Université du Québec
à Rimouski

FORÇAGE CLIMATIQUE ET ANTHROPOGÉNIQUE RÉCENT DANS L'ESTUAIRE POKEMOUCHE AU NORD-EST DU NOUVEAU-BRUNSWICK, CANADA : ÉVIDENCES PALYNOLOGIQUES

Mémoire présenté

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PAR

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RÉSUMÉ

Cette étude vise à retracer les conditions climatiques du passé dans la côte nord-est du Nouveau-Brunswick à partir de deux séquences sédimentaires courtes couvrant la période des derniers 1000 ans. Les carottes ont été prélevées, l'une à l'amont (eaux douces), l'autre à l'aval (eaux saumâtres du lac Inkerman) dans le bassin de la rivière et l'estuaire Pokemouche respectivement. Des reconstitutions quantitatives des paramètres climatiques ont été réalisées à partir des assemblages polliniques en utilisant la technique des analogues modernes (MAT). Les conditions marines ont été estimées à partir des assemblages de kystes de dinoflagellés et combinées avec les résultats de perte au feu (LOI_{550}) et des analyses élémentaires et isotopiques du carbone et de l'azote.

Dans le Lac Inkerman les faibles influx polliniques et des traceurs d'apport d'eau douce (*Pediastrum* sp. et *Halodinium* sp.) suggèrent l'instauration de conditions plus chaudes et sèches pendant l'Optimum Climatique Médiéval (AD 1000-1200). L'augmentation de l'influx pollinique et l'augmentation du pourcentage du pollen de bouleaux indiquent la mise en place de conditions plus froides et humides pendant le Petit Âge glacière (« PAG » ou « Little Ice Age, LIA » en anglais), entre AD 1200-1850. Les influx de kystes de dinoflagellés, ainsi que des traceurs d'apport d'eau douce et de productivité benthique (réseaux organiques de foraminifères) augmentent drastiquement durant le même période, suggérant une augmentation des productivités primaires et benthiques en lien avec des précipitations et des apports de nutriments durant cette période. La reconstitution des paramètres climatiques saisonniers, basée sur la stratigraphie pollinique, suggère des étés plus froids et humides et des hivers plus froids pendant le LIA. La diminution drastique de l'influx de palynomorphes terrestres et marins simultanément avec la diminution de l'influx des traceurs d'apport d'eau douce après AD 1850 jusqu'au présent, suggèrent la reprise de conditions plus sèches après le LIA, ce qui coïncide avec des étés et hivers plus chauds documentés selon les données historiques-instrumentales de température et de précipitation post AD 1850. L'augmentation des pourcentages de pollen de Poaceae et *Ambrosia* sp. témoigne du début des activités agricoles après l'arrivée des premiers colons français et britanniques (vers AD 1725 et 1780 respectivement).

Mots clés : Anthropisation, dinokystes, estuaire, lac Inkerman, Nouveau-Brunswick, pollen, reconstitution climatique, rivière Pokemouche.

ABSTRACT

This study aims to retrace the past climatic conditions along the northeast coast of New Brunswick (NB) Canada, from two short sedimentary sequences covering the last 1000 years. The cores were collected, one upstream (fresh waters), the other downstream (brackish waters) in the Pokemouche River and Estuary respectively. Quantitative reconstruction of climatic parameters from pollen assemblages were done using the Modern Analogue Technique (MAT). Marine conditions were estimated from dinoflagellate cyst assemblages. These results were combined with loss on ignition (LOI_{550}) measurements and elemental and isotopic analyses of carbon and nitrogen.

In downstream Lake Inkerman the low influxes of pollen, spores and freshwater tracer (*Pediastrum* sp. and *Halodinium* sp.) suggest the installation of warmer and drier conditions during the Medieval Climate Optimum (1000 - 1200 AD). Increased pollen and spores influxes and rise in percentage of birch pollen indicate the installation of colder and wetter conditions during the Little Ice Age (LIA, between 1200 - 1850 AD). During the LIA the dinocyst, freshwater tracer and foraminifer lining (benthic productivity) influxes increased drastically, suggesting an increase in precipitations and discharge of nutrients during this period. The reconstructions of seasonal climatic parameters based on pollen stratigraphy indicate the installation of colder and wetter summers with colder and dry winters during this period. The drastic decrease in the influx of terrestrial and marine palynomorphs simultaneously with the decrease of freshwater tracer influxes after 1850 AD to the present, suggests the recovery of drier conditions after the LIA, which coincides with warmer summers and winters documented according to historical-instrumental temperature and precipitation data post AD 1850 . The pollen increases of Poaceae and *Ambrosia* sp., both point to the beginning of agricultural activities after the arrival of the first French (about AD 1725) and British settlers (about AD 1780).

Keywords: Anthropization, dinocysts, estuary, Lake Inkerman, New Brunswick, pollen, Pokemouche River, climate reconstruction.

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INTRODUCTION GÉNERALE

Plusieurs études paléoclimatiques régionales ont documenté l'évolution de la végétation et de certains paramètres environnementaux au cours de l'Holocène au Nouveau-Brunswick (Jetté et Mott, 1995; Korpijaakko et Woolnough, 1977; Mott et al., 2004; Mott, 1975; Osvald, 1970). Dans la plupart des cas, les études palynologiques antérieures se sont concentrées sur l'étude de la transition entre la dernière période glaciaire et l'interglaciaire actuel. La majorité des séquences sédimentaires ont été analysées dans les sections basales (couvrant la déglaciation de la Gaspésie, entre 13 et 9 cal. Ka; Jetté et Mott, 1995), avec un contrôle chronologique précaire (peu de mesures d'âge, certaines possiblement sous-estimées ou surestimées), ce qui résulte en de nombreuses incertitudes en ce qui concerne l'interprétation paléoclimatique du passé récent du Nouveau-Brunswick.

Dans ce projet, la reconstitution paléoclimatique est réalisée en utilisant une approche palynologique sur la base d'une analyse quantitative (basée sur le pollen) et qualitative (basée sur les kystes de dinoflagellés) des microfossiles à paroi organique dérivés des séquences de sédimentaires récentes récoltées au sein de la rivière et l'estuaire Pokemouche. D'une part, l'établissement des liens entre les données de température, précipitations et les données historiques des changements d'usage du territoire et, d'autre part, les changements observés dans les données palynologiques est possible grâce à une chronologie basée sur la mesure de l'activité du ^{210}Pb.

Dans cette étude les assemblages de palynomorphes terrestres (pollen et spores) sont utilisés pour corréler l'enregistrement des variations sur la partie terrestre du bassin versant tandis que les palynomorphes marins (dinokystes) reflètent les variations dans l'écosystème aquatique estuarien. Cette corrélation est basée sur le principe selon lequel la similarité existante entre un assemblage fossile et un autre moderne répond à l'imposition des conditions climatiques et environnementales communes de développement (Fréchette et al., 2008). Le pollen est produit par les gymnospermes (conifères) et les angiospermes (plantes à fleurs, incluant les arbres feuillus), tandis que les spores sont produites surtout par les bryophytes (mousses) et les ptéridophytes (« fougères ») (Pons, 1970). Les changements observés dans l’abondance des réseaux organiques de foraminifères permettent de confirmer des changements dans la productivité benthique (de Vernal et al., 1992), tandis que les algues d’eau douce (telle que *Pediastrum* sp. et les kystes de ciliés tel que *Halodinium* sp.) reflètent les apports fluviaux (Richerol et al., 2008).

Les flux de palynomorphes terrestres enregistrés dans les sédiments des systèmes côtiers sont directement liés au mélange des apports polliniques de la végétation locale, régionale ou lointaine à travers des apports éoliens et fluviaux, et répondent aux forçages climatiques, aussi bien qu’à l’activité humaine (Simonneau, 2012).

À partir de l’analyse pollinique des séquences sédimentaires, la variabilité du climat en lien avec la végétation peut être retracée (p. ex. Fréchette et al., 2008; Fréchette et al., 2018; et Mott et al., 2004). Le pollen est un traceur qui permet d'établir des relations quantitatives entre les assemblages et les paramètres climatiques modernes (de température et précipitations) pour la région subarctique, grâce au développement d’une vaste base de données de référence (Whitmore et al., 2005). Les reconstitutions de ces paramètres sont basées sur la méthode des analogues modernes (MAT; Guiot, 1990) en utilisant une base de données de 1010 sites de l’est du Canada (Fréchette et al., 2018), pour lesquels les assemblages polliniques, la végétation et le climat sont connus.

Cependant, la complexité des mécanismes qui contrôlent l’accumulation du pollen a été rapportée. Le transport du pollen associé aux modifications de l'intensité ou la direction des vents (Hooghiemstra et al., 1987; Mudie, 1982; Mudie et McCarthy, 2006), les fluctuations du niveau relatif des lacs (Asnong et Richard, 2003), les changements morphométriques des bassins et des débits fluviaux (Chmura et Liu, 1990; Heusser, 1983; Heusser et Balsam, 1985) pourraient potentiellement influencer les influx polliniques. Ainsi, non seulement les changements de l’abondance des populations végétales autour des bassins sont enregistrés, mais aussi les variations des conditions du site (Asnong et Richard, 2003).

Dans la période historique, les changements de l'usage du territoire ont eu des impacts directs sur la végétation (Landry, 2001; Wynn, 1981). L'analyse pollinique fournit des repères liés à l’activité anthropique au fil du temps. Au Nouveau Brunswick, Mott (1975) trouve des évidences de perturbations humaines dans les portions les plus récentes des séquences polliniques postglaciaires. Vers le sommet des profils polliniques, la diminution progressive de l'abondance de *Tsuga* sp. et du pollen d‘autres essences de bois durs au profit de *Picea* sp. a été corrélée avec la perturbation de la végétation par les premiers colons.

Les variations de l’abondance de kystes de dinoflagellés ont été largement utilisées comme des traceurs indirects de changements de température de l’eau, de salinité, de la glace de mer et de la productivité primaire qui permettent d'établir des liens avec les changements des paramètres climatiques (p. ex. Bringué et Rochon, 2012; Cormier et al., 2016; de Vernal et al., 2001; Richerol et al., 2014). Les travaux récents indiquent que l’augmentation de la température et des précipitations favorise la prolifération des groupes d’algues mixotrophes dans les lacs et les milieux côtiers (Baig et al., 2017; Hallegraeff, 2016; Zhou et al., 2016). Le ruissellement, quant à lui, agit comme un vecteur d’introduction de nutriments depuis le bassin versant vers l’estuaire, en stimulant la production planctonique (Paerl et al., 1990).

Dans un milieu anthropisé, les tensions exercées par l’industrialisation, la croissance démographique, le déboisement, les pratiques agricoles intensives et l’urbanisation ont des impacts directs sur les bassins versants qui se traduisent par des apports accrus de nutriments du milieu continental vers les zones côtières (Savage et al., 2010; Zimmerman et Canuel, 2000). Cet enrichissement de nutriments est reconnu comme une menace responsable de l’augmentation de la production algale dans les rivières, les lacs et les zones côtières (Nixon, 1995; Rabalais et al., 2009).

Des travaux réalisés au lac Inkerman (bassin versant de l’estuaire Pokemouche, NB), dans le cadre desquels les pigments fossiles ont été utilisés comme traceurs de la variabilité algale, montrent une augmentation dans les indicateurs de l’abondance totale des algues (β- carotène) et des algues vertes (chlorophylle *b*) entre 1900 et 1950, associée à la période de développement de l’agriculture traditionnelle intensive (Ady et Patoine, 2016). Cela suivie par un déclin associé à l’expansion de l’extraction mécanisée de tourbe qui aurait diminué la pénétration de la lumière dans la colonne d’eau en augmentant la turbidité (Ady et Patoine, 2016). En revanche, Harris et al. (2006) ont estimé que la variabilité spatiale des assemblages de diatomées dans une série de seize lacs du sud-est du Nouveau-Brunswick au cours du siècle dernier peut être attribuée au réchauffement climatique récent.

Dans la plupart des cas, l'impact des changements environnementaux naturels et anthropiques sur la productivité primaire dépend des caractéristiques spécifiques de chaque bassin versant et des organismes ciblés. Cette spécificité et l'absence d'un suivi rigoureux de la dynamique des estuaires constituent des contraintes majeures pour obtenir des précisions sur l'impact des activités humaines et du climat sur l'écosystème.

Pour retracer les conditions climatiques du passé le long de la côte nord-est du Nouveau-Brunswick, plus spécifiquement dans l'estuaire de la rivière Pokemouche, nous proposons d'utiliser les assemblages de pollen et de kystes de dinoflagellés comme traceurs. Les assemblages de kystes de dinoflagellés préservés dans les sédiments seront utilisés pour estimer les variations climatiques du milieu estuarien. Le dénombrement du pollen et des spores, ainsi que les indices de pollen arboréen (AP) et non arboréen (NAP), serviront à caractériser l'évolution du couvert végétal autour de la zone d'étude en lien avec les activités anthropiques et pour la reconstitution de l'évolution climatique en milieu continental.

ORGANISATION DU MEMOIRE

Ce mémoire est présenté sous la forme d'un article scientifique rédigé en anglais, qui sera soumis prochainement à la revue internationale *Review of Palaeobotany and Palynology* sous la référence :

Aguilar, I., Rochon,A., Patoine A., sera soumis prochainement. Evidences of recent climatic and anthropogenic forcing from palynological record in Pokemouche Estuary in Northeastern New Brunswick, Canada.

CHAPITRE I

EVIDENCES OF RECENT CLIMATIC AND ANTHROPOGENIC FORCING FROM PALYNOLOGICAL RECORD IN POKEMOUCHE ESTUARY IN NORTHEASTERN NEW BRUNSWICK, CANADA

1. INTRODUCTION

Several regional paleoclimatic studies have documented the evolution of vegetation and environmental parameters during the Holocene in New Brunswick (NB; Jetté and Mott, 1995; Korpijaakko and Woolnough, 1977; Mott et al., 2004; Mott, 1975; Osvald, 1970). Previous palynological studies have focused mostly on the transition between the last glacial period and the present interglacial, with precarious chronological control and limited use of quantitative paleoclimatic reconstructions of NB's recent geological past (the last ~1000 years).

This study proposes an analysis of paleoenvironmental fluctuations, climatic and anthropic, registered in the last 1000 years in the sediments of the Pokemouche River and Estuary system (fresh and brackish water environments) based on terrestrial (pollen, spores, freshwater algae) and marine (dinoflagellate and ciliate cysts, organic linings of foraminifers) organic palynomorph assemblages.

The changes in pollen and spore assemblages recorded before and during the Little Ice Age (LIA), conceivably reflects the evolution of the vegetation in response to climatic conditions (Richard and Grondin, 2009). However, the impact of anthropic activities on the east coast of NB following the arrival of the first settlers (Wynn, 1981), in addition to population growth, logging, intensive agricultural practices and industrial peat harvesting, are expected to induce changes of the vegetation cover and consequently these changes should be reflected in the composition of the pollen assemblages over the recent geological past (Fréchette et al., 2018) .

The variations of dinoflagellate cyst assemblages are interpreted in terms of changes in surface water conditions (temperature, salinity, sea ice and primary productivity), allowing for land-ocean correlations. In anthropized environments, plankton responds to the tensions exerted by industrialization, population growth, deforestation and intensive agricultural practices, which often result in increased algal production (Nixon, 1995; Rabalais et al., 2009).

We hypothesize that the climatic and anthropogenic forcings have left traces in the palynological record of the sedimentary sequences of the northeast coast of NB. Therefore, the parallel fluctuations observed in our sequences could be interpreted as co-variations in terrestrial and marine habitats. To verify this, we conducted the analysis of the pollen, spore and dinoflagellate cyst (dinocysts) assemblages in two sediment cores collected in downstream Lake Inkerman and upstream of the Pokemouche River. We have also used the organic remains of freshwater (*Pediastrum* sp.) and brackish (*Halodinium* sp.) organisms to document the freshwater inputs in Lake Inkerman through time. Our results document the evolution of vegetation, climate and human activities over the last 1000 years.

2. ENVIRONMENTAL SETTING

2.1. PHYSIOGRAPHY AND GEOLOGY

The Pokemouche River and Estuary Basin occupies an area approximately 500 km^2, is oriented SW-NE and measures approximately 41 km in length from the headwaters at Haut de Val-Doucet to the outlet channel of the river which crosses the system of barrier islands to the Gulf of St. Lawrence (CGERP, 2003). The elevation difference between coastal areas, and the headwaters is about 100 m. The Pokemouche River and Estuary are fed by about twenty tributaries of short length (Figure 1; CGERP, 2003).

The estuary can be divided into two physiographic parts: (I) Pokemouche Inner Bay, consisting of a shallow barrier system separated from the Gulf of St. Lawrence by a series of barrier islands and connected by an outlet channel; and (II) the section which flows into Lake Inkerman (a body of shallow and brackish water with an area about 3.5 km^2) and extends upstream to the tidal limit near the Pollard Creek mouth (NBDNR, 2008) downstream from sampling site 1 (Figure 1).

The Pokemouche basin is underlain by sedimentary rocks of Pennsylvanian age (upper of two subsystems of the Carboniferous Period of the Paleozoic Era, from 323.2 ± 0.4 to

298.9 ± 0.15 Ma) composed of gray sandstone, interbedded mudstone and conglomerate (NBDNR, 2008). A glaciofluvial deposit consisting of blankets and plains of sand, silt, with some gravel and clay, generally 0.5 to 3 m thick, is present along the upper area of the Pokemouche River (Rampton, 1984).

2.2. HYDROGRAPHICAL PARAMETERS

The surface temperature, salinity and water depth were measured on board using a multi-parameter probe YSI model 85. Upstream, in the Pokemouche River (site 1; Figure 1), the surface temperature was 8.8 °C and it decreased by 0.1 °C every 50 cm. The main channel of the Pokemouche River averages ~ 1.2 m in depth. In Inkerman Lake the temperature ranged from 10.2 to 9.3 °C from the surface down to 2.1 m depth. The salinity was 3.3 ‰ at the surface and 7.3 ‰ at the bottom. The maximum depth measured during the sampling campaign at the center of the lake was 2.1 m. The semi-diurnal tides range from 0.5 to 1.6 m (elevations above sea level (Environment Canada, 2013)).

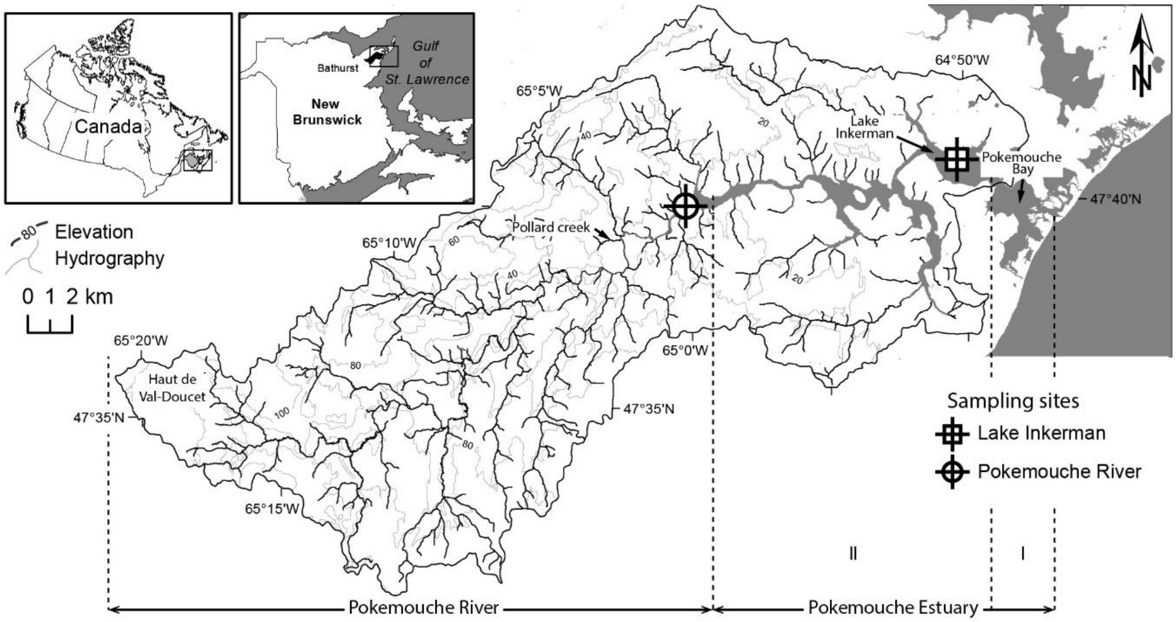


Figure 1. Location of the Pokemouche basin showing the (I) lower estuary and (II) the upper estuary. Though the estuary section is said to extend to the Pollard Creek mouth (NBDNR, 2008), we set it downstream of the Pokemouche sampling point based on the absence of marine/brackish palynomorphs in the Pokemouche core. Modified from published maps of the Service New Brunswick (2002, 2014)

2.3. CLIMATE AND VEGETATION

Ecological Stratification Working Group (1996) proposes a harmonized classification system that has evolved from previous works to provide a uniform national ecological approach to terrestrial ecosystem classification. The study area is classified into the Atlantic Maritime ecozone in the Maritime lowlands ecoregion. In this classification, the closed mixed wood forest is mainly composed of red spruce, balsam fir, red maple, hemlock, and eastern white pine and dominates well-drained areas. Wetlands are extensive and support dwarf black spruce at their perimeters.

Alder swamps rim the streams and tend to have a peaty shoreline. Organic soils developed on the surroundings of Lake Inkerman, towards the northeast (bogs of Grande-Anse and Chemin Pallot) to the southeast. On these organic soils, *sphagnum* represents the main plant element, accompanied by black spruce, alder and white birch.

More recently, the New Brunswick ecological land classification system includes a detailed description of the ecodistricts in the Maritime province of New Brunswick (Godin and Roberts, 1994). In this classification, upstream Pokemouche River is within the Tabusintac Ecodistrict, itself within the Eastern Lowlands ecoregion (itself within the Atlantic Maritime ecozone). This ecodistric is largely cover by coniferous forests. Black spruce dominates the poorly drained soils and it is accompanied by balsam fir, jack pine, and occasional white pine, whereas large stands of jack pine are frequent in sandy soils. Balsam fir, red spruce, hemlock, and white spruce tend to occur on the mid-slope sites. Pure tolerant hardwood communities are infrequent and grow only on the steeper slopes and ridgetops (trembling aspen, white birch, and red maple).

Downstream Pokemouche Estuary is within the Caraquet Ecodistrict, itself in the Eastern lowlands ecoregion. This ecodistrict correspond to a coastline ~10 km wide that surrounds the Acadian Peninsula, where 70 % of the area is covered by a forest of shade intolerant hardwood species like the red maple (*Acer rubrum*), trembling aspen (*Populus tremuloides*), gray birch (*Betula populifolia*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*) and beech (*Fagus* sp.).The three later species occur only as “traces along the inland perimeter. The black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*) are frequently found in valley bottoms. Mid-slopes are covered by red maple (*Acer rubrum*), red spruce (*Picea rubens*), white pine (*Pinus strobus*), balsam fir (*Abies balsamea*) and eastern hemlock (*Tsuga canadensis*). They are often in poorly drained areas accompanied by cedar (*Thuja occidentalis*), tamarack (*Larix laricina*) and black spruce (*P. mariana*).

The climate is warm in summer, with cold and snowy winters. The mean temperature of the warmest month of the year (July) is 19.1 °C, the average of the coldest month of the year (January) is -10.8 °C, and the total annual precipitation is 1110 mm (station BATHURST A, Environnement et Changement climatique Canada (2013)).

During winter, the polar air masses move inland, and the prevailing winds blow from the west or northwest (Mott, 1975). The winters in the area are stormy, owing to the formation of a low pressure area on the southeast coast and the transit of cyclonic storms across the province (Mott, 1975). In summer (June-August) the southerly-southwesterly winds dominate (Government of Canada Climate Web site http://climate.meteo.gc.ca/) when the low-pressure front moves towards the north.

2.4. CLIMATIC VARIABILITY OF THE LAST 1000 YEARS

Before the establishment of warmer conditions over the last ~160 years, historical meteorological evidence, as well as archaeological, palynological and glaciological records at different latitudes, from the Arctic to Patagonia (Lamb, 1965; Villalba, 1994), suggest the establishment of a warmer climatic period between about AD 900 and 1200, which was followed by a cold phase characterized by a decline of temperatures between AD 1200 and 1850.

During the warmest period, known as the Medieval Warm Period (MWP), the evidences show that, in the neighboring lands of England, the annual mean temperatures must have been 0.5°C below present values, while in Greenland they were between 2 and 4°C above modern values (Lamb, 1965).

The coldest recent climatic phase, termed the little ice age (LIA), was a favorable period for the global extension of the glacial masses. During this period the annual mean temperature was ~1 °C lower than today (Moberg et al., 2005; Soon and Baliunas, 2003). The difficulty to narrow the limits of the LIA cold period in the arctic-subarctic region dates back to the pioneering studies until today and no consensus has yet been achieved. However, the earliest start of this period is dated about AD 1200 (Grove, 2001; Larsen et al., 2011; Nicolle et al., 2018) and the termination is reported around AD 1850 (Grove, 2001; Linge et al., 2009; Massa et al., 2012).

2.5. LAND USE CHANGES

The pollen record and land use changes recorded between 1868 and 2005 were used to document the impact of human activities. In an anthropized environment, the industrialization, population growth, deforestation, livestock farming, intensive agriculture and urbanization have direct impacts on watersheds, which leads to increasing nutrient inputs from the continental environment to coastal areas (Ady and Patoine, 2016; Rabalais et al., 2009). The known consequences of this eutrophication include algal blooms (e.g., diatoms and dinoflagellates), contamination of water supplies and anoxia/hypoxic conditions in the watersheds (Savage et al., 2010; Zimmerman and Canuel, 2000).

Around AD 1725, French immigrants settled definitely in the Caraquet Ecodistrict (Zelazny et al., 2007). Between AD 1780 and 1851, the population increased substantially with British settlements, from fewer than 4 000 persons to almost 200 000 (Wynn, 1981).

The commercial exploitation of wood products began in the nineteenth century (Dussault and Blais, 2011). This activity increased largely after AD 1805, with the exports of timber rising from 100 000 t in AD 1805-1812 to 417 000 t in AD 1825 (Wynn, 1981). Lumber camps were preferably located near a body of water and in the center of areas to be harvested, and the logs were thrown into the water to be taken to a port, shipyard or sawmill. These activities extended into Shippagan, Pokemouche, Tracadie and Tabusintac regions (Landry, 2001).

During the period between AD 1900 and 1950, the largest expansion of agricultural activities was reported. Ady and Patoine (2016) used the most important crops in terms of surface occupied as indicators of land transformations in Gloucester County (enclosing the Pokemouche basin). The areas occupied by hay, oat, wheat and barley harvest increased around AD 1920, representing about 2.5% of county land. The juxtaposition of the historical record of agricultural indicators and peat exploitation between AD 1868 and 2005 in terms of surface shows that mechanized peat extraction was not registered prior to AD 1950 in Pokemouche basin, and the progressive increase of this commercial activity coincides with the decrease of agricultural harvest after AD 1950.

3. MATERIAL AND METHODS

3.1. SAMPLING

Two short sedimentary sequences were collected in the Pokemouche River and Estuary in May 2017 using a polycarbonate tube (6 cm of diameters) attached to a Watermark Universal Corer®. The Core-9 (58 cm in length) was collected upstream in Pokemouche River (47°39.97’ N; 64°59.93’ W) at 1.3 m depth. Data from this core will be referred to as “Pokemouche” hereafter. The Core-16 (39 cm in length) was collected downstream in Lake Inkerman (47°41.08’ N; 64°50.39’ W) at 2.1 m depth, in brackish waters. Data from this core will be referred to as “Lake Inkerman” hereafter. Both were described based on their texture and color by visual inspection in the laboratory after acquisition of X-ray images and X-ray fluorescence (XRF) analysis. For assigning color, the sediments were compared with the Munsell Color Chart (Pendleton and Nickerson, 1951). Some analyses were done continuously on the whole core (see following sections). Then the cores were split longitudinally to obtain an “archive half” and a “working half to collect sub-samples. The sampling method followed by each protocol is described below.

3.2. ACQUISITION OF X-RAY IMAGES

X-ray images from whole cores were obtained using a Geotek Standart X-ray CT system (XTC). Continuous images were obtained using a source radiation of 90 keV and 90 mA. The spot size was 90 µm. These images illustrate the internal structure of sediments of the scanned core (diameter: 6 cm). To invert the color and apply saturation and brightness adjustments, the software GQuickView was used. The resulting images are displayed on a gray scale. Darker zones represent the silty sediment, and finer sediments appear lighter.

3.3. XRF ANALYSES

XRF measurements were obtained directly at the split core surface of the archive half of each core, using the MSCL fitted with a sensor Olympus DELTA Professional handheld XRF spectrometer at the Institut des sciences de la mer de Rimouski (ISMER). The split core surface was covered with a thin film to avoid contamination of the unit and desiccation of the sediment. The measurements were taken at 0.5 cm intervals. The increase in Mn/Ti ratio is used as indicator of post-depositional organic matter oxidation (Croudace and Rothwell, 2015).

3.4. CHRONOSTRATIGRAPHY OF THE SEDIMENTARY SEQUENCE

The chronostratigraphic framework of each sediment core was established based on ^{210}Pb measurements by alpha spectrometry at the GEOTOP research center in Montreal. The analyses were performed at 1 cm interval on the uppermost 20 cm. A ^{14}C date on a carbonate shell from Lake Inkerman by Accelerator Mass Spectrometry (AMS was measured at the A. E. Lalonde AMS Laboratory.

The activity of the ^{210}Pb was measured by alpha spectrometry via ^{210}Po. The ^{210}Po is in secular equilibrium with ^{210}Pb, which allows the determination of the activity of ^{210}Pb total experimentally measured in the samples. The excess ^{210}Pb was calculated as the difference between the measured ^{210}Pb activity in the samples and the supported ^{210}Pb (Ghaleb, 2009). The supported ^{210}Pb value is estimated as the sum of the mean of the three deepest activity determinations of ^{210}Pb plus its standard deviation, following the approach proposed by Sorgente et al. (1999).

The sedimentation rate was calculated using the constant rate of supply model (CRS). For both sediment sequences older than the ^{210}Pb record, we assumed a constant rate of sedimentation and extrapolated ages using age-depth models. The ‘best fit’ linearly interpolated age models were made with the R software package BACON (Blaauw and Christen, 2011) by combining the radiocarbon date and absolute ^{210}Pb dates (calculations are reported in appendix I, tables 4 and 5).

The conventional radiocarbon age was calibrated (cal. AD 1135±80) using the software Oxcal version 4.3.2 (Ramsey, 2017) with the Marine13 curve (Reimer et al., 2013) and confidence interval of 95%.

3.5. GRAIN SIZE DISTRIBUTION

High-resolution particle size analyses were performed on sediment samples every 1 cm using a Beckman Coulter laser diffraction grain-size analyzer which has a detection range of 0.04–2000 µm. Each sub-sample (about 2 g) was pre-treated to eliminate organic matter using wet oxidation to avoid damaging grains during pre-treatment. The organic matter was removed with hydrogen peroxide attack. Each sub-sample was mixed with 50 ml of H_2O_2 (30 %), stirred and heated to 70 °C. The oxidant was continually added to the sample until the reaction ceased (between 1-3 h). When the reaction was finished, the temperature was raised to 150 °C to evaporate the remaining H_2O_2. The deflocculation was done by mixing wet sediment with an electrolytic solution of sodium hexametaphosphate (20 g/L), and subsequently shaken for 3 h. The diagrams of grain-size distribution were made with the data yielded by the program *LS13320C v5.03*. The sand, silt and clay contents are expressed in percentage (average ± standard deviation).

3.6. LOSS ON IGNITION

All gravimetric measurements were made using a balance Denver SI-234 at Université de Moncton, Campus de Shippagan (UMCS). The mass per unit volume of the sub-samples (about 5 g, collected at 1 cm intervals) of wet sediment was measured by Hydrostatic weighing. The samples were subsequently dried at 60 °C for 48 hours. With the volume of the sample, the dry bulk density was calculated and expressed as dry weight of the sample per unit volume (g/cm^3). The “Loss On Ignition” ($LOI_{550)}$ corresponds to the loss by incineration between 60 °C and 550 °C. This value is used to estimate organic matter (OM) content present in sediments (Meyers and Teranes, 2001).

3.7. ELEMENTAL AND ISOTOPE ANALYSES

The organic carbon content (% C_{org}), total nitrogen (N_{total}) and stable isotope ratios $\delta^{15}N$ and $\delta^{13}C$ of the bulk sediments were performed using a Costech elemental combustion system (Model 4010) coupled to a Thermo Finnigan Delta Plus XP Isotope Ratio Mass Spectrometer (IRMS). For this analysis 5 g of wet sediment was subsampled at 2 cm intervals.

The N_{total} content was obtained by combustion of a first aliquot of the dried and ground bulk sample. The content of C_{org} corresponds to the residual carbon content in a second aliquot subjected twice to acid hydrolysis with 1 N HCl. The results are expressed in dry weight percent. The remaining gases (N_2 and CO_2) recovered in the line of extraction system are separated for isotopic measurements. The $\delta^{13}C$ and δ^{15} N correspond to the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios and these values are reported with respect to a standard known as Pee Dee Belemnite (PDB) and atmospheric $N_{2,}$ respectively, and both are expressed in parts per mil (‰).

3.8. PALYNOLOGICAL ANALYSES

The standard palynological procedure from Rochon et al. (1999) was used to recover the palynomorphs throughout the cores (pollen, spores, dinoflagellate and ciliate cysts, organic linings of benthic foraminifers and freshwater algae).

A volume of approximately 5 cm^3 of wet sediment was sampled by hydrostatic weighing and placed into an ultrasonic bath (VWR Model 50T) for 3 min. A *Lycopodium clavatum* spore tablet (12 100 ± 1 892 spores per tablet, Batch 414 831) was added to the samples prior to sieving through two Nitex® membranes of 100 and 10 µm mesh size to eliminate macro remains, sand and silt particles. The 10-100 µm fraction was treated with hot hydrochloric acid (10 %, in four series of 10 min), alternating with hot hydrofluoric acid (49 %, twice for 10 min and once overnight) to dissolve the carbonate and siliceous fractions, respectively. The treated sample was sieved again with a 10 µm mesh size Nitex® membrane to eliminate fine particles and fluorosilicate gels produced during the acid treatments. The remaining fraction was preserved with five drops of phenol and stored at 4 °C.

For slide preparation, the 10-100 µm fraction was centrifuged, and the supernatant removed. The remaining fraction was homogenized with a vortimixer and a drop of the homogenized fraction was mounted in glycerin jelly between slide and cover slip using a glass micropipette. A minimum of 50 *Lycopodium clavatum* marker grains was counted in each sample, which yielded pollen counts of > 560 grains (average 1 082 ± 496 grains), and 110 ± 40 dinocysts in the Lake Inkerman core. The samples were analyzed at 2 cm intervals.

The counts were performed with a transmitted light microscope (Leica® 5500B) and Nikon Eclipse 80i at 400× magnification. For the identification of pollen and spores we used the pollen Atlas of Richard (1970) and Bassett et al. (1978), the identification key from McAndrews et al. (1973) and the reference collection of the paleophytogeography and palynology laboratory of the University of Montreal. Dinoflagellate cysts (dinocysts) taxa were identified using the identification keys in Rochon et al. (1999).

The palynomorph concentration (cysts or grains/cm^3) was calculated using the following equation:

$$\begin{matrix} Palynomorph \\ concentration \end{matrix} = \left[\frac{\begin{matrix} L.\, clavatum\ per\ tablet \\ (12\,100\ spores) \end{matrix}}{Volume\ of\ sediment\ (cm^3)} \right] * \left[\frac{\text{N° of palynomorphs counted}}{\text{N°marker grains counted}} \right]$$

The influxes (palynomorphs/cm^2/yr) are obtained by multiplying the palynomorph concentrations (palynomorphs/cm^3) by the sedimentation rate (cm per year). This makes it easier to assess changes in vegetation and plankton productivities in environments where sedimentation rates vary through time. The relative abundances (%) of pollen grains were calculated based on the sum of all pollen grains (trees + shrubs + herbs) excluding spores. Pollen taxa with low representation were grouped under the categories “Other trees”, “Other shrubs” and “Other herbs” (7 in each category, see Table 1).

The spore influxes include both ferns (monolete and trilete spores) and clubmosses (*Lycopodium* sp.). *Sphagnum* sp. spores influxes are calculated separately. The arboreal pollen (AP) is the sum of the percentages of tree pollen. The shrub pollen represents the sum of *Betula* sp. < 25 µm, *Alnus crispa*, *Alnus rugosa* and other shrubs percentages. The herb pollen represents the sum of Cyperaceae, Poaceae, *Ambrosia* sp., *Rumex* sp. and other herbs. The percentage of non - arboreal pollen (NAP) include shrubs and herbs. The total pollen is represented by AP-NAP diagrams in which spores were not included. Reworked cysts, algae and other palynomorphs were excluded for the calculation of the percentage of dinocysts.

Table 1. List of taxa not included in the pollen diagram in Lake Inkerman and Pokemouche River cores

Other trees	Lake Inkerman (%)	Pokemouche River (%)
Type *Ulmus*	0.8	0.8
Fraxinus sp.	1.9	1.3
Type *Larix*	0.2	1.6
Type *Juglan*	0.3	0.5
Celtis occidentalis	0.1	-
Carya sp.	0.2	0.4
Tilia americana	0.1	0.1
Others shrubs		
Corylus sp.	1.4	1.2
Salix sp.	0.3	1.5
Type *Ostrya-Carpinus*	1.0	1.4
Ilex sp.	0.5	0.5
Prunus pensylvanica	0.2	
Caprifoliaceae	-	0.3
Myricaceae	-	1.2
Others herbs		
Chenopodiaceae	1.3	0.4
Ericaceae	0.5	0.5
Caryophyllaceae	-	0.2
Ranunculaceae	0.1	-
Tubuliflorae	0.2	2.5
Artemisia sp.	1.0	1.4

3.9. STATISTICAL APPROACH

3.9.1. POLLEN AND DINOCYST ASSEMBLAGE ZONES

The Pollen Assemblage Zones (PAZ) and Dinocyst Assemblage Zones (DAZ) were defined using the software CONISS (Grimm, 1987), which carries out depth-constrained hierarchical cluster analysis from the relative abundance of each taxon. Dendrograms were constructed with the Tilia Sofware (Grimm, 1991) using the incremental sum of squares method and squared Euclidean distance as dissimilarity measure. Dendrograms are shown in appendix II (figures 11 to13).

3.9.2. PALEOCLIMATIC RECONSTRUCTIONS

The reconstruction of past climate and vegetation was carried out using the Modern Analog Technique (MAT) described by Guiot (1990), and following the method described by Fréchette et al. (2018). The procedure was adapted to the Eastern Canadian context, integrating a database of 1010 modern pollen assemblages (composed of 52 pollen taxa) for which vegetation and climate are known. This information belongs to a database compiled by Whitmore et al. (2005).

For both sites, the reconstruction of climatic parameters was performed with the "bioindic" module (ftp://ftp.cerege.fr/R/Package_bioindic) developed on the R platform (http://cran.r-project.org). This procedure provides 1) the five best modern analogs retained; 2) the dissimilarity between postglacial pollen assemblages; 3) the geographical coordinates of the analogs; 4) the name of the reconstructed vegetation type (biome). A dissimilarity index lower than 0.75 means that the fossil assemblage is considered "equivalent" or "similar" to local modern assemblages.

The degree of reliability of climate reconstructions of the MAT is given by the correlation between inferred and observed values [Pearson correlation coefficient (R^2) and the root mean square error (RMSEP)]. The validation test (made on 808 observations) yields high correlation coefficients for the privileged variables used in this study: Mean temperature of the warmest month of the year ($R^2 = 0.89$; RMSE = 1.18), mean precipitation for June-July-August ($R^2 = 0.75$; RMSE = 28.1), mean temperature of the coldest month of the year ($R^2 = 0.88$; RMSE = 2.20), mean precipitation for December, January, February ($R^2 = 0.79$; RMSE = 38.3) and total annual precipitation ($R^2 = 0.81$; RMSE = 107.24). The reconstructed climatic parameters were expressed as an anomaly and compared to the 1981-2010 Climate Normals. These parameters were used to summarize the average of local climatic conditions and as indicators of the seasonal variation summer/winter. The historical period of the record was compared with instrumental data. There is a shift between ^{210}Pb chronology from palynological samples and historical data (10-30 years) and the resolution by ^{210}Pb chronology is considerably lower than that from instrumentally measured data, because of these direct statistical correlations were not made.

3.10. HISTORICAL INSTRUMENTAL CLIMATE DATA (PRECIPITATION AND TEMPERATURE)

According to the Government of Canada Climate Web site (http://climate.weather.gc.ca/) the Bathurst station (47°37'12" N; 65°39'00" W - Altitude: 12.2 m; Climatological ID: 8100500), located 60 km west of Lake Inkerman, is the nearest station with the most complete meteorological record between 1871 to 1972 (Environnement et Changement climatique Canada, 2011).

The recent instrumental temperature and precipitation values of reference correspond to Canadian Climate Normals recorded between 1981 and 2010 from Bathurst A station (47°37'45.050" N; 65°44'54.020" W - Altitude: 58.8 m; Climatological ID: 8100503, (Environnement et Changement climatique Canada, 2013). These data were used to construct the curve of temperature and precipitations of July and January between AD 1872 and 2010.

4. RESULTS

4.1. SEDIMENT CHARACTERISTICS

Lake Inkerman core is composed of silty (9-20 µm) organic-rich sediments. Grain size analyses show it is composed mainly of silt-sized particles (88.7 ± 3.5 %) and lesser proportions of clays (9.9 ± 2.8 %). High-resolution X-ray images reveal layering. The color of the sediment is olive gray (Munsel's index: 5Y 3/2). The upper 5 cm are characterized by very fine sand content that reaches a maximum of 18.5 %. The indicator of redox conditions Mn/Ti ratio has a relatively stable value of 0.05 (Figure 2).

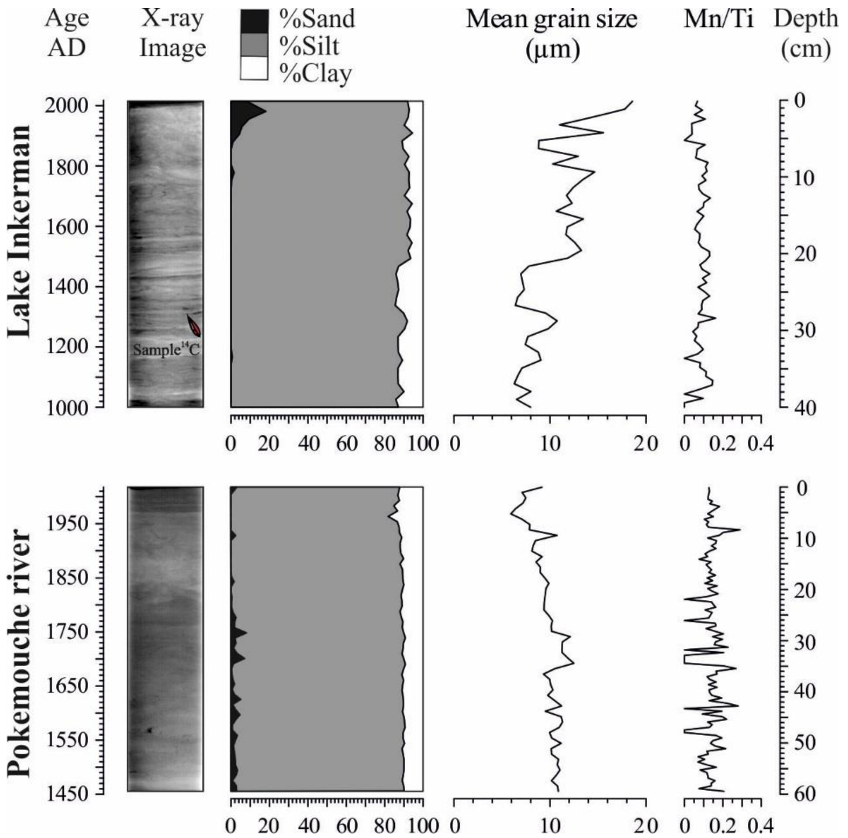


Figure 2. Sedimentological analyses from Lake Inkerman and Pokemouche River showing (left to right): black and white X-ray image of split core surface, grain –size distribution of the detrital fraction, mean grain-size and geochemical ratio Mn/Ti

The core from Pokemouche River is composed of massive silty organic-rich sediments (8-10 µm). Grain size analyses indicate that it is composed of 87.1 ± 1 % of silt, 10.2 ± 0.4 % of clay and 2.5 ± 0.5 % of sand. The color is very dark grayish brown (Munsel's index: 10YR 3/2). The Mn/Ti ratio is stable around 0.15 (Figure 2). In the Pokemouche River, silt proportion increased between AD 1750 and 1950 at the expense of sand (between 4 and 6 cm downcore).

4.2. CHRONOSTRATIGRAPHIC FRAMEWORK

The conventional radiocarbon age (1269 ± 26 BP) of the mussel valve cf. *Mytilus edulis* from Lake Inkerman sediments, collected at 28 cm downcore, was calibrated (cal. AD 1135 ± 80) using the software Oxcal version 4.3.2 (Ramsey, 2017) with the Marine13 curve (Reimer et al., 2013) and confidence interval of 95%.

The ^{210}Pb profiles for both cores illustrate an exponential decrease (Appendix I, Figure 11). The excess ^{210}Pb were calculated by subtracting supported ^{210}Pb from the total ^{210}Pb activity. ^{210}Pb total activity profiles indicates a supported ^{210}Pb activity of 15.15 Bq/Kg at 10.5 cm in Lake Inkerman core. In this core, based on the CRS model of the ^{210}Pb and ^{14}C, prior to AD 1200, the ages are extrapolated and the sediment accumulation rate yields a value of 0.5 mm/yr. The sedimentary sequence has a rapid increase in sedimentation rates from AD 1200 to 1900 (2.5 mm/yr). During the last century the sedimentation rate had an average value of 0.7 mm/yr. This core represents 1 000 years of sedimentary record (Figure 3).

A bioturbation zone was defined from ^{210}Pb measurements in the uppermost 2 cm of the sediments from Pokemouche River. The data from this zone was not used for establishing chronology by ^{210}Pb. The excess ^{210}Pb activity reached an equilibrium with the supporting ^{210}Pb in AD 1870 (at 14.4 cm downcore), which allowed calculating an accumulation rate of 1.4 mm/yr until AD 2000 (at 2.5 cm from the top). For sediments older than AD 1870, we assumed an extrapolated constant rate of sediment accumulation of 1 mm/yr in the absence of datable material. This core spans approximately the last 500 years of sedimentation (Figure 3).

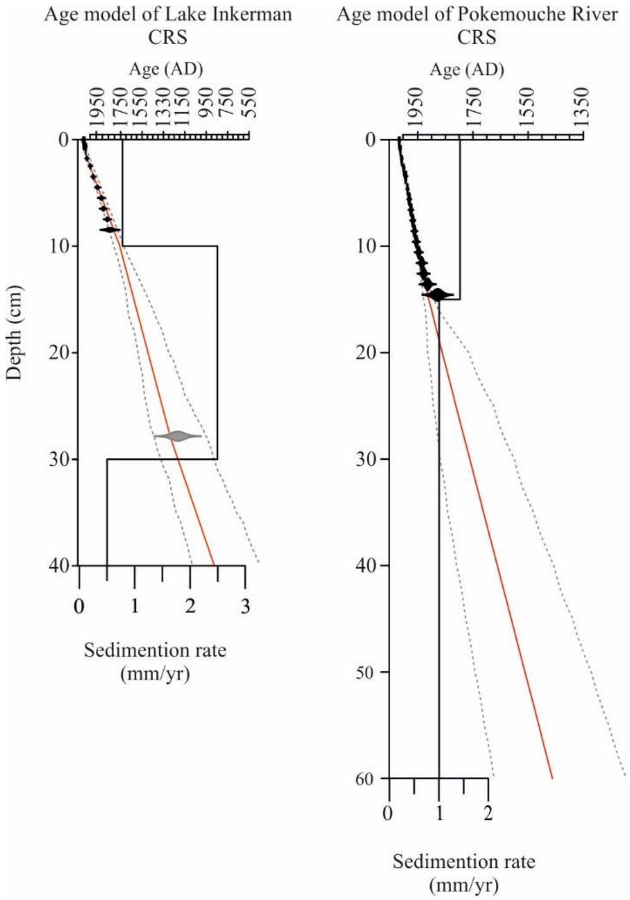


Figure 3. Age model of Lake Inkerman and Pokemouche River cores. Radiometric chronologies showing ^{210}Pb measurements and sedimentation rates. AMS-^{14}C age in Lake Inkerman is represented by a gray diamond. Model built using the R-package Bacon (Blaauw & Christen, 2011). The solid red line represents the age-depth curve from interpolation. The area between the two dotted lines represents uncertainties on ages expressed as 2-standard deviations (equivalent to 95 % confidence intervals on measurements). The black stepped line shows the changes in sedimentation rates along depth

4.3. ELEMENTAL AND ISOTOPE ANALYSIS

The C_{org}/N_{total} ratio remains stable at about 10 throughout Lake Inkerman core, a value characteristic of algal organic matter (OM) (Sterner et al., 2008). Between AD 1000 and 1200, the % C_{org}, $\delta^{13}C$ and LOI_{550} decrease from 5 to 3 %, -18 to -21 ‰ and 15 to 10 % respectively (Figure 4). The content of C_{org} varies between 3 and 5 % from AD 1200 to 1900. At the same time the LOI_{550} profile confirms the general trend of organic C_{org} variability, ranging between 10

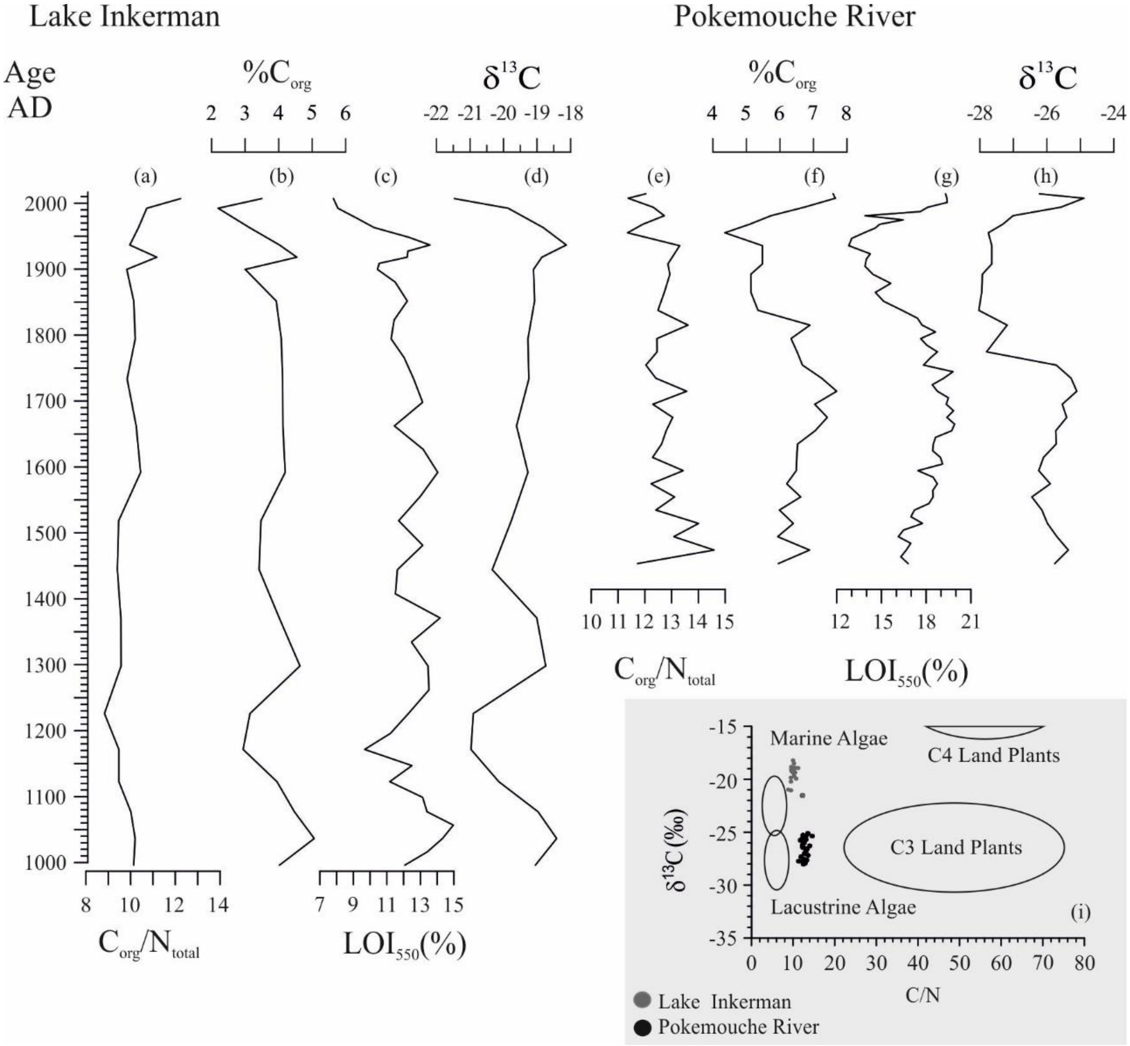


Figure 4. Organic carbon percentages, Carbon -nitrogen ratios, carbon isotopic ratio and loss on ignition 550°C of sediments from Lake Inkerman (a-d) and Pokemouche River (e-h). C/N vs $\delta^{13}C$ diagram shows the mixture of OM components (Meyers and Teranes, 2001) (i)

and 13 %. The carbon isotopic signature in this period varies between -21 and -18 ‰ and increases towards the top. Between AD 1900 and 1950, C_{org} and LOI_{550} reach their maximum values (4.5 and 13.5 % respectively). In the same period the $\delta^{13}C$ shows a peak of - 18 ‰ before decreasing to more negative values ($\delta^{13}C$ depletion) of -22 ‰. During the last 50 years, C_{org} and LOI_{550} decreased from 4.5 to 2 % and 14.5 to 7 %, respectively. The position of samples on the C/N vs $\delta^{13}C$ diagram (Figure 4i) indicates that the main source of organic carbon in Lake Inkerman sediments came from marine algae.

The bulk C_{org}/N_{total} ratio in the sedimentary sequence from Pokemouche River ranges between 11 and 14 throughout the core. Between AD 1450 and 1720 the contents of C_{org} and OM (LOI_{550}) increase progressively upwards from ~6 to 8 % and ~16 to 20 %, respectively. In the same period, the $\delta^{13}C$ values range between -27 and -25 ‰. Between AD 1720 and 1950, the C_{org} and LOI_{550} content progressively decreased from 8 to 4 % and 20 to 12 %, respectively. This decrease is accompanied by a shift in the isotopic organic carbon signal. The decline of $\delta^{13}C$ values from -25 to -28 ‰. From AD 1950 to the present, the % C_{org} and LOI_{550} increase from 4 to 8 % and 12 to 19 %, respectively. The isotopic ratio of organic carbon increases from -28 to -25 ‰. The C/N vs $\delta^{13}C$ diagram (Figure 4i) indicates that the organic carbon in the sediments from Pokemouche River is a mixture of lacustrine algae and C3 land plants.

4.4. PALYNOLOGICAL ANALYSES

The hierarchical clustering that allowed defining dinocyst and pollen zones were built separately, and both yielded nearly similar limits. Therefore, the marine and terrestrial palynomorph zonations were combined into assemblage zones (here referred to as DAZ and PAZ, respectively). The sedimentary sequence of Lake Inkerman is a more condensed section covering almost twice the time recorded in the Pokemouche River core. The basal assemblage zones, older than AD 1450 (PAZ I and PAZ IIA) defined in the sediments from Lake Inkerman (Figure 5) are absent in the Pokemouche River core (Figure 6). The PAZ IIB from Lake Inkerman is correlated with the PAZ II (between AD 1450 to 1800) defined at the base of Pokemouche River core.

4.4.1. POLLEN ASSEMBLAGES ZONES (PAZ)

The pollen composition of both cores reflects the presence of characteristic assemblages of the mixed forest typical of valley bottoms and mid-slopes of the Acadian Peninsula. The arboreal fraction is represented by *Pinus* sp. (pine), whose abundances rarely exceed 30 %. *Picea* sp. (black and red spruce) reach a maximum of 30 % of the total pollen. Arboreal *Betula* pollen (grey and yellow birch) varies between 5 and 30 %. Other species present in low abundance (< 10 %) are the type *Tsuga* sp. (eastern hemlock, < 5 %), *Fagus (*beech, 10 %) and *Acer* sp. (maple).

The shrub pollen of *Betula* (< 25 µm) is well represented in both sedimentary records and its abundance varies between 5 and 40%, followed by *Alnus crispa* and *Alnus rugosa* (5 - 15 % and < 5 % respectively). The content of herb pollen is consistently low in both sites and reaches its maximum abundance in PAZ (III) of both cores, where they do not exceed 5 %.

4.4.1.1. Lake Inkerman

In this core, three PAZ were distinguished (Figure 5) based on the hierarchical clustering. PAZ I (AD 1000 - 1200) shows an AP/NAP ratio of ~1 and is characterized by a higher average pollen percentage of trees (~ 50 %) and shrubs (~ 45 %) and lower amounts of herbs pollen (~ 5 %). This unit is characterized by a low average pollen influx of 2 386 grains/cm^2/yr. *Pinus* sp. (~ 20%) is the dominant tree. *Picea* sp. is the second most abundant tree taxon and declines from ~15 to 10% from the base to the top of the zone. *Abies* sp. is present in low abundance (< 1 %). The *Tsuga* sp. pollen content is relatively stable at ~5 %.

Betula sp. > 25 µm varies between 5 and 20 %. The abundances of *Quercus* sp. and *Acer* sp. are less than 2 % and are relatively stable throughout the zone. *Fagus* sp. pollen decreases gradually from the bottom to the top of PAZ I, from 10 to 5 %. In this zone the shrub pollen is abundant and is represented by *Betula* sp. (< 25 µm) ranging between 30 and 55 %, with less than 5 % of *A. crispa* and *A. rugosa* pollen. The Poaceae are present in low abundance (< 3 %). The upper limit of this zone corresponds approximately with the inception of the Medieval Warm Period (MWP).

PAZ II (AD 1200 – 1850) is marked by maximum pollen and spore influxes. The species composition is similar to that of PAZ I, and only the abundances of certain taxa are different. The division in two sub-zones (IIA and IIB) at AD 1500, coincides with a relative decrease in the spores and pollen influxes.

Sub-zone PAZ IIA spanned a period from AD 1200 to AD 1500 and is characterized by a high pollen influx marked by a peak of 18 000 grains/cm^2/yr at de bottom, and a progressive decrease towards the top of the sub-zone to 10 000 grains/cm^2/yr. Two important changes in the relative abundance of tree pollen are observed: the increase of *Picea* sp. with respect to PAZ I (from ~ 5 to 10 %), and a peak of abundance of *Betula* sp. > 25 μm pollen of 30 %. The abundances of *Quercus* sp. and *Acer* sp. are stable, and less than 2 %. *Fagus* sp. remains constant at 5 %. *Betula* sp. < 25 μm abundance vary between 30 to 40 %. *Alnus crispa* remains relatively constant at 3 %. *Alnus rugosa* and other shrubs are present at the bottom (about 2 %) and remain very low towards the top of the sub-zone (< 1 %). The herb pollen abundance remains low (< 3 %), but more diverse at the family level. Cyperaceae and Poaceae abundances are very low and sporadic within this unit. The influx of spores is significantly higher in this sub-zone. Influxes of ferns and clubmosses range between 100 - 300 spores/cm^2/yr, and *Sphagnum* sp. vary between 300 – 700 grains/cm^2/yr. The lower limit of this IIA sub-zone corresponds roughly with the beginning of the LIA.

Sub-zone PAZ IIB spanned a period from AD 1500 to AD 1850 and is marked by a high pollen influx, varying between 10 000 and 18 000 grains/cm^2/yr. *Picea* sp and *Pinus* sp. remain relatively constant at 8 % and 15% respectively. *Tsuga* sp. and *Betula* sp. > 25 μm decrease from ~ 5 to 2 %, and ~ 15 to 10 % respectively. *Abies* sp. is present in very low percentage near the top of the unit, while *Fagus* sp. remains constant at 10%. The composition and abundance of shrub pollen are also similar to those registered in sub-zone IIA. The herbs pollen abundance remains low (< 4 %). Cyperaceae and *Ambrosia* sp. are present sporadically within this sub-zone. Poaceae increase to 1% from AD 1700. The influxes of both fern and moss spores vary between 200 and 400 spores/cm^2/yr. *Sphagnum* sp. influx is significantly higher here ranging 300 - 800 grains/cm^2/yr relative to PAZ I. The upper limit of this zone corresponds approximately to that of the end of the LIA.

PAZ III is subdivided into 2 subzones based on the hierarchical clustering. The sub-zone PAZ IIIA (AD 1850-1950) is marked by the drastic decline of pollen (from 15 000 to 4 000 grains/cm^2/yr), and spore influxes (from 700 to 200 spores/cm^2/yr). This zone is also characterized by a progressive increase of tree pollen. *Picea* sp. increases from 10 to 20 %

and *Pinus* sp. from 15 to 30 %. *Tsuga* sp. abundance remains relatively constant at 3 %. The relative abundance of *Betula* sp. > 25 µm decreases from ~ 10 % down to ~ 2 %, while *Quercus* sp. and *Acer* sp. increase slightly in this unit. *Fagus* sp. remains relatively constant at 5 %. Here, the relative abundance of birch shrubs (*Betula* sp. < 25 µm) declines steadily towards the top from ~ 50 to ~ 30 %. *Alnus crispa* and *A. rugosa* are present at ~ 2 % and ~ 1 % respectively. The herbs remain low (< 3 %) and they are dominated by Poaceae.

Sub-zone PAZ IIIB (AD 1950 to present) is characterized by low pollen influxes (average 3 980 grains/cm^2/yr) and the maximum abundance of arboreal pollen. In this sub-zone *Picea* sp., *Pinus* sp. and *Abies* sp. (softwoods) all reach their maximum abundance (~ 35 %, ~ 26 % and 4 - 5 %, respectively). Conversely, the abundances of *Tsuga* sp., *Acer* sp. and *Fagus* sp. (hardwoods) decrease down to 2 %, 3 % and 4 % respectively. *Betula* sp. (< 25 µm) decreases from 40 % to 25 %, and *A. rugosa* disappears completely. The herbs are also marked by an increase of Poaceae and “Other herbs”. Fern and moss spore influxes also decrease slightly towards the top of the sub-zone.

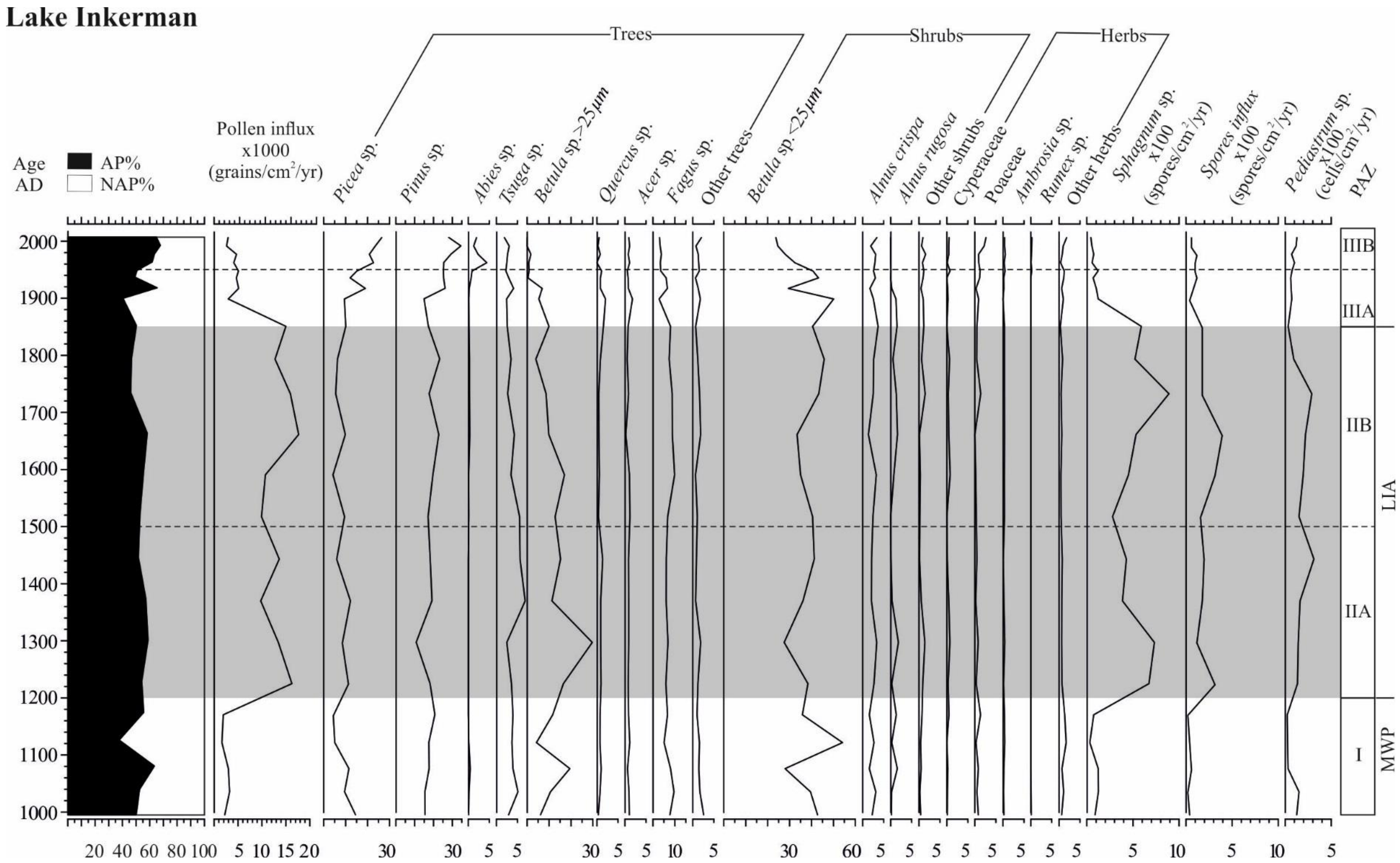


Figure 5. Lake Inkerman pollen-percentage diagram and Pollen Assemblage Zones (PAZ). The pollen sum corresponds to the arboreal (AP) and non-arboreal pollen percentage (NAP = shrubs + herbs). Influxes of pollen, *Sphagnum* sp., spores (ferns and clubmosses) and freshwater palynomorphs (*Pediastrum* sp.) plotted against the chronology are shown. Dotted lines represent the limits of sub-zones. The external solid lines to the right represent the limits of the MWP and LIA

4.4.1.2. Pokemouche River

The pollen diagram of the Pokemouche River core is composed of two PAZ (Figure 6). PAZ II (AD 1450 - 1800) is characterized by the dominance of AP (about 60 %) and lower amounts of shrubs and herbs pollen (NAP; ~ 35 % and ~ 5 % respectively). *Picea* sp. increases from ~ 10 to 20 %. Conversely, *Pinus* sp. shows a steady decline towards the top, from ~ 30 to 20 %. *Tsuga* sp. decreases towards the top from 3 to 1.5 % *Betula* sp. > 25µm and *Fagus* sp. abundances remain relatively stable at 10 % and 5 % respectively. *Acer* sp. is present at less than 1 %. The shrubs pollen of *Betula* sp. (< 25 µm) and *A. crispa* are present in almost the same proportions, both representing approximately 30% of the total pollen sum. *Alnus rugosa* is present in low abundance (< 2 %). The herbs represent only ~ 5% of the pollen sum. The Poaceae increase towards the top from 1 to 3 %. *Ambrosia* sp. remains low throughout this PAZ (< 1 %) and *Rumex* sp. appears at the top of the zone around AD 1750. The average spore influx ranges between 400 and 800 spores/cm^2/yr. *Pediastrum* sp. influx increased from ~ 100 to 700 cells/cm^2/yr. The upper limit of this PAZ coincides with the end of the LIA.

PAZ III is divided into 2 sub-zones based on the cluster analysis. Sub-zone IIIA (AD 1800 - 1950) shows a slight decreasing trend and is marked by a peak of pollen influx from 3 900 to 14 800 grains/cm^2/yr at the top. The most abundant tree taxa are *Picea* sp., *Pinus* sp. and *Betula* sp. > 25 µm, which decrease towards the top to values of 15 %, 20 % and 15 % respectively to 5 %. The progressive decrease of the *Tsuga* sp. and *Fagus* sp., which began in the underlying PAZ II, continues in this unit, declining from ~ 3 to < 1 %. The unit shows a progressive increase towards the top of pollen percentage of shrubs and herbs and a decrease of tree pollen. In this zone *Betula* sp. < 25 µm decreases from 20 to 5 %. The dominant shrub pollen taxon is *A. crispa*, whose abundance is about ~ 20 % with a peak of 65 % at the top of the sub-zone. *Alnus rugosa* and Poaceae increase from ~ 1 to 12 %, and ~ 1 to 6 % respectively. *Ambrosia* sp. and *Rumex* sp. remain low throughout the zone (< 1 % each). The average influx of spores and *Pediastrum* sp. increased upward from 400 to 500 and 100 to 250 palynomorphes/cm^2/yr, respectively).

Sub-zone PAZ IIIB (AD 1950 to present) is characterized by an average pollen influx of 5 100 grains/cm^2/yr. Here, the average pollen percentage of trees shows an increase from 10 to 40 % with higher amounts of shrub and herb pollen (~ 50 % and 10 % respectively). *Picea* sp. abundance is stable at ~10 %, while *Pinus* sp. varies between 20 and 15 %. *Abies* sp. and *Tsuga* sp. are present in low abundance (< 1 %). *Betula* sp. varies between 5 and ~ 1 %. *Quercus* sp. and *Fagus* sp. are present in low abundance (< 1 %). *Acer* sp. shows a slight increase towards the top from 1 to 3 %.

Betula sp. < 25 µm increases from 5 to 25 %. *Alnus crispa* is the most abundant shrub pollen in this unit (~ 20 %). *Alnus rugosa* decreases from 15 to 5 %. Cyperaceae and *Ambrosia* sp. increase slightly towards the top (both, from < 1 to 3 %), and the Poaceae vary between 2 and 5 %. *Rumex* sp. remains present in low abundance (< 1 %). Influxes of spores of ferns decrease slightly towards the top from 800 to 400 spores/cm^2/yr. The *Sphagnum* sp. influx increases from 50 to 100 spores/cm^2/yr and *Pediastrum* sp. influx ranges between 100 and 300 cells/cm^2/yr.

4.4.2. DINOCYST ASSEMBLAGE ZONES (LAKE INKERMAN)

Lake Inkerman is characterized by the presence of 10 dinocyst taxa: *Pentapharsodinium dalei*, *Operculodinium centrocarpum*, *Islandinium* sensu lato (including *I. minutum* and *I. minutum* var. *cezare*), *Brigantedinium* spp. and *Echinidinium* spp. Other protoperidinoids include: *Selenopemphix quanta*, *Lejeunecysta* cf. *sabrina* and *Stelladinium* cf. *robustum)* common in nutrient-rich environments (Zonneveld et al., 2013), accounted for less than 5 % of assemblages.

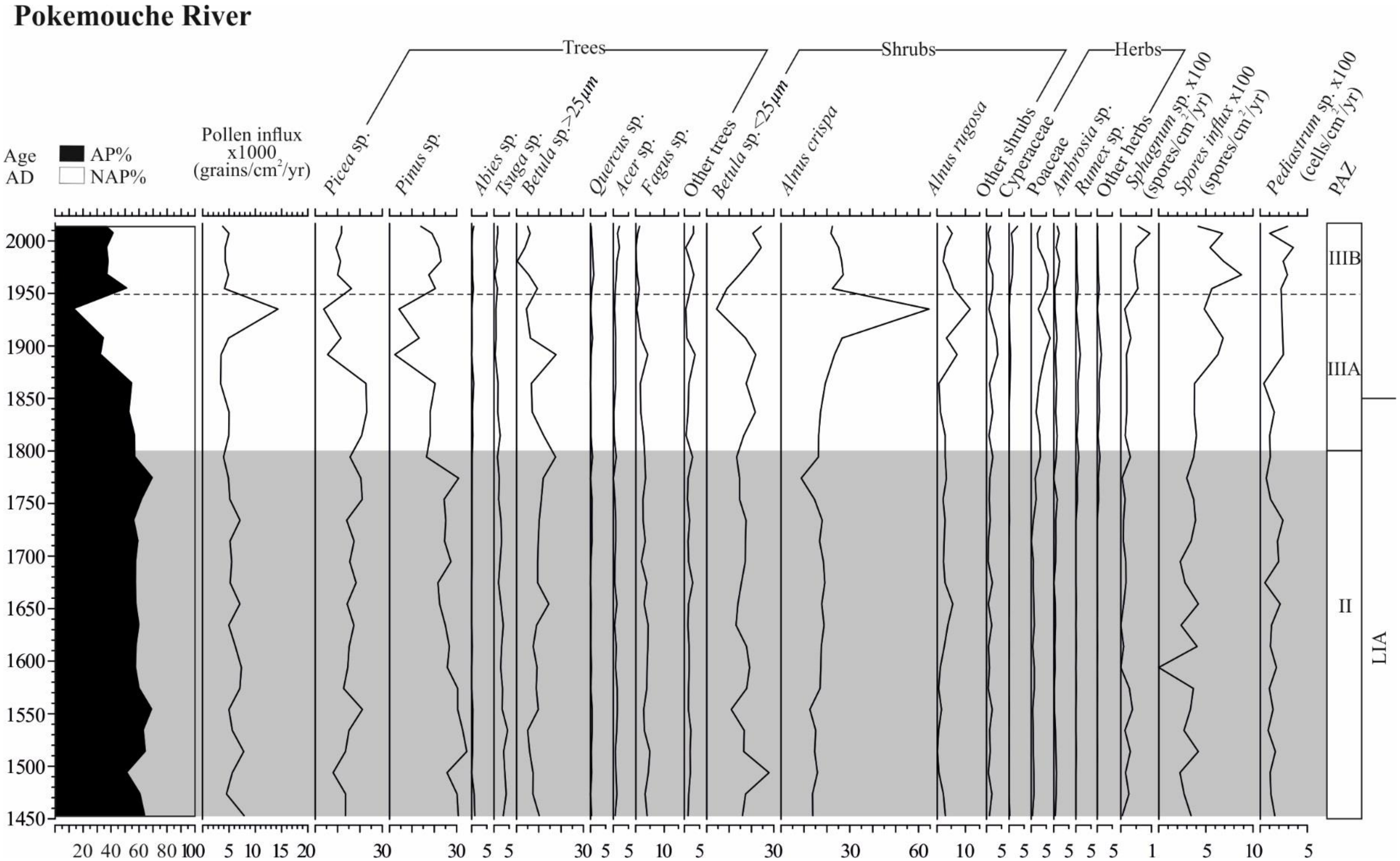


Figure 6. Pokemouche River pollen-percentage diagram and Pollen Assemblage Zones (PAZ). The pollen sum corresponds to the arboreal (AP) and non-arboreal pollen percentage (NAP = shrubs + herbs). Influxes of pollen, *Sphagnum* sp., spores (ferns and clubmosses) and freshwater palynomorphs (*Pediastrum* sp.) plotted against the chronology are shown. The dotted line represents the limits of sub-zones. The external solid line represents the upper limit of the LIA

The dominant dinocyst species is the phototrophic *Spiniferites* cf. *mirabilis* (25 - 70 %). Important morphological variations characterized this taxon. These specimens are relatively small (30 - 35 µm wide and 34 - 40 µm long) compared to the "typical" *S. mirabilis* (44 - 48 µm wide and 58–60 µm long) for the regular form described by Morzadec-Kerfourn et al. (1979). They are characterized by an apical boss and by short (5-10 µm) and incompletely developed gonal and intergonal processes (Figure 7).

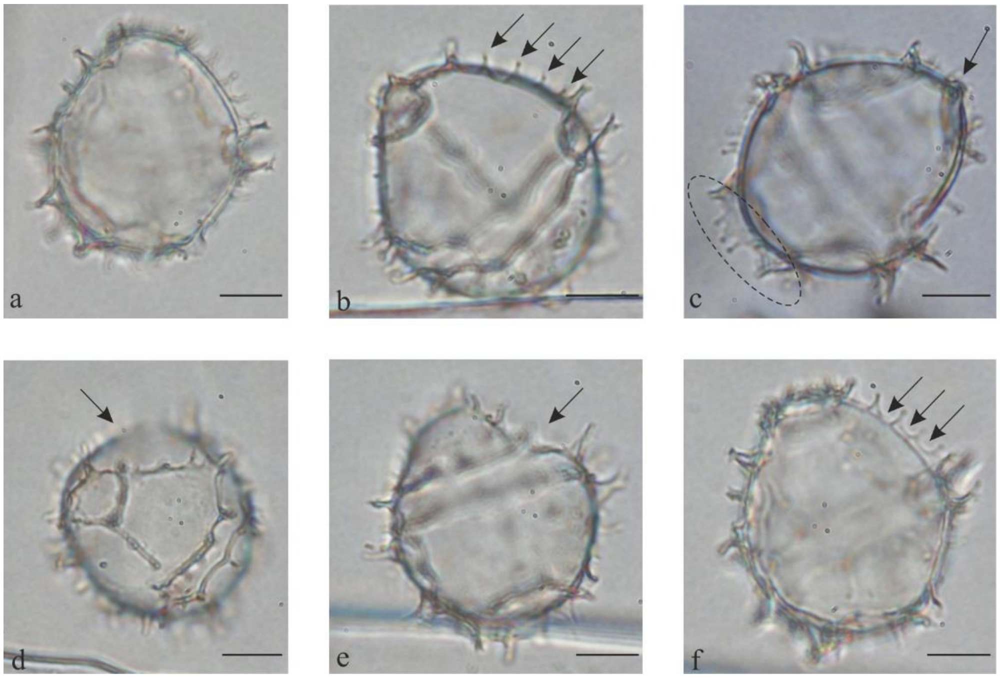


Figure 7. Atypical *Spiniferites* cf. *mirabilis* morphology observed in specimens from recent sediments of Lake Inkerman. (a) Note the ovoidal to subspherical shape of the central body, (b) mid focus showing 4 short intergonal processes (arrows) along a major suture (c) a relatively high crests on the antapical region (dotted circle) and well developed apical boss (arrow) (d) high focus on apical zone showing archeopyle (arrow) (e) mid focus on lateral side showing precingular dorsal archeopyle (arrow), (f) low or absent sutural septa in the apical area between reduced processes (arrows). Scale bars 10 µm

The DAZ I (between AD 1 000 and 1 200) is characterized by a low dinocyst influx (~ 250 cysts/cm^2/yr, Figure 8). This zone is also characterized by low and stable foraminifer linings, *Halodinium* sp. and *Pediastrum* sp. influxes (~ 25, ~ 20 and ~ 100 cells/cm^2/yr respectively). *Spiniferites* cf. *mirabilis* decreases progressively towards the top from 60 to 50 %. *Operculodinium centrocarpum* decreased towards the top from 5 to 3 %. Cysts of *P. dalei* and *Brigantedinium* spp. are present in low abundance (< 4 and < 6 % respectively).

Islandinium s.l. and Protoperidinoids percentages increase from 20 to 40 % and 1 to 3 % respectively.

The overlying DAZ II (between AD 1200 and 1850) is characterized by a maximum influx of dinocysts, varying between 500 and 2 000 cysts/cm^2/yr. The foraminifer lining influx remained stable at about 200 linings/cm^2/yr, *Halodinium* sp. influx shows a peak of 180 cells/cm^2/yr and *Pediastrum* sp. influx increases from 20 to 300 cells/cm^2/yr. The limits of this DAZ correspond approximately to those of the LIA. This unit is subdivided into two sub-zones. Sub-zone IIA (between AD 1200 and 1500) is marked by the decrease of *S.* cf. *mirabilis* from ~ 45 to 30 %. *Operculodinium centrocarpum* increases and shows a peak (~ 6 %) around AD 1450, followed by the cyst of *P. dalei* that reaches its maximum abundance, defining the upper limit of sub-zone IIA around AD 1500. Here, *Echinidinium* spp. is not abundant but increases slightly from 2 to 4 %, while the abundance of *Brigantedinium* spp. is persistently low (< 5 %). *Islandinium* s.l and Protoperidinoids decrease from 50 to 35 % and from 5 to 2 % respectively in this sub-zone.

In sub-zone PAZ IIB (AD 1500 - 1850), the marine palynomorph influxes reach their maximum values: dinocyst ~ 1 800 cysts/cm^2/yr, foraminifer linings ~ 600 linings/cm^2/yr, *Halodinium* sp. ~ 190 cells/cm^2/yr and *Pediastrum* sp. ~ 260 cells/cm^2/yr. The percentage of *S.* cf. *mirabilis* remains stable at around 40%. *Operculodinium centrocarpum* and the cyst of *P. dalei* decrease from 6 to 2 % and 40 to 2 % respectively. In contrast, *Echinidinium* spp. reaches a peak of maximum abundance (~ 7 %) in this sub-zone about AD 1650, followed by the peak of maximum abundance of *Brigantedinium* spp. (~ 10 %) near the top of the sub-zone at around AD 1830. *Islandinium* s.l. shows a sustained increase towards the top from 25 to 40%, and Protoperidinoids increase slightly upwards from 2 to 3 %. The separation of the dinocyst assemblages into two sub-zones at AD 1500 matches with minimum *Halodinium* sp. *and Pediastrum* sp. influxes (~ 70 and ~ 130 cells/cm^2/yr respectively), the increase of foraminifer lining influx (from 200 to 600 linings/cm^2/yr) and a peak of the cyst of *P. dalei*.

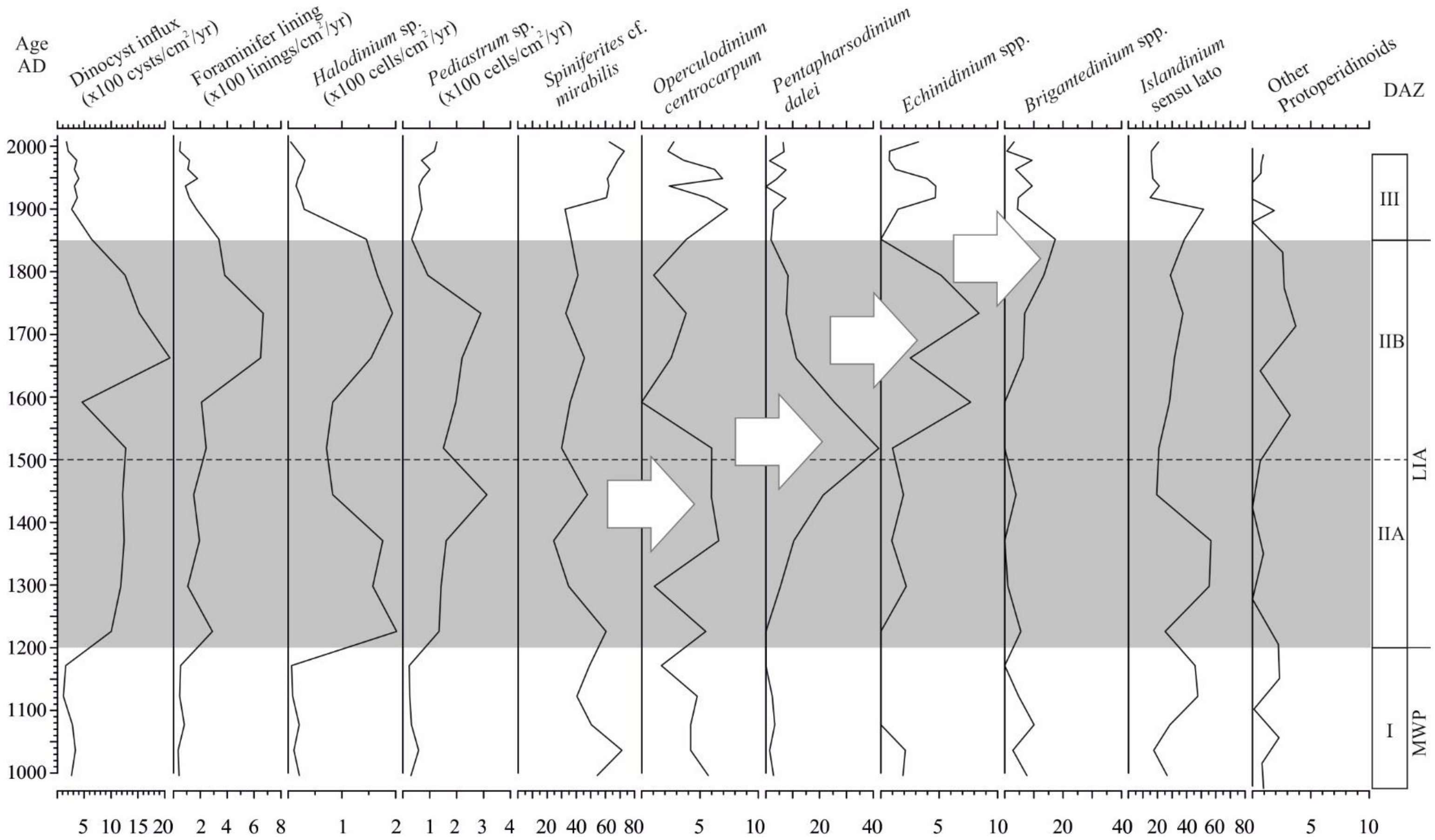


Figure 8. Dinocyst, foraminifer lining, *Halodinium* sp and *Pediastrum* sp influxes curves. Relative abundance of dinocysts taxa (%) and Dinocysts Assemblage Zones (DAZ) in Lake Inkerman according to time (age AD). Phototrophic taxa include: *S.* cf. *mirabilis*, *O. centrocarpum* and cyst of *P. dalei*. Heterotrophic taxa: *Echinidinium* spp., *Brigantedinium* spp., *Islandinium* s.l (including *I. minutum* and *I. minutum* var. *cezare*) and other protoperidinoids (*S. quanta*, *L.* cf. *sabrina* and *S.* cf. *robustum).* The horizontal dashed line in bold indicates the sub-assemblages. White arrows show successional changes from autotrophic species towards heterotrophic taxon. The external solid lines represent the limits of the LIA

The DAZ III (AD 1850 to present) is distinguished from the underlying assemblage by a sharp decrease of all marine and freshwater palynomorph influxes. *Spiniferites* cf. *mirabilis* shows an increase from 30 to 70 %. *Operculodinium centrocarpum* shows a maximum of ~ 5 % and cyst of *P. dalei* have a persistent low abundance (~ 5 %). *Echinidinium* spp. shows a peak of ~ 5 % between AD 1920 and 1950. Inversely, the abundance of *Islandinium* s.l. and *Brigantedinium* spp. decrease from 40 to 15 % and 10 to 5 %, respectively. Protoperidinoids have a persistent low abundance (~ 1 %).

4.5. PALEOCLIMATIC RECONSTRUCTION

4.5.1. BIOMES

The results of the paleo-reconstruction of vegetation from Lake Inkerman and Pokemouche River are compiled in tables 2 and 3, respectively. These tables include the information of the 5 closest modern analogs for each sample in both cores.

The reconstructed vegetation using the MAT for both Lake Inkerman and Pokemouche River cores is consistent with the modern vegetation present in the Canadian Maritime Provinces/Gaspé located in eastern New Brunswick (about 68° W; Fréchette et al. (2018). This region belongs to the bioclimatic domain of mixed forest, sub-zone balsam fir-yellow birch (SBj) characterized by pollen assemblages composed of *Betula* - *Pinus* - *Picea* (in decreasing abundance) whose total abundance is less than 10%.

The most relevant feature in the reconstruction from Lake Inkerman is the retention of some modern analogs belonging to the bioclimatic domain of the mixed forests of southwest Quebec (SBb / SBj: *Pinus* - *Betula* - *Picea* - herbs - *A. crispa*) in PAZ III (from AD 1850 to the present). This feature is associated with the decrease in the dominance of *Betula* sp. < 25 µm content and the increase of *Picea* sp. in pollen assemblages post AD 1850. This represents a transitional vegetation between the balsam fir-white birch and balsam fir-yellow birch forest association. The reconstruction of the vegetation from the Pokemouche River core also showed that the vegetation of the region belongs to the bioclimatic domain of mixed forest, sub-zone balsam fir-yellow birch (SBj). Conversely to the assemblages of Lake Inkerman, the total percentage of *Betula* sp. is less than 40 % and *A. crispa* is always greater than ~5 %. A minority of analogs belong to the tundra forest and the boreal forest (3 and 28 respectively, see table 3).

4.5.2. CLIMATE

Figure 9 presents the profiles of selected reconstructed parameters: Mean temperature of the warmest month of the year, mean precipitation in June-July-August, mean temperature of the coldest month of the year, mean precipitation in December-January-February and total annual precipitation. The profiles are presented according to Pollen Assemblage Zone and local chronology.

The reconstructed parameters based on the MAT for the historical period are consistent with Climate Normals (1981 -2010) with respect to the confidence interval. They can be synthesized referring to two periods. First, from AD 1000 to 1850, a time period recorded in the sedimentary sequence from Lake Inkerman and covered partially in the Pokemouche River core (from AD 1450), second, from AD 1850 to present covered by both sediment cores.

4.5.2.1. Period between AD 1000 and 1850 (both cores):

During this period, the reconstructed parameters show a mutual coherence in both cores. The PAZs covering this period (I and II) are characterized by the dominance of *Betula* sp., *Pinus* sp., *Tsuga* sp., *Picea* sp. and *Fagus* sp. (Figures 5, 6). These taxa are typical of the mixed eastern forest in response to cool climate (Fréchette et al., 2018). PAZ I covers between AD 1000 and 1200, which corresponds with the end of the MWP. According to our age model, PAZ II covers from AD 1200 to 1850, a period corresponding to the LIA, which is characterized by cooler climate conditions than present.

The closer modern analogs for PAZs I and II at Lake Inkerman have dissimilarity index values lower than 0.20. The closer modern analogs for PAZ II at Pokemouche River have dissimilarity index values lower than 0.33. Modern analogs selected for PAZs I and II in both cores mainly come from the mixed forest biome (Table 2).

The reconstructed mean temperature of the warmest month of the year profile shows a stable value of about 18.1 °C, approximately 1°C below the modern temperature of reference illustrated by the anomaly curve (Figure 9). The mean precipitations in June, July and August show an increase upwards between AD 1000 and 1350 (from 280 to 290 mm), and a slight decrease between AD 1350 and 1500 (from 290 to 280 mm). This trend is followed by an increase in summer precipitations between AD 1500 and 1850 (from 280 to 290 mm).

The mean temperature of the coldest month of the year also illustrates a persistence of colder conditions in the winter during the LIA. The mean temperature is about -12°C, one degree below the current climate normal for the winter months. The mean precipitations for December, January and February, indicates the installation of relatively drier winters compared to the present. The average winter precipitations are about 250 mm and remains without important variations until AD 1850. The total annual precipitations reconstructed during the LIA does not present significant variations and remains close to 1 050 mm, very close to the actual reference value. The paleoclimatic parameters reconstructed for Pokemouche River begin to diverge significantly with respect to climate normals (1981-2010) between AD 1800 and 1850. Negative temperature anomalies reach 3 °C in summer and up to 5 °C in winter during this short period of 50 years, a difference likely due to uncertainties in the age model.

4.5.2.2. Period from AD 1850 to present:

In this period, the reconstructed parameters show marked differences between the Inkerman Lake and the Pokemouche River cores.

Lake Inkerman

PAZ III covers this period, and is marked by the dominance of *Betula* sp., *Pinus* sp., *Picea* sp., *Tsuga* sp. and *Fagus* sp., an assemblage characteristic of mixed forest in cool climate. The closest modern analogs for PAZ III have dissimilarity index values lower than 0.2. Since most depths show a close analogy with present-time bioclimatic subdomain (SBj), we can say that Lake Inkerman showed little change through time in the sources and mechanisms of pollen transport (relative to Pokemouche).

Table 2. Results of paleoclimatic reconstructions of Lake Inkerman. Sites in the Maritime Provinces (Bb1) belong to bioclimatic subdomain of balsam fir-yellow birch (SBj), (*Betula-Pinus-Alnus crispa-Picea*). Depth, age of samples and dissimilarity index that quantifies the dissemblance between fossil and the 5 nearest modern assemblages are indicated. The Pollen Assemblage Zone (PAZ) to which each fossil assemblage belongs is also indicated. The number of analogs retained according to the type of reconstructed vegetation is shown. Also shown are the average geographical coordinates of the modern analogs, the percentage of the key taxon characterizing the assemblage (% total of *Betula*) and the bioclimatic subdomain for reconstructed vegetation

Depth (cm)	Age (years AD)	Dissimilarity index					PAZ	Mixed forest W.	Mixed forest E.	Approx. location of analogs by zone		Key taxon (%) *Betula*	Reconstructed vegetation
								SBb/SBj	SBj	Lat. (°N)	Long (°W)		
		1	2	3	4	5		Bc2	Bb1				
0.5	2007	0.20	0.22	0.23	0.23	0.23	IIIB	3	2	47.13 ± 0.69 New Brunswick	68.18 ± 6.37	28.2	Maritime Provinces (Bb1) bioclimatic subdomain: balsam fir-yellow birch (SBj)
1.5	1993	0.18	0.18	0.19	0.21	0.22		2	3			31.2	
2.5	1978	0.14	0.16	0.16	0.17	0.17		1	4			34.5	
3.5	1963	0.11	0.12	0.18	0.18	0.21		1	4			39.6	
4.5	1949	0.09	0.12	0.13	0.16	0.17		0	5			35.2	
5.5	1937	0.09	0.09	0.16	0.16	0.18	IIIA	0	5			39.1	
7.5	1918	0.12	0.13	0.18	0.19	0.19		0	5			46.9	
9.5	1900	0.17	0.18	0.19	0.21	0.21		0	5			40.1	
11.5	1852	0.14	0.16	0.17	0.18	0.20		0	5			58.2	
13.5	1794	0.13	0.16	0.16	0.18	0.19	IIB	0	5	46.86 ± 0.58 New Brunswick	67.05 ± 1.70	55.5	
15.5	1734	0.15	0.16	0.20	0.21	0.22		0	5			56.4	
17.5	1662	0.15	0.15	0.18	0.19	0.20		0	5			45.2	
19.5	1592	0.16	0.19	0.20	0.20	0.21		0	5			55.4	
21.5	1518	0.12	0.13	0.14	0.18	0.20		0	5			56.9	
23.5	1444	0.15	0.18	0.19	0.20	0.21	IIA	0	5			63.9	
25.5	1371	0.14	0.14	0.15	0.21	0.21		0	5			50.6	
27.5	1298	0.20	0.21	0.23	0.25	0.26		0	5			61.7	
29.5	1226	0.15	0.16	0.16	0.17	0.18		0	5			62.2	
31.5	1172	0.17	0.17	0.20	0.22	0.24	I	0	5	46.81 ± 0.68 New Brunswick	67.13 ± 1.85	51.0	
33.5	1123	0.14	0.17	0.19	0.20	0.21		0	5			60.6	
35.5	1077	0.13	0.13	0.17	0.18	0.20		0	5			48.6	
37.5	1036	0.12	0.16	0.16	0.17	0.18		0	5			56.4	
39.5	996	0.11	0.15	0.15	0.16	0.18		0	5			61.1	

Table 3. Paleoclimatic reconstructions for Pokemouche River. Site in the Maritime Provinces (Bb1) belong to bioclimatic subdomain of balsam fir-yellow birch (SBj), (*Betula-Pinus-A. crispa-Picea*). Analogs belonging to the tundra forest and the boreal forest in bold. Depth, age of samples and the dissimilarity index of the 5 nearest modern assemblages are indicated. The Pollen Assemblage Zone (PAZ) of each fossil assemblage and the number of analogs retained according to the type of reconstituted vegetation are shown. Also shown are the average geographical coordinates of the modern analogs, the percentage of the key taxon and the bioclimatic subdomain for reconstructed vegetation

Depth (cm)	Age (years AD)	Dissimilarity index					PAZ	Forest tundra	Boreal forest W.		Boreal forest E.		Mixed forest W.	Mixed forest E.	Approx. location of analogs by zone		Key taxon (%) Betula	Reconstructed vegetation
								Ab	PL/PM	PM/SBb	PM	PM/SBb	SBb/SBj	SBj	Lat. (°N)	Long (°W)		
		1	2	3	4	5		Ab1	Aa1a	Aa1b	Aa2b	Aa2c	Bc2	Bb1				
0.5	2014	0.34	0.34	0.35	0.37	0.37	IIIB							5	49.03 ± 4.31 Québec	78.00 ± 12.14	29.3	Maritime Provinces (Bb1) bioclimatic subdomain: balsam fir-yellow birch (SBj)
1.5	2008	0.33	0.36	0.37	0.38	0.39							2	3			26.7	
3.5	1994	0.31	0.33	0.33	0.34	0.38		2					2	1			28.1	
5.5	1981	0.29	0.33	0.35	0.36	0.37				1			2	2			20.2	
7.5	1968	0.35	0.41	0.42	0.44	0.44			1				2	3			20.1	
9.5	1955	0.31	0.36	0.40	0.40	0.40			3		1			1			18.3	
11.5	1936	0.43	0.45	0.56	0.58	0.59	IIIA				1			4			8.8	
13.5	1908	0.33	0.35	0.40	0.42	0.42					1			4			23.6	
15.5	1892	0.42	0.44	0.44	0.46	0.49		1						4			39.6	
17.5	1865	0.24	0.26	0.26	0.26	0.26			2			2		1			24.3	
19.5	1838	0.23	0.24	0.25	0.26	0.26						2		3			28.7	
21.5	1815	0.27	0.28	0.29	0.29	0.30						2		3			28.7	
23.5	1795	0.24	0.31	0.31	0.31	0.32	II					1		4	47.20 ± 1.81 Maine	68.95 ± 7.20	30.9	
25.5	1775	0.20	0.25	0.27	0.28	0.30				1			1	3			26.6	
27.5	1755	0.22	0.28	0.28	0.28	0.29			1	1		1	1	1			25.8	
29.5	1735	0.23	0.30	0.32	0.34	0.34							1	4			27.7	
31.5	1715	0.22	0.30	0.31	0.31	0.32							1	4			27.0	
33.5	1695	0.26	0.30	0.31	0.32	0.32			1				2	2			26.7	
35.5	1675	0.33	0.37	0.37	0.37	0.38			2			1		2			25.0	
37.5	1655	0.31	0.31	0.36	0.38	0.39						1		4			28.4	
39.5	1635	0.33	0.36	0.37	0.38	0.39			1					4			22.0	
41.5	1615	0.27	0.31	0.33	0.34	0.34							1	4			25.2	
43.5	1595	0.25	0.29	0.33	0.34	0.34							1	4			28.3	
45.5	1575	0.25	0.29	0.32	0.37	0.38							2	3			26.7	
47.5	1555	0.24	0.31	0.31	0.33	0.34				1			1	3			20.7	
49.5	1535	0.25	0.27	0.31	0.33	0.33							2	3			21.8	
51.5	1514	0.23	0.24	0.29	0.33	0.33							2	3			22.4	
53.5	1494	0.24	0.25	0.30	0.31	0.31								5			35.2	
55.5	1474	0.26	0.28	0.31	0.31	0.36							2	3			24.7	
57.5	1454	0.22	0.26	0.27	0.27	0.32							1	4			26.2	

Mean temperature of the warmest month of the year increased from ~ 18 to ~ 18.6 ° C. The reconstructed data show a covariation with the curve of instrumental data. A negative anomaly persists, but decreases towards the top from -0.8 to -0.4 °C. Mean precipitations in June-July-August decrease from ~ 290 to ~ 270 mm.

Mean temperature of the coldest month of the year increases slightly towards the top from - 12 to - 11 °C. The negative temperature anomaly is decreasing progressively towards the top from -1 to 0 °C. Mean precipitations for December-January-February increase from 250 to 290 mm. The total annual precipitations maintain a stable value of ~ 1 100 mm. This value differs from the increasing trend towards the top shown by the instrumental data profile, although this variation falls within the confidence interval. This range of reconstructed seasonal climatic conditions are characteristic of the mixed forest.

Pokemouche River

PAZ III is marked by the dominance of non-arboreal pollen (ranging between 60 and 90%). The dominant tree pollen are *Pinus* sp., *Picea* sp. and *Fagus* sp, which are characteristic of an open mixed forest (Figure 6). The closest modern analogs have dissimilarity index values ranging between 0.23 and 0.43. The modern analogs selected for this zone come from boreal forest, forest tundra and mainly mixed forest biomes (Table 2).

The reconstructed temperature fluctuations from Pokemouche core are similar to those of the historical values, although the deviation is larger than for Lake Inkerman. Within the Pokemouche core, the fluctuations and anomalies of the reconstructed parameters for PAZ III are higher with respect to PAZ II. Mean temperature of the warmest month of the year ranges between 13 and 17 °C. The negative temperature anomaly varies from -1 to -6 °C. Mean precipitations in June-July-August remain stable at ~ 280 mm. Mean temperature of the coldest month of the year ranges between -7 and - 21 °C. The temperature anomaly in winter ranges between 4 and -10 °C. Mean precipitations for December-January-February covary with the temperature and oscillates between 160 and 280 mm. The total annual precipitations range between 800 and 1 200 mm.

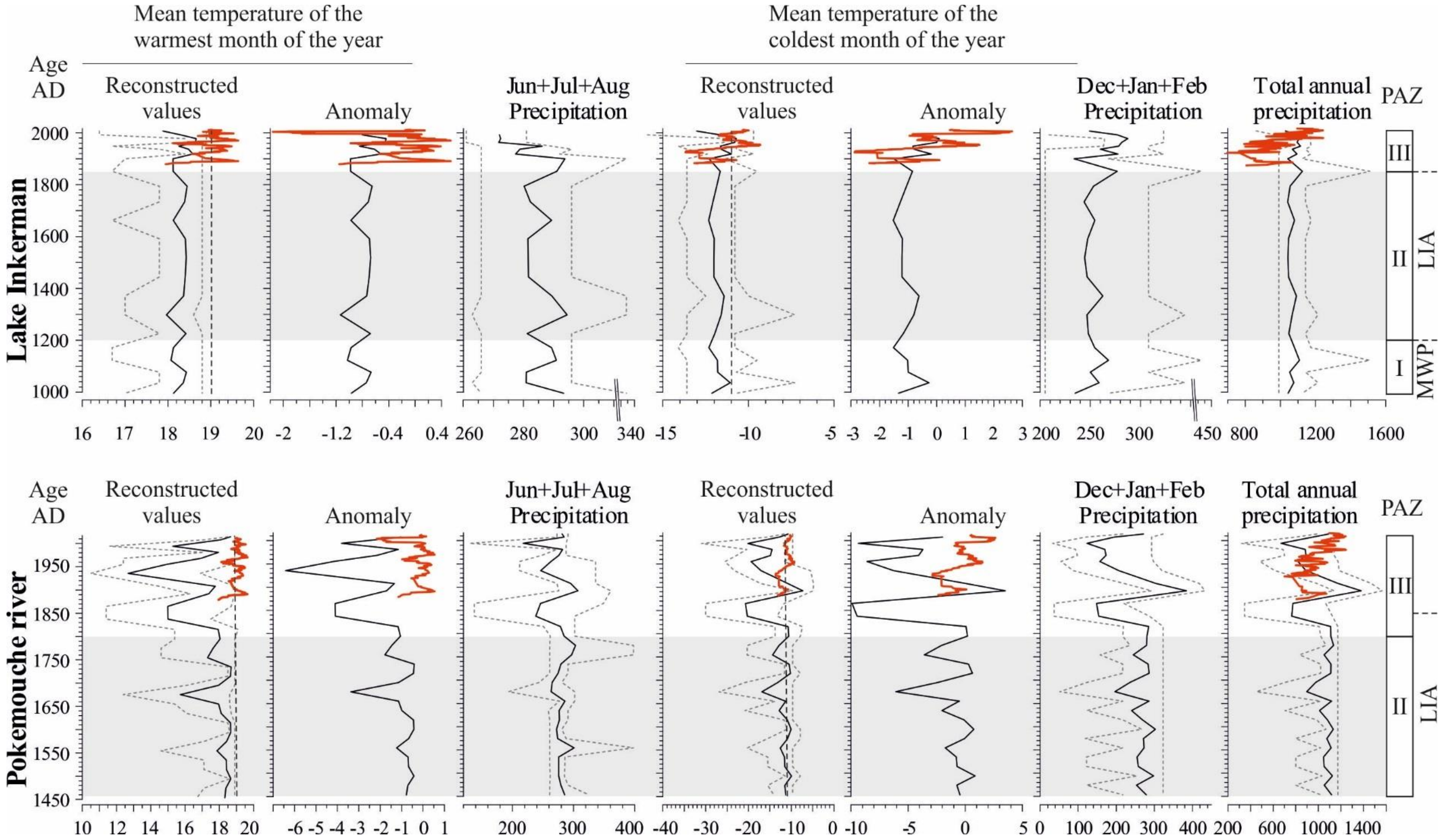


Figure 9. Paleoclimatic reconstructions using MAT from Lake Inkerman and Pokemouche River. The diagram shows the curve of reconstructed values of the best modern analogue (with the lowest Dissimilarity index): thick black line. The minimum and maximum values among the 5 nearest modern analogues retained: gray dashed line. The anomalies were calculated based on climate normals between 1981 and 2010. Modern values of reconstructed parameters: black dashed vertical line. Historical-instrumental data: red line

5. DISCUSSION

5.1. CLIMATE AND ANTHROPOGENIC FORCING IN PALYNOMORPH RECORDS

The Lake Inkerman core was collected downstream, near the mouth of the river, upstream from the Pokemouche Bay that connects the estuary with the waters of the Gulf of St. Lawrence. In this core, the fossil pollen assemblages are composed of species characteristic of the mixed temperate forest, dominated by pine and spruce pollen accompanied by hemlock pollen and hardwood species, such as birch and beech in minor proportions. Pollen from riparian and wetland species, such as shrub birch and alder, represent local vegetation in the vicinity of the river and the estuary, surrounded by an open forest. Whitmore et al. (2005) indicate that the actual climatic conditions of sites in southeastern Quebec belonging to the temperate mixed forest are characterized by a mean temperature of 18.1 °C in July, -15.2 °C in January and an average annual precipitations around 996 mm. Prentice et al. (1992) indicated that a January temperature above -15 ° C is generally required for a mixed forest.

In this core, PAZ I (from AD 1000 to 1200) is marked by a low influx of both terrestrial (Figure 5) and marine (Figure 8) palynomorph potentially associated with reduced freshwater runoff. Spores influxes remain very low, which suggests reduced or limited precipitations, due to the affinity of ferns and clubmousses with humid environments (Benca, 2014; Mehltreter et al., 2010). Low *Pediastrum* sp. and *Halodinium* spp. influxes into the lake support this interpretation of reduced freshwater input. This period may therefore be characterized by limited nutrient inputs from freshwater runoff. This could explain the sustained low dinocysts influxes. A relative decrease in OM content (shown by % C_{org} and LOI_{550}) suggests a general decrease of the productivity. The low foraminifer lining influx confirms a regime of low benthic productivity. The systematic reduction of indicators of benthic and planktonic productivity strengthens the hypothesis of the imposition of nutrient limitation as a result of reduced precipitations. In this PAZ I, pollen assemblages show stable and very low pollen influxes with respect to the overlying PAZ II. Here the pollen of *Picea* sp. has a persistent tendency to decline, probably in response to the deterioration of climatic conditions for its development.

According to our chronological framework from Lake Inkerman, PAZ I corresponds approximately with the late MWP (Lamb, 1965). The reconstructed mean temperature of the warmest month of the year is ~18 °C, the mean temperature of the coldest month of the year is about -12 °C and the average annual precipitations around 1100 mm. The conditions (absolute values) necessary for the development of vegetation represented by PAZ I (mixed temperate forest) are in accord with the temperature and precipitation values yielded by the reconstructions. However, the corresponding anomalies (approximately -1 °C) differ from those expected for the MWP. The expected anomalies for MWP in neighboring lands are about 0.5 °C below present values, while in Greenland they are 2 to 4 °C above modern values (Lamb, 1965).While climate reconstructions of PAZ I suggest a cold period, the decrease of *Picea* suggests a warming trend (Richard et Grondin,2009). Hence, this period (PAZ I) is more probably a late phase of the transition towards colder climatic conditions.

In PAZ II, both ferns and mosses influxes increased and might be associated with moist and cold summers. According to Barber (1981) and Lavoie et al. (1995), an increase in precipitation associated with low temperature promote the formation of peat. The climatic conditions indicated above could favor the development of the peat bogs that surround the Lake Inkerman and which are abundant on the east coast of the Acadian peninsula. A sharp increase of *Halodinium* sp. and *Pediastrum* sp. influxes during this time interval also suggest that the area was subject to intense freshwater inputs, hence higher precipitations.

The paleoclimatic reconstructions for PAZ II show the establishment of climatic conditions dominated by colder and wetter summers with colder and drier winters in the period between ~AD 1200 and 1850 in Lake Inkerman. This period corresponds to the LIA, when relatively colder conditions were established in the world and earlier (~AD 1200) in the North Atlantic region (Grove, 2001). The PAZ II in Lake Inkerman covers this time interval and is defined by the drastic increase of both terrestrial and marine palynomorph influxes.

Higher precipitation enhances chemical weathering thus increasing the influx of major ions and nutrients to the lake. This could explain the succession of dinocyst during the LIA, from phototrophic species between AD 1200 and 1500 to heterotrophic species between

AD 1500 and 1850, under conditions of increased precipitation and nutrient inputs (Figure 8). Between AD 1200 and 1500 organisms with high rate of absorption (e.g diatoms) will outcompete phototropic dinoflagellate species at a time when nutrient availability is low. As nutrient availability increases due to precipitations and weathering (AD 1400-1500), phototrophic dinoflagellate productivity is favored. Between AD 1500 and 1850, the increase of heterotrophic dinoflagellates could be a consequence of them grazing on the phytoplankton in the water column. Diatoms are probably the more significant prey of heterotrophic dinoflagellates (Sherr and Sherr, 2007). In such a scenario the dinoflagellates would thrive. Are part of this succession, from earliest to latest: *O. centrocarpum*, cyst of *P. dalei*, *Echinidinium* spp. and *Brigantedinium* spp. (Figure 8). There is a simultaneous increase in the foraminifer lining influx during LIA (Figure 8), dinocyst influx and the freshwater input. These parallel trends between foraminifers and dinocysts often reflect a between the benthic and planktic productivities in relatively shallow waters (Ellegaard et al., 2017).

Nevertheless, the taxa that constitute this succession appear to tolerate a wide range of environmental conditions. *Operculodinium centrocarpum* is ubiquitous, although morphological variations in Arctic environments might be associated with phenotypes adapted to low salinity and cold environments (Zonneveld et al., 2013). The cyst of *P. dalei* is another ubiquitous taxa but is more specific of sub-Arctic environments (de Vernal et al., 2001). *Echinidinium* spp. has a cosmopolitan distribution with its highest relative abundances at sites with conditions of high productivity. *Brigantedinium* spp. is cosmopolitan. Its distribution does not show any preference of temperature, salinity, nutrient availability or productivity (Devillers and de Vernal, 2000).

An interesting feature in the Lake Inkerman paleoclimatic reconstructions is the relative decrease in summer precipitations between AD 1350 and 1500. This change is reflected in the palynological record and is correlated with the transition between PAZ IIA and IIB. This corresponds to synchronized minimums of pollen, spores, *Halodinium* sp. and *Pediastrum* sp. influxes, with a peak in the percentage of cyst of *P. dalei*. A period of relatively dry conditions into the LIA (AD 1350-1500) decreases the inputs of freshwater and could leave a more pronounced “marine imprint" during periods with reduced precipitations.

These conditions (dry climate, low precipitations, marine influence) lead to the increase of some autotrophic species that occur commonly in marine environments (e.g., cyst of *P. dalei*), while pollen and freshwater algae production and transport are reduced. In general, synchronized fluctuations of both terrestrial and marine palynomorphs (planktonic and benthic) in PAZ II, illustrate the contemporaneous variations within and around the estuary.

PAZ III (from AD 1850 to present) is characterized by a sharp decline in the pollen influx and the increase in the percentage of arboreal pollen (AP %). In general, this last trend is generated by the increase of *Picea* sp., *Pinus* sp. and *Abies* sp. upcore. The simultaneous increase in AP % and the decline in the pollen influx could be interpreted as a decrease on the density of the forest cover presumably by prolonged human disturbance through logging. Herbs, especially Poaceae, are well represented in this unit which indicates an opening of the forest, pointing out the agricultural production.

In the presence of a more open forest cover, contributions of airborne bisaccate pollen (the most common pollen morphology among extant conifers having two sacci or “sacs”) with more distant sources are better represented in terms of percentage in a pollen assemblage. It is quite possible that the increase of *Picea* sp., *Pinu*s sp. and *Abies* sp are the result of long-distance transport. White pine is generally overrepresented in pollen assemblages and is an important pollen producer. This thermophilic species is very abundant in Maine and the region of New England in general. The preferential direction of the winds during the summer (from southwest) would be responsible for the extralocal pollen contributions. Before AD 1850, birches dominated forests and they are great producers of pollen. The logging of birch could explain the decrease of the pollen influx and the better representation (in percentages) of pollen contributions of more distant regions and of more thermophilic trees (e.g., *Quercus* sp. and *Acer* sp.).

A shift in the trend of reconstructed paleoclimatic parameters during the last 160 years defines a change of climatic conditions in PAZ III. The climatic reconstructions from Lake Inkerman core show the development of seasonal conditions dominated by warmer and drier summers with warmer winters in the period from ~ AD 1850 to present. These climatic conditions are consistent with those reported by historical instrumental data (Environnement et Changement climatique Canada, 2011).

The bulk C/N (Figure 4b) and C/N vs. $\delta^{13}C$ diagram (Figure 4i) indicate that the main source of OM in the sediments came from marine algae in the whole sediment sequence. Between AD 1000 and 1950 the C_{org} and LOI_{550} curve is relatively stable. A maximum of OM (C_{org} and LOI_{550}) suggests a discrete increase in primary productivity between AD 1900 and 1950. This increase is concomitant with the peak of pigments reported by Ady and Patoine (2016) in the sediments of Lake Inkerman during the same period. This study concluded that there is a positive correlation between the period of expansion of non-industrial agriculture and the increase in the abundance of photoautotrophic algae (especially measured in 1920 associated to soil nutrient runoff to the lake). Our palynological record shows no evidence of a dinoflagellate increase during this period linked with the C_{org} and LOI_{550} peaks, which would be associated with algal growth stimulated by an increased nutrient supply. However, the Poaceae and *Ambrosia* sp. pollen increase during the twentieth century can be interpreted as indicators of human deforestation and/or agriculture activities.

The Pokemouche River core was sampled upstream, far from the marine and tidal influence of the estuary. PAZ II (between AD 1450 and 1800) defined at the base of this core is correlated roughly with the PAZ IIB from Lake Inkerman. The most notable difference between the two pollen sequences during the LIA (PAZ II) is the magnitude of the pollen influxes, which are lower in the Pokemouche River core. According to Davis and Brubaker (1973), the pollen influxes of two nearby locations surrounded by the same type of vegetation may vary due to differences in taphonomic processes specifically linked to lake morphology and morphometry. Consequently, morphological differences (width, shape and perimeter) between Lake Inkerman and the main tributaries of the Pokemouche River could induce the differences in the pollen influxes. The preservation of pollen, spores and dinoflagellate cyst specimens is excellent in all samples, which suggests that there was little to no effect of taphonomic processes.

The % C_{org}, LOI_{550} and $\delta^{13}C$ values illustrate the differences in the type and accumulation processes of OM into the core, between AD 1450 and 1750. The diagram C/N vs. $\delta^{13}C$ (Figure 4i) shows that the elemental and isotopic ratios of sedimentary OM from Pokemouche River is an indistinguishable mixture of OM from terrestrial vascular plants and lacustrine algae in the whole sequence. A progressive increase of % C_{org} and LOI_{550} between AD 1450 and 1750 suggests an increase in primary productivity.

The paleoclimatic reconstruction shows the establishment of climatic conditions dominated by colder and wetter summers and colder and drier winters with respect to the climate normal values (1981-2010). In this core (Pokemouche), the negative temperature anomaly characteristic of the end of the LIA climatic conditions (1°C) at the top of PAZ II is recorded 50 years earlier (around AD 1800) than in Lake Inkerman. This discrepancy between both cores is probably associated with the uncertainty of the age model.

PAZ III from Pokemouche River covers from AD 1800 to present. Sub-zone IIIA, defined between AD 1800 and 1950, is characterized by the progressive decrease of arboreal pollen percentage in favor of the shrub and herb pollen towards the top of the zone. This is considered as the first sign of deforestation process documented in recent archives at the beginning of the 19th century.

The pollen influx is low with a slight decreasing trend through the 19th century. After AD 1900, the pollen influx increases by a factor of 3 around 1950. This trend matches with the peak of *A. crispa* and the increase of *A. rugosa* (from 1 to 10%) which, according to Mallik et al. (1997), are the most effective and competitive shrubs for forest reoccupation after clear cutting. This peak between AD 1900 and 1950 matches well with the expansion period of agricultural exploitation (Ady and Patoine, 2016), suggesting an increase of *Alnus* pollen resulting from the decrease of arboreal taxa. Progressive decrease of pollen percentage of spruce, birch, beech, pine and hemlock could be associated with forest harvesting process which started in 1800, considering that they are species of commercial interest.

Also, in sub-zone PAZ IIIA, herbs pollen becomes more abundant, another evidence of the impact of anthropogenic activities. The increase in Poaceae, Cyperaceae and *Ambrosia* sp. pollen and abrupt increase of *Alnus* sp. post AD 1850 documented in lake sediments has also been reported in studies of other regions as an indicator of agricultural activities (Colpron-Tremblay and Lavoie, 2010; Neil et al., 2014; Pérez-Obiol et al., 2012).

Particularly, the Poaceae pollen increased since AD 1730, which indicates agricultural activities and could be associated with the disturbance of the vegetation by French and British settlers that arrived in the Acadian Peninsula around ~ 1725 AD.

The colonization period coincides with a decrease in OM content recorded in the C_{org} and LOI_{550} profiles (between AD 1720 and 1950). The stability of the Mn/Ti ratio suggests that this drop in OM is not associated with post-depositional changes of redox conditions (Figure 2). This change is more likely associated with an anthropogenic impact. When soil plowing or agricultural activities lead to soil organic content depletion (Campy and Macaire, 2003; Douglas, 1967), the sediments became increasingly inorganic and were mainly composed of clays, siliceous silts and carbonates (Figure 2). Higher silt load in the water column could have decreased primary production because of increased turbidity and concomitant decreased light penetration. On the other hand, there is a shift of $\delta^{13}C$ from ~ -25 to ~ -28‰ between AD 1720 and 1950. This decline in the isotopic signal could be explained by a relative increased contribution of woody land plants relative to C4 plants to the bulk sedimentary OM. Such contribution might be associated with the log rafting that was the main transportation method of the early logging industry, which expanded rapidly from AD 1800 in New Brunswick (Lamb, 1965).

From AD 1950 to present in subzone PAZ IIIB, pollen influx decreases relative to PAZ IIIA. The arboreal pollen percentage increases from 10 to 40 % and remains stable for the remainder of the time period covered by our record (~60 years). This trend is similar to the relative abundances of pine and spruce pollen. Despite increase of pollen percentages of these conifers, shrub and herbs pollen are more abundant (60%). The herb pollen, particularly the Poacea, *Ambrosia* and Cyperaceae are well represented here, attesting to an open forest cover, probably as a result of logging and agricultural harvesting. It is likely that *Picea* sp., *Pinus* sp. and *Acer* sp. pollen increases recorded from AD 1950 to present represent extra-local vegetation origin, which may be a consequence of logging of species that are abundant pollen producers, such as birch, or the decline of the number of farms and of surface areas devoted to agriculture, leading to a local reforestation of the catchment area (cf. Ady and Patoine, 2016).

The climatic parameters derived from the Pokemouche River reconstructions point to the establishment of summers and winters between AD 1800 to present cooler than those recorded during the LIA, conversely to the reconstructions from Lake Inkerman during the same period. Given the proximity between both study sites (~12 km), it is unlikely they experienced different climatic conditions. The important deviations between historical-instrument values of temperature and the reconstructed anomalies for Pokemouche (Figure 9) lead us to interpret the latter with caution. The strong negative anomalies with respect to the climate normals, which vary between 4 and 3.5 °C in summer and reach values of up to 6 °C during the winter, are confirmed by the important deviation between the reconstructed values and the historical-instrumental values compiled (Figure 9).

Furthermore, some of the selected Pokemouche analogs belong to the forest tundra biome, clearly a result incompatible with what is known from the environment of New Brunswick (Godin and Roberts, 1994). Therefore, we suggest that some pollen assemblages from PAZ III could be "disturbed", most likely by anthropogenic activities. Fréchette et al. (2018), point out that it is possible to have modern pollen assemblages of low quality that establish links with the wrong biomes. This occurs particularly in mixed forest sites where the anthropic imprint, rich in herbaceous and shrubs taxa, does not allow a correct bioclimatic reconstruction. Lake Inkerman has a greater capacity to record regional changes, and thus better reflects large-scale climatic variability, probably as a result of a better exposure for the reception of airborne pollen associated to its geographical position. Upstream in the Pokemouche River, the record of local changes is more favored.

5.2. DINOCYSTS AND BRACKISH ENVIRONMENTS

Low dinocyst diversity and concentrations measured in the Lake Inkerman core are characteristic of low salinity environments (Pospelova et al., 2004). In Pokemouche River the dinocysts are absent. Another singularity found among species is the presence of atypical morphology (Figure 7) of *Spiniferites* cf. *mirabilis*, the most abundant taxa. This phenomenon has been reported both in laboratory cultures (Rochon et al., 2009) and studies of spatial distribution of dinocysts in environments of known salinity gradients (Ellegaard et al., 2017). Experiments by Ellegaard et al. (2017) and Rochon et al. (2009) have shown morphological changes in cysts of *Spiniferites* cf. *mirabilis* in response to lowered salinity. In addition, Limoges et al. (2013) documented the presence of atypical *S. mirabilis* in surface sediments from the Gulf of Mexico potentially conditioned by the salinity gradient.

6. CONCLUSIONS

The quantitative and qualitative palynological approach used to study sediments of the Pokemouche River and Estuary allowed us to interpret and reconstruct the paleoclimatic context of the northeast coast of New Brunswick over the last 1000 years. The study of pollen assemblages upstream and pollen and marine palynomorphs downstream in the estuary provides a perspective on the impact of natural environmental changes and anthropogenic activities on the recent history on this transitional ecosystem.

During de MWP, the low pollen, spores and *Pediastrum* sp. influxes in the Lake Inkerman core indicate the installation of warmer and dryer conditions in the Pokemouche Estuary.

Both cores show that, during LIA (~AD 1200–1850):

- Increase in spores, *Pediastrum* sp. and pollen fluxes, as well as pine and birch pollen percentages, indicate the establishment of cool and humid conditions;
- Climatic reconstructions based on pollen assemblages indicate colder and moist summers, combined with winters colder than the normal climate (-1°C), coinciding with an increase of terrestrial, marine and freshwater tracers influxes, which remained high throughout this period;
- The fact that a continuous increase in summer freshwater input began with the onset of the LIA is consistent with a natural increase of the influx of all palynomorphs. The synchronized increase in freshwater tracer influxes (*Pediastrum* sp. and *Halodinium* sp.) and foraminifers, dinocysts and pollen influxes indicate that seasonal precipitations seemed to sustain the planktonic, benthic and terrestrial productivities within the basin.

The paleoclimatic reconstructions of Lake Inkerman show a slight warming and a decrease in summer precipitation after AD 1850, which could explain the synchronized decrease of benthic and planktonic palynomorphs associated with a decrease in freshwater runoff and subsequent transport of nutrients to the lake. However, the decline in pollen and spores influxes in this core could be the result of human activities rather than climate changes.

In Pokemouche River, the impacts of anthropogenic activities were recorded early around AD 1720. A progressive decrease in the organic matter content and the synchronized decrease of arboreal pollen reflect changes in the vegetation cover of the basin. This could be associated with the intensification of non-industrialized wood exploitation by the first settlers. The pollen assemblages also document the growth of agricultural activities since AD 1850, with the increase of herb pollen (Poaceae). The period between AD 1925 and 1950 highlights a reforestation phase marked by the increase of *A. crispa* and *A. rugosa.*

The comparison of the reconstructions from both cores with the historical-instrumental data suggest that pollen assemblages recorded in Lake Inkerman yield more coherent results of the recent climatic history of the Acadian Peninsula , most likely associated with better exposure to the influence of riverine, terrestrial and marine environments. In contrast, upstream in Pokemouche River, the palynostratigraphic record and paleoclimatic reconstructions reflect more clearly the impacts of changes in land use (agriculture, peat exploitation) post AD 1800.

CONCLUSIONS GÉNÉRALES

L’étude palynologique des séquences sédimentaires prélevées de l’estuaire et la rivière Pokemouche nous a permis de retracer l’évolution des conditions environnementales des derniers 1000 ans et d’estimer l’influence des facteurs climatiques et celle liée à des activités anthropiques en utilisant une approche multi-traceurs.

Bien que des études paléoclimatiques précédentes portant sur la distribution des assemblages polliniques dans la région du Nouveau-Brunswick aient été réalisées auparavant, la plus-value de nos travaux est déterminée par la combinaison de palynomorphes terrestres et marins qui nous donne une vision globale de l’évolution des conditions environnementales dans la rivière, l’estuaire et son bassin versant.

Nos résultats suggèrent que dans le lac Inkerman les faibles influx polliniques et de *Pediastrum* sp. sont associés à l'installation de conditions chaudes et sèches pendant l’optimum climatique médiéval entre AD 1000 et 1200 (PAZ I). Cette tendance peut être liée à un faible apport d’eau douce signalé par le déclin de l’abondance de traceurs d’eau douce, conséquence de l’installation d’un régime de pluviosité plus faible, ainsi que par les apports réduits des spores de mousses et de fougères qui sont plus performants en conditions froides et humides.

Cette période est suivie par l’augmentation drastique des influx polliniques, de *Pediastrum* sp., et par l'augmentation de l’abondance du pollen de bouleau entre AD 1200 et 1850 (PAZ II), suggérant une augmentation de la productivité terrestre et pélagique et indiquant l’installation de conditions plus froides et humides. Cette variation est attribuable à une augmentation des précipitations et des apports de nutriments dans le milieu estuarien.

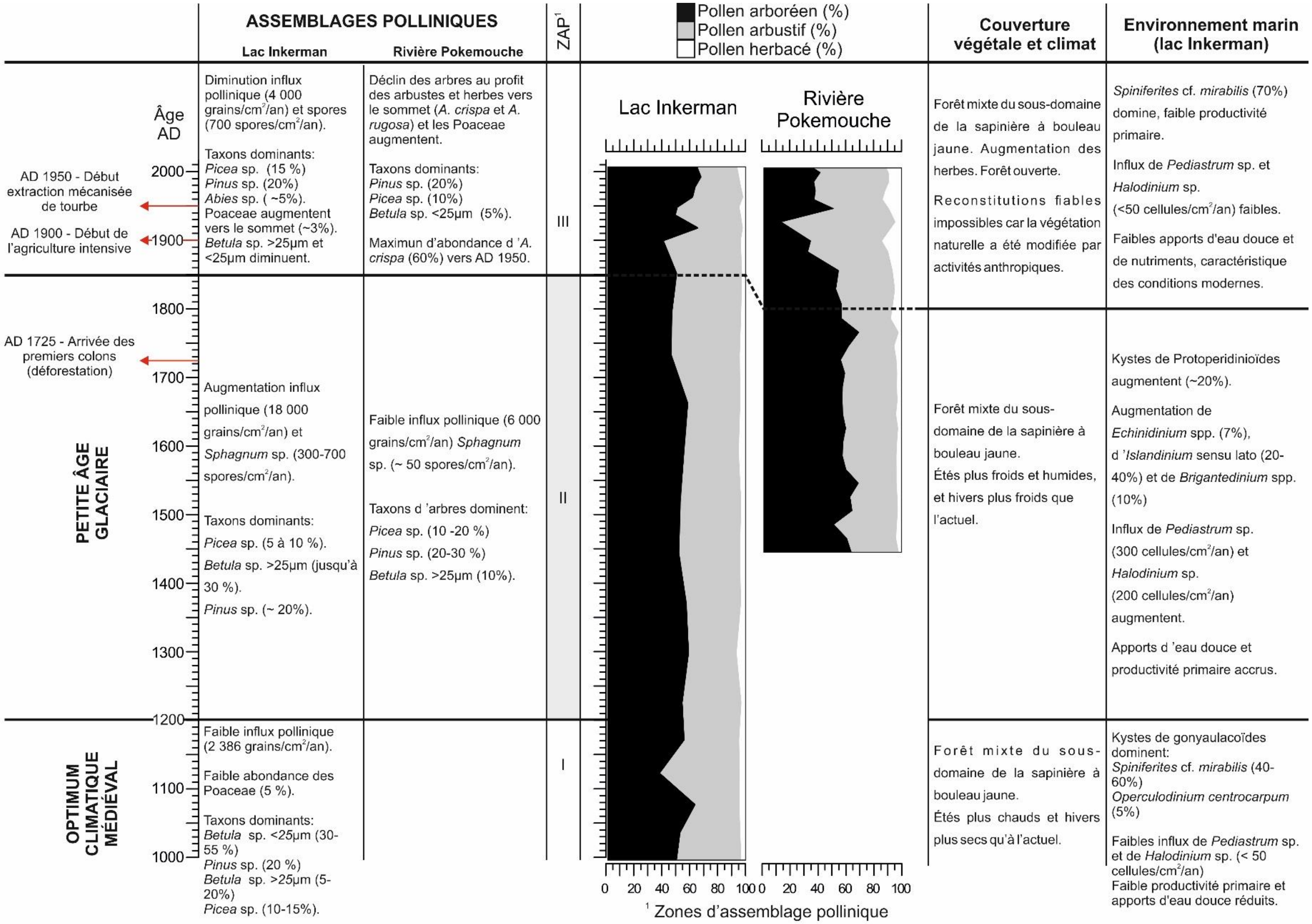
La reconstitution des paramètres climatiques saisonniers met en évidence l’établissement d’étés plus froids et humides et des hivers plus froids durant cette période qui coïncide avec la Petite Âge Glaciaire. Il semble donc que l’augmentation des l’influx de palynomorphes terrestres et marins entre AD 1000 et 1850 réponde à une variabilité climatique naturelle.

L’augmentation de l’abondance des Poaceae entre AD 1700 et 1730 dans les deux séquences (lac Inkerman et rivière Pokemouche) signale l’activité anthropique associée à l’arrivée des colons dans la Péninsule acadienne. Les Poaceae constituent la famille de plantes la plus importante du point de vue économique, fournissant des aliments de base issus de cultures céréalières telles que le maïs, le blé et l’orge qui représentent le groupe de plantes cultivées par les nouveaux colons arrivants en Acadie.

En combinant l'analyse des assemblages polliniques, avec le pourcentage de carbone organique et le signal isotopique de la matière organique dans la séquence sédimentaire de la rivière Pokemouche, il est possible de mettre en évidence le processus de déforestation documenté historiquement à partir de AD 1800. Le déclin des influx polliniques entre AD 1800 et 1950 dans les sédiments de la rivière Pokemouche reflète les perturbations anthropiques sur la végétation. Le degré de déforestation est associé aux activités agricoles dérivées de l’installation de colons combinée à l’essor de l’exploitation commerciale de bois dans la région. Ces activités contribuent à l’érosion des terres. Quand les sols organiques de surface ont été épuisés, les sédiments sont devenus de plus en plus inorganiques et étaient constitués principalement de silt, d’argile siliceuse, ainsi que de carbonates. L’apport de silt dans la colonne d’eau aurait pu augmenter la turbidité et diminuer la production primaire, et donner lieu à l’appauvrissement en carbone organique. La diminution du signal isotopique de carbone organique pourrait avoir été causée par une augmentation des apports terrestres de plantes C3 (dont le fractionnement est plus intense que celui des plantes C4), notamment par la drave d’essences commerciales. Le pollen de Cyperaceae et d’Asteraceae (*Ambrosia* sp.) et l’augmentation abrupte d’*Alnus* sp., arbuste pionnier de la reforestation, témoignent de l’impact des activités agricoles intensives entre AD 1900 et 1950.

Les sédiments du bassin versant Pokemouche ont un important potentiel pour les études paléo-environnementales. Des études complémentaires des sédiments provenant de la portion marine du bassin versant, tels que la baie Pokemouche en aval du lac Inkerman, pourraient contribuer à documenter le rôle de l’activité anthropique et la tendance climatique régional du passé sur l’enregistrement des assemblages de kystes de dinoflagellés. La salinité plus élevée dans cette zone pourrait permettre l’utilisation de fonctions de transfert sur les assemblages de kystes de dinoflagellés afin de reconstituer quantitativement l’évolution climatique de ce milieu.

La figure 10 est la synthèse de ce chapitre que contextualise l’évolution du couvert végétal et les paramètres climatiques reconstitués dans le temps.



	ASSEMBLAGES POLLINIQUES				
	Lac Inkerman	**Rivière Pokemouche**	ZAP[1]	**Couverture végétale et climat**	**Environnement marin (lac Inkerman)**
	Diminution influx pollinique (4 000 grains/cm^2/an) et spores (700 spores/cm^2/an). Taxons dominants: *Picea* sp. (15 %) *Pinus* sp. (20%) *Abies* sp. (~5%). Poaceae augmentent vers le sommet (~3%). *Betula* sp. >25µm et <25µm diminuent.	Déclin des arbres au profit des arbustes et herbes vers le sommet (*A. crispa* et *A. rugosa*) et les Poaceae augmentent. Taxons dominants: *Pinus* sp. (20%) *Picea* sp. (10%) *Betula* sp. <25µm (5%). Maximun d'abondance d '*A. crispa* (60%) vers AD 1950.	III	Forêt mixte du sous-domaine de la sapinière à bouleau jaune. Augmentation des herbes. Forêt ouverte. Reconstitutions fiables impossibles car la végétation naturelle a été modifiée par activités anthropiques.	*Spiniferites* cf. *mirabilis* (70%) domine, faible productivité primaire. Influx de *Pediastrum* sp. et *Halodinium* sp. (<50 cellules/cm^2/an) faibles. Faibles apports d'eau douce et de nutriments, caractéristique des conditions modernes.
PETITE ÂGE GLACIAIRE	Augmentation influx pollinique (18 000 grains/cm^2/an) et *Sphagnum* sp. (300-700 spores/cm^2/an). Taxons dominants: *Picea* sp. (5 à 10 %). *Betula* sp. >25µm (jusqu'à 30 %). *Pinus* sp. (~ 20%).	Faible influx pollinique (6 000 grains/cm^2/an) *Sphagnum* sp. (~ 50 spores/cm^2/an). Taxons d 'arbres dominent: *Picea* sp. (10 -20 %) *Pinus* sp. (20-30 %) *Betula* sp. >25µm (10%).	II	Forêt mixte du sous-domaine de la sapinière à bouleau jaune. Étés plus froids et humides, et hivers plus froids que l'actuel.	Kystes de Protoperidinioïdes augmentent (~20%). Augmentation de *Echinidinium* spp. (7%), d '*Islandinium* sensu lato (20-40%) et de *Brigantedinium* spp. (10%) Influx de *Pediastrum* sp. (300 cellules/cm^2/an) et *Halodinium* sp. (200 cellules/cm^2/an) augmentent. Apports d 'eau douce et productivité primaire accrus.
OPTIMUM CLIMATIQUE MÉDIÉVAL	Faible influx pollinique (2 386 grains/cm^2/an). Faible abondance des Poaceae (5 %). Taxons dominants: *Betula* sp. <25µm (30-55 %) *Pinus* sp. (20 %) *Betula* sp. >25µm (5-20%) *Picea* sp. (10-15%).		I	Forêt mixte du sous-domaine de la sapinière à bouleau jaune. Étés plus chauds et hivers plus secs qu'à l'actuel.	Kystes de gonyaulacoïdes dominent: *Spiniferites* cf. *mirabilis* (40-60%) *Operculodinium centrocarpum* (5%) Faibles influx de *Pediastrum* sp. et de *Halodinium* sp. (< 50 cellules/cm^2/an) Faible productivité primaire et apports d'eau douce réduits.

[1] Zones d'assemblage pollinique

Figure 10. Synthèse de l'évolution du couvert végétal et les paramètres climatiques reconstitués dans le temps

ANNEXE I

Table 4. Calculation of sedimentation rates from ^{210}Pb activity (^{210}Pb experimental ± uncertainty) of Lake Inkerman using CRS model (Sanchez-Cabeza and Ruiz-Fernández, 2012)

Code ID	**Depth mid point (cm)**	**Density (g/cm^3)**	**^{210}Pb (dpm/g)**	**±**	**^{210}Pb (Bq/kg)**	**±**	**^{210}Pb (Bq/Kg) excess**	**Ln (^{210}Pb Bq/Kg) excess**	**^{210}Pb (Bq/m^2) excess by section**	**^{210}Pb accumulated (Bq/m^2)**	**t (yr)**	**Year (AD)**	**Sedimentation rate (mm/yr)**
	0									605.47	0.0	2017	
Lake Inkerman 0-1		0.54	2.98	0.13	49.69	2.16	36.54		196.85				
	0.5							3.60		408.62	12.6	2005	0.8
Lake Inkerman 1-2		0.68	2.09	0.10	34.78	1.65	21.63		146.33				
	1.5							3.07		262.29	26.8	1991	0.7
Lake Inkerman 2-3		0.49	1.76	0.09	29.38	1.45	16.23		79.57				
	2.5							2.79		182.72	38.4	1979	0.9
Lake Inkerman 3-4		0.49	1.61	0.08	26.91	1.31	13.76		67.82				
	3.5							2.62		114.89	53.3	1964	0.7
Lake Inkerman 4-5		0.43	1.29	0.07	21.56	1.10	8.40		35.88				
	4.5							2.13		79.01	65.3	1952	0.8
Lake Inkerman 5-6		0.38	1.28	0.07	21.35	1.13	8.19		30.76				
	5.5							2.10		48.25	81.1	1936	0.6
Lake Inkerman 6-7		0.41	0.87	0.05	14.58	0.84	1.42		5.78				
	6.5							0.35		42.48	85.2	1932	0.8
Lake Inkerman 7-8		0.42	0.85	0.05	14.08	0.81	0.93		3.90				
	7.5							-0.07		38.57	88.3	1929	0.7
Lake Inkerman 8-9		0.46	1.18	0.06	19.62	0.92	6.47		29.97				
	8.5							1.87		8.61	136.4	1881	0.2
Lake Inkerman 9-10		0.47	0.90	0.05	14.99	0.77	1.84		8.61				

Table 5. Calculation of sedimentation rates from ^{210}Pb activity (^{210}Pb experimental ± uncertainty) of Pokemouche River using CRS model (Sanchez-Cabeza and Ruiz-Fernández, 2012)

Code ID	**Depth mid point (cm)**	**Density (g/cm^3)**	**^{210}Pb (dpm/g)**	**±**	**^{210}Pb (Bq/kg)**	**±**	**^{210}Pb (Bq/Kg) excess**	**Ln (^{210}Pb Bq/Kg) excess**	**^{210}Pb (Bq/m^2) excess by seccion**	**^{210}Pb accumulated (Bq/m^2)**	**t(yr)**	**Year (AD)**	**Sedimentation rate (mm/yr)**
	0									1164.64		2017	
Pokemouche River 0-1		0.24	4.11	0.16	68.43	2.7	49.88		117.39				
	0.5							3.91		1047.25			
Pokemouche River 1-2		0.21	5.63	0.21	93.80	3.6	75.25		161.31				
	1.5							4.32		885.95			
Pokemouche River 2-3		0.22	5.98	0.22	99.61	3.7	81.06		180.18				
	2.5							4.40		705.77	16.1	2001	1.4
Pokemouche River 3-4		0.24	4.72	0.18	78.66	3.1	60.11		142.23				
	3.5							4.10		563.54	23.3	1994	1.5
Pokemouche River 4-5		0.24	3.81	0.15	63.43	2.5	44.88		106.40				
	4.5							3.80		457.14	30.0	1987	1.6
Pokemouche River 5-6		0.28	2.87	0.12	47.83	2.0	29.29		81.52				
	5.5							3.38		375.62	36.3	1981	1.6
Pokemouche River 6-7		0.25	2.71	0.11	45.20	1.8	26.65		66.10				
	6.5							3.28		309.52	42.5	1975	1.5
Pokemouche River 7-8		0.27	2.40	0.10	39.95	1.7	21.40		58.33				
	7.5							3.06		251.19	49.2	1968	1.7
Pokemouche River 8-9		0.26	2.07	0.08	34.56	1.4	16.01		41.95				
	8.5							2.77		209.24	55.1	1962	1.4
Pokemouche River 9-10		0.31	1.93	0.08	32.18	1.3	13.63		41.89				
	9.5							2.61		167.35	62.2	1955	1.2
Pokemouche River 10-11		0.28	1.93	0.10	32.11	1.6	13.56		38.23				
	10.5							2.61		129.12	70.5	1947	0.9
Pokemouche River 11-12		0.32	1.83	0.09	30.42	1.6	11.87		38.12				
	11.5							2.47		91.00	81.8	1936	1.3
Pokemouche River 12-13		0.32	1.66	0.09	27.66	1.4	9.11		29.01				
	12.5							2.21		61.99	94.1	1923	0.9
Pokemouche River 13-14		0.32	1.56	0.08	25.92	1.4	7.38		23.61				
	13.5							2.00		38.38	109.4	1908	0.9
Pokemouche River 14-15		0.34	1.59	0.09	26.46	1.4	7.91		26.52				
	14.5							2.07		11.86	147.1	1870	
Pokemouche River 15-16		0.32	1.34	0.07	22.25	1.2	3.70		11.86				

ANNEXE II

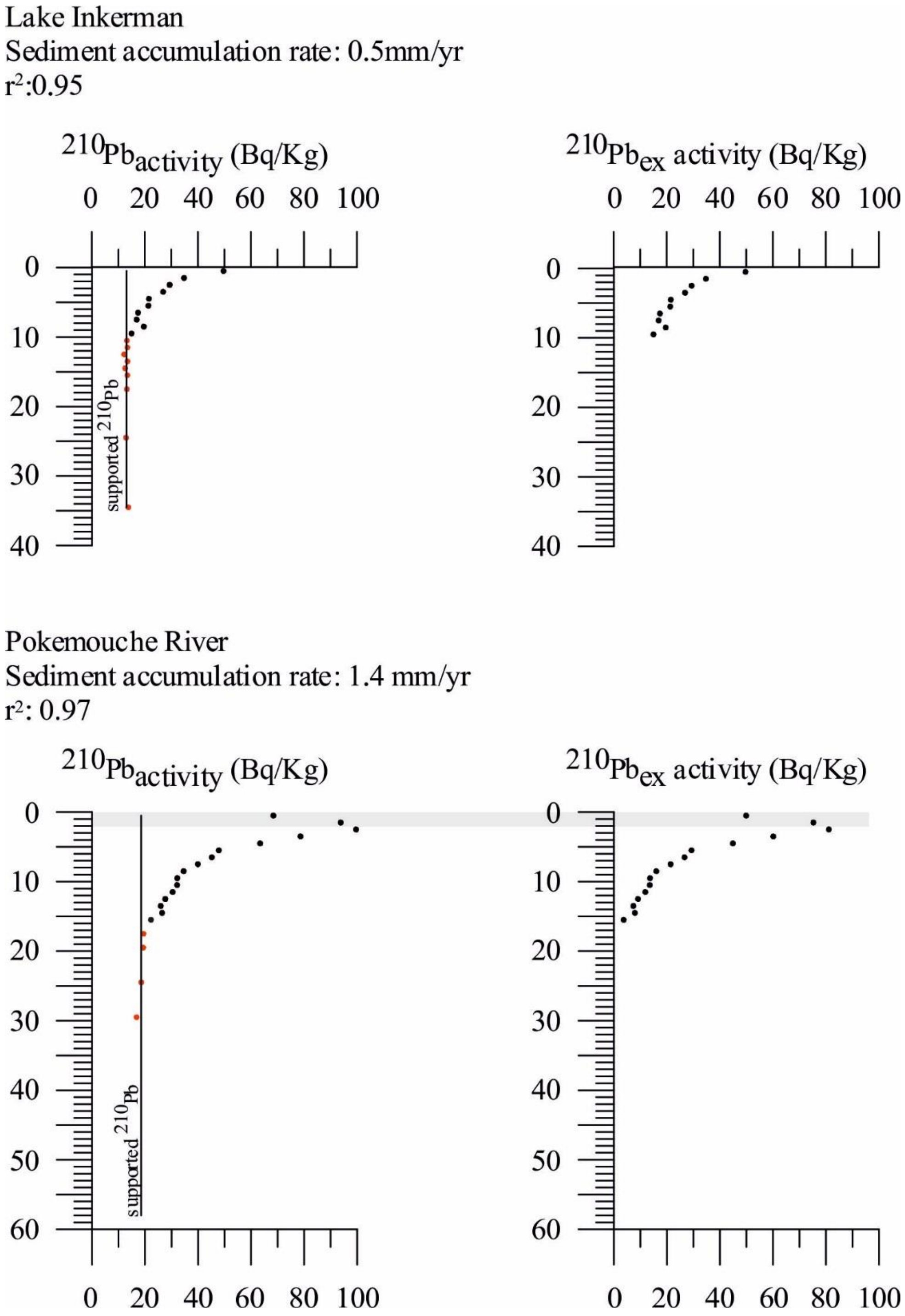


Figure 11. The ^{210}Pb activity and the excess ^{210}Pb activity from Lake Inkerman and Pokemouche River cores. The gray box represents the bioturbation zone in the uppermost 2 cm in the Pokemouche river core. Red dots not used for the model.

ANNEXE III

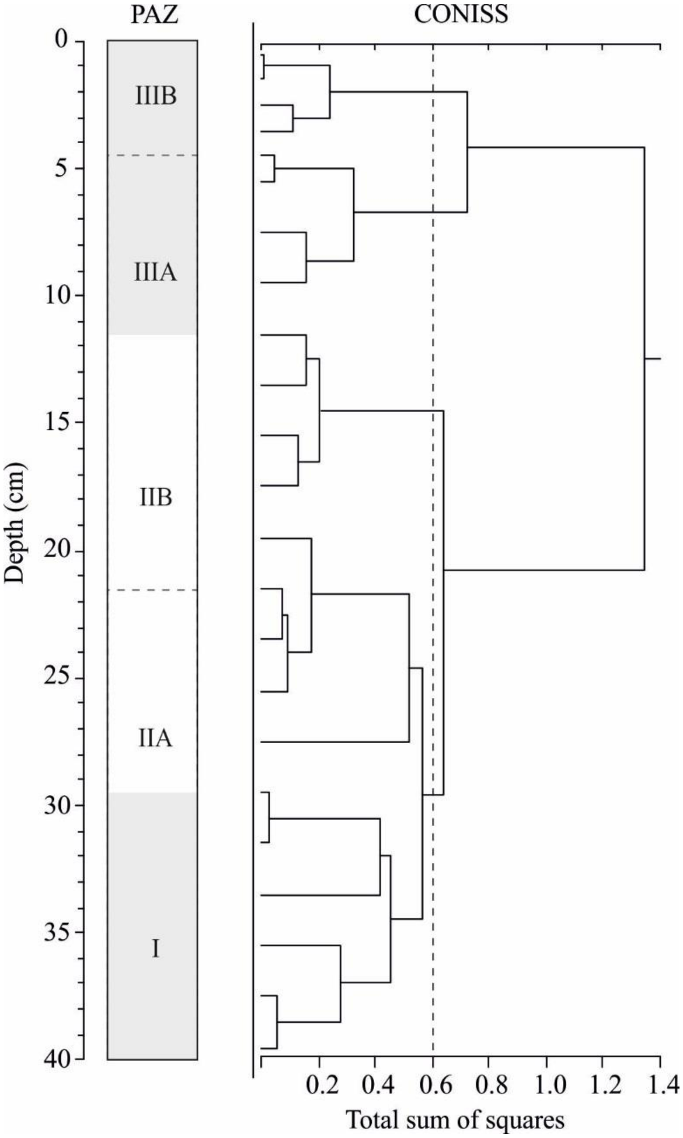


Figure 12. Dendrogram of Pollen Assemblage Zones (PAZ) CONISS from Lake Inkerman. Dashed vertical line indicates significant level of first order agglomeration

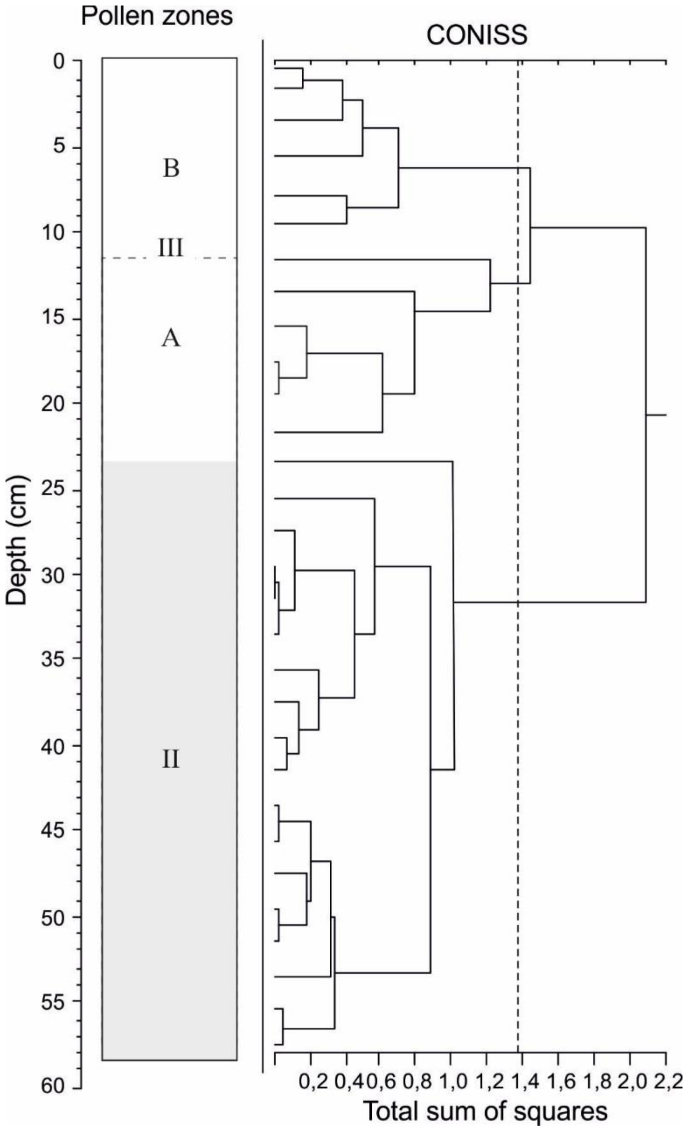


Figure 13. Dendrogram of Pollen Assemblages Zones (PAZ) CONISS from Pokemouche River. Dashed vertical line indicates cutoff for level of first order agglomeration

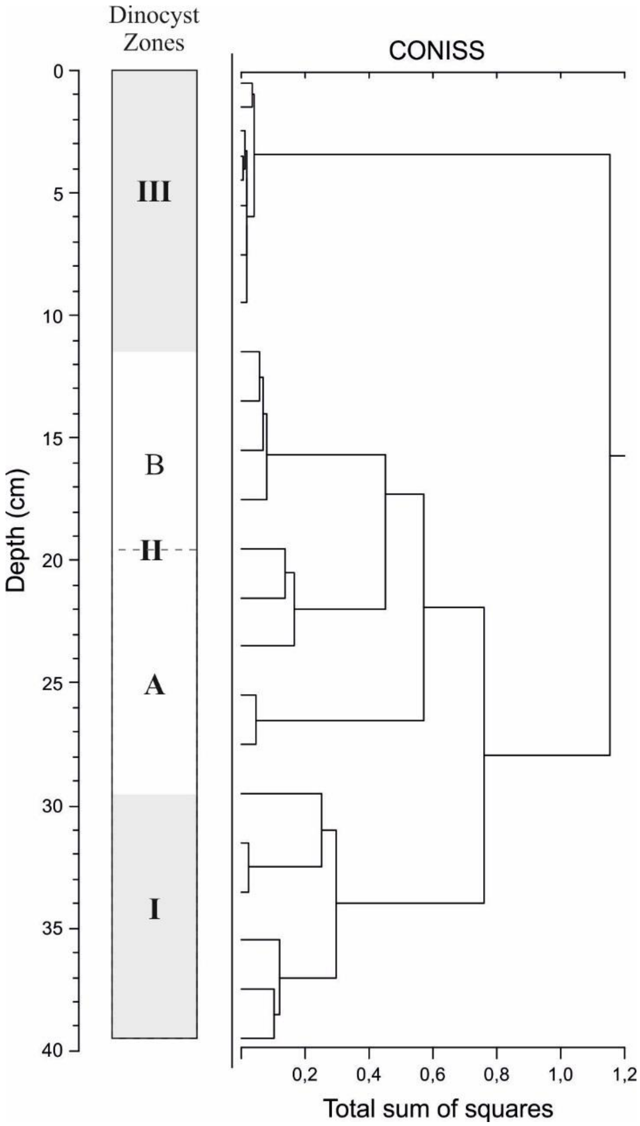


Figure 14. Dendrogram of Dinocyst Assemblages Zones (DAZ) from Lake Inkerman. Dashed vertical line indicates cutoff for level of first order agglomeration

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