development. The first was of native Canadian origin, and was marked by the appearance of corn, weedy grasses and purslane in the pollen record. The second agricultural period was that of European settlement. European settlement is associated with land clearing in the area, and this is clear in the pollen record. The appearance of, or increase in sorel, grass and ragweed was indicative of land clearing between 1820 and 1840. With the expansion of weed and cultivated plant pollen, most tree pollen declined. However, some tree species appear to have carried on strongly through settlement in the area (either holding their own or expanding), such as elm, poplar, birch and cedar.

Campbell and Campbell (2000)

Campbell and Campbell (2000) used pollen and charcoal analysis to investigate the effects of land use history on the vegetation of Elk Island National Park, Alberta. The Park is located at the southern transition from boreal forest to aspen parkland, and agriculture is one of the land uses in the area. Three sites were selected on a north-south transect that total <17 km in length. Pollen and charcoal results differed significantly between the three sampling locations, presumably because samples were more representative of the area immediately surrounding them than they were of the study area in general. Time-averaged results showed a decline in pine from north to south. All three sites showed a historic increase in poplar and decrease in charcoal that corresponds with periods of active fire suppression and unintentional fire suppression due to agricultural activities around the park.

Strong (1977)

Strong (1977) used the distribution of pollen in a large area of southern Alberta to determine the impact of human settlement on the natural vegetation of the area. The area studied was approximately 98,000 km^2 with three general vegetation formations including short grass prairie, mixed grass prairie, and Aspen parkland. Sediment cores were sampled from nine lakes in the region, with a minimum of two cores from each major sediment location. Modern vegetation formations in southern Alberta were identified from the percentage of pollen species in the first 0-1 cm of core. The location of pre- and post-settlement vegetation boundaries was based on changes in the pollen percentages that coincided with changes in the texture of clastic sediments, and carbonate and organic content. Common dandelion (*Taraxacum officinale*) native to Europe and Russia, and introduced into North America during European settlement was also used as an indicator of the pre- and post settlement boundary. The presence of *Chenopodiaceae/Amaranthaceae* pollen was also used as an indicator of settlement and land-use change. The author suggested that prior to settlement, the vegetation in southern Alberta consisted of four vegetation formations 1) short grass prairie, 2) mixed grass prairie, 3) fescue grassland, and 4) groveland belt of the aspen parkland. The land area of these formations was determined to be somewhat different relative to their present day ranges. For example, short grass prairie was thought to have expanded, possibly due to the impact of grazing on the mixed grass prairie. The mixed grass prairie had a reduced aerial extent, haven given way to the short grass prairie. European settlement appears to have had major effect on the vegetation in southern Alberta. Fire control, elimination of the bison, grazing, and agriculture are the major factors that led to this modification. Difficulties encountered in the study included the identification and removal of pollen from extra-regional areas that would interfere with the regional analysis. For example, *Pinus* and *Picea* pollen are easily identified and removed. It was impossible to identify and remove other prairie grass species pollen that may have interfered with the regional analysis.

Mott (1973)

Mott (1973) examined palynology of four sites in central Saskatchewan to determine the late-glacial and post-glacial vegetations and climatic history of the area. Lake sediment cores were taken and analysed for pollen samples and radiocarbon dated. The four sample lakes were widely separated geographically and were from different vegetation zones. Therefore, individual pollen assemblages were required for each of the areas surrounding the four study lakes. The author reported that spruce trees were abundant in late glacial time. Periods of drought and glaciation markedly altered the plant assemblages from spruce forest to grassland and back again. The authors indicated that to have a better understanding of the impact of these cycles on the regional vegetation, further study was required.

Multi-technique Approaches

Lepofsky et al. (2003)

In southern British Columbia Lepofsky *et al*. (2003) used a multitechnique approach to investigate the origins Chittenden Meadow, a small (<10 ha) opening in a matrix of riparian vegetation on the floodplain of the Skagit River. The meadow had been subject to grazing in the late 19th century. Dendrochronological techniques were applied to mature ponderosa pine (*Pinus ponderosa*) in and around the meadow to determine timing of establishment. To locate documented use of fire by aboriginal people near the meadow, ethnographic reports and other historic documents were searched that pertained to aboriginal bands in the region. The meadow itself was searched for archaeological evidence of use. Sixty small test pits were dug, and excavated to the C-horizon. Four depressions suspected to be cultural in origin were also excavated. Charcoal remains found in these sites were dated to develop a fire history within the meadow. There are distinct differences between forest and meadow soils. Soil profiles were recorded in the meadow and in the surrounding forested area in order to determine the pedagogical history of the study area. Dendrochronological analysis was again applied, this time to determine the timing of modern tree encroachment on the meadow. The species, height and age of all trees were documented in three 15 m wide belts crossing the meadow and extending 20 m into the surrounding forest on either side. Results indicated that the meadow was of ancient non-human origin. Soil profiles differed dramatically between the meadow and the surrounding forest. Tree encroachment into the meadow was not synchronous with local flooding, fire exclusion or the cessation of grazing. There was also evidence of previous generations of Ponderosa pine in the meadow, indicating that the meadow has been distinct from the forest for hundreds of years. It was concluded that the Chittenden Meadow was a consequence of landform, climate and fire.

Lavoie and St-Louis (1999)

Lavoie and St-Louis (1999) reconstructed the spread of grey birch (*Betula populifolia*) in the Bas-

St-Laurent region of Quebec using herbarium specimens, historic botanical surveys, aerial photographs, company records and dendrochronology. Herbarium specimens of grey birch and a related hybrid were requested from 24 herbaria, from three provinces and the United States. Data on selected specimens were incorporated into a GIS. Historic botanical surveys conducted in the Bas-Saint-Laurent region were carefully consulted for any mention of grey birch. Because grey birch is commonly found in mined peatlands in the region, all mined bogs located between Riviere-Ouelle and Matane were visited during the summer of 1997 to check for the presence of the species and to find the oldest individual on each site. Mining histories of the bogs in the area were reconstructed using aerial photographs from 1930 to 1995 and archived documents from peat companies. In each peatland, every grey birch >2 m in height was sampled. Individuals were positioned using a GPS. Tree cores were taken from all sampled trees. Samples of old-field patches (63 sites) were investigated in the same way as abandon peat mines within the geographical limits of the species between 1965 and 1994. Results indicated that migration of grey birch was greatly facilitated by the presence of large abandoned peat mines, and that old field patches were numerous, but to small to encourage substantial invasion by grey birch.

Pellerin and Lavoie (2003)

Pellerin and Lavoie (2003) reconstructed historic vegetation dynamics of 16 mires on an agricultural plain in the Bas-St-Laurent region of southern Quebec (a 176 km^2 study area). The study employed dendroecological techniques, the analysis of plant macrofossils and pollen, and the examination of aerial photographs. Mires ranged in size from 1.5 to 157.7 ha, and 400 m^2 sampling quadrats were selected in each based on aerial photographs and pre-study vegetation sampling. In each quadrat, 75 randomly selected stems were cored for dendroecological analysis. A peat monolith was extracted at the center of each quadrat for macrofossil analysis, and complete peat cores were extracted from seven of the mires for pollen analysis. The recent evolution of the forest cover in each mire was analyzed using 13 series of aerial photographs taken between 1948 and 1995. Images were digitised and classified using digital image processing software. Drainage ditches were also digitized to investigate the potential impacts of these features on the mires. No fire scars were found in any of the 16 mires, but charcoal layers were found in the peat monoliths. Fire dates were determined through interviews with landowners and linear interpolation from the pollen settlement/farming marker (*c.* 1800). Results of this study indicate that prior to European colonization in the area, mires were open and dominated by *Sphagnum* mosses. Many sites in the study area have since become forested, and have little or no *Sphagnum.* Aerial photographs indicate that between 1948 and 1995 forest cover in the mires increased from 22.5 to 56.5%. A dry climatic period, human induced drainage and fire appear to be the primary causes of vegetation change.

Lachance and Lavoie (2004)

Plant species assemblages of ombrotrophic peatlands in the Bas-Saint-Laurent region are heavily influenced by human activities. Lachance and Lavoie (2004) used spatial analysis, reference sites, and palaeoecological data and information from Pellerin (2003) to evaluate the relative influence of anthropogenic factors on the distribution of plants species and to characterize plant assemblages in the peatlands. Detrended Correspondence Analysis (DCA) and Canonical Correspondance Analysis (CCA) were used to relate vegetation gradients to abiotic and spatio-historical variables, and community structure. The authors reported that anthropogenic factors accounted for the majority of the change in species assemblages in the peatlands studied. Abiotic factors (*e.g.*, water table level, peat thickness) accounted for 17% of the variation. Agriculture and other anthropogenic activities are therefore highly disruptive to plant assemblages, even in relatively disturbance resistant systems (*i.e*., peatlands).

Boyle et al. (1997)

Boyle *et al*. (1997) performed a reconstructive study in the Lower Fraser River Basin of British Columbia. Previously published data, air photos and other historic material were used to map the 828 km^2 study area between Hope and Vancouver. The purpose of the study was to investigate land cover changes in the basin between pre-1827 and 1930, and 1930 and 1990. The study area vegetation was grouped into categories for each time interval. One of ten classifications was assigned to the land cover including: coniferous forest, deciduous forest, mixed forest, fen, swamp, bog, marsh, cleared, agriculture and urban. Not all of the same types of historic records were available for each of the study years. To reconstruct the pre-1827 land cover of the basin, Snell's method (1987) of examining current soil types to determine past land cover was used. A detailed current soil survey of the area was correlated with descriptions and data from historical and other accounts. For instance, soils classified as gleysols and organics were assigned to fens and swamps/marsh/bog according to their nearest equivalent as was determined from the data in of North *et al*. (1979), North and Teversham (1984) and Kelley and Spilsbury (1939). Forest age structure was estimated based on historical accounts of tree sizes. There were insufficient data to determine the forest types and changes with elevation; thus, only two forested communities were identified, coniferous forest and deciduous/mixed forest. The original configuration of the lakes in the study area was determined using maps of the New Westminster District (1905). Aerial photos from 1930 were used to characterize the 1930 land cover, along with data from logging accounts as related by McCombs and Chittenden (1990) and available forestry data (Forest Branch, 1930). Landsat imagery was used to characterize the 1990 land cover, along with forestry inventory data, a land-use map of the Lower Fraser Valley (Moore, 1990), and an inventory of wetlands in the basin (Ward *et al*., 1992). The boundary for each land cover class was transposed onto a copy of the Landsat image for each of the three time periods, and then digitized. Land cover class areas were calculated using the digitized data.

Existing literature and ongoing research were used to assess the effects of changes in land cover on water quality and volume and air quality. Enough research had been completed on soil carbon in the Lower Fraser Basin to be able to calculate the change in soil carbon since 1827. A loss of 20% from agricultural soils and a loss of 32% from urban soils were the conservative estimates. No data on net primary productivity (NPP) could be found for ecosystems in the Lower Fraser Basin, so values from similar ecosystems were used to provide estimates of NPP.

Changes in plant populations and aquatic life were assessed through existing literature and ongoing research. Discussions with BC Ministry of Environment, Lands and Parks wildlife biologist Bob Forbes indicated that little is known about the size of the animal populations prior to European arrival in the basin. Using estimates of land cover prior to 1827 and knowledge of specific animal species' behaviour, an estimate of the number of each animal species that would have occupied the valley was made.

Results included:

- Documentation of changes in area and percentage of each of the 10 classes of land cover over the time period under investigation;
- Estimates of changes in tree species abundance, including documentation of the loss western white pine and yellow cypress, and the significant decline of western red cedar and Sitka spruce. Douglas fir, western hemlock and balsam fir considerably increased;

- A decline in mean forest age occurred between <1827 and 1990;
- 43% of organic carbon has been lost from the soil due to land cover change since <1827;
- Nutrient loading and pesticides (from agriculture) have caused fish and bird kills in the basin.
- NPP has decreased by 15% since 1827;
- In addition to the loss of plant communities over the past 100 years approximately 5% of native plant species have become locally extinct in the Lower Fraser Basin, primarily due to urbanization and clearing for agricultural purposes (Boyle *et al*., 1995). The introduction of alien species has resulted in the replacement of native vegetation, with the result that 41% of all plant species in the Fraser Valley are now non-native (Boyle *et al*., 1995);
- Black bear has decreased, black-tail deer has increased, while Roosevelt elk and grizzly bears have been extirpated, and water fowl have declined dramatically between <1827 and 1990. (data from Environment Canada, 1992); and,
- Changes in water quality and quantity have impacted upon salmonid populations between <1827 and 1990.

<u>Herbarium Specimens</u>

Lavoie et al. (2003)

Lavoie *et al*. (2003) determined the impact of exotic species on wetland plant diversity and reconstructed the spread of invasive species in the St. Lawrence River wetlands. Sampling stations (n=713) along a 560 km corridor of the St. Lawrence River were used and historical analysis was carried out to establish the year of arrival for the invasive species. This was accomplished using herbarium specimens from the five main herbaria in Quebec, and two

Canadian government herbaria. Year of sampling, location and species information for each specimen was used to reconstruct spread of invasive species over the past two hundred years. Botanical surveys conducted in the study area were also scanned for any mention of exotic species and their abundance. Data were entered into a geographical information system (GIS). A total of 2,667 herbarium specimens were examined, including common reeds, flowering-rush and purple loosestrife. 1965 specimens were actually used in the reconstruction process. Few species were sampled before 1926, though flowering-rush was first collected in 1905, purple loosestrife in 1883 and common reed in 1820. Between 1926 and 1950, flowering-rush and purple loosestrife spread rapidly along the St. Lawrence River. Purple loosestrife has continued its expansion, while the spatial distribution of flowering-rush has not changed much since 1950. Common reed expanded its range after 1950. There is a weak linear relationship between exotic species cover and species richness, which may reflect the impact of exotic plants on native species. However, there is no relationship between the relative exotic cover and the diversity of wetland plants. In fact, low diversity sites can be dominated by either an exotic species or a native plant species. In other sites, exotic species seem to have had little impact on plant communities and can even contribute to increased diversity.

Aquatic

Sediment Cores

Hall et al. (1997)

Hall *et al*. (1997) compared diatoms, fossil pigments and historical records as measures of Lake eutrophication in central British Columbia. This paper had several objectives, the first being to document the trophic history of Lake William through the analysis of diatoms and algal pigments in a sediment core. The second was to make quantitative estimates of past total phosphorus (TP), based on published weighted-averaging transfer functions from modern diatom data in surrounding lakes, and to compare these inferences with 20 years of recorded TP measurements from the lake. Fossil pigments were analyzed for the purpose of investigating historical changes in algal biomass and community composition, and potential relationships with TP. Results showed that Lake William had been productive throughout the last 200 years. Diatoms typical of alkaline, eutrophic conditions were continuously present between ~1765 to 1990 AD (before the advent of settlement and ranching in the area in ~1860). Fossil pigments indicated the presence and importance of filamentous cyanobacteria, cryptophytes, diatoms, chlorophytes, and siliceous algae or dinoflagellates in past algal communities. Comparison of the diatom-TP weighted average model predictions with measured TP in the lake showed that hindcasts were similar to average summer TP measurements. In contrast, there was no significant relationship between TP and past algal abundance.

Reavie et al. (1998)

The purpose of this study was to use sedimentary fossil diatoms to infer past trends in limnological variables and shoreline habitat of two fluvial lakes (Lake Saint-Francois and Lake Saint-Louis). Diatom taxa that show an affinity for certain substrate types are likely to provide information on past aquatic habitats. For instance, if a taxon is known to occur in association with macrophytes, and it increases over some period in a sedimentary profile, it may be assumed that macrophyte density also rose during that time. Thus, the relative contributions of three major habitats (i.e., green algae (Cladophora), macrophytes and rocks) to the sedimentary diatom assemblages were calculated using a reconstructive method developed by Reavie and Smol (1997). Using correspondence analysis, fossil assemblages were ordinated relative to modern periphytic assemblages. Based on the relative nearness of any one fossil sample to the modern samples, the influence of each substrate on that fossil assemblage can be predicted. Results indicate that agriculture, population growth and waterway construction coincided with increases in littoral macrophytes and algae. The presence of a certain diatom species (Stepanodiscus binderanus v. oestrupii) indicated a state of high nutrient conditions between 1940 and 1960. Its decrease in abundance in Lake Saint-Louis after 1950 suggests a recent improvement in water quality.

Reavie et al. (2002)

A comparison was made between palaeolimnological and mass-balance models for inferring long-term nutrient changes in southeastern Ontario lakes. A total of 50 lakes were used in this study. The first method applied was the inference of total phosphorus (TP) based on the analysis of historic diatom communities from sediment cores. The second method was a Lakeshore Capacity Model (LCM), a mass-balance model based on phosphorus export coefficients that relate lakes and their watershed characteristics to epilimnetic nutrient concentrations. Both models hindcasted significant increases in TP in roughly half the study lakes. A lake-by-lake comparison indicated differences in model output. In fact, a paired comparison of LCM and diatom-based inferences of pre-1850 TP showed no correlation. Longer environmental gradients would likely improve the performance of training sets (modern assemblages and corresponding TP measurements) in the regions where such nutrient transfer functions are applied to historic diatom communities. The LCM model was calibrated in the Haliburton region (outside the study area, and on the Precambrian shied), and this is part of the reason its inferences were not reliable.

Strong (1991)

Strong (1991) analyzed grain type, size and distribution in lake sediment cores from nine water bodies in southern Alberta. Results indicated relatively greater quantities of organic matter and an increased abundance of silt in post-European settlement sediments. These greater abundances were attributed to increased lake nutrient levels and increased wind erosion due to the development of agriculture in the region. Results indicated that changes varied with location, degree and type of disturbance in the vicinity of the collection basin. Several lakes had increased organic matter contents, suggesting they received greater quantities of nutrients than during the pre-settlement period. The principal mode of erosion changed. A major increase in the proportion of silt implies that wind erosion became dominant after settlement. Prior to settlement most lake sediments were dominated by poorly sorted sediments indicative of short-distance water transport.

Cottingham et al. (2000)

Cottingham *et al*. (2000) examined the impact of nutrient addition on aquatic ecosystem predictability using fossil pigment analysis. High performance liquid chromatography was used to identify sedimentary carotenoids, chlorophylls, and derivatives for years between 1943 and 1990, and for 14 additional years ranging from 1793 to 1940. The concentrations of fossil pigments were strongly correlated with annual phytoplankton standing crop and allowed for identification of changes in the phytoplankton community to the algal function group level. The authors determined that anthropogenic eutrophication could destabilize aquatic ecosystems (increase variability) and obscure impacts of global climate change. The authors also found that increased community and ecosystem variability often diminished biodiversity (Cottingham *et al*., 2000).

APPENDIX D: Glossary

Before Present (BP) F	A year numbering system, used for past time, relating dates to the year 1950. For example, 12,000 BP means 12,000 years before 1950.
Biocoenosis	A community or natural assemblage of organisms. The term often is used as an alternative to ecosystem, but strictly it is the fauna/flora association excluding physical aspects of the environment.
Biodiversity	Biodiversity is a measure of biological variety that at the scale of ecosystems comprises species richness and relative abundance (or evenness). Biodiversity retains ecological, economic and cultural value, and it is a feature of all levels of biotic organization, from genes to biomes, and beyond.
Claustic	Composed of broken fragments that have been derived from pre-existing rocks by weathering and erosion and transported some distance from their place of origin.
Dendrochronology	The dating of past events and variations in the environment and climate by studying the annual growth rates of trees. (Dendroclimatology is the use of tree growth rings as proxy indicators of past climates.)

Fonds All material produced or gathered by a specific person or organization over time.

GIS Geographic information system

Hindcast The process of using past data/information to predict the status and organization of historic ecosystems, landscapes *etc*. Typically used in relation to past predictive models.

Midden Piles of refuse or debris that may have been left through the activities of animals.

Ombrotrophic Condition of an ecosystem that derives its nutrient input largely from rainwater; for example, raised bogs.

Palaeoecology The study of ancient ecosystems. Palaeoecologists use data from such sources as tree rings, geologic deposits, fossils (pollen is a particularly popular tool), and coral bores to reconstruct the climate and ecology or ancient ecosystems.

Palynology The study of spores, pollen, and other plant material remains that are resistant to acid extraction from their substrate.

Palynomorphs Spores, pollen, charcoal, and other microscopic plant remains that can be uniquely identified.

Phytoliths Minute parts of silica in the cells of plants that are specific to certain parts of the plants. Phytoliths survive even after the plant decomposes or burns, which allows them to serve as efficient clues to archaeologists on harvesting periods and techniques, *etc*. They can also help differentiate between wild and domestic plant species.

Plats A diagram or map drawn to scale showing all essential data pertaining to the boundaries and subdivisions of a tract of land. It is often a legal document.

Taphonomy The study of what happens to a fossil, from the time of its initial creation (*e.g.*, the death of an organism or the imprint left by the movement of an organism) and the time that the fossil is discovered by a palaeontologist. For example, shells or bones can be moved my running water, and later be compressed by overlying sediment.

Varve An annual layer of sediment or sedimentary rock.