USING PALYNOLOGICAL MODERN ANALOGUES TO LOCATE A BURIED DIKELAND SOIL IN A RECOVERING BAY OF FUNDY SALT MARSH

by

Maria-Theresia Graf

Department of Geography

McGill University, Montreal

October 2004

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of Master of Science

Your file Votre référence
ISBN: 0-494-12456-3
Our file Notre référence
ISBN: 0-494-12456-3

ABSTRACT

The upper Bay of Fundy's Cumberland Basin contains an estimated 16,500 hectares of salt marsh, nearly all of which have been diked and converted to agricultural lands since the arrival of the Acadians in the late 17th century. John Lusby Marsh is a 600 ha salt marsh that was diked and farmed for approximately 250 years, until dikes breached in the late 1940s and the marsh was restored to tidal conditions. Since dike breach, the reclamation surface has been buried beneath approximately 1 m of tidally-imported sediments. The purpose of this study was to develop modern pollen analogues for three different grassland land uses common in the upper Bay of Fundy: salt marsh, actively farmed dikeland and fallow dikeland. These modern analogues can then be used to locate the reclamation surface and reconstruct a sequence of historic land uses in John Lusby Marsh and, possibly, in other restored salt marshes around the Bay of Fundy. Fifty surface samples were collected: 17 from the salt marsh, 22 from a farmed dikeland and 11 from a fallow dikeland. Using discriminant analysis it was possible to differentiate the three land use types based on their pollen spectra. It was possible to further discriminate agricultural practices that involved cattle grazing or manuring from those that did not, by including coprophilous fungal spore counts in the palynological analysis. A sediment core that contained the reclamation surface was extracted in John Lusby Marsh, and a trial set of eight fossil pollen spectra was compared to the modern analogues. Discriminant analysis classified the fossil samples into a plausible sequence of historic land uses which included phases when the marsh was diked and farmed. A comparison of the soil characteristics and pollen spectra from this study

to those in a previously published study of a nearby salt marsh at Amherst N.S. suggest that flooding of a dikeland was misinterpreted as a sudden increase in the rate of sea level rise. Historical air photos support this conclusion by showing that the sampling location was indeed diked and farmed before the 1940s.

RÉSUMÉ

La majorité des environs 16,500 ha de marais salins du Basin Cumberland de la Baie de Fundy supérieure ont été endigués et convertis en terrains agricoles depuis l'arrivé des Acadiens á la fin du 17$^{\text{iéme}}$ siècle. Les 600 ha du Marais Salin John Lusby furent endigués et cultivés durant environ 250 ans, jusqu'à la rupture des digues á la fin des années quarante et le retour aux conditions naturelles. Depuis la rupture des digues, les terres agricoles ont été enfouies sous environs 1 m de sédimentation. Le but de cette étude est de développer des analogues modernes de pollen pour les trois usages différents des marais dans la Baie de Fundy supérieure: marais salin, terres endiguées cultivées, terres endiguées en friche. Ces analogues modernes peuvent être utilisés pour localiser les terres agricoles enfouies et reconstruire l'historique des usages des sols du Marais John Lusby et possiblement d'autres marais salins restaurés autour de la Baie de Fundy. Cinquante échantillons de surface ont été collectés: 17 du marais salin, 22 de terres endiguées cultivées, et 11 de terres endiguées en friche. L'analyse discretionnaire à permis de différencier les trois usages de sols différents basés sur le spectre de pollen. Il est aussi possible de détecter les pratiques agricoles tel la mis en pâture ou fertilisation avec du fumier en incluant la somme des spores fongiques coprophileuse dans les analyses palynologiques. Une carotte de sédiments content les terres agricoles a été extrait du Marais John Lusby, et une série d'essaie de huit spectres de pollen fossilisés ont été comparé aux analogues modernes. L'analyse discretionnaire à classifié les échantillons fossilisés par leurs usages historiques les plus probables incluant les périodes durant lesquelles les marais furent endigués et cultivés. En comparant les

caractéristiques des sols et des spectres de pollens de cette étude a celle d'une étude publiée d'un marais salin proche d'Amherst N.S. nous voyons que l'inondation des terres endigués a possiblement été mal interprété comme étant due a une montée soudaine du nouveau de la mer. Les photos aériennes supportent cette conclusion en montrant que l'endroit échantillonné était en fait endigué et cultivé avant les années 1940.

ACKNOWLEDGEMENTS

Dr. Gail Chmura, my thesis advisor, was instrumental in every aspect of this research project, providing me with careful guidance, keen insight and kind encouragement every step of the way. I offer her my heartfelt gratitude. Financial support was generously provided by NATEQ and the Centre for Climate and Global Change Research. Logistical help from Vernon Rodd and his staff at the Nappan Experimental Farm was much appreciated and John Shaw is kindly thanked for allowing me the use of his Ejkelkamp auger. Many thanks go to C. Beth Beecher for being such a meticulous, adventurous and pleasant field assistant, as well as Grace Hung for her help on the reconnaissance trip. Thank you also to Oxana Kapoustina, Elaheh Sarvi, Mike Pistilli and Ismat Lotia, the laboratory assistants who did all my pollen extractions and spared me from handling toxic chemicals during my pregnancy.

On a personal note, I especially wish to thank my husband Bob Levac for the unwavering support he shows me in every aspect of my life, for laughing and crying with me, and for being an all-around amazing human being and friend. I thank my dear friend Muriel Abraham for the moral support and many days spent taking care of Lily while I finished writing, and Philip Lemieux for helping to make this educational experience a time of invaluable personal growth. Lastly, I would like to dedicate this work to my little Lily who was with me during the many long hours spent at the microscope counting pollen and who has brought me boundless joy from the very moment she came to be.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Bay of Fundy is a sediment-rich macrotidal basin extending northeastward from the Gulf of Maine. It is bordered to the northwest by New Brunswick and to the southeast by Nova Scotia (Figure 1). The Bay is famous for its extreme tides, which twice each day fluctuate up to 6 m in the outer bay and up to 16 m at its two heads – the Cumberland Basin to the north and the Minas Basin to the south (Canadian Hydrographic Survey, 1998). Tidal marshes have developed all along the Bay's more sheltered stretches of coast, with by far the largest marshes having formed at the head of the Cumberland Basin on the expansive, low-lying Isthmus of Chignecto (Figure 2).

Salt marshes are recognized as vital wetland habitat (e.g., Reed and Moisan, 1971), as potentially important CO_2 sinks (Magenheimer et al., 1996, Connor et al., 2001, Chmura et al., 2003), and as coastal energy dissipation zones which protect settlements and infrastructure from erosion and flooding (Pethick, 2002). The upper Bay of Fundy's Cumberland Basin once contained an estimated 16 500 ha of salt marsh, most of which was diked and converted to farm lands between the 17th and 20th centuries (Ganong, 1903). Pockets of salt marsh remain only along the most seaward dikes or in small patches elsewhere along the coast. Diking and draining a salt marsh leads to a variety of ecological impacts (Warren et al., 2002), including decreases in nutrient processing, sediment trapping and nursery habitat, changes in habitat structure for tidal marsh dependent bird species and muskrats (Benoit and Askins, 1999), and the loss of tide dependent salt marsh invertebrates. Furthermore, the loss of marsh area changes the morphology, and so the energy balance, within an estuary, possibly

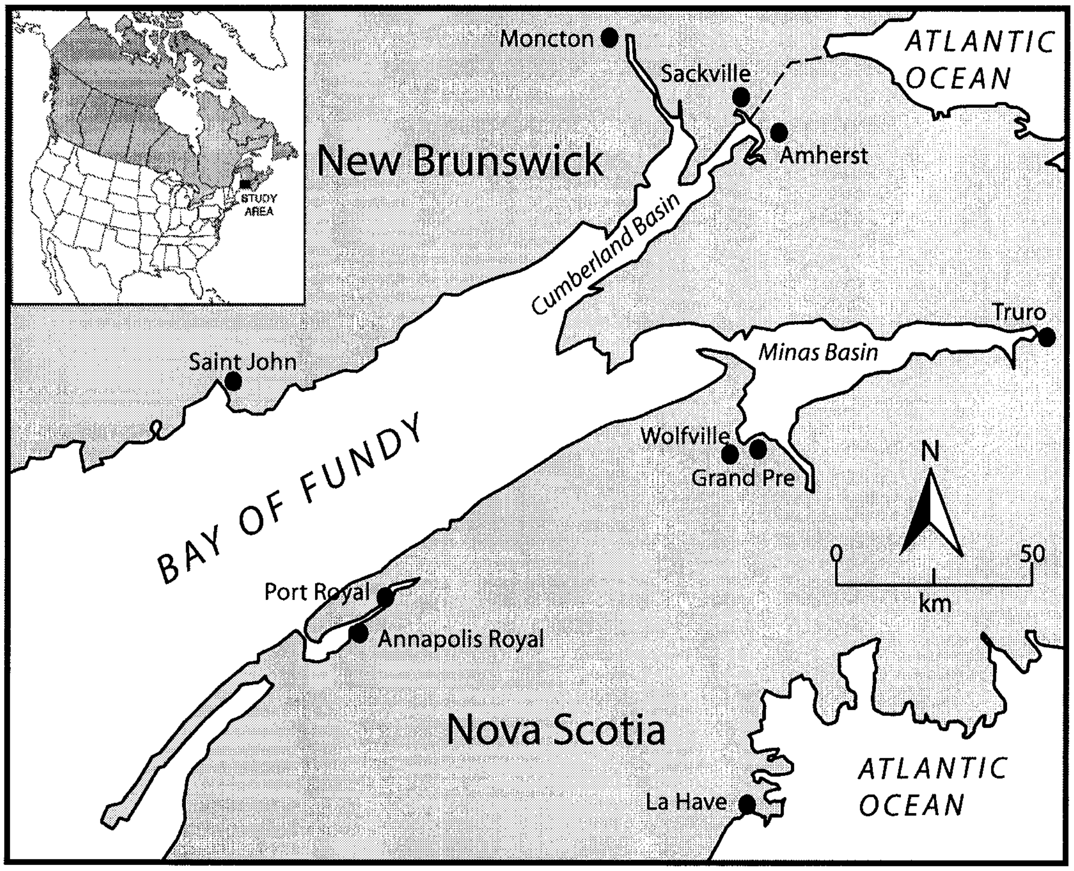

Figure 1: Study area map showing the upper Bay of Fundy and the Cumberland Basin.

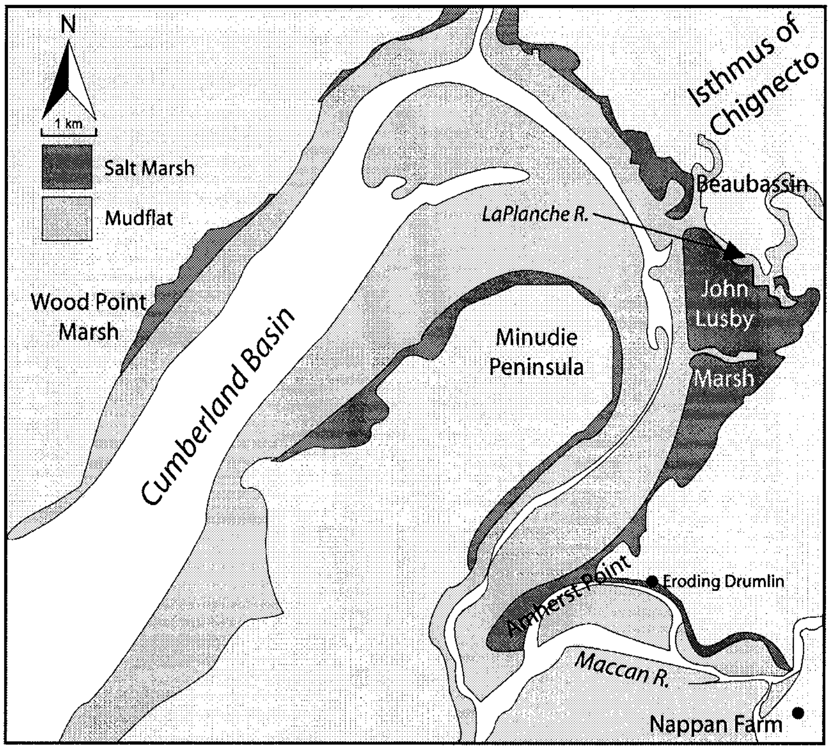

Figure 2: The Cumberland Basin, showing John Lusby Marsh, Minudie, Nappan Farm and surroundings.

leading to tidal amplification, coastal erosion and increased wave propagation (Owen, 1984, Pethick, 2002). Certainly, dikes arrest tidal sedimentation in the reclaimed areas. In the Bay of Fundy, sea levels have been rising an average of 2 mm yr^{-1} during the late Holocene (Shaw and Forbes, 1990). The cessation of sediment accretion in the reclaimed dikelands has caused many of them to lose elevation within the tidal frame, thus dramatically increasing flood risk.

There is a growing effort to mitigate coastal hazards and habitat loss by restoring reclaimed dikelands to tidal conditions or engineering coastal areas in the hope that salt marshes will become established (Callaway et al., 1997). Restoration projects that have been undertaken and monitored include the large scale restoration of 5040 ha of former salt marsh in Delaware Bay (Weinstein et al., 2001), several marsh areas on Long Island Sound (Warren et al., 2002), various marshes along the east, west and gulf coasts of the U.S. (summarized by Zedler and Callaway, 2000), in the Netherlands (de Jonge and de Jong, 2002, Bakker et al., 2002), and the UK (MacLeod et al., 1999, Pethick, 2002). There is cause for concern that restoration will not return a wetland to its pre-disturbance condition, nor that engineered wetlands will function like their natural counterparts (Portnoy and Giblin, 1997, Zedler and Callaway, 2000). Specifically, studies have shown that restored and engineered wetlands are subject to unpredictable sedimentation or erosion due to modified tidal regimes, lack topographic complexity, have insufficient soil organic matter and nutrients and therefore fail to support desired plant and animal communities.

No controlled restoration projects have been conducted in the upper Bay of Fundy; however, there are sites where marshes were 'accidentally' restored due to dike failure caused by storm surges or insufficient maintenance. Have such marshes 'recovered' from extended periods of diking and farming? How do modern sedimentation rates, vegetation composition and marsh hydrology reflect the 'original' pre-diking marsh that existed prior to human settlement?

In order to examine such questions it is first necessary to find the now buried reclamation surface in such a restored marsh. Once found, it may be possible to reconstruct ecosystem characteristics of the marsh prior, during and after diking. In addition, if the date of dike breach is known, the depth of the reclamation surface will show the ability of breached dikelands to accrete sediment and rise back to a salt marsh sustaining elevation within the tidal frame.

The aim of this study was to use palynological techniques to locate a buried reclamation surface that may or may not be visually identifiable. Modern analogue pollen assemblages for salt marsh and dikeland environments were used to infer the historical land use and vegetation types preserved in a sediment profile at different depths (and so at different times). A pollen assemblage of a modern day salt marsh or dikeland agricultural soil should closely resemble the pollen assemblage of these ecosystems in the recent past (i.e., the timescale of interest to this study, which is within the last 350 years). This paper presents the compilation of modern analogue pollen assemblages for three different modern and historical grassland land uses in the Cumberland Basin: salt marsh, farmed dikeland hayfields and pastures, and fallow dikelands, all grass-dominated ecosystems to which I refer collectively as grasslands. The farmed dikelands land use could be further divided into hayed/unmanured and grazed/manured land uses by means of coprophilous fungal spore percentages. These assemblages were then used as a basis to locate the buried dikeland agricultural soil by reconstructing historical land uses in a sediment core extracted from a restored salt marsh. In addition, decadal-scale sedimentation rates in a restored marsh were calculated based on the depth of sediment that had accumulated over the reclamation surface since dike breach.

LITERATURE REVIEW

Relative sea levels in the Bay of Fundy have been rising at a rate of 21.2 cm per century or roughly 2 mm yr^{-1} through a combination of isostatic and eustatic effects (Shaw and Forbes, 1990). Vertical salt marsh accretion rates have been keeping pace over the long term. The Intergovernmental Panel on Climate Change (IPCC) projects rates of eustatic sea level rise of 9 cm to 88 cm by 2100, with the most likely value being 49 cm (Church and Gregory, 2001). This means that relative sea level may rise 70 cm, or even 109 cm, by 2100 in the Bay of Fundy, values more than triple or quadruple the historical rates. In order for Cumberland Basin salt marshes to outpace this rise, even the highest estimated rates of historical sediment accretion must be exceeded. Can the upper Bay of Fundy salt marshes keep pace with such sea level rise? Annual accretion rates suggest that very rapid sediment accumulation is possible over the short term but available long-term measurements do not reflect continuous aggradation at such high rates.

In Wood Point Marsh (Figure 2), Chmura et al. (2001) measured sediment deposition rates as high as 30-50 mm in the *Spartina alterniflora* dominated low marsh and 10-20 mm in the *Spartina patens* dominated high marsh over a single year. At Amherst Point (Figure 2), Shaw and Ceman (1999) calculated long-term aggradation rates from 10.4 cm per century (~1 mm yr^{-1}) to 53.3 cm per century (~5.3 mm yr^{-1}), an average of 25.9 cm per century (~2.6 mm yr^{-1}) since 2900 BP. Longer-term accretion rates are lower likely due to sediment autocompaction (Kaye and Barghoorn, 1964), and the thicker the substrate the greater the potential for post-depositional settlement of peats and clays. Greensmith and Tucker (1986) found that frequent re-wetting alone can hydrocompact fine silty soil as much as 4-6 m per 30-40 m thickness of strata. The addition of overburden pressure by accumulating sediments can further compact such soils. Laboratory tests in which pressure was applied to different sediments for the duration of one hour, showed that Holocene coastal silty clay soils compacted 5-6 times more than silty sands. Furthermore, coarse fibrous peats tend to decrease in thickness by 80-90% due to draining, decomposition and compaction. Hence, in order for a marsh surface to aggrade within the tidal frame, the thickness of material added must exceed the subsidence rate due to autocompaction and the rate of local and eustatic sea level increase (Kaye and Barghoorn, 1964). Cahoon et al. (1995) found that vertical sediment accretion rates in southeastern U.S. salt marshes considerably and consistently overestimated salt marsh surface elevation increases by a factor of as low as 1.5 and often as high as an order of magnitude. This study shows that short term sediment accumulation rate studies can not predict whether a salt marsh can be sustained during a period of rapid sea level rise. Likewise, studies of millennial scale salt marsh accretion rates can not sense salt marsh responses to relatively short term (century-scale or less) sea level rise events.

Medium-term time scale (decadal) salt marsh accretion rates for this region would shed light on salt marsh response to changes over the past 50-60 years. The conventional technique used to calculate sedimentation rates over this time scale is cesium-137 dating, which measures cesium levels at different depths of a sediment profile. The highest levels of cesium were deposited during the nuclear bomb tests in the 1950s and 1960s with concentrations in the sediments peaking in 1963, and sediments deposited over this peak are known to have accumulated since then (Pennington et al., 1973). This method was attempted in the upper Bay of Fundy but failed to detect a sufficiently clear signal, likely due to signal dilution by the unusually high sediment accumulation rates (Chmura, personal communication). A different approach to assess decadal accretion rates is needed.

A reclamation surface (i.e., the dikeland soil) that was buried after dike breach is an identifiable and datable sediment layer. Once identified, the amount of sediment that has accumulated above it since dike breach can be measured. While this depth will not yield salt marsh accretion rates under 'natural' circumstances, the rates will indicate the potential of upper Bay of Fundy restored and undisturbed salt marshes to keep pace with accelerated sea level rise, be it due to dike breach or accelerated global sea level rise. Can a buried reclamation surface be identified based on visible and pedological characteristics alone?

A pedological analysis of a dikeland soil that was farmed for 100 years was conducted near Wolfville, N.S., in a former salt marsh along the Minas Basin (Beke, 1990). After one century of being drained and farmed, the original salt marsh or mud flat soil developed moderate to strong structural features due to dehydration, shrinkage and drainage. It displayed weak A-B-C horizons with pedogenic development to the cambic horizon stage, and organic carbon accumulated in the surface mineral horizon. The moderate to strong structure not only distinguished this soil from salt marsh soils, but also from other upland soils in the region, indicating that dikeland soils develop unique and identifiable physical characteristics; however, the soil structural features and faint horizons are difficult to discern using soil coring techniques.

Locating the reclamation surface in a restored salt marsh was used to determine decadal scale sedimentation rates in macrotidal Pagham Harbour in southern England (Cundy et al., 2002). Pagham Harbour was reclaimed in 1846 and was restored to tidal marsh conditions during a storm surge in 1910, only 64 years later. A distinctive black, compact and organic-rich sedimentary unit, containing the humified remains of herbaceous plants, was identified at ca. 0.5 m beneath the modern surface and assumed to be the reclamation surface. According to lead-210 dating this layer was between 109 and 164 years old. Decadal scale sedimentation rates were calculated based on the amount of sediment that had accumulated over the reclamation surface since 1910 and were found to average 5 mm yr^{-1}. In the upper Bay of Fundy sediment accumulation rates need to be nearly twice this amount for salt marshes to keep pace with projected rates of sea level rise.

In addition to visual identification of the reclamation surface at Pagham Harbour, an analysis of diatoms in this layer, as well as those above and below, was conducted in an effort to conclusively identify the reclamation surface based on changes in salinity. The diatom analysis did not provide direct evidence of salinity changes associated with reclamation, as might be expected if tidal flooding was arrested for a period of 64 years; however, diatoms are unlikely to be produced in a dikeland. The identification and reconstruction of the reclamation surface could have been improved with pollen analysis because the vegetation characteristics of a dikeland soil are dramatically different from those of a tidal marsh. While the authors mention the presence of humified remains of herbaceous plants in the assumed reclamation soil, the change in vegetation from a salt marsh to a dikeland could have been better identified and described by the fossil pollen contained in the sedimentary sequence.

Palynological techniques may prove to be a more reliable means of identifying the buried soil in the salt marsh sediment sequence. In their keystone 1985 palaeoecological reconstruction of a Long Island salt marsh, Clark and Patterson established the utility of analyzing pollen in a salt marsh sedimentary sequence to reconstruct the historic roles of watershed and sea level changes on salt marsh development. By comparing the pollen assemblages from a coastal marsh and a nearby lake they were able to distinguish local vegetation changes in the salt marsh during the last 1000 years, from those that were occurring on a regional scale, including those resulting from anthropogenic influences. They showed that salt marsh sediments contain sensitive records of local salt marsh and regional upland vegetation changes, that changes in pollen signatures can be linked to tide-gauge records, and that short-term changes in sea level are reflected in the pollen record. Their historical reconstruction of the salt marsh indicated periods of salt and fresh water conditions due to sea level changes, as well as local vegetation changes due to land clearing, agriculture and mosquito control.

Beecher and Chmura (2004) studied the pollen-vegetation relationships in three outer Bay of Fundy salt marshes in order to assess the utility of pollen in palaeoenvironmental reconstructions and to define salt marsh modern analogues for northern salt marshes. They looked at the salt marsh pollen-vegetation relationship in larger scale vegetation zones dominated by graminoids (i.e., *S. alterniflora* low marsh and *S. patens* high marsh) and in smaller forb patches within these larger scale zones. Poaceae pollen sources are notoriously difficult to distinguish and so of little use in palaeoenvironmental reconstruction or to distinguish the larger grass zones. In the smaller forb patches, pollen from at least seven types of forbs reliably indicated their source vegetation, a very useful finding because forbs are more abundant in the cooler environments of northern marshes. Beecher (2001) concluded that salt marsh palaeoreconstruction is possible despite small scale heterogeneity caused by regional sources of some salt marsh pollen types, and by extra-regional pollen sources that are not represented by the local salt marsh vegetation (probably due primarily to tidal influences). Furthermore, she was able to identify modern analogues for northern salt marshes.

The use of modern analogues represents an uniformitarian approach to palynology. If the palynological study of a modern ecosystem or land use generates a pollen assemblage that is characteristic of that environment, then a fossil pollen assemblage that is similar to the modern one is assumed to represent a similar ecosystem or land use in the past. Pollen extracted from surface samples collected in specific vegetation zones or land use types is used to calibrate the modern pollen assemblages, against which fossil assemblages can be compared and classified. Early uses of this comparative method are reviewed by Wright (1967) and recent works reflect a broad range of ecosystems studied. These include the natural and human-modified woodlands and grasslands of southwest Turkey (Vermoere et al., 2001), the semi-arid, high altitude plains and grasslands of central South Africa (Sugden and Meadows, 1989), mowed and grazed grasslands in western Norway (Hjelle, 1999), and various wetland sub-environments in the Florida Everglades (Willard et al., 2001).

Several of the many statistical methods and approaches that can be used are discussed by Overpeck et al. (1985) and Liu and Lam (1985).

Liu and Lam (1985) discuss the utility of discriminant analysis (DA) for reconstructing Holocene vegetation changes in northeastern North America using modern and fossil pollen assemblages. Discriminant analysis requires the analyst to compile sets of modern pollen assemblages that were collected from a variety of surface samples in each of the different ecosystems or land use types under consideration. The pollen samples are then classified, a priori, based on the ecosystem or land use from which they stem. Discriminant analysis derives a series of canonical functions that best account for, and describe, the differences in pollen assemblages between the various land uses or ecosystems. These results are plotted on a graph of the two canonical functions that account for the majority of statistical variance observed. With DA, one can also identify the probabilities that each sample has been correctly or incorrectly classified in its land use or ecosystem type. When fossil pollen assemblages are plotted against these canonical functions, they will plot nearest to the modern assemblage they most resemble, and analysis results will again include probabilities of correct and incorrect classification, and the probability that a modern analogue exists for the given fossil assemblage.

Liu and Lam (1985) classified 121 surface samples as belonging to one of five distinct vegetation zones. Samples were collected along a transect spanning northeastern North America and classified as deciduous forest, mixed forest, boreal forest, boreal woodland (forest and barren), and tundra. The DA evaluated the 121 samples according to the five a priori groups into which they were classified and assessed them in terms of probability of correct group membership. Plotted centroids for each of the five groups were clearly separated from each other and 115 of the 121 samples were found to be classified correctly. The six misclassified samples were collected near vegetation boundaries and classified into the closest adjacent vegetation zone. When fossil pollen assemblages from a lake sediment core in the region were plotted against the same two canonical discriminant functions used to classify the modern analogues, the fossil samples were classified with the modern analogue they most resembled. Most fossil samples had modern analogues but one group of five samples was found to be without a modern analogue. These samples were thought to represent an early post-glacial boreal woodland for which no modern analogue exists in the study area.

Sugden and Meadows (1989) used a similar approach in their study in central South Africa. Modern analogue pollen assemblages were compiled for four different vegetation or land use zones ranging from environments dominated by: 1. low, drought-resistant shrubs; 2. shrubby grasslands; 3. open grasslands; and 4. areas of hydrophytic vegetation. The DA clearly separated the four vegetation zones. Two of the four modern vegetation zones proved to be modern analogues for 17 of 22 fossil pollen assemblages, the hydrophytic and the open grassland vegetation zones. Five very similar fossil assemblages were found to be without modern analogue and thought to represent a period during which now extinct animals grazed the area.

In a study conducted in southwest Turkey, Vermoere et al. (2001) used DA and principal components analysis (PCA) to discriminate 64 modern pollen assemblages into the 14 vegetation zones from which they were collected, and determine if modern analogues existed for nearby fossil assemblages. Their PCA plots allowed them to separate their pollen spectra into the groups from which they were sampled despite the fact that the first and second principal components used accounted for only 32% of total variance. Their use of DA is somewhat questionable because several of their a priori groups were composed of single samples yet they used 15 taxa in their analysis. This goes against general DA conventions which state that the sample size of the smallest group should be greater than the number of predictor taxa used (Tabachnick and Fidell, 2001). DA and PCA are both useful techniques to elucidate patterns in complex ecological data sets; however, it is important that users are aware of the inherent limitations.

One study using modern analogue pollen assemblages as palaeoenvironmental proxies in a coastal wetland was conducted in the Florida Everglades (Willard et al., 2001). Modern analogue pollen assemblages were compiled from 170 surface samples collected in eight different vegetation types by means of cluster analyses. Using these, it was possible to reconstruct hydrologic and edaphic changes in the coastal wetland for the past ~2500 yr, and changes could be correlated with both climatic and anthropogenic land use changes. This study is important to the present work because it shows that the modern analogue approach has been successfully applied in a coastal wetland to reconstruct a sequence of changes occurring due to both natural and anthropogenic influences.

Hjelle (1999) used the modern analogue approach to discriminate between different modern and historic grassland land uses in western Norway. She also attempted to identify specific pollen types that are indicative of specific grassland land uses (i.e., grazing and mowing of meadows) in order to determine if fossil pollen assemblages or the presence/absence of indicator types can be used to distinguish between these land use practices for archaeological purposes. Using both classification

(DA and two-way indicator species analysis) and ordination techniques (correspondence analysis and canonical correspondence analysis), her results allowed her to separate long-term grazed meadows from mowed meadows, but not previously mowed fields that are now grazed, from those that were traditionally mowed. Hjelle found that *Galium, Cirsium* and *Succisa* pollen types were more indicative of grazing than mowing, and *Achillea, Alchemilla* and *Conopodium majus* types were associated more strongly with mowing. This is likely due to the fact that unpalatable plant types are avoided by grazers and allowed to mature and pollinate. In mowed meadows such selection does not occur. Perhaps an enumeration of coprophilous fungal spores would have assisted in the discrimination of mowed from grazed meadows.

Fungi that use the excrement of animals as their primary growth substrate are known as coprophiles. Herbivore dung and the succession of fungi that develops within it have been studied and documented (Webster, 1970, Richardson, 1972 and 2001, Angel and Wicklow, 1975 and 1983, Parker, 1979, Wicklow, 1992). Dung fungi must be able to efficiently disperse their spores so that fresh substrates can be reached and colonized because their substrates decompose and shrink (Wicklow, 1992). As such, coprophiles produce abundant spores, which are discharged and wind dispersed or carried to fresh dung by arthropods (Malloch and Blackwell, 1992). Both of these means of dispersal and transport are most efficient over relatively short distances because fruit bodies are situated close to the ground where wind dispersal is less efficient (as compared to tree pollen) (van Geel, 2003). Consequently, coprophilous fungal spores indicate a relatively local presence of animals. Spores from many types of coprophilous fungi are preserved in palynological preparations and can be identified and counted alongside pollen (van Geel, 2003). The relative abundance of dung fungal spores in sediments has been used as an indicator of grazing by domesticated herbivores (Davis, 1987, van Geel, 2003) and as an indicator for Pleistocene megafaunal extinction (Davis, 1987, Burney et al., 2003).

Coprophilous fungal spores may be used to identify cattle-related agricultural practices in modern and historical sediments. Several types of such spores produced by Ascomycetes are commonly found in the dung of domestic herbivorous mammals (Richardson, 1972 and 2001, van Geel, 2003) including sheep, cows, goats and horses, but also in the dung of non-domesticated herbivores such as moose, deer and elk, and even Pleistocene megafaunal herbivores (Davis, 1987). As such, fossil spores are occasionally present in most sediments but become very common only after the introduction of domesticated pasture animals. Such indicators may not be useful in typical meadows and hayfields that are regularly manured; however, since dikelands are well known for their exceptional fertility and are rarely, if ever, manured, significant variations in the abundance of coprophilous fungal spores in a sedimentary sequence would highlight periods during which the dikelands were used for cattle grazing. When fertility did decline in dikeland fields it was easier to "tide" the fields than to manure them (Ganong, 1903). "Tiding" simply meant allowing the sediment-laden tides to overflow the fields for a period long enough to deposit a fresh layer of revitalizing, nutrient-rich mud. In fact, upland fields were often "marine manured" using marsh mud (Smith et al., 1989). Chignecto farmers were known to rely heavily on cattle production (Clark, 1968); hence, coprophilous fungal spores may be a useful tool for differentiating between grazed and non-grazed land uses.

Study Area

John Lusby Marsh, at the head of the Cumberland Basin (Figure 2), is a dikeland that has been restored to tidal marsh conditions. The 600 ha marsh was originally diked by Acadian settlers in the late 17th century but the dikes breached in the late 1940s. It extends from the south shore of the La Planche River to just north of Amherst Point and the Maccan River. It is one of many upper-bay dikelands that became neglected during the Great Depression of the 1930s and WWII when, due to a shortage of available labour, many dikes failed and the farmlands went "out to sea" – a local expression used to describe a dikeland's return to salt marsh conditions upon dike breach or removal. Recognizing the potential economic and infrastructural loss of dikeland neglect, the Canadian government implemented the Maritime Marshland Rehabilitation Act in 1948. Many abandoned dikelands were reclaimed through this widespread dike repair, maintenance and construction programme; however, the dikes in John Lusby Marsh were never restored. It has been designated a Ramsar Wetland of International Importance due to its high waterfowl use and is managed by the Canadian Wildlife Service as part of the Chignecto National Wildlife Area, which also includes the Amherst Point Migratory Bird Sanctuary.

Historic records show that John Lusby Marsh was diked and farmed for as much as 260 years. Not only would soil characteristics have changed dramatically over this time, but the dikeland's elevation fell as much as 52 cm within the tidal frame (not including soil autocompaction) as local sea levels rose and tidal sedimentation was prevented. When the dikes breached in John Lusby Marsh, the salt marsh was faced with a sudden and large increase in sea level, and soil and elevation conditions may not have been suitable for the re-establishment of salt marsh vegetation. Today, John Lusby Marsh is the largest continuous portion of salt marsh remaining in the Bay of Fundy (Environment Canada, 2002). While the marsh has gained elevation within the tidal frame and supports typical species of salt marsh vegetation, it is not known whether today's marsh ecosystem functions in the same way it did prior to reclamation.

Dikeland History of John Lusby Marsh

The French were the first Europeans to settle in Nova Scotia (Clark, 1968). The earliest permanent colony was established in 1605 at La Have on the southwestern Atlantic coast of the province (Figure 1). By 1640 most of the original colonists remaining in Nova Scotia had moved to Port Royal. By 1671 the population of Port Royal had grown to roughly 350 individuals and the settlement was the focus of ongoing English attacks (Clark, 1968). It is at this time that the first families emigrated from Port Royal to settle other marsh areas around the Bay of Fundy. The first two settlements to spring up were at the two heads of the Bay of Fundy, Grand Pré on the Minas Basin and Beaubassin on Chignecto Bay in the Cumberland Basin. In 1672, Jacques Bourgeois led his and five other families to Beaubassin, the region that includes modern-day John Lusby Marsh (Figure 2). As was their custom, they quickly began diking small parcels of marshland, converting the deep fine-grained marsh sediments to agricultural soils of seemingly inexhaustible fertility. The community prospered and censuses indicate that the population grew to 127 persons by 1686, 174 persons by 1698, and 271 persons by 1707 (Clark, 1968). Population distributions during this time show that, locally, dikes were likely being built along both sides of the Missaguash and La Planche rivers (Figure 3). John Lusby Marsh was probably diked during this time.

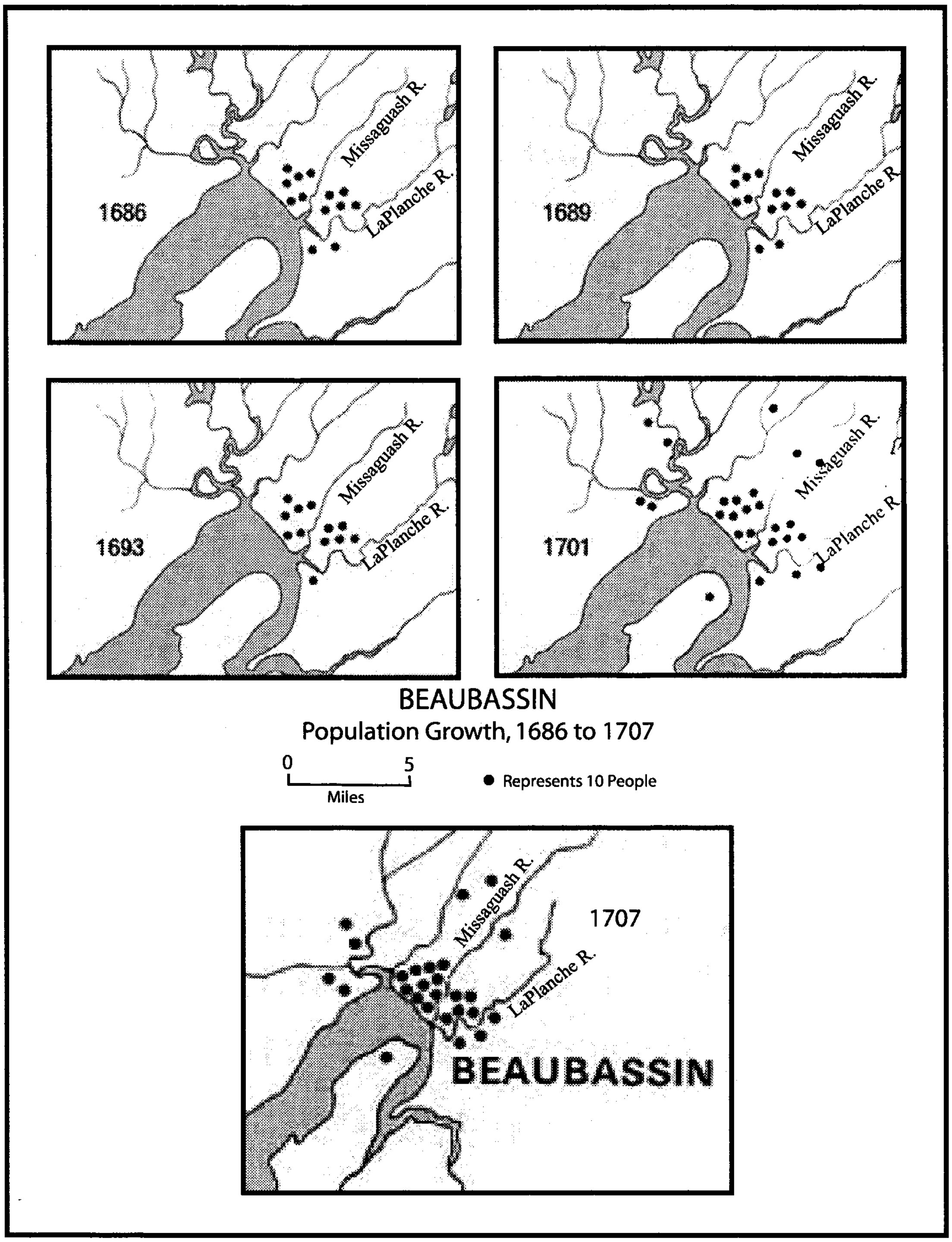

Figure 3: Trends in population growth in Beaubassin, 1686 to 1707. Adapted from Clark (1968).

Residents engaged in the typical pursuits of dikeland agriculture, with a stronger focus on raising cattle than was noted in the other settlements (Clark, 1968). This is likely due to the massive extent of the Chignecto marshes and their ability to provide ample hay for fodder and bedding under both natural and diked land uses. In 1686 there were 19 farms with a total of 236 heads of cattle, 116 sheep and 189 swine in Beaubassin and by 1707 this number had grown to 42 farms with 510 heads of cattle, 476 sheep and 334 swine.

By 1755 a French map shows dikes enclosing virtually all of the larger marshes in the Beaubassin area, including John Lusby Marsh, those to the north in the Tantramar Marsh, and those to the west on the Minudie peninsula (Figure 4). The local population east of the Missaguash River had grown to roughly 850 people by this time (Clark, 1968), suggesting that the area was well established agriculturally. This was the year of the infamous Acadian Expulsion in which nearly all of the Acadian population was stripped of their belongings, loaded onto ships and taken to whatever colonies would accept them (McCreath and Leefe, 1983). The British were rapidly diminishing whatever hold the French still had over the area and in order to secure Acadian loyalty, they strongly pressured the local population to take the Oath of Allegiance to His Majesty or to quit the country. The Acadians, loyal neither to the French nor the English, refused any oath other than one that would grant them neutrality. Since this was not an option the English would entertain, a large-scale deportation was implemented.

The English were left with large amounts of farmland but with no one to farm them (McCreath and Leefe, 1983). In 1759, the remnant of a hurricane caused severe damage to dikes over a wide area. This and further dike neglect may have caused some

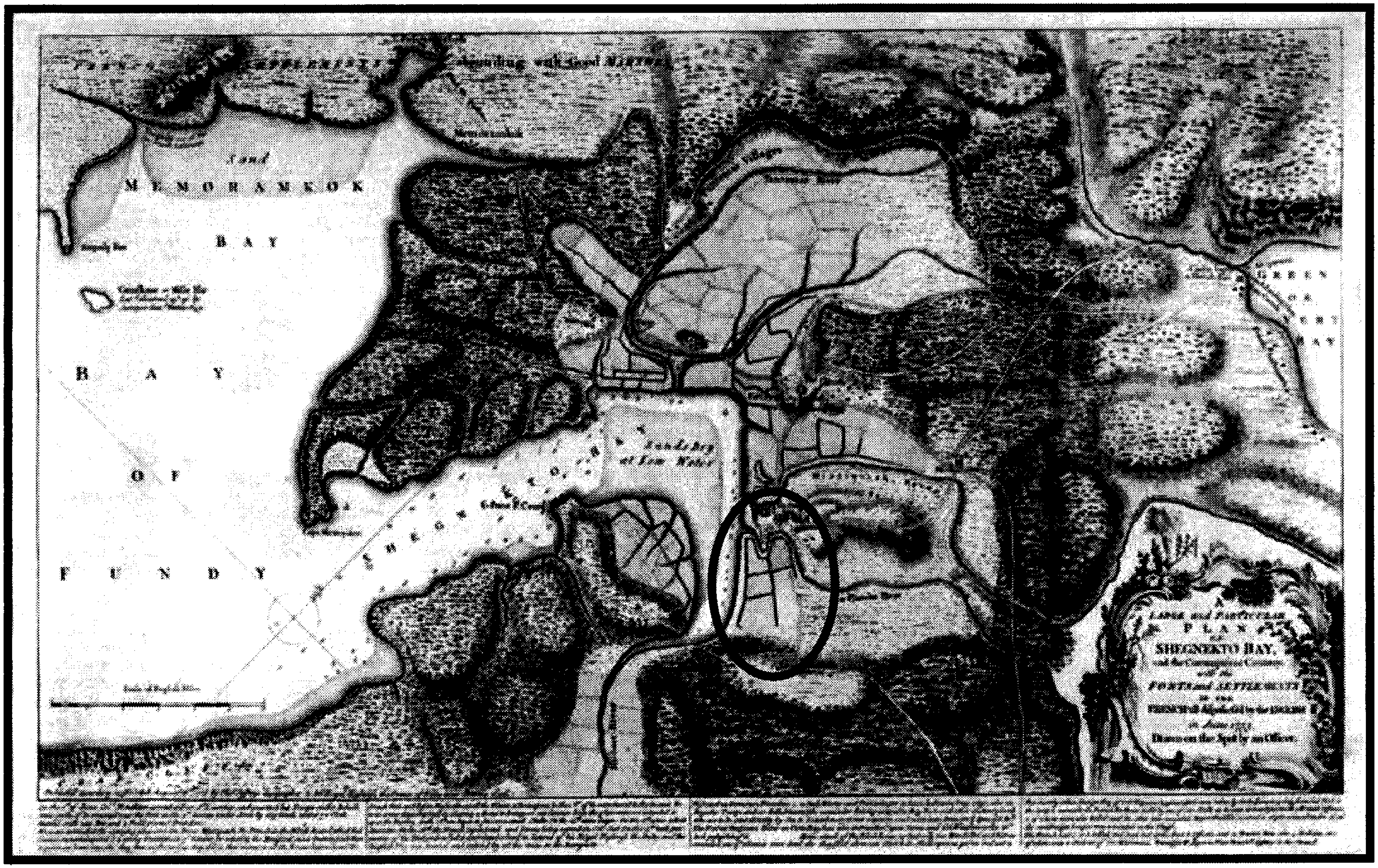

Figure 4: Beaubassin and vicinity in 1755 (New Brunswick Museum Archives, 1987). Note the extensive dikelands, including the dikes enclosing today's John Lusby Marsh (circled).

marsh to go out to sea while the remaining tracts lay fallow. Resettlement efforts were slow and new colonists did not come to Chignecto until 1762-63. This meant that local dikelands and dikes were left unattended for at least seven years, many probably more, and they were resettled by a New Englander population that was unfamiliar with both dikeland farming and dike maintenance (Wynn, 1979). In Chignecto especially, early New England settlers did not possess the skills and labour necessary to tend to the dikelands the way their Acadian predecessors had. Many new arrivals elected to clear uplands and did not make immediate use of the fertile dikelands available to them. It is likely that several more years passed and it was late into the 1770s or early 1780s before the marshes were once again in full production.

Air photos show that John Lusby Marsh remained in agricultural production until the mid-1940s (Figure 5). The 1931 photo shows that the marsh was speckled with barns and was criss-crossed by roads, drainage dales and ditches. A government wharf on the marsh, built in 1906, was serviced by a railroad and used to export local fish and produce. The 1945 photo shows that between 1931 and 1945 local dikes were still being maintained, as can be seen by the changes in dike configuration around Sharps Creek. By 1947 however, the dike around Sharps Creek had failed and subsequently, all agricultural activities were abandoned and never resumed.

Local Salt Marsh Vegetation

Salt marshes are characterized by their unique vegetation. Regular flooding renders the soil saline and inhospitable to all vegetation except halophytes that are specially adapted to tolerate such conditions. In the upper Bay of Fundy, *S. alterniflora*, which can tolerate both saline conditions and periods of frequent and extended

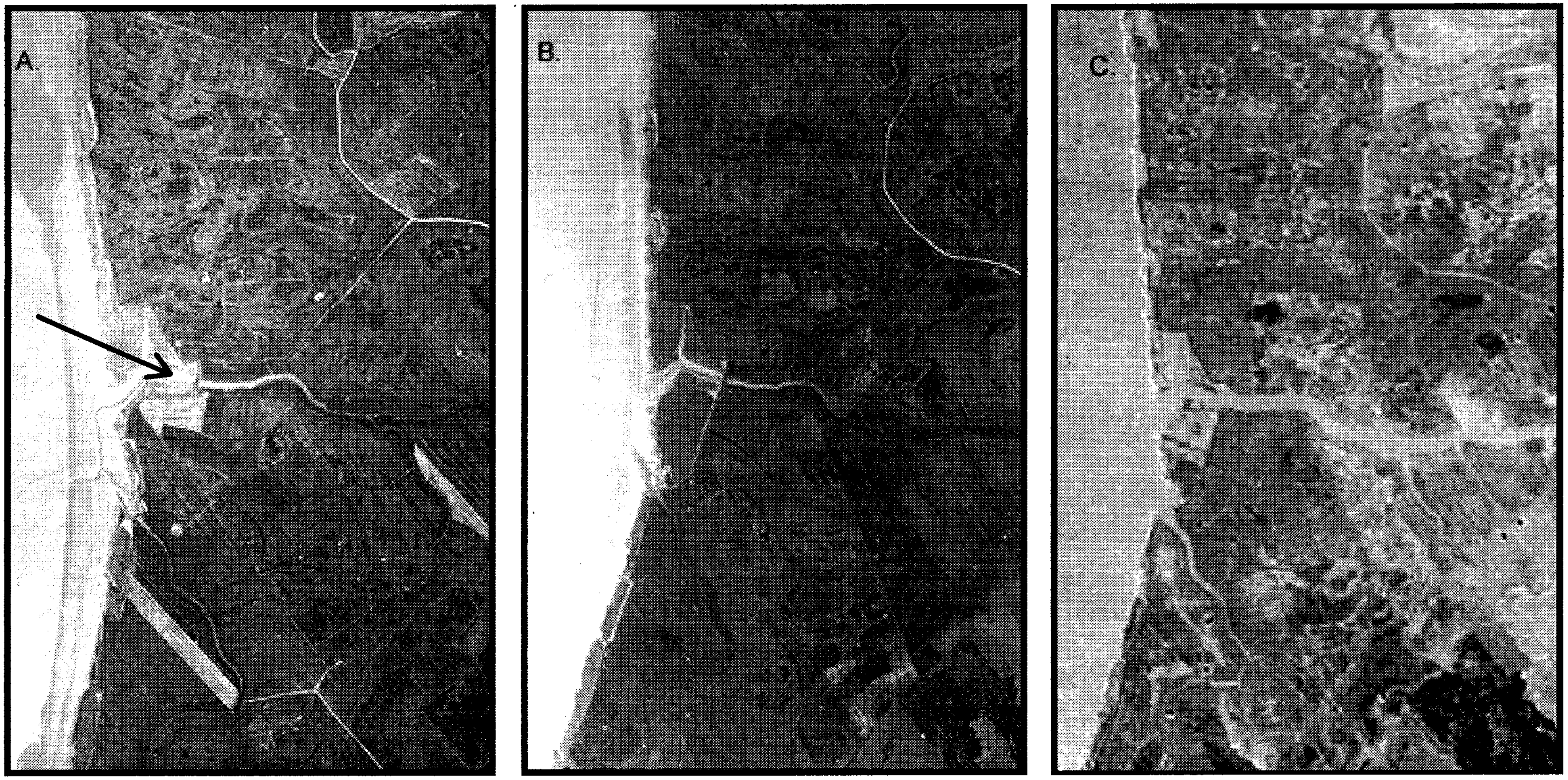

Figure 5: Historical air photo sequence of Sharps Creek (arrow) in John Lusby Marsh. Photo A (National Air Photo Library, 1931) shows the area in 1931 with well maintained dikes enclosing Sharps Creek, the outer salt marsh edges and other small creeks. Also visible on the air photo are roads, field configurations and barns (small white squares). In July of 1945 (Photo B) (National Air Photo Library, 1945) the dike configuration around Sharps Creek has been changing, indicating ongoing maintenance of the dikes. By November 1947 (Photo C) (National Air Photo Library, 1947) the dike around Sharps Creek has been breached. Subsequent photos show that it was never rebuilt.

inundation, is first to colonize a mudflat once it reaches the critical elevation within the tidal range (Ganong, 1903). It is also found along the lower sections of tidal creek banks that are flooded on a daily basis and in regularly flooded local depressions throughout the marsh. *Salicornia europeae, Spergularia canadensis, Suaeda maritima,* and *Atriplex patula* often establish themselves at slightly higher elevations in newly developing marshes. Once the new salt marsh becomes more established, this species assemblage is usually incorporated into the lower range of the *S. patens* high-marsh zone. This is the grass that evokes the term 'salt meadows' in many salt marsh descriptions and it is found almost mono-specifically at elevations just above the *S. alterniflora* zone; however, in higher areas it becomes increasingly mixed with *Limonium nashii, Plantago maritima, Puccinellia maritima, Juncus gerardii, Triglochin maritima, Hordeum jubatum, Glaux maritima* and several species of *Atriplex.* Mixtures of these species are especially noticeable along creek bank levées and areas that are only flooded by the highest monthly tides. *Spartina pectinata* and *Carex sp.* are common along the most upland edges of the salt marshes.

Local Dikeland Vegetation

Diking a parcel of salt marsh arrests the regular supply of fresh sediment and saline water to the soil. With time, usually several years but less than a decade (Clark, 1968, Ganong, 1903, Hatvany, 2002), rainfall and surface drainage leaches the salts from surface sediments and upland grasses, herbs and shrubs quickly replace the halophytes (Ganong, 1903). Dikeland fields are drained by an extensive network of dales and ditches that discharge water through the dikes at low tide by means of one-way flap gates which keep out the sea water at high tide. Early Acadian farmers introduced to the dikelands typical English hay species such as *Phleum pratense* (Timothy) and *Agropyron repens* (Couch grass). These were extremely well suited to local conditions and easily established themselves as the dominant dikeland grass cover. Plant succession in a newly drained dikeland will now progress to a *Phleum-Agropyron* association on its own and persist as long as ideal field conditions are maintained (i.e., good drainage with no tidal flooding) and with minimal need for fertilization. Other common plants in dikeland meadows include grasses such as *Festuca rubra, Poa pratensis* and *Phalaris arundinaceae*, legumes such as *Trifolium pratense, T. repens* and *Vicia cracca,* and weeds such as *Taraxacum officionale, Leontodon sp.,* and *Stellaria gramineae.*

Local Fallow/Abandoned Dikeland Vegetation

In abandoned dikelands where drainage is not maintained but the dikes remain functional, it appears that shrubs, herbs and mosses begin to establish themselves (Figure 6). In some of the fallow and somewhat neglected dikelands of Minudie Marsh (Figure 2 and 6), *Spiraea latifolia* is very abundant, as are moss polsters, *Alnus* and *Betula*. If dikes fail and are not repaired and the dikeland has not fallen too far below current high tide levels (due to soil compaction during drainage and zero-influx of tidally imported sediment while diked), halophytes quickly re-establish themselves (Ganong, 1903). If the area has fallen too far below sea, it will revert to mudflats until enough sediment has accumulated to once again raise it to the elevation necessary for salt marsh development.

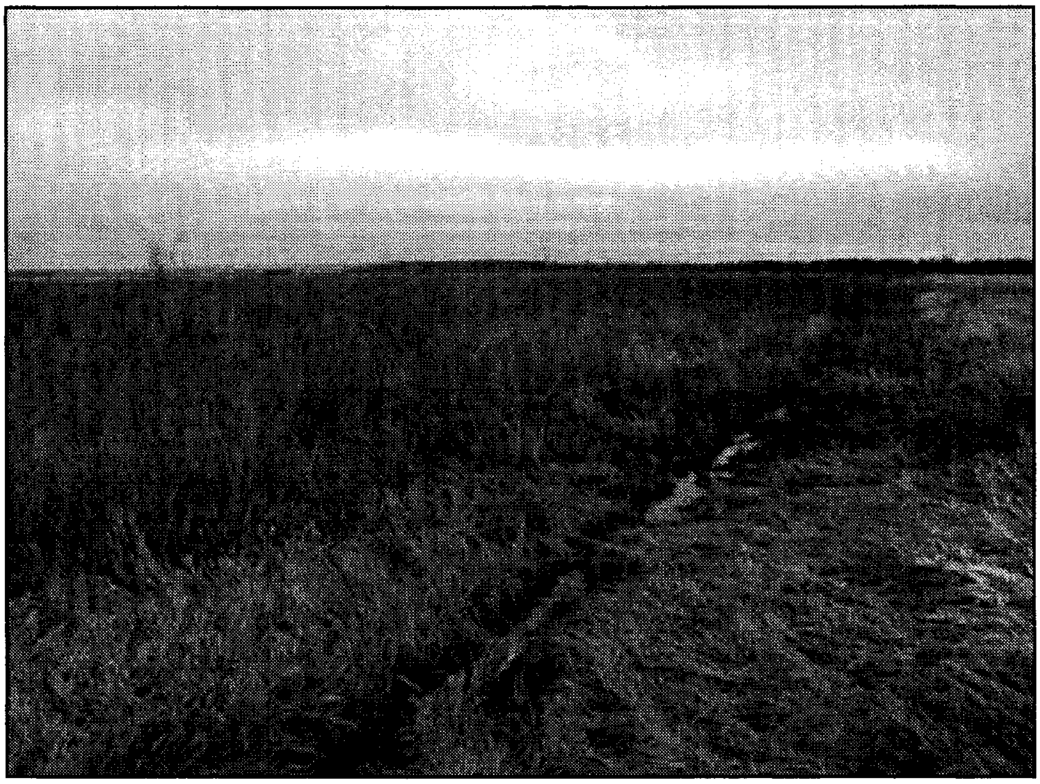

Figure 6: Fallow dikeland at Minudie Marsh. Note the growth of small and large shrubs, as well as the old drainage ditch. (Photo taken May 15, 2003.)

METHODS

Field Sampling

Modern dikeland soil samples were taken in hayed and grazed meadows at Agriculture and Agri-Food Canada's Nappan Experimental Farm on May 12, 2002. Seventeen samples were collected from hayed plots and a grazed field was sampled at five different locations (Table 1). The top 1 cm of soil was used for pollen analysis. The vegetation in the fields and dales consisted of various grasses yielding Poaceae-type pollen including *Agropyron repens, Phleum pratense*, *Festuca rubra, Poa pratensis* and *Spartina pectinata,* legumes yielding Fabaceae-type pollen including *Trifolium repens, Trifolium pratense* and *Vicia cracca.* Other plants observed were *Stellaria gramineae* which yields Caryophyllaceae-type pollen, and *Taraxacum officionalis* which has Asteraceae Liguliflоreae-type pollen.

Soil from John Lusby Marsh was collected between July 23 and August 2, 2002. Twelve surface samples were collected in areas where different plant species dominated so that the full range of variability was represented (Table 1). These were plots dominated by (pollen type produced shown in brackets): *Atriplex sp.* (Cheno-Am), *Secale sp.* (Poaceae), *Solidago sempervirens* (Asteraceae Tubulifloreae-type), *Spartina pectinata* (Poaceae), *S. patens* (Poaceae), *S. alterniflora* (Poaceae), *Carex sp.* (Cyperaceae), *Triglochin maritima* (*Potamogeton*-type), *Limonium nashii* (Plumbaginaceae), *Sueada sp.* (Cheno-Am), *Hordeum jubatum* (Poaceae) and *Juncus gerardii* (Juncaceae but pollen is not visible in palynological preparations). *Puccinellia maritima* (Poaceae) was present in the plots where *Atriplex sp.* and *Hordeum jubatum*

Sample ID	A Priori Group / Land Use	Description, Comments (all samples are 1 cm deep surface samples unless otherwise noted)
JL1	John Lusby Marsh	*Atriplex littoralis*-dominated with some *Puccinellia maritima,*and unidentified grasses
JL2	John Lusby Marsh	*Secale sp.*-dominated with minor amounts of small forbs
JL3	John Lusby Marsh	*Solidago sp.*-dominated with fine grass
JL4	John Lusby Marsh	*Spartina pectinata* mixed with some *S. patens, Atriplex sp.*, unidentified forbs and fine grasses
JL5	John Lusby Marsh	Monospecific stand of *Carex sp.* at uppermost marsh edge
JL6	John Lusby Marsh	Mix of *Triglochin maritima, S. patens and Glaux maritima* in high marsh
JL7	John Lusby Marsh	Monospecific high marsh stand of *S. patens*
JL8	John Lusby Marsh	Monospecific stand of *Spartina alternifora* along creekbank.
JL9	Wood Point Marsh	*Limonium nashii* in high marsh
JL10	John Lusby Marsh	Monospecific stand of *Sueada sp.*
JL11	John Lusby Marsh	Mix of *Hordeum jubatum, Puccinellia maritima* and other unidentified grasses in high marsh
JL12	John Lusby Marsh	Monospecific high marsh stand of *Juncus gerardii*
JL13	John Lusby Marsh	Monospecific *S. patens*
JL14	John Lusby Marsh	Monospecific *S. alterniflora*
JL15	John Lusby Marsh	Monospecific *S. patens*
JL16	John Lusby Marsh	Monospecific *S. patens*
JL17	John Lusby Marsh	Monospecific *S. alterniflora*
N1	Nappan Farm – Hayfield	Unfertilized hayfield with clover, grasses, dandelion, some mosses
N2	Nappan Farm – Hayfield	Dry patch in unfertilized hayfield with fine grasses and mosses
N3	Nappan Farm – Hayfield	Unfertilized hayfield with clover, dandelion, other legumes, coarse and fine grasses
N4	Nappan Farm – Hayfield	Manured hayfield with grasses, unidentified forbs and dandelion
N5	Nappan Farm – Hayfield	Manured hayfield with dandelion, legumes and various grasses
N6	Nappan Farm – Hayfield	Fertilized hayfield with grasses, some mosses and dandelion in vicinity
N7	Nappan Farm – Hayfield	Fertilized hayfield with grasses, and dandelion
N8	Nappan Farm – Hayfield	Fertilized hayfield with uniform coarse grass cover
N9	Nappan Farm – Hayfield	Fertilized hayfield with grass, dandelion and small forbs
N10	Nappan Farm – Hayfield	Fertilized hayfield with grasses, small forbs and dandelion
N11	Nappan Farm – Hayfield	Fertilized hayfield with dandelion, grasses, and small forbs
N12	Nappan Farm – Hayfield	Fertilized hayfield with grasses, and dandelion
N13	Nappan Farm – Hayfield	Fertilized hayfield with fine and coarse grasses, and small forbs

Table 1: Origin and description of soil samples taken both for modern pollen analogue analysis and core samples for historic land use interpretation.

Sample ID	A Priori Group / Land Use	Description, Comments (all samples are 1 cm deep surface samples unless otherwise nted)
N14	Nappan Farm – Hayfield	Fertilized hayfield with dandelion, grasses, and other small forbs
N15	Nappan Farm – Hayfield	Fertilized hayfield with clover, grasses, and small forbs
N16	Nappan Farm – Hayfield	Fertilized hayfield with dandelion, grasses, and small forbs
N17	Nappan Farm – Hayfield	Fertilized hayfield with dandelion, grasses, and small forbs
N18	Nappan Farm – Grazed Field	Dandelion, grasses, small forbs
N19	Nappan Farm – Grazed Field	Sampled dale with algal cover, grasses, clover. and dandelion in vicinity
N20	Nappan Farm – Grazed Field	Hummocky area with grasses and some dandelion in vicinity
N21	Nappan Farm – Grazed Field	Clover patch with grasses, moss and dandelion in vicinity
N22	Nappan Farm – Grazed Field	Beneath fence line with *Cirsium sp., Achileae sp.,* dandelion, clover, fine grasses, mosses and others in vicinity
M1	Minudie Fallow	Dale bank with *Alnus,* grasses and dandelion-type
M2	Minudie Fallow	*Spiraea latifolia* thicket on bank
M3	Minudie Fallow	1.5 m from dale in grasses and dandelion-type
M4	Minudie Fallow	7-8 m from dale bank in grass
M5	Minudie Fallow	Moss polster
M6	Minudie Fallow	Soil next to moss polster
M7	Minudie Fallow	Shrub *(Betula and Spiraea)* and grass understory
M8	Minudie Fallow	Shrub mix *(Alnus sp., Betula sp., S. latifolia)*
M9	Minudie Fallow	Denser shrubs
M10	Minudie Fallow	*Alnus sp.* near *Picea sp.*
M11	Minudie Fallow	*Picea* litter
A1	Unknown	Core sample – sampled at 113 cm in layer A1 (110-115 cm) (Figure 9)
A2	Unknown	Core sample – sampled at 115.5 cm in layer A2 (115-116 cm) (Figure 9)
A3	Unknown	Core sample – sampled at 119 cm in layer A3 (116-121.5 cm) (Figure 9)
A4	Unknown	Core sample – sampled at 122 cm in layer A4 (121.5-122.5 cm) (Figure 9)
A5	Unknown	Core sample – sampled at 123 cm in layer A5 (122.5-123.5 cm) (Figure 9)
A6	Unknown	Core sample – sampled at 124 cm in layer A6 (123.5-125 cm) (Figure 9)
A7	Unknown	Core sample – sampled at 129 cm in layer A7 (125-140 cm) (Figure 9)
A8	Unknown	Core sample – sampled at 144 cm in layer A8 (140+ cm) (Figure 9)

Table 1: (Continued)

were collected, and *Glaux maritima* (*Glaux maritima)* and *S. patens* were also abundant in the *Triglochin maritima* sampling plot. In addition, five surface samples were sectioned from the tops of sediment cores collected during this sampling period, three from virtually monospecific *S. patens* high marsh zones and two from *S. alterniflora* low marsh zones. Only the top 1 cm of soil was used for the pollen analysis.

The surface litter was sampled from a fallow dikeland at Minudie Marsh on May 15, 2003. Eleven samples were collected along a transect beginning at a dale and finishing in a stand of *Picea sp.* in an effort to sample the full range of local vegetation. The sample sites included a dale bank dominated by *Alnus* shrubs with grasses and Composites, *Spiraea latifolia* thickets on top of the dale bank, grassier areas with and without Composites, a moss polster, shrubby areas with *Betula, Alnus* and *S. latifolia* of various densities, and *Picea.* General vegetation observations were made, although these were sparse because the growing season had scarcely begun.

Using an Eijkelkamp hand auger, a 40 cm long and 6.35 cm diameter core was manually extracted from the old dikeland surface on July 23, 2002, near an old drainage sluice exposed along the seaward edge of John Lusby Marsh (Figure 7). The sluice is buried beneath about 100 to 120 cm of salt marsh sediment and has been exposed by wave erosion at the salt marsh edge. The sluice was used for drainage during the agricultural phase of John Lusby Marsh. Just south of the sluice, at approximately the same depth below the modern marsh surface, are the buried remnants of a government-operated wharf that was built in 1906 and used for exporting local produce and fish (Figure 8). Stones, bricks and wood from the wharf that were buried after dike breach are now also exposed by erosion. The occurrence of both features at the same level is striking evidence that this was the dikeland surface just prior to dike breach.

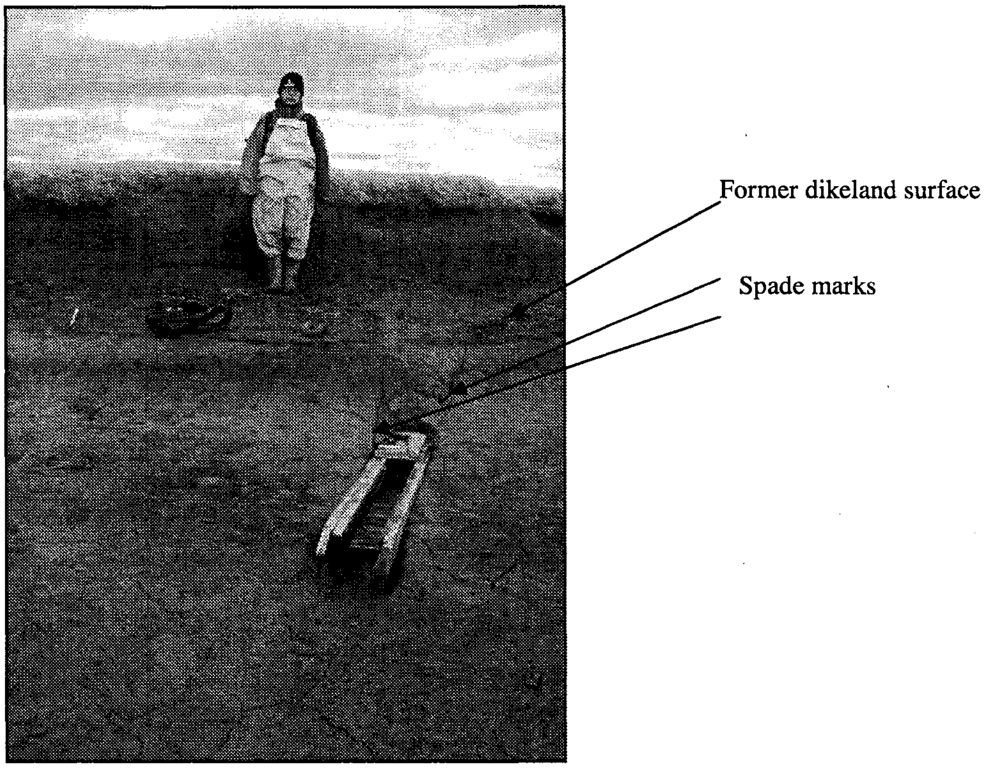

Figure 7: Buried drainage sluice exposed in erosional scarp along western edge of John Lusby Marsh. Note the spade marks showing how the sluice was buried about 40 cm below the former dikeland surface. (Photo taken May 11, 2002.)

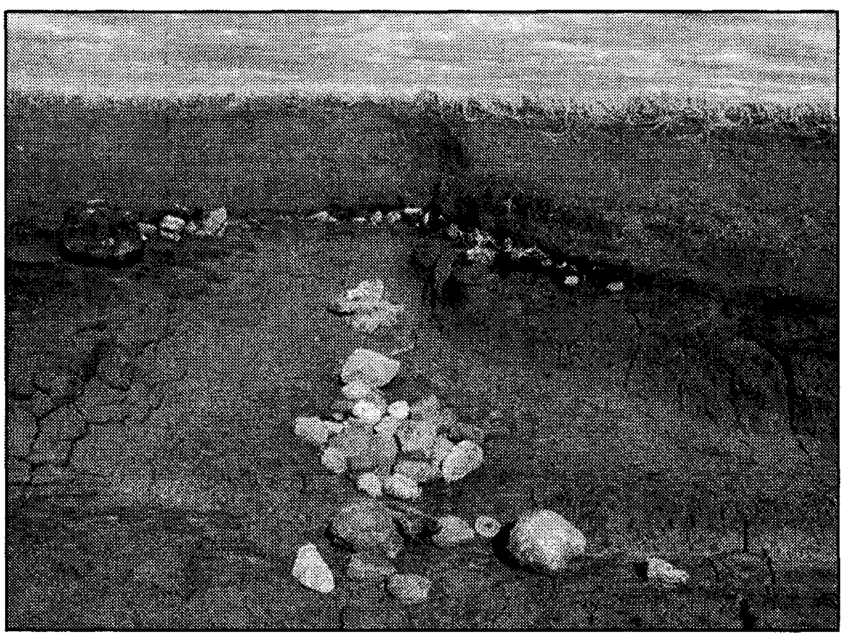

Figure 8: Buried wharf site exposed just south of exposed sluice above. This wharf was built in 1906 and used to export local produce and other goods. Note red knapsack (top left) for scale. (Photo taken May 11, 2002.)

The core revealed a sequence of distinctly coloured layers ranging from grey to brown to black (Figure 9). The uppermost 15 cm of the core (~110 to 125 cm depth below marsh surface) contain what are believed to be the soils of the farmed reclamation surface. Compared to the lower section of the core, which is composed of black-speckled grey clayey silts, these soils are much browner, more loosely structured and contain many fine roots. The darkest layer (A6) contains abundant charcoal, which gives it its nearly black colour and renders it visually very distinct from the grey soils below. Above this sharp transition zone, the soils are also clearly layered, a feature that is not evident in the lower grey silts.

Small amounts of soil (<1 cm^3) were taken from each of eight differently coloured soil layers and used for pollen analysis. A similar sequence of soil layers was also identified in two other exploratory cores taken several metres back from the marsh edge at depths between 110 and 130 cm from the marsh surface. The core was labeled and transferred to plastic tubing for transport to laboratory facilities. The cored samples used in this study thus represent the top 40 cm of dikeland agricultural soil now buried about 1 m below the present-day marsh surface.

Laboratory Preparations and Analysis

Standard procedures used for pollen extraction (Moore et al., 1991) included treatments with HCl, KOH, glacial acetic acid, acetolysis and hot HF. Samples were sieved through a 125 μm sieve and retained on a 10 μm sieve. A tablet containing a known concentration of *Lycopodium* spores was added to each sample (Stockmarr, 1977). Aliquots were stained with safranin and mounted in glycerine jelly. Pollen and spore identification was performed using a 630 x magnification oil immersion lens,

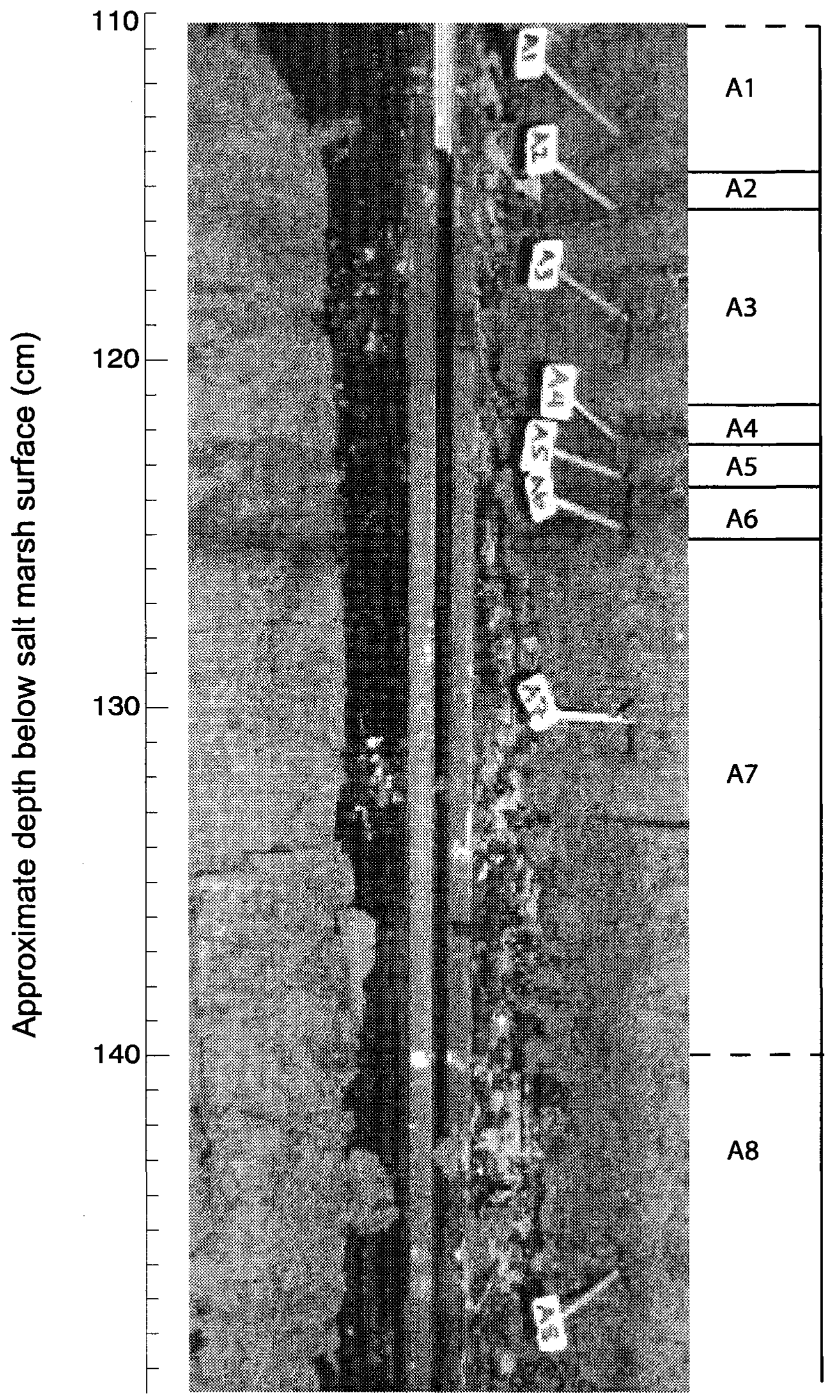

Figure 9: Photo of Core A (two halves split open) showing the eight depths of A1-A8 selected for pollen analysis. Note the abrupt colour changes, especially between the black speckled gray unit A7 and the much darker and organic unit A6. Similar horizons. ranging in thickness from 11-35 cm, were identified throughout John Lusby Marsh at depths varying from 80 cm to 130 cm from the marsh surface.

McGill's Palaeoenvironmental Research Laboratory reference collection, and several palynomorph identification keys (McAndrews et al., 1973; Moore et al., 1991; Kapp et al., 2000). In total, 50 surface samples were counted, with pollen counts averaging 822 grains per slide but ranging from 408 grains per slide to 1362 grains per slide. In the eight sediment core samples, the average number of pollen grains counted per slide was 805, ranging from 457 to 1156 grains per slide. On many slides Poaceae counts were so high that larger numbers of pollen grains were counted in order to gain a better palynological representation of the local flora. The aim was to have at least 200-300 non-grass pollen grains in each count. Pollen was counted along evenly spaced transects covering the entire slide so as to minimize the potential effects of differential sorting during slide mounting. Grains that could not be identified because they were corroded, torn or folded were counted as indeterminate and included in the total pollen sum. Indeterminate pollen grains accounted for less than 5% of pollen counts in all samples, with the majority being less than 1%. Psimpoll 2.30 plotting software was used to produce all pollen diagrams (Bennett, 1997) and all pollen data were analyzed as percentages of the total pollen sum.

Coprophilous fungal spore counts were carried out for 36 of the 50 surface samples, including the eleven fallow land use samples from Minudie Marsh, ten salt marsh samples from John Lusby Marsh, eight samples from Nappan Farm that have not been grazed or manured for approximately 100 years, and seven samples that are either grazed seasonally or manured bi-annually. Fungal spores were counted separately from the pollen counts and spore types identified included *Sordaria*-type, *Tripterospora*-type, *Cercophora*-type, *Chaetomium*-type, *Podospora*-type and *Sporormiella*-type. Identification was based on illustrations and descriptions found in van Geel et al.

(2003). The percentage of total fungal spores for the different samples were calculated based on *Lycopodium* marker grain counts and converted to percentages of the total pollen sum based upon the number of *Lycopodium* counted in pollen transects.

Statistical Analyses

Discriminant Analysis (DA)

All DA calculations were performed using SPSS 11.0 (SPSS Inc., 1999). Discriminant analysis classified samples into three groups based on a priori criteria. These were modern restored salt marsh, modern agricultural dikeland, and fallow dikeland. Squared Mahalanobis Distance (SMD) was used to calculate the maximum difference between a priori grouped sample centroids. Once discriminant functions are calculated to separate the groups as distinctly as possible, DA can then assign group memberships to other samples whose identity is unknown (Liu and Lam, 1985). The analysis requires that the data under consideration meet a set of five assumptions that are often unsupportable for ecological data. The five assumptions are: (1) all samples were chosen randomly from within their a priori land use type; (2) all groups have equal probability that an unknown (i.e., fossil) sample belongs to that group; (3) the samples used to calculate the discriminant functions are correctly classified into their a priori group; (4) the variance-covariance matrices of the groups are statistically equal; and (5) the variables are normally distributed within each group. Statistical evidence shows that certain assumptions can be violated without causing significant effects in classification results (Williams, 1983; Liu and Lam, 1985; Sugden and Meadows, 1989).

For this study assumption one can be met with the reservation that in areas with distinctly patchy vegetation (i.e., John Lusby high marsh, Minudie Marsh), samples were specifically collected from within such patches to ensure that, as much as possible, the full range of variability in the vegetation was reflected in the modern analogues. The second assumption is not entirely met because unequal numbers of samples were collected from the three a priori land use types. Assumption three is met because the three sampling locations are clearly distinct, both geographically and in terms of land use management. Assumption four can be tested statistically using Box's M statistic, as can assumption five by using measures of multivariate skewness and kurtosis. In testing assumption four, the Box's M statistic was found to be 872.7 with a corresponding F value of 6.6. With 90 and 3,314.2 degrees of freedom, the Box's M was significant at the 0.0 level, which means that there is no significant difference between the variance-covariance matrices tested. Assumption five was not tested because it is rarely fully met with ecological data sets; however, many authors confirm that limited departures from normality will not seriously affect classification results (Davis, 1973; Nie et al., 1975; Williams, 1983; Liu and Lam, 1985; MacDonald and Ritchie, 1986).

The smallest a priori group contained eleven samples and the DA was performed using only nine taxa variables. This complies with the additional requirement that the sample size of the smallest group should be greater than the number of predictor taxa used (Tabachnick and Fidell, 2001). Tree pollen types were grouped into coniferous and deciduous and the shrub category includes *Betula, Alnus, Corylus, Myrica,* and *Ostrya* (excluding *Spiraea latifolia* which is listed with Rosaceae and kept separate). Legumes were grouped together, as were fern and moss spores (including *Dennestaedtia,* *Sphagnum, Dryopteris, Equisetum, Isoetes*, non-exotic *Lycopodium, Osmunda, Polypodium, Schleroderma* and *Selaginella*), and fresh water wetland pollen types (including *Typha, Myriophyllum,* Nymphaceae and *Callitriche*). Very infrequently observed pollen types (i.e., *Cornus, Dicranum, Crucifera, Hyperzia, Monotropa uniflora,* and *Portulaceae)* with very low counts (<5 grains) in very few samples (<3) were not included in the statistical analysis. This grouping reduced the data into 17 pollen groups: coniferous trees, deciduous trees, shrubs, Caryophyllaceae, Cheno-Am-type, Asteraceae Liguliflloreae-type, Asteraceae Tubulifloreae-type, Cyperaceae, Fabaceae, *Plantago maritima,* Poaceae, *Polygonum*, *Potamogeton*-type, Ranunculaceae, Rosaceae, fresh water wetland types, and fern and moss spores. The best DA results (96% correct classification) using different combinations of these groups were obtained with the following groups: Asteraceae Liguliflloreae-type, Asteraceae Tubulifloreae-type, Fabaceae, fern and moss spores, Poaceae, shrubs, coniferous trees, deciduous trees and *Potamogeton*-type. Pollen abundances from these nine groups do not add up to 100% of the pollen counted in any of the samples.

The probability of modern analogue for both a priori classified (surface) samples and unknown (fossil) samples (Liu and Lam, 1985) was also calculated with SPSS. In essence, the probability of modern analogue compares the pollen signature of an individual sample to the overall pollen signature of all the samples in the vegetation class from which it was originally collected. A land use class in which many modern analogue surface samples have low probabilities of modern analogue likely has vegetation characteristics that are very patchy and although all samples stem from that particular land use class, vegetation characteristics within that land use class are very varied. For example, in John Lusby Marsh and Minudie Marsh, special care was taken to collect surface samples from distinct vegetation patches rather than from areas of uniform vegetation (despite the fact that large areas of the salt marsh have virtually monospecific vegetation types (*S. alterniflora* low marsh zones and *S. patens* mid-high marsh zones). Conversely, the samples collected in the hayed meadows at Nappan Farm were collected along a grid and the vegetation in general was more homogenous than in the other two land use classes. In this case, the probabilities of modern analogue of the surface samples should be quite high. In the grazed meadows at Nappan Farm, efforts were made to collect surface samples in a variety of vegetation zones, including along fence lines and dales. For the fossil samples, probabilities of modern analogue values indicate the strength of the resemblance to its assigned modern vegetation region. Fossil samples with low probabilities of modern analogue may stem from a vegetation type for which no modern analogue was established, or they may strongly resemble an equally atypical modern sample from the assigned land use class.

Combined DA of modern samples with 'unknown' fossil samples from the John Lusby Marsh core was used to explore the probability that fossil pollen assemblages reflected the land uses described by the modern analogues. The DA assesses each unknown sample in terms of how it compares with the discriminant functions generated by the a priori groups. Hence, in a graph of discriminant functions, unknown samples will plot nearest to the modern analogue they most resemble. In addition, SPSS was used to generate casewise statistics which give the probability of each sample belonging to the assigned group, the probability of its misclassification, the probability of modern analogue and the squared Mahalanobis' distance of each sample to the nearest and second nearest group centroids.

Analysis of Variance (ANOVA)

Analysis of variance was performed with SPSS 11.0 (SPSS Inc., 1999) to determine if abundances of coprophilous fungal spores varied with agricultural land use practices (i.e., grazing and manuring). ANOVA was used to compare the means of dung fungus percentages in the four different land uses.

RESULTS

Modern Pollen Assemblages

The pollen diagram of the 17 pollen groups and taxa used in the discriminant analysis of the 50 surface samples is shown in Figure 10. Pollen types indicative of salt marshes include those from trees, P*otamogeton*-type, Cheno-Am-type and Cyperaceae. Several of these pollen types, such as P*otamogeton*-type, Cheno-Am-type, Cyperaceae and *Caryophyllaceae,* have conspicuously high numbers in only one of the 17 salt marsh samples. This is always due to the fact that several of the salt marsh samples were collected in distinct patches of certain vegetation types. Sample JL6 was collected near *Triglochin maritima* which produces *Potamogeton*-type pollen. Similarly, JL5 was collected in a stand of *Carex sp.* and so contains abundant Cyperaceae pollen. In general, salt marsh samples contained higher percentages of tree pollen relative to the dikelands, especially the farmed dikelands. Plant spores too tended to be abundant in the salt marsh and in the fallow dikelands. It should be noted that samples M5 and M6 were collected in and adjacent to a moss polster. The pollen type most indicative of the farmed dikelands was Asteraceae Ligulifloreae-type, normally very rare in pollen

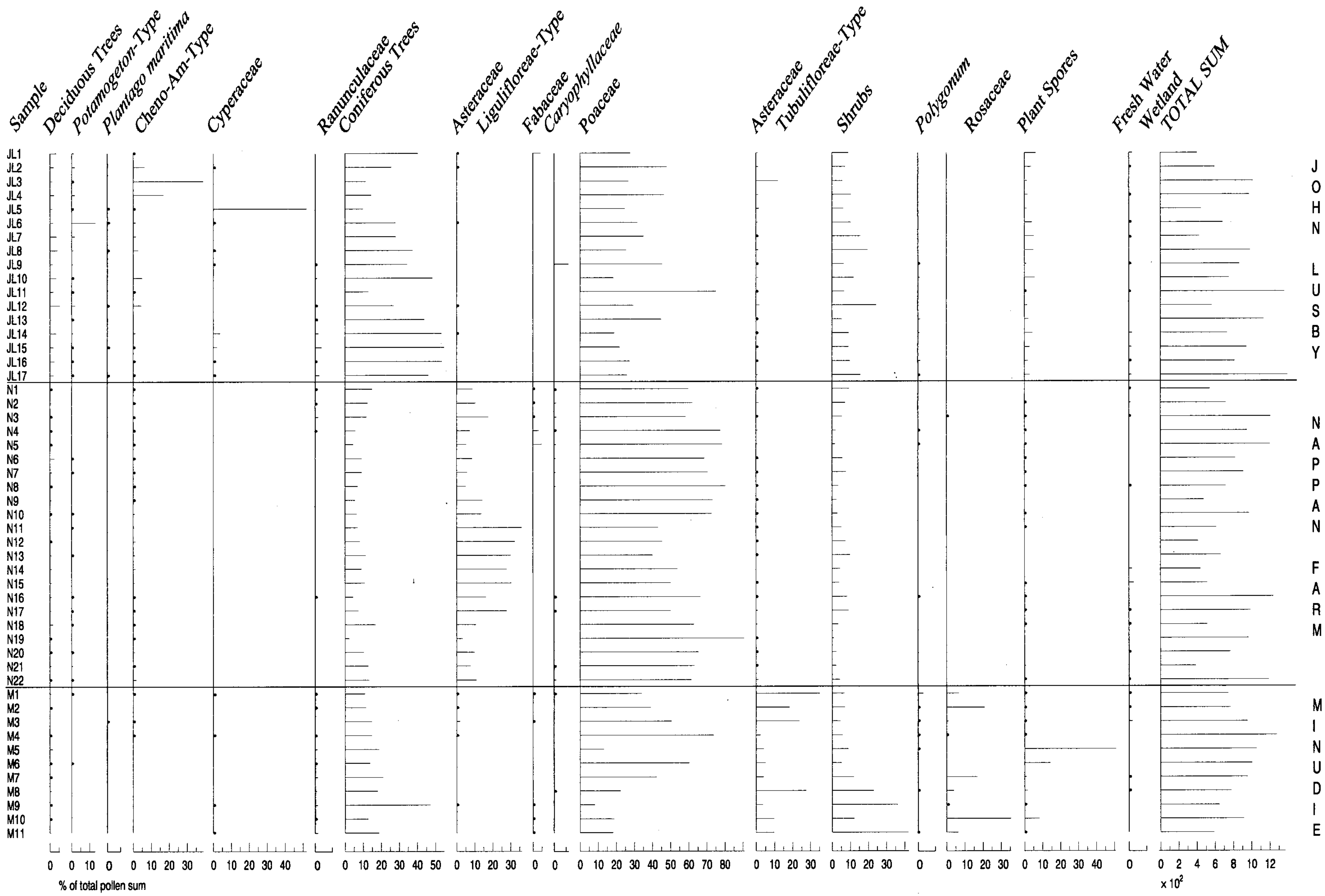

Figure 10: Modern analogue pollen assemblages for John Lusby Marsh, Nappan Farm and Minudie Marsh as percentages of the total sum.

studies, which was present in every sample with percentages ranging from 3 to 36 of the total pollen sum. Poaceae pollen was also distinctly more abundant in the farmed dikelands while tree and shrub pollen percentages were lower relative to the salt marsh and the fallow dikeland. Asteraceae Tubulifloreae-type pollen was most abundant in the fallow dikelands with percentages ranging from 2 to 35. In addition, shrub and Rosaceae pollen were abundant in this land use type.

Discriminant Analysis

The trends observed in the pollen diagram are reflected in the results of the DA according to the classification function coefficients given for the nine taxa in each of the three land use types (Table 2). Of the nine pollen taxa used in the discriminant analysis, deciduous tree and *Potamogeton*-type pollen were important to the classification of salt marsh samples. Asteraceae Liguliflorea-type and Fabaceae pollen were strong indicators of farmed dikelands. Poaceae pollen also had the highest classification function coefficient in the farmed dikeland land use class; however, this pollen type was also important in classifying the salt marsh and fallow dikeland samples. Higher percentages of Asteraceae Tubulifloreae-type and shrub pollen figured strongly in the fallow dikeland classification. Coniferous tree pollen percentages appeared to be considerably higher in the salt marsh than the dikelands on the pollen diagram; however, this is not strongly reflected in the DA where the classification function coefficients were very similar for all three land use types.

The first two discriminant functions accounted for 100% of the variance in the data set. Function one accounted for 58.3% of the variance and function two for 41.7%.

Table 2: Classification function coefficients determined with Fisher's linear discriminant functions.

Taxa	Salt Marsh	Farmed Dikeland	Fallow Dikeland
Coniferous Trees	86.03	81.87	88.76
Deciduous Trees	122.71	-130.36	-371.04
Shrubs	106.78	148.58	181.10
Asteraceae Liguliflorae-Type	97.64	166.63	115.35
Asteraceae Tubuliflorae-Type	126.58	146.03	209.09
Poaceae	97.91	133.13	121.75
Potamogeton-Type	112.51	55.61	37.32
Plant Spores	92.30	122.79	159.45
Fabaceae	61.58	162.08	57.35
(Constant)	-42.97	-64.32	-62.56

Table 3 lists the casewise results of the surface sample discriminant analysis and Table 4 contains the standardized discriminant function coefficient for each of the nine taxa used in the analysis. All but three samples clearly cluster around the distinctly separated centroids of the three a priori land use types (Figure 11). Two samples were misclassified by the DA. These plotted on the peripheries of their a priory group and the dikeland agricultural group. Sample M7, although correctly classified by the DA, actually plots quite centrally to all three land use types, suggesting it bears characteristics of them all.

All but two samples were classified into their a priori group yielding a correct classification percentage of 96%. Sample JL11 was collected in the salt marsh but was misclassified in the dikeland agricultural group. The second highest predicted group for this sample was salt marsh. Compared to the correctly classified samples, the squared Mahalanobis distance (SMD) to its highest predicted group centroid (agricultural dikeland) was relatively large (3.584) and relatively small (9.240) to the second highest predicted group centroid (salt marsh). This suggests that this sample bore resemblances to both these groups and statistical discrimination was difficult. Sample M4 was also misclassified in the DA. Its actual group membership is fallow dikeland but the DA predicted with a 95% probability that it too belongs to the agricultural dikeland group. Its second highest predicted group was the a priori group from which it was collected and again, relative to correctly classified samples, the differences in the SMDs between the two centroids are relatively small (3.883 to the agricultural centroid and 10.002 to the fallow dikeland centroid). Sample M7 is also quite interesting because, although the DA predicted correctly that it belongs to the fallow dikeland group with an SMD of 4.523, the sample's SMD to the salt marsh group is also relatively small (9.949). This

Sample Name	A Priori Group	Highest Predicted Group	Prob. of Modern Analogue	Prob. of Group Membership	Squared Mahalanobis Distance to Centroid	Second Highest Predicted Group	Prob. of Group Membership	Squared Mahalanobis Distance to Centroid	Discriminant Scores Function 1	Discriminant Scores Function 2
JL1	1	1	0.417	1.000	1.749	2	0.000	27.569	-2.363	-2.811
JL2	1	1	0.633	0.999	0.914	2	0.001	15.684	-1.518	-1.300
JL3	1	1	0.197	0.987	3.244	3	0.013	11.870	-2.529	0.308
JL4	1	1	0.572	0.999	1.117	2	0.001	14.894	-1.422	-1.268
JL5	1	1	0.966	1.000	0.070	3	0.000	24.507	-2.625	-1.290
JL6	1	1	0.578	1.000	1.096	2	0.000	34.198	-3.244	-2.180
JL7	1	1	0.947	1.000	0.108	2	0.000	24.841	-2.448	-1.821
JL8	1	1	0.844	1.000	0.338	3	0.000	29.694	-3.006	-1.678
JL9	1	1	0.674	1.000	0.789	2	0.000	16.529	-1.660	-1.095
JL10	1	1	0.383	1.000	1.919	3	0.000	36.706	-3.741	-2.007
JL11	1	**2	0.170	0.945	3.548	1	0.055	9.240	0.498	-0.770
JL12	1	1	0.469	1.000	1.516	2	0.000	32.617	-2.949	-2.619
JL13	1	1	0.316	0.995	2.305	3	0.003	13.818	-1.501	-0.310
JL14	1	1	0.184	1.000	3.388	3	0.000	44.033	-3.968	-2.539
JL15	1	1	0.635	1.000	0.909	3	0.000	29.984	-3.408	-1.523
JL16	1	1	0.734	1.000	0.618	3	0.000	32.107	-3.154	-1.851
JL17	1	1	0.654	1.000	0.850	3	0.000	18.823	-2.697	-0.602
N1	2	2	0.486	0.999	1.442	3	0.001	15.298	1.514	0.316
N2	2	2	0.745	1.000	0.589	3	0.000	18.969	1.766	-0.050
N3	2	2	0.977	1.000	0.047	3	0.000	25.263	2.464	-0.336
N4	2	2	0.815	1.000	0.410	3	0.000	26.374	2.847	-0.107
N5	2	2	0.854	1.000	0.316	3	0.000	28.790	2.907	-0.378
N6	2	2	0.120	0.980	4.237	1	0.020	12.024	0.969	-2.041
N7	2	2	0.597	0.999	1.031	1	0.000	17.004	1.435	-0.124
N8	2	2	0.705	1.000	0.698	3	0.000	18.363	1.941	0.190

** denotes misclassified sample

Table 3: Casewise statistics of discriminant analysis.

Sample Name	A Priori Group	Highest Predicted Group	Prob. of Modern Analogue	Prob. of Group Member-ship	Squared Mahalanobis Distance to Centroid	Second Highest Predicted Group	Prob. of Group Member-ship	Squared Mahalanobis Distance to Centroid	Discriminant Scores Function 1	Function 2
N9	2	2	0.953	1.000	0.096	1	0.000	26.222	2.608	-0.723
N10	2	2	0.868	1.000	0.283	3	0.000	25.691	2.726	-0.138
N11	2	2	0.188	1.000	3.338	3	0.000	42.259	4.190	-0.631
N12	2	2	0.335	1.000	2.185	3	0.000	37.144	3.840	-0.419
N13	2	2	0.766	1.000	0.533	1	0.000	29.207	2.927	-0.997
N14	2	2	0.468	1.000	1.519	1	0.000	32.258	3.224	-1.414
N15	2	2	0.404	1.000	1.813	1	0.000	33.311	3.316	-1.483
N16	2	2	0.861	1.000	0.300	3	0.000	26.375	2.784	-0.175
N17	2	2	0.559	1.000	1.162	3	0.000	32.846	3.428	-0.348
N18	2	2	0.229	0.988	2.951	1	0.012	11.736	0.971	-1.531
N19	2	2	0.832	1.000	0.367	3	0.000	21.230	2.285	0.071
N20	2	2	0.705	1.000	0.700	1	0.000	17.146	1.540	-0.401
N21	2	2	0.320	0.991	2.280	1	0.009	11.614	0.875	-0.766
N22	2	2	0.639	1.000	0.895	1	0.000	17.387	1.496	-0.158
M1	3	3	0.254	1.000	2.743	1	0.000	41.522	-1.577	4.892
M2	3	3	0.608	1.000	0.997	1	0.000	16.720	-1.251	2.416
M3	3	3	0.727	1.000	0.637	2	0.000	25.138	-0.241	3.753
M4	3	**2	0.143	0.954	3.883	3	0.045	10.002	0.907	0.795
M5	3	3	0.192	1.000	3.300	1	0.000	43.703	-1.584	5.062
M6	3	3	0.244	0.991	2.823	2	0.009	12.203	0.416	2.369
M7	3	3	0.104	0.929	4.523	1	0.062	9.949	-0.875	1.238
M8	3	3	0.068	1.000	5.385	1	0.000	51.185	-1.542	5.604
M9	3	3	0.634	1.000	0.912	1	0.000	24.306	-1.892	3.406
M10	3	3	0.349	0.998	2.108	1	0.002	14.817	-1.951	2.325
M11	3	3	0.201	1.000	3.209	2	0.000	41.730	-0.726	5.143

** denotes misclassified sample

Table 3: (Continued)

Table 4: Standardized discriminant function coefficients.

Taxa	**Function 1**	**Function 2**
Coniferous Trees	-0.108	0.092
Deciduous Trees	-0.295	-0.781
Shrubs	0.423	0.925
Asteraceae Liguliflor eae-Type	1.001	-0.061
Asteraceae Tubulifloreae-Type	0.038	0.925
Poaceae	1.038	0.431
Fabaceae	0.224	-0.079
Potamogeton-Type	-0.164	-0.222
Spores	0.269	0.895
Percent of total variance	58.3	41.7

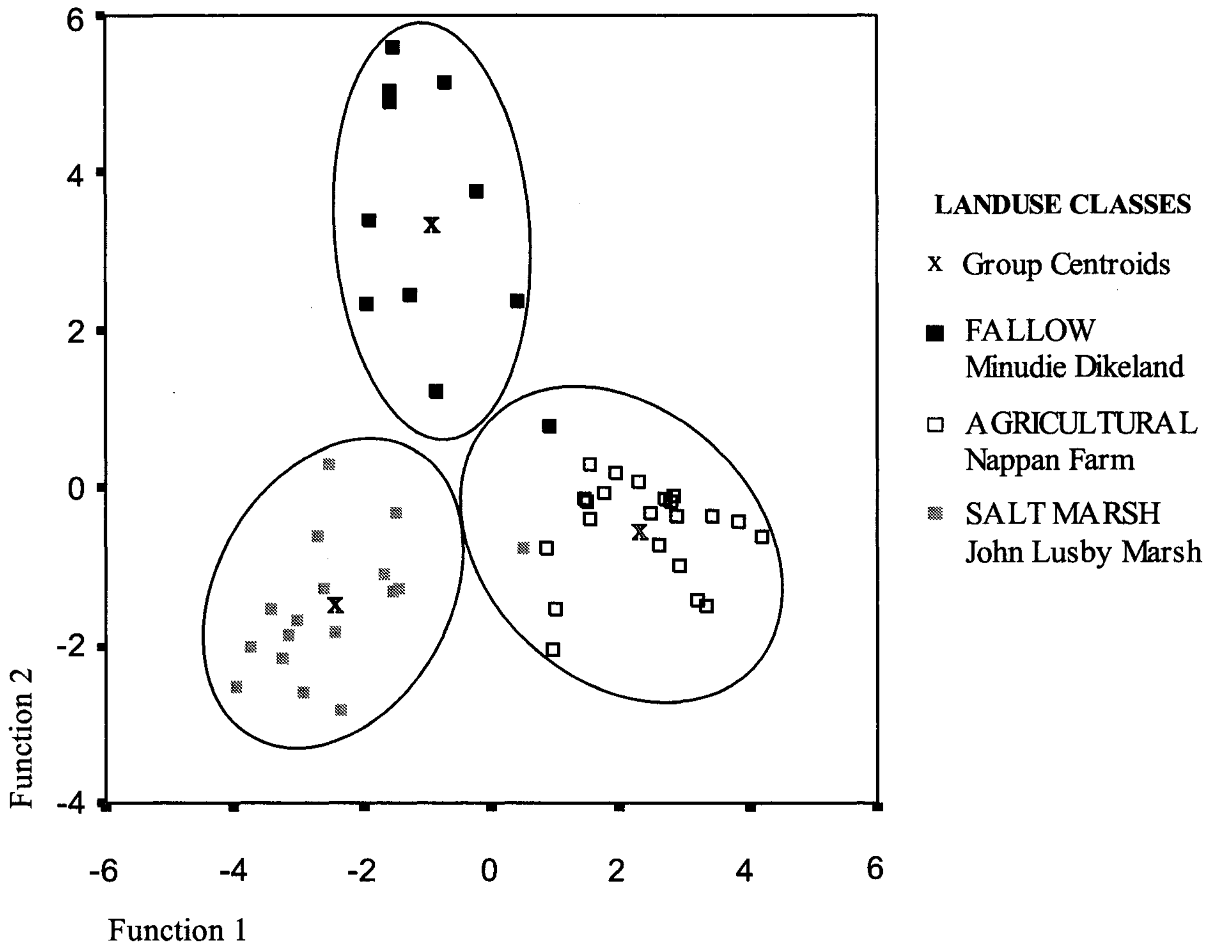

Figure 11: Plot of modern samples along discriminant functions 1 and 2.

sample had the lowest probability of correct group membership of all the samples analyzed with 93%. In Minudie and John Lusby marshes, samples were collected in a broad range of vegetation types and both of the misclassified samples come from the vegetation patches that most resemble the agricultural land use (i.e., extremely high numbers of Poaceae pollen).

I have grouped the probabilities of modern analogue for the surface samples into three categories (high = >0.7, moderate = 0.3-0.7, and low = <0.3) for each of the three land use classes. In John Lusby Marsh, four samples had high probabilities of modern analogue, ten samples had moderate values and three samples scored low. At Nappan Farm, probabilities of modern analogue were high for eleven samples, moderate for eight, and low for only three. Lastly, at Minudie Marsh only one sample had a high probability of modern analogue, three had moderate probabilities and seven samples had low probabilities. This reflects the vegetation distribution in each of the three land use classes. The agricultural samples most resembled each other because the vegetation distribution in that land use class was relatively homogenous compared to the salt marsh and fallow dikeland land uses where I attempted to collect samples representing the wide variety of vegetation present. Both misclassified samples had very low probabilities of modern analogue (0.170 for JL11 and 0.143 for M4). Two other samples with very low probabilities of modern analogue were M7, for reasons previously discussed, and N6 which was correctly classified within its dikeland agricultural land use class. It appears that statistically at least, this sample does not strongly resemble the other members of this land use class. It may be due to the fact that deciduous tree pollen counts in sample N6 are the highest in its land use class, approaching a level similar to those in the salt marsh environment (Figure 10).

Coprophilous (Dung) Fungal Spore Analysis

Attempts to single out grazed or manured agricultural land uses from the others using DA and PCA were unsuccessful using palynological techniques alone, so counts of dung fungal spores were carried out on a 36-sample subset of the 50 surface samples in order to determine if the abundance of coprophilous fungi could assist in this. An ANOVA was carried out to determine if coprophilous fungi counts, as a percentage of total pollen sum, could distinguish grazed or manured fields from hayed or unmanured fields as well as fallow and marsh conditions. Coprophilous fungal spore percentages were significantly higher in grazed or manured fields. The ANOVA generated an F-value of 7.88 with a critical F-value of 2.90, at a confidence level of greater than 99.9% (Figure 12).

Fossil Pollen Assemblages

The soil profile of core A, its soil characteristics, pollen percentages and land use types predicted by the DA are shown on Figure 13. The different soil layers within which samples A1 to A8 were collected are clearly visible on the photograph of the sediment core due to colour differences. The lower layers from which samples A8 and A7 were taken were much greyer in colour and more sparsely rooted than the browner-toned layers above. In addition, these sediments were less friable and contained more clay. The three brown to black layers just above, from which samples A6, A5 and A4 were collected, contained less clay but many more fine roots than the layers below. Of the six uppermost layers, the layer containing sample A3 most resembled layers A7 and A8 in terms of soil texture, colour and structure, whereas the uppermost two layers, A2

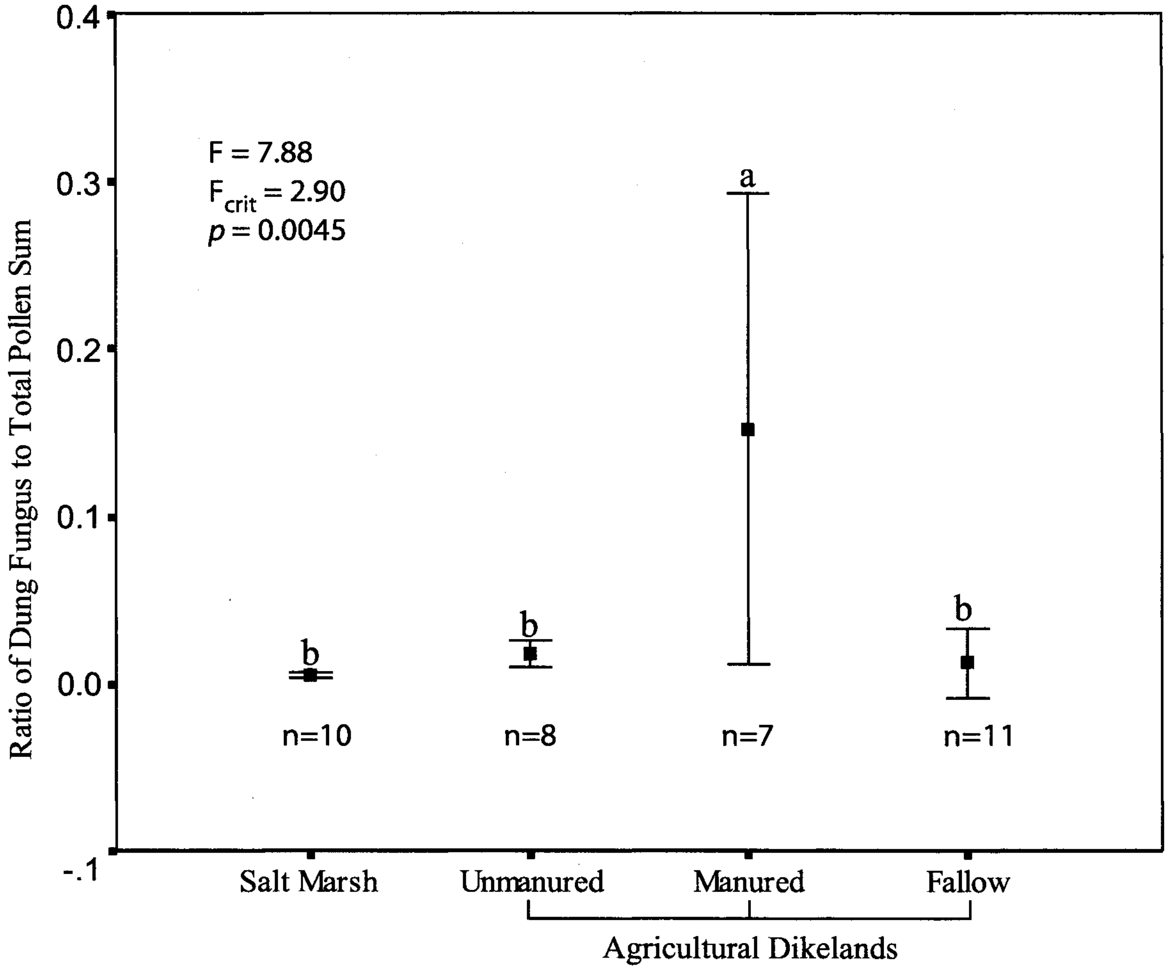

Figure 12: ANOVA results and means with standard error bars of dung fungus concentrations in the four different grassland land uses as percentages of total pollen sum (of 36-sample subset). Means labelled with the same letter are not significantly different. n=sample numbers.

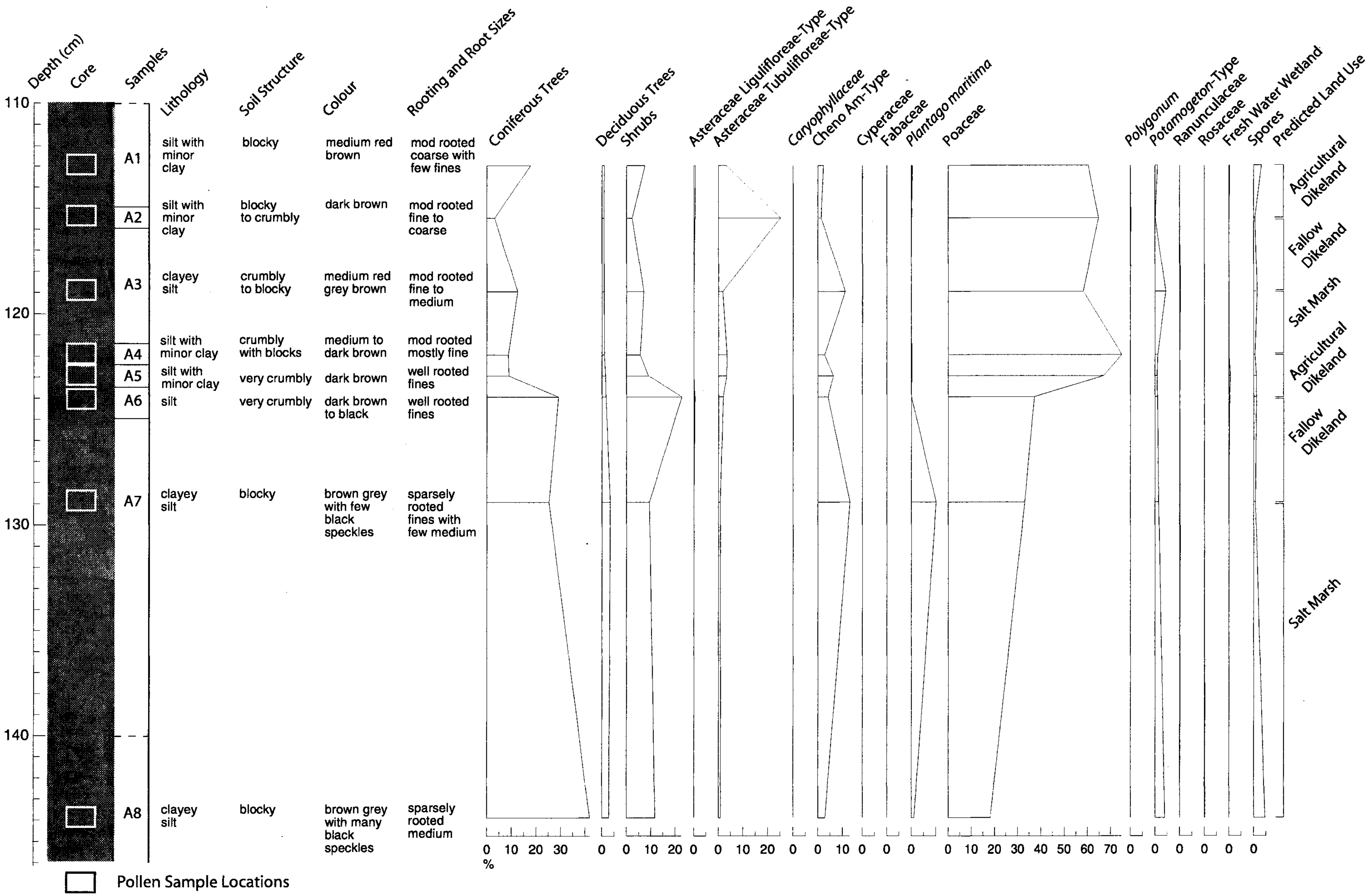

Figure 13: Soil characteristics, pollen percentages and predicted land use profile of Core A. Note that "mod" means "moderately well rooted".

and A1 tended to resemble layers A4 to A6 in terms of texture, colour and rooting, but not in soil structure. The pollen profiles show that tree pollen percentages are highest in the lower two layers. Shrub pollen percentages peak in layer A6 and Poaceae pollen percentages increase dramatically in layers A1 through A5. Asteraceae Tubulifloreae-type pollen is more abundant in the upper six layers.

Discriminant analysis was used to classify the eight fossil pollen assemblages from the sediment core taken in John Lusby Marsh with respect to the modern surface samples. The casewise statistics from the DA are presented in Table 5 and a plot of the eight samples on the first two discriminant functions is shown on Figure 14. For sample A1, the DA predicts that there is a 60% probability that its pollen assemblage reflects an agricultural land use, but there is also a strong 25% probability that it was fallow. The analysis does suggest (i.e., 85% certainty-see casewise statistics) that the pollen assemblage in sample A1 represents a dikeland rather than a salt marsh land use; however, the SMDs to both dikeland centroids are quite large. The probability of modern analogue is also very low for this sample (0.030). Of the eight fossil samples, this is the sample that had the weakest correlation with a modern analogue so it is also possible that this sample represents a fourth type of environment that was not sampled in the modern study, which is for now without a modern analogue.

Sample A2 was classified as fallow dikeland with a 100% certainty, a very small SMD to the fallow group centroid, and with a probability of modern analogue of 0.506, the highest of all eight samples. Samples A3, A4, A5, A7 and A8 were also classified into their respective modern analogue land uses with probabilities of 89% or better. The land uses are salt marsh for samples A3, A7 and A8, and agricultural dikeland for A4 and A5 (Figure 14). The probabilities of modern analogue are quite low for all of

Table 5: Discriminant analysis results for Core A.

Sample Name	Highest Predicted Group	Prob. of Modern Analogue	Prob. of Group Member-ship	SMD To Centroid	Second Highest Predicted Group	Prob. of Group Member-ship	SMD to Centroid	DiscriminantScores	
								Function 1	Function 2
A1	2	0.030	0.601	7.022	3	0.254	8.743	-0.058	0.541
A2	3	0.506	1.000	1.362	2	0.000	19.884	0.229	3.384
A3	1	0.107	0.897	4.472	2	0.097	8.926	-0.620	-0.440
A4	2	0.179	0.980	3.437	3	0.011	12.404	0.676	0.234
A5	2	0.083	0.892	4.980	1	0.080	9.812	0.231	0.120
A6	3	0.047	0.641	6.119	1	0.350	7.329	-1.193	0.903
A7	1	0.292	1.000	2.463	2	0.000	34.374	-2.961	-2.977
A8	1	0.272	1.000	2.604	3	0.000	40.006	-3.890	-2.230

Group 1 = Salt Marsh, Group 2 = Farmed Dikeland, Group 3 = Fallow Dikeland

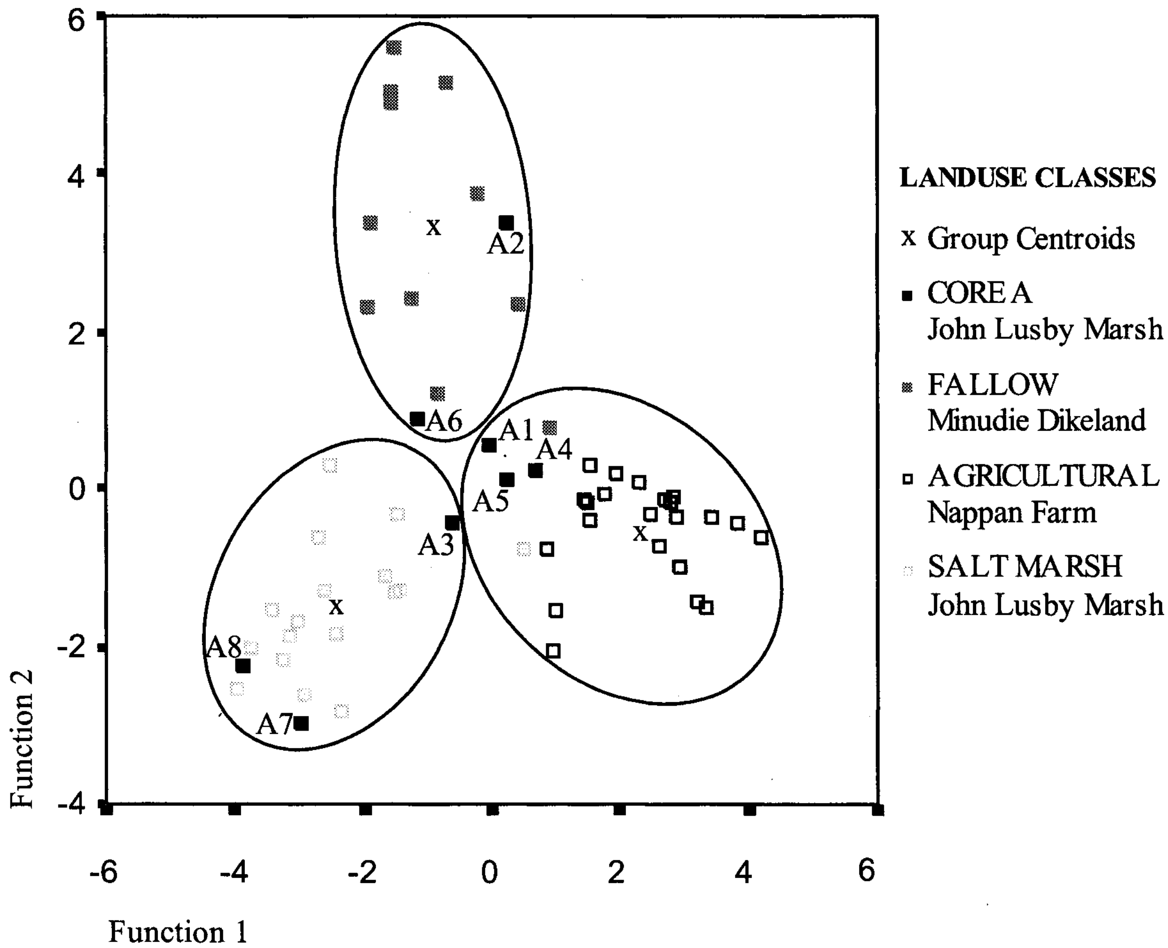

Figure 14: Plot of fossil samples along discriminant functions 1 and 2, superimposed over modern analogue samples.

these samples, ranging from 0.083 to 0.179 for samples A3, A4 and A5, and reaching values of 0.292 and 0.272 for samples A7 and A8 respectively. The only other weakly classified sample is A6, which was grouped as fallow with a 64% probability and as salt marsh with 35% probability. This layer is sandwiched between a salt marsh layer below and an agricultural layer above.

DISCUSSION

Modern Pollen Assemblages

The two dikeland environments were distinguished from each other and from the salt marsh by locally produced pollen types. The agricultural dikeland group was strongly influenced by the greater abundance of pollen from Poaceae, as well as Fabaceae and Asteraceae Liguliflloreae-type pollen, whereas shrubs, Rosaceae, and Asteraceae Tubulifloreae-type pollen characterized the fallow dikeland. Vegetation reflecting these pollen types was observed in abundance at the sample sites. *Potamogeton*-type pollen (produced locally in the salt marsh by *Triglochin maritima*) and non-locally produced deciduous tree pollen types best separated the salt marshes from the dikelands. This is very interesting considering that salt marshes are treeless. John Lusby is a large marsh and, relative to nearby Minudie Marsh and Nappan Farm, it is well removed from strong arboreal influences. Regular tidal import most likely accounts for the large difference in arboreal pollen between the salt marsh and the dikelands (Clarke and Patterson, 1985).

While it was possible to distinguish active agricultural grasslands from the fallow and salt marsh grasslands in the modern analogues based on pollen assemblages alone, it was not possible to detect differences between grazed or manured and hayed or unmanured agricultural practices. Coprophilous fungi can distinguish grazed or manured land uses from all the others. The dung fungal types used are handily incorporated into pollen analyses because the fungal spores are easily identifiable, their size is comparable to pollen grains, and they are not destroyed by the chemical treatments used in palynological preparations. Van Geel (2003) used the presence of coprophilous fungal spores to strengthen interpretations of historical grazing at a Roman Period settlement in the Netherlands. Fungal spore counts have also been used to interpret historical changes in the populations and distributions of Pleistocene megafauna and other kinds of herbivores (Davis, 1987, Burney et al., 2003). These previous studies based their conclusions solely on the qualitative interpretation of pollen and fungal spore diagrams. They did not employ statistical techniques or modern analogues to determine the natural variability in fungal spore counts. This study clearly shows that regular cattle grazing or application of cattle dung results in a statistically significant increase of coprophilous fungal spores in the soil. An important next step will be to incorporate dung fungal spore counts into the larger scale historical land use reconstruction of John Lusby Marsh. A trial count of dung fungal spores in core A found only very small numbers of spores at the depths studied; however, this core was taken at the extreme seaward edge of John Lusby Marsh in an area that would have been well removed from barns and farmsteads. If John Lusby Marsh was indeed used for cattle grazing as the literature suggests, it is likely that the livestock was kept more landward, nearer to farmsteads and away from the outer dikes where escaping cattle would have been in danger of becoming trapped in the soft sediments of adjacent mudflats. An analysis of a sediment profile taken nearer to where farmsteads would have been located may generate quite different results.

Fossil Pollen Assemblages

The deepest two core samples, A8 (~140+ cm), and A7 (~125 cm to 140 cm) were classified as salt marsh. This is confirmed visually because these sediments resemble the grayish salt marsh sediments that are common throughout Bay of Fundy salt marshes; however, the sediments from 125 cm to 140+ cm contain black specks and, with decreasing depth, they become increasingly more friable and brown (Figure 13). Poaceae pollen percentages were relatively low in samples A8 and A7 (18% and 33% respectively), deciduous tree pollen comprised 2.8% in A8 and 3.4% in A7, and *Potamogeton*-type pollen 3.9% in A8 and 1.5% in A7. These are all strong indications of a salt marsh environment as confirmed by the classification function coefficients for the different pollen types generated by the DA (Table 2). The probabilities of modern analogue were quite low for these two samples (0.292 and 0.272) due to the heterogeneity of modern analogue surface samples collected in the salt marsh. The samples' positions on the DA plot (Figure 14), do confirm that the modern land use they most resemble is salt marsh. As well, their proximity to other salt marsh surface samples JL1, JL10, JL12 and JL15, suggests that these fossil samples are not necessarily without modern analogues.

Sample A6, at 123.5-125 cm depth, has a very dark brown colour and is visually very distinct from the sediments below (Figure 9). This layer contains many fine roots and is more friable than the soils below. The sediment is palynologically distinct from those above and below because it contains large amounts of shrub pollen, which resulted in its classification as fallow dikeland. This classification had an associated certainty of 64%, the lowest of all eight samples, and the second most likely classification was salt marsh (35%). Grass pollen accounted for 37% of the total pollen sum, a relatively high percentage, but still much lower than would be expected in a farmed soil according to the DA. The probability of modern analogue was 0.047, the lowest of the eight fossil samples. The soil texture in A6 is somewhat coarser than in A7 and A8 suggesting that surface drainage may have leached clays and salts down into A7 and A8. Sample A6 also contained abundant charcoal, indicating fire. This sample likely represents the transitional period after initial salt marsh reclamation during which the new dikeland was prepared for agricultural use. The charcoal fragments and shrub pollen suggest that the land lay fallow for long enough to develop a thick shrubby vegetation cover which required burning before the soil could be cultivated. This fossil sample most resembles sample M7 of the Minudie Marsh modern analogues which was collected in a shrubby patch with a grass understory.

A sequence of events around the time leading up to the Acadian Expulsion may explain the charcoal and pollen assemblage of A6. We know that the Beaubassin settlement suffered several attacks by the British between 1696 and 1750, especially by General Church, who more than once set fire to Acadian fields and barnyards (McCreath and Leefe, 1983). For example, in May 1704 Church raided Chignecto, burning houses, barns and churches, smashing dikes, and slaughtering livestock. After the Acadians were expelled in 1755, the fields lay fallow and dikes were neglected for some time before the dikelands returned to agricultural production. While fallow, shrubs would likely have become established on the neglected dikelands and may have required burning before cultivation could resume.

Samples A5 (~122.5 – 123.5 cm) and A4 just above (~121.5-122.5 cm), are visually almost as dark as A6 below and they are clearly much darker than the silts typical of the salt marsh (Figure 9). The DA classified both samples as most strongly resembling the agricultural modern pollen analogue, although probabilities of modern analogue are quite low (0.083 for A5 and 0.179 for A4). Coniferous tree pollen declines, as does shrub pollen, and grass pollen percentages increase dramatically from the sediments below (Figure 13) suggesting, due to a lack of dung fungal spores, that the area was used for hay production. Soil colour, texture and rooting characteristics clearly support the conclusion that these layers are part of an agricultural horizon.

The layer from 116-121.5 cm depth, characterized by sample A3, represents a return to salt marsh conditions. The percentages of tree and shrub pollen rise, grass pollen declines, and *Potamogeton*-type and Cheno-Am levels increase dramatically (Figure 13). Salt marsh conditions would account for the 6 cm thickness and grayish brown colour of this layer, compared to the much thinner dikeland layers above and below (Figure 9). The entire sequence of layers A1 to A3 may be interpreted as representing a "tiding", a multi-year period during which tidal inundation was used to replenish dikeland fertility. According to Ganong (1903), "several inches to a foot or more" of fresh mud settled on the marsh during a tiding, which usually lasted between one and three years. Hence, the 11.5 cm (total thickness of A1-A3) of new sediment could easily have accumulated over layer A4 as the result of a tiding. In the absence of ploughing A3, the deepest layer, retained the characteristics of a salt marsh. The pollen assemblage of the darker brown layer, A2, above it (~115-116 cm) reflects the characteristics of a modern fallow dikeland because dikelands were kept fallow for a few years after tiding for soil desalinization. The topmost layer (~110-115 cm) containing sample A1 has the characteristics of resumed agricultural activity, although this was the layer with the lowest probability of correct classification in the DA (60%). Its next most likely modern analogue group was fallow with a 25% probability of correct classification, leaving a 15% 'resemblance' to salt marsh conditions. Trees, shrubs and grasses all figure prominently in the pollen assemblage with percentages of 19, 7 and 60 (Figure 13). Less well-represented pollen types also include the two Asteraceae-types, spores, Cheno-Ams and *Plantago*. Considering that this agricultural soil probably had less time to develop before being buried by salt marsh sediments than the agricultural layers below containing samples A4 and A5, this uncertain classification and mixture of modern analogue signals is not surprising. In addition, if the agricultural lands were left fallow for some years before dike breach in the late 1940s the agricultural signal may have been diluted. Although classified as salt marsh, sample A3 plots very close to the agricultural group on Figure 14. This may be due to the fact that this layer directly overlies sample an agricultural soil (A4 and A5) in the sedimentary sequence. A2 has the highest probability of modern analogue of all the fossil samples, plotting close to the fallow group centroid and distant from the other two land use classes. Not surprisingly, sample A1 has the lowest probability of modern analogue of the fossil samples which is to be expected due to its relatively uncertain land use classification.

Another factor that can not be ruled out to account for the accumulation of the 11.5 cm of sediments containing samples A1-A3 is the Saxby Gale of 1869 and subsequent events (Boomer, 1907, Parkes et al., 1999, Ruffman, 1999). This infamous storm overtopped most, if not all, dikes by as much as 1.7 -2.1 m throughout the Bay of Fundy, including the marshes west of Amherst (Parkes et al., 1999). Lida Boomer

(Boomer, 1907 - unpublished), who lived just above John Lusby Marsh, wrote in a handwritten book that "the barriers which had for a century and a half withstood the turbulent tides, were overwhelmed" by the Saxby Gale. She also describes dikes being swept away again in the fall of 1900. A new 6 foot (180 cm) dike was built that same fall, only to be washed away, once again, the following spring. Finally, a 7 foot (210 cm) high dike with a 13 foot (400 cm) base was required to secure the dikelands against the tides and storms which had troubled the area for the past 30 years. Lida notes that the dikelands were notably more fertile after these events.

Correlation to Dated Sequences

One of the difficulties with the interpretation of core A is the lack of temporal context for anything but the uppermost transitional boundary of dikeland soil to salt marsh soil. It is known that local dikes breached in the late 1940s. The sluice and nearby buried wharf site confirm where the dikeland surface was at that point; however, this study did not investigate the age of the dikeland sediments below this boundary. In 1999, Shaw and Ceman published a chronology of deposits in a Cumberland Basin salt marsh near Amherst Point only a few hundred metres south of John Lusby Marsh (Figure 2). Their aim was to develop a sea level history for the upper Bay of Fundy by dating salt marsh aggradation. They observed a stepped pattern of sea level rise attributed to eustatic sea level changes superimposed on regional tectonic subsidence and tidal range expansion.

Shaw and Ceman sampled seaward of old and modern dikes, and adjacent to an eroding drumlin at Amherst Point (Figure 2). They collected a series of 26 cores along a transect extending 70 m outward from the drumlin. From this, they developed a vertical and lateral stratigraphy of marsh sediments (Figure 15) that accreted over the last 4000 years. Analyses included a radiocarbon ^{14}C chronology from plant macrofossils along the entire transect, and a detailed palynological and lithological description from a single core at the 37 m point of the transect.

Shaw and Ceman identified four phases of rapid aggradation and so rapid eustatic sea level rise from 900-600 BC, 100 BC-AD 200, AD 700-1100 and AD 1600 to present. Interspersed were phases of slow salt marsh aggradation, interpreted as periods of slower sea level rise. Stratigraphic sections containing pollen and foram assemblages indicative of low marsh conditions were interpreted as periods of rapid sea level rise while assemblages indicating high marsh conditions indicated periods of slower or no sea level rise. Figure 15 shows the stratigraphy of the cores along the transect extending from the drumlin. Much of the analysis was based on the core sampled at 37 m (core 37 -Figure 15). At this site, the elevation of the marsh surface at the time of sampling was approximately 7.55 m above mean sea level. Lithologic Unit 6, at approximately 110 to 130 cm below that marsh surface, is a zone that was interpreted as a period of slow or no sea level rise according to the pollen and foram assemblages. Radiocarbon dates obtained from *S. alterniflora* roots collected at approximately 118 cm and 131 cm date this horizon at 315±55 and 290±55 radiocarbon years. Calibration of these dates using the OxCal v. 3.9 program (Bronk Ramsey, 1995 and 2001) places the former age between 1440 – 1670 AD (at 95.4% probability) and the latter age at multiple time periods, but between 1450 – 1680 AD with 89.6% probability. At the upper boundary of unit 6 are abrupt changes in the lithology, pollen and foram assemblages, indicating a transition from high to low marsh.

Er

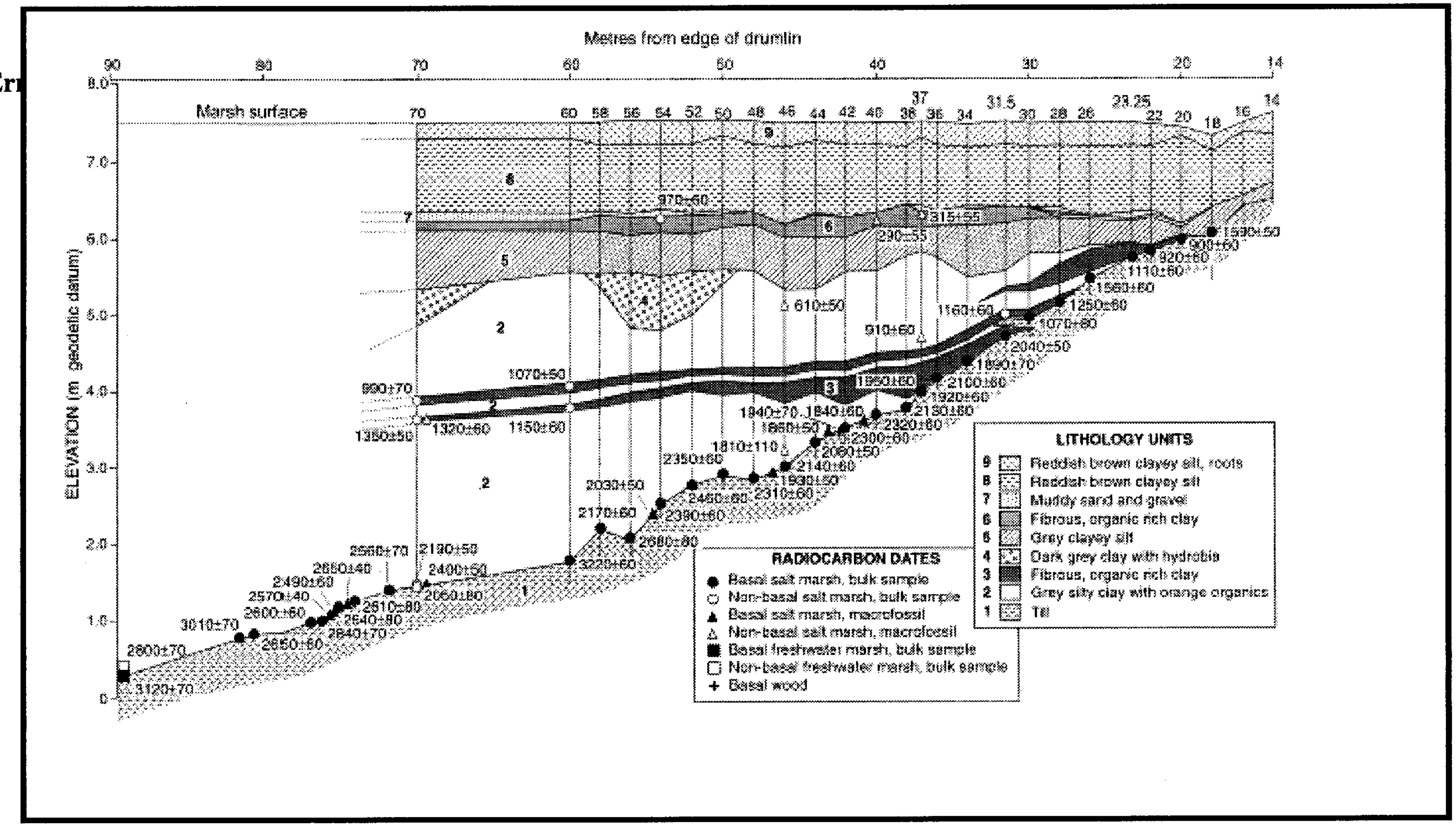

Figure 15: Detailed soil stratigraphy along sampling transect extending outward from drumlin (from Shaw and Ceman, 1999). Please note lithological units 5 and 6 which are very similar to the sediments described in core A.

Lithologic unit 6 and 5 are particularly interesting because they strongly resemble the sediments studied in core A. For example, the black speckled grey sediments from which John Lusby Marsh samples A7 and A8 were taken resemble the salt marsh sediments described by Shaw and Ceman in unit 5. At Amherst Point, the black speckled grey clay/silt layer is 130 cm to 185 cm deep, comparable to the depth of the speckled layer in John Lusby Marsh, just a few hundred metres away. Unit 6 contains laminations of black, fibrous, sandy clayey silt layers with plant roots interlaminated with layers of grey clay. The thickness of unit 6 is about 15-20 cm, very similar to the thickness of the brown/black organic layers described in core A.

The similarities of core A and lithologic units 5 and 6 suggested that a closer look at Shaw and Ceman's pollen assemblages was necessary, as well as their interpretation of the sediment origin. Their pollen zones 2, 3 and 4 were interpreted as follows (Figures 16, 17). Pollen zone 2 represents a long period of abundant tree pollen and lesser percentages of herbaceous pollen, especially grass. It is noted that these sediments contained a higher proportion of tree pollen (likely tidally imported), rather than locally produced marsh pollen, similar to what was found in modern and fossil salt marsh pollen assemblages from John Lusby Marsh. Pollen zone 3, which coincides with lithological unit 6, contains much lower levels of arboreal pollen with high percentages of Poaceae, Asteraceae Tubulifloreae-type and Asteraceae Liguliflloreae-type pollen. These characteristics resemble those of layers A1, A2, A4, A5 and A6 in the John Lusby Marsh core, which were interpreted as farmed or fallow dikeland soils based on the modern analogues collected at Nappan Farm. Shaw and Ceman interpreted pollen zone 4 as a return to salt marsh conditions, with increased arboreal

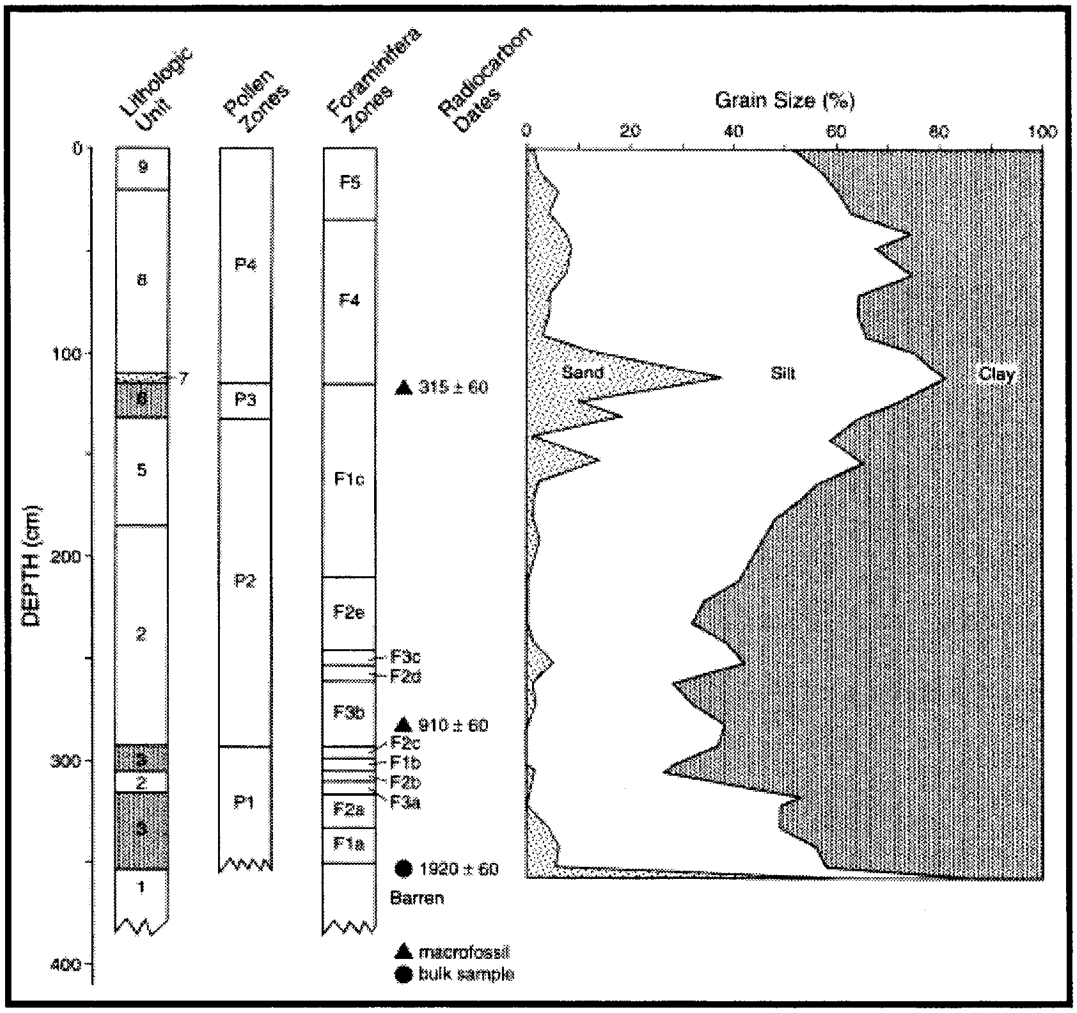

Figure 16: Core 37 sediment, pollen and foraminiferal profile. From Shaw and Ceman (1999) Figure 4.

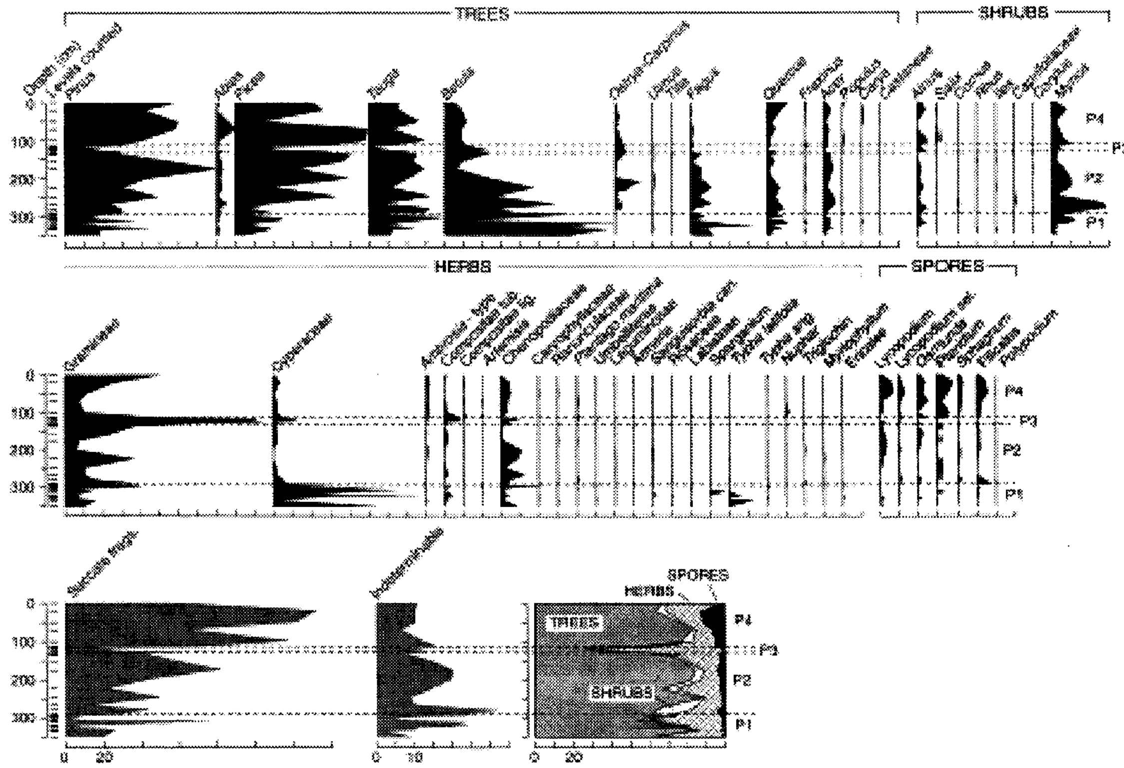

Figure 17: Detailed pollen profile for core 37. From Shaw and Ceman (1999).

influence, low Poaceae percentages and higher amounts of *Ambrosia*-type pollen that is often linked to human activities. The abrupt transition between Pollen Zones 3 and 4, as well as the simultaneous changes in lithology, foram composition and soil texture, signal an abrupt change in sea level conditions that was interpreted by Shaw and Ceman as an abrupt transgressive event. According to their carbon dates, this event would have occurred sometime after 1670 AD, considering the dates given for Lithologic Unit 6.

The similarities between core A and lithologic units 5 and 6 are striking although the layers have been interpreted quite differently. I interpret layers A1 – A6 of core A as a buried dikeland soil where tidal influences were artificially arrested. Shaw and Ceman's unit 6 was interpreted as representing an environment that was located above the elevation of Highest High Water, outside the reach of the highest tides, during a period of zero sea level rise, or sea level fall.

Further investigation reveals that the salt marsh sampled by Shaw and Ceman is also a dikeland restored to tidal marsh conditions as can be seen on the 1939 aerial photograph shown in Figure 18. It is likely that the now eroded old dike failed around the same time as others in the area and that the strip of marsh in the Shaw and Ceman study has undergone land use changes very similar to those that have now been documented in John Lusby Marsh. Shaw and Ceman's radiocarbon dates for unit 6 can therefore be considered valid dates for the dikeland sediments in core A. These dates certainly place the sediments interpreted as dikeland soils into the period during which Acadians, and their successors, have farmed the local salt marshes.

This dikeland scenario creates problems for Shaw and Ceman's interpretation of rapid sea level rise from 1600 to present. Prior to 1600 their research identified a period

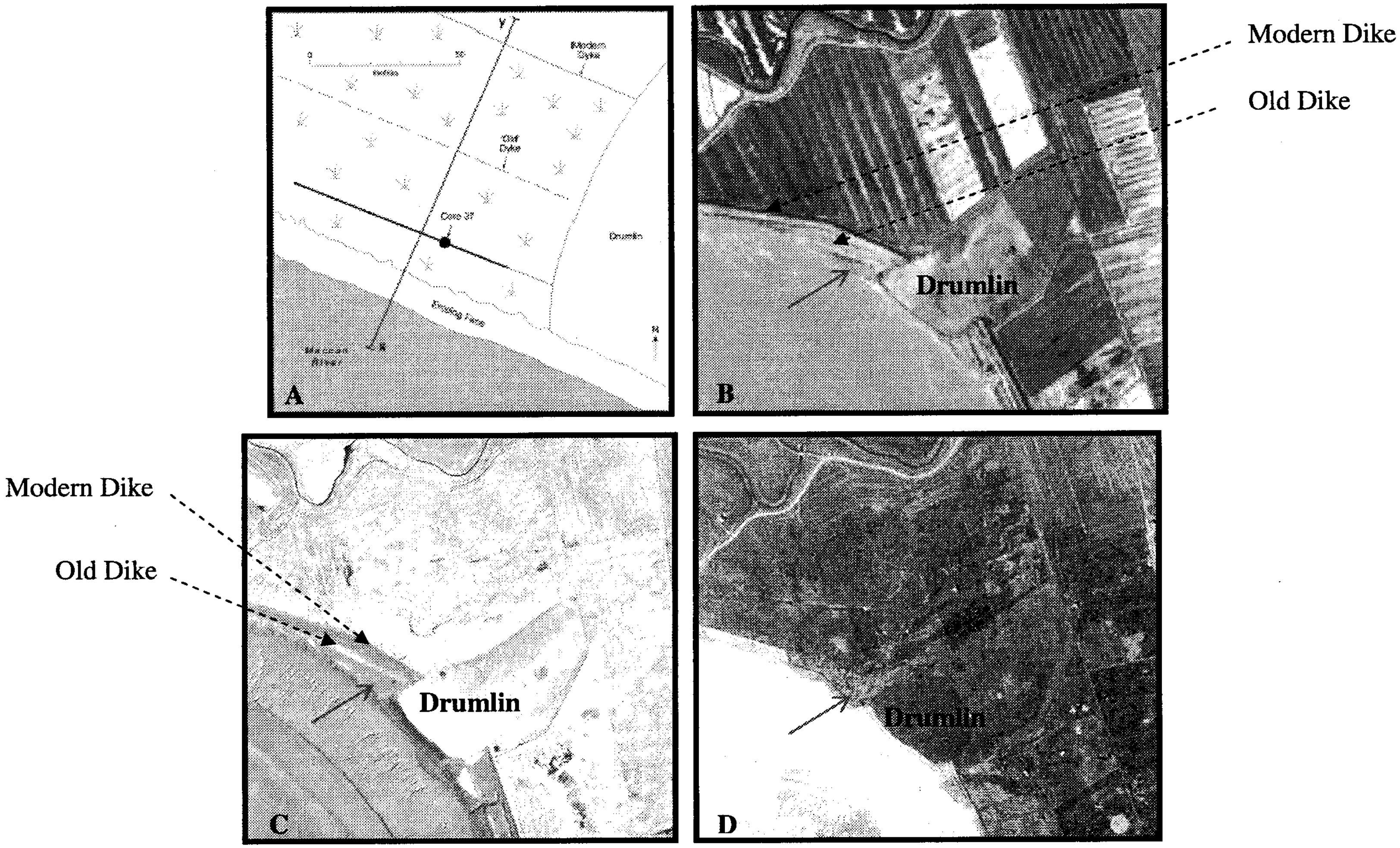

Figure 18: Location Map (Fig. 2 in Shaw and Ceman, 1999) and air photos of Core 37 sample site. Solid arrows mark site of Core 37 on historical air photos. A: location of Core 37 with positions of old and modern dikes. B: 1993 air photo (Service Nova Scotia, 1993) of site relative to old and modern dikes. C: 1964 air photo (National Air Photo Library, 1964) showing a larger tract of marsh seaward of the old dike (dashed arrow) than existed in 1993. D: 1939 air photo (National Air Photo Library, 1939) showing an even older dike (in the shape of a W) seaward of the Core 37 site, illustrating that the core site is located on an old dikeland surface that is slowly being eroded. Elements of the dikeland configuration are still visible in 1964 but have virtually disappeared by 1993.

of slow marsh aggradation from 1100-1600 which they interpreted as a period of slow sea level rise. Their interpretation that lithologic unit 6 represents high marsh conditions and lithologic unit 7 represents a major transgressive event followed by low marsh conditions through units 8 and 9 appears to be incorrect because they sampled an old dikeland. Consequently the period of slow sea level rise from 1100-1600 may not have been terminated by a period of no sea level rise immediately followed by a sudden transgressive event and rapid sea level rise. Instead, the period of slow sea level rise between 1100 and 1600 was artificially interrupted by the construction of dikes which inhibited marsh aggradation and falsely implied zero sea level rise (lithological unit 6) until the 1940s when the dikes failed. Dike breach (an artificial sudden transgressive event) would have introduced sediments to a site now up to 50 cm lower in the tidal frame giving the false appearance of the very rapid sea level rise interpreted in lithological units 7, 8 and 9. It is impossible to say at what pace sea level has been rising in the upper Bay of Fundy since the 1600s because of the artificially influenced salt marsh aggradation at Amherst Point. A study of salt marsh aggradation in a regional marsh that, with 100% certainty, has never been diked is necessary to determine actual regional rates of sea level rise from 1600 until the deployment of the Saint John tide gauge in 1961.

Lessons from Dikeland Recovery

This study shows that on the order of 100-130 cm of sediment has accumulated on some or all of the surface of John Lusby Marsh in the roughly 55 years since dike breach. This gives a sediment accumulation rate measured on a decadal time scale of 18-24 mm yr^{-1}, a number which falls nicely between the sedimentation rates of 1-5.3

mm yr^{-1} recorded on a millennial time scale (Shaw and Ceman, 1999) and 10-50 mm yr^{-1} observed on an annual time scale (Chmura et al., 2001). If sea level does rise the average predicted value of 49 cm by 2100, upper Bay of Fundy salt marshes are not in danger of drowning. A 49 cm sea level increase by 2100 translates into an annual rise of 5 mm yr^{-1}, which added to the current rate of 2 mm yr^{-1} (Shaw and Forbes, 1990) gives a rate of 7 mm yr^{-1}. In fact, even if sea level rises by the maximum predicted value of 88 cm by 2100, these salt marshes will be able to keep pace because, locally, this increase translates into an 11 mm yr^{-1} rise in sea level, well within the range of 18-24 mm yr^{-1} sediment accumulation that has taken place since 1946.

SUMMARY AND CONCLUSIONS

This study aimed to identify a buried salt marsh reclamation surface so it could be used as a dateable layer within an upper Bay of Fundy salt marsh sedimentary sequence. The depth of the reclamation surface, buried beneath tidally-imported sediment after dike breach, was then used to calculate medium term sedimentation rates in this highly sedimentary environment where conventional cesium-137 dating techniques had failed. In order to identify the buried dikeland soil in a stratigraphic sequence, surface soil samples were collected from John Lusby Marsh (a dikeland restored to tidal marsh conditions in the late 1940s) and nearby diked marsh at Minudie Marsh and Nappan Experimental Farm. From these, modern analogues of salt marsh and dikeland pollen assemblages were compiled for three grassland land use types: salt marsh, farmed dikeland and fallow dikeland. Discriminant analysis was able to discriminate between these land uses according to their pollen assemblages. The associated probabilities of modern analogue for the surface samples reflected the vegetation diversity of the three land use types, with the agricultural samples indicating a relatively homogenous vegetation cover, and the samples from John Lusby Marsh and Minudie Marsh reflecting the broader and more heterogeneous range of vegetation types present there. The farmed dikeland land use was further divided into grazed or manured land use and hayed or unmanured land use based on the presence and relative proportions of coprophilous fungal spores.

Discriminant analysis was also used to compare eight fossil soil samples from a sediment core in John Lusby Marsh to the modern samples. Although probabilities of modern analogues for several of the samples were quite low, the technique did reveal a plausible sequence of historic land use practices. I was able to identify in John Lusby Marsh periods when the marsh was naturally tidal, diked and farmed, and diked and left fallow. Several of the layers could be cursorily linked to historic events although no absolute dates were available for any but the uppermost dikeland to salt marsh boundary. It was possible however, to date the agricultural soil layers by means of a study conducted by Shaw and Ceman (1999) in adjacent Amherst Point Marsh. They radiocarbon dated what I believe to be the corresponding agricultural layer in Amherst Point Marsh as being roughly 300 years old.

Probabilities of modern analogue could be improved by collecting more samples in the salt marsh and fallow dikeland ecosystems. For example, in John Lusby Marsh it may be useful to divide the salt marsh modern analogue category into three sub-classes: *S. alterniflora*-dominated low marsh, *S. patens*-dominated mid-high marsh, and the patchily vegetated high marsh. Collecting multiple samples in each of these three zones and incorporating these subclasses into the DA may tighten statistical spread which causes the low probabilities of modern analogue of many of the surface samples. This may then further strengthen the classifications of fossil samples against the modern analogues, enhancing historic land use reconstruction. In essence, the statistical strength needed to confidently classify the fossil samples using the modern analogues was sacrificed by attempting to account for the vegetative diversity of these environments.

The boundary between the buried agricultural layer and the salt marsh sediments above was observed visually and palynologically in core A, at a depth of approximately 100-130 cm. This gives a decadal scale sedimentation rate of approximately 18-24 mm yr^{-1}, a figure that reasonably falls between the measured millennial scale sedimentation rate of 1-5.4 mm yr^{-1} and annual sedimentation rate of 10-50 mm yr^{-1}. These results suggest that upper Bay of Fundy salt marshes are not susceptible to drowning under any of the IPCC predicted sea level rise scenarios (Church et al., 2001) and will continue to serve as valuable coastal buffer zones.

This study shows that palynological techniques can confirm the presence of a buried agricultural soil in a sedimentary sequence from a salt marsh. Moreover, four specific grassland land uses can be distinguished by palynological characteristics, which included the presence and relative proportions of various pollen types and percentages of coprophilous fungal spores. This study marks the first attempt at incorporating dung fungal spores into a palynological analysis using controlled conditions, which makes the work a significant contribution to the fields of palaeoecology and archaeology. Coprophilous fungal spore counts are under utilized in palynological analyses yet they require no special treatment during sediment collection and pollen extraction, they are easily identifiable, and they offer a new dimension of information about historical ecosystems and land uses.

The establishment of modern analogues for the three grassland land uses provides a foundation on which to base further palaeoecological studies in the extensive Bay of Fundy dikelands. Using pollen assemblages collected in modern agricultural and fallow dikelands to identify and interpret agricultural soil horizons now buried under thick layers of sediments in a restored salt marsh, allows us to better understand the region's anthropogenic and geomorphic history. The buried dikeland soils may give us a clearer insight into historical land uses in the area such as whether the dikelands were used for cattle grazing or hay production. Interspersed salt marsh layers within an agricultural sedimentary sequence may provide information regarding tiding practices or historical dike breaches.

Lastly, a careful examination of the 1999 work of Shaw and Ceman shows that their interpretation of very slow sea level rise followed by very rapid sea level rise in the upper Bay of Fundy since 1600 needs to be re-evaluated. Historical air photos show that their sample site was located in what once was a dikeland rather than a never disturbed salt marsh. As such, the presently accepted patterns of late Holocene sea level rise in the Bay of Fundy may not be correct.

REFERENCES

Angel, K., Wicklow, D.T., 1975. Relationships between coprophilous fungi and fecal substrates in a Colorado grassland. Mycologia 67, 63-74.

Angel, K., Wicklow, D.T., 1983. Coprophilous fungal communities in semiarid to mesic grasslands. Canadian Journal of Botany 61, 594-602.

Bakker, J.P., Esselink, P., Dijkema, K.S., van Duin, W.E., de Jong, D.J., 2002. Restoration of salt marshes in the Netherlands. Hydrobiologia 478, 29-51.

Beecher, C.B., 2001. Modern pollen and vegetation relationships in Bay of Fundy salt marshes. M.Sc. Thesis, Department of Geography, McGill University, Montreal.

Beecher, C.B., Chmura, G.L., 2004. Pollen-vegetation relationships in Bay of Fundy salt marshes. Canadian Journal of Botany 82(5), 663-670.

Beke, G.J. 1990. Soil development in a 100-year-old dike near Grand Pré, Nova Scotia. Canadian Journal of Soil Science 70, 683-692.

Bennett, K.D., 1997. C Programs for Plotting Pollen Diagrams and Analyzing Pollen Data, Psimpoll 2.30. Department of Plant Sciences, University of Cambridge, Cambridge.

Benoit, L.K., Askins, R.A., 1999. Impact of the spread of *Phragmites* on the distribution of birds in Connecticut tidal marshes. Wetlands 19, 194-208.

Boomer, L., 1907. Unpublished. Cumberland County Museum, Amherst, N.S.

Bronk Ramsey, C., 1995. Radiocarbon Calibration and Analysis of Stratigraphy: The OxCal Program. Radiocarbon 37(2), 425-430.

Bronk Ramsey, C., 2001. Development of the Radiocarbon Program OxCal. Radiocarbon 43(2A), 355-363.

Burney, D.A., Robinson, G.S., Pigott Burney, L., 2003. *Sporormiella* and the late Holocene extinctions in Madagascar. Proceedings of the National Academy of Sciences of the United States of America 100(19), 10800-10805.

Cahoon, D.R., Reed, D.J., Day, J.W.Jr., 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Baghoorn revisited. Marine Geology 128, 1-9.

Callaway, J.C., Zedler, J.B., Ross, D.L., 1997. Using tidal salt marsh mesocosms to aid wetland restoration. Restoration Ecology 5, 135-146.

Canadian Hydrographic Survey, 1998. Canadian Tide and Current Tables Volume 1 Atlantic Coast and Bay of Fundy. Fisheries and Oceans Canada, Sidney, British Columbia.

Chmura, G.L., Coffey, A., Crago, R., 2001. Variation in surface sediment deposition on salt marshes in the Bay of Fundy. Journal of Coastal Research 17(1), 221-227.

Chmura, G.L., Anisfeld, S., Cahoon, D., Lynch. J., 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles 17(4), 22-1 - 22-12.

Church, J.A., Gregory, J.M., 2001. In: Houghton, J., Ding T.Y., and Griggs, D.J. (Eds.), Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 11: Changes in Sea Level. Cambridge University Press, Cambridge.

Clark, A. H., 1968. Acadia: The Geography of early Nova Scotia to 1760. University of Wisconsin Press, Madison.

Clark, J.S., Patterson, W.A. III, 1985. The development of a tidal marsh: upland and oceanic influences. Ecological Monographs, 55(2), 189-217.

Connor, R.F., Chmura, G.L., Beecher, C.B., 2001. Carbon accumulation in Bay of Fundy salt marshes: implications for restoration of reclaimed marshes. Global Biogeochemical Cycles 15(4): 943-954.

Cundy, A.B., Long, A.J., Hill, C.T., Spencer, C., Croudace, I.W., 2002. Sedimentary response of Pagham Harbour, southern England to barrier breaching in AD 1910. Geomorphology 46, 163-176.

Davis, J.C., 1973. Statistical Data Analysis in Geology. John Wiley and Sons, New York.

Davis, O.K., 1987. Spores of the dung fungus *Sporormiella*: increased abundance in historic sediments and before Pleistocene megafaunal extinction. Quaternary Research, 28, 290-294.

de Jonge, V.N, de Jong D.J., 2002. Ecological restoration in coastal areas in the Netherlands: concepts, dilemmas and some examples. Hydrobiologia 478, 7-28.

Environment Canada, 2002. Chignecto National Wildlife Area Data Sheet (online). The Green LaneTM, Environment Canada's World Wide Web site. Available from http://www.ns.ec.gc.ca/wildlife/ramsar/chignect.html [updated 11 June 2002; cited 11 June 2002].

Ganong, W.F., 1903. The vegetation of the Bay of Fundy salt and diked marshes: An ecological study. Botanical Gazette 36, 161-186, 280-302, 349-367, 429-455.

Greensmith, J.T., Tucker, E.V., 1986. Compaction and Consolidation. In: van de Plassche, O. (Ed.), Sea level research: a manual for the collection and evaluation of data. GeoBooks, Norwich.

Hatvany, M.G., 2002. The origins of the Acadian aboiteau: An environmental-historical geography of the Northeast. Historical Geography 30, 121-137.

Hjelle, K.L., 1999. Modern pollen assemblages from mown and grazed vegetation types in western Norway. Review of Palaeobotany and Palynology 107, 55-81.

Kapp, R.O., Davis, O.K., King, J.E., 2000. Ronald O. Kapp's Pollen and Spores, Second Edition. American Association of Stratigraphic Palynologists.

Kaye, C.A., Barghoorn, E.S., 1964. Late Quaternary sea-level change and crustal rise at Boston, Massachusetts, with notes on the autocompaction of peat. Geological Society of America Bulletin 75, 63-80.

Liu, K.-B., Lam N.S., 1985. Paleovegetational reconstruction based on modern and fossil pollen data: an application of discriminant analysis. Annals of the Association of American Geographers 75(1), 115-130.

MacDonald, G.M., Ritchie, J.C., 1986. Modern pollen spectra from the western interior of Canada and the interpretation of Late Quaternary vegetation development. New Phytologist 103, 245-268.

MacLeod, C.L., Scrimshaw, M.D., Emmerson, R.H.C., Chang Y.-H., Lester, J.N., 1999. Geochemical changes in metal and nutrient loading at Orplands Farm managed retreat site, Essex, UK (April 1995-1997). Marine Pollution Bulletin 38(12), 1115-1125.

Magenheimer, J.F., Moore, T.R., Chmura, G.L., Daoust, R., 1996. Methane and carbon dioxide flux from a macrotidal salt marsh, Bay of Fundy, New Brunswick. Estuaries, 19(1), 139-145.

Malloch, D., Blackwell, M., 1992. Dispersal of fungal diaspores. In: G.C. Carroll and D. T. Wicklow (Eds.), The Fungal Community: its organization and role in the ecosystem, Second Edition, Marcel Dekker, New York, pp. 147-171.

McAndrews, J.H., Berti, A.A., Norris, G., 1973. Key to Quaternary Pollen and Spores of the Great Lakes region. Royal Ontario Museum, Toronto.

McCreath, P.L., Leefe, J.G., 1983. A History of early Nova Scotia. Four East Publications, Tantalon.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis. Blackwell Scientific Publications, Oxford.

National Air Photo Library, 1931. Cumberland Basin air photo, 1:15,450. Roll A3529 Photo 81. Ottawa, Ontario.

National Air Photo Library, 1939. Cumberland Basin air photo, 1:22,500. Roll A6615 Photo 47. Ottawa, Ontario.

National Air Photo Library, 1945. Cumberland Basin air photo, 1:18,000. Roll A8217 Photo 41. Ottawa, Ontario.

National Air Photo Library, 1947. Cumberland Basin air photo, 1:32,600. Roll A11774 Photo 19. Ottawa, Ontario.

National Air Photo Library, 1964. Cumberland Basin air photo, 1:10,000. Roll NS A18578 Photo 135. Ottawa, Ontario.

New Brunswick Museum Archives, 1987. A large and particular plan of Shegnekto Bay and the circumjacent country with the forts and settlements of the French till dispossess'd by the English in June 1755. Drawn on the Spot by an Officer. // Publish'd according to the Act August 16th 1755 by Thos. Jefferys Geographer to his Royal Highness the Prince of Wales near Charing Cross.

Nie, N.H., Hull, C.A., Jenkins, J.G., Steinbrenner, K., Brent, D.H., 1975. SPSS: Statistical Package for the Social Sciences. McGraw-Hill, New York.

Overpeck, J.T., Webb, T., III, Prentice, I.C., 1985. Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs. Quaternary Research 23, 87-108.

Owen, M., 1984. Effectiveness of saltings in coastal defence. Ministry of Agriculture Committee. HC707. HMSO, United Kingdom.

Parker, A.D., 1979. Associations between coprophilous ascomycetes and fecal substrates in Illinois. Mycologia 71, 1206-1214.

Parkes, S.L., Ketch, A., O'Reilly, C.T., Shaw, J., Ruffman, A., 1999. The Saxby Gale of 1869 in the Canadian Maritimes - A case study of flooding potential in the Bay of Fundy. Preprint volume of the AMS 23rd Conference on Hurricanes and Tropical Meteorology, 10-15 January 1999, Dallas, TX., pp 791-794

Pennington, W., Cambray, R.S., Fisher, E.M., 1973. Observations on lake sediments using fallout 137Cs as a tracer. Nature 242, 324-326.

Pethick, J., 2002. Estuarine and tidal wetland restoration in the United Kingdom: policy versus practice. Restoration Ecology 10(3), 431-437.

Portnoy, J.W., Giblin A.E., 1997. Effects of historic tidal restrictions on salt marsh sediment chemistry. Biogeochemistry 36, 275-303.

Province of Nova Scotia Department of Agriculture and Marketing, 1987. Maritime Dykelands, the 350 Year Struggle. Province of Nova Scotia.

Province of Nova Scotia - Service Nova Scotia and Municipal Relations, 1995 – 1:10,000 colour air photos, Roll 95001 Photo 10, Roll 95002 Photos 14, 93. Amherst, Nova Scotia.

Reed, A., Moisan, G., 1971. The *Spartina* tidal marshes of the St. Lawrence Estuary and their importance to aquatic birds. Naturaliste Canadien 98, 905-922.

Richardson, M.J., 1972. Coprophilous ascomycetes on different dung types. Transactions of the British Mycological Society 58(1), 37-48.

Richardson, M.J., 2001. Diversity and occurrence of coprophilous fungi. Mycological Research 105(4), 387-402.

Ruffman, Alan, 1999. A Multi-disciplinary and Inter-scientific Study of the Saxby Gale: an October 4-5, 1869 hybrid hurricane and record storm surge [Abstract]. 1999 Seminar Series, Earth Sciences Department, Dalhousie University, Newfoundland.

Service Nova Scotia, Nova Scotia Geomatics Centre, 1993. Cumberland Basin air photo, 1:30,000. Roll 93012 Photo 26. Amherst, Nova Scotia.

Shaw, J., Ceman, J., 1999. Salt-marsh aggradation in response to late-Holocene sea-level rise at Amherst Point, Nova Scotia, Canada. The Holocene 9(4), 439-451.

Shaw, J., Forbes, D.L., 1990. Short- and long-term relative sea-level trends in Atlantic Canada. In: Davies M.H. (Ed.), Proceedings of the Canadian Coastal Conference, Kingston Ontario, 8-11 May 1990. National Research Council, Ottawa.

Smith, D.C., Konrad, V., Koulouris, H., Hawes, E., Borns, H.W., Jr., 1989. Salt marshes as a factor in the agriculture of Northeastern North America. Agricultural History 63(2), 270-294.

SPSS Inc. (1999). SPSS Base 10.0 for Windows User's Guide. SPSS Inc., Chicago.

Stockmarr, J., 1977. Tablets with spores used in absolute pollen analysis. Pollen et Spores, 13, 615-621.

Sugden, J.M., Meadows, M.E., 1989. The use of multiple discriminant analysis in reconstructing recent vegetation changes on the Nuweveldberg, South Africa. Review of Palaeobotany and Palynology 60, 131-147.

Tabachnick, B.G., Fidell, L.S., 2001. Using Multivariate Statistics. Allyn and Bacon, Boston.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G., Hakbijl, T., 2003. Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. Journal of Archaeological Science 30, 873-883.

Vermoere, M., Vanhecke, L., Waelkens, M., Smets E., 2001. Modern pollen studies in the territory of Sagalassos (Southwest Turkey) and their use in the interpretation of a Late Holocene pollen diagram. Review of Palaeobotany and Palynology 114, 29-56.

Warren, R.S., Fell, P.E., Rozsa, R., Brawley, A.H., Orsted, A.C., Olson, E.T., Swamy, V., Niering, W.A., 2002. Salt marsh restoration in Connecticut: 20 years of science and management. Restoration Ecology 10(3), 497-513.

Webster, J., 1970. Coprophilous fungi. Presidential Address, Transactions of the British Mycological Society 54(2), 161-180.

Weinstein, M.P., Teal, J.M., Balletto, J.H., Strait, K.A., 2001. Restoration principles emerging from one of the world's largest tidal marsh restoration projects. Wetlands Ecology and Management 9, 387-407.

Wicklow, D.T., 1992. The coprophilous fungal community: An experimental system. In: G.C. Carroll and D. T. Wicklow (Eds.), The Fungal Community: its organization and role in the ecosystem, Second Edition, Marcel Dekker, New York, pp.715-728.

Willard, D.A., Weimer, L.M., Riegel, W.L., 2001. Pollen assemblages as paleoenvironmental proxies in the Florida Everglades. Review of Palaeobotany and Palynology 113, 213-235.

Williams, B.K., 1983. Some observations on the use of discriminant analysis in ecology. Ecology 64(5), 1283-1291.

Wright, H.E., Jr., 1967. The use of surface samples in Quaternary pollen analysis. Review of Palaeobotany and Palynology 2, 321-330.

Wynn, G., 1979. Late eighteenth-century agriculture of the Bay of Fundy marshlands. Acadiensis 81, 80-89.

Zedler, J.B., Callaway, J.C., 2000. Evaluating the progress of engineered tidal wetlands. Ecological Engineering 15, 211-225.