PROJECT REPORT
2001-7
FINAL PROJECT REPORT

sustainable
forest
management
network

réseau
sur la
gestion durable
des forêts

Long-term response of boreal plain lake phytoplankton to fire – A paleolimnological approach

A Network of Centres of Excellence
Un réseau de centres d'excellence

T. Charette and E.E. Prepas

For copies of this or other SFM publications contact:

Sustainable Forest Management Network
G208 Biological Sciences Building
University of Alberta
Edmonton, Alberta, T6G 2E9
Ph: (780) 492 6659
Fax: (780) 492 8160
http://www.ualberta.ca/sfm

ISBN 1-55261-116-7

Long-term response of boreal plain lake phytoplankton to fire – A paleolimnological approach

by

T. Charette and E.E. Prepas

Department of Biological Sciences
University of Alberta
Edmonton, AB T6G 2E2

May 2001

ABSTRACT

Paleolimnology offers the only feasible approach to examine long-term and reference conditions in lakes impacted by such an unpredictable event as forest fire. The fire and phytoplankton history of pristine aquatic ecosystems in a remote area of the Buffalo Head Hills were examined using information contained in the sediments of strategically-selected lakes. Six lakes, four with >93% of their watersheds burned in 1982 and two outside the fire's range, were extensively studied. Three sediment cores were taken from the deepest part of the study lakes. These cores were sectioned at 2.5mm intervals and were analyzed for pigment with the participation of Dr. James P. Hurley, University of Wisconsin, Madison. Also, the accuracy of the ^{210}Pb chronology of the sediment cores was verified using forest fire history and the charcoal content of the sediment. This study shows that although the ^{210}Pb method used to determine the chronology of lake sediments is commonly used, it can be imprecise and must be accompanied by other independent dating techniques. Also, preliminary results indicate that phytoplankton, particularly diatoms, chrysophytes and dinoflagellates, react to watershed disturbance by an increase in abundance.

ACKNOWLEDGEMENTS

This study was funded by SFMN, Daishowa-Marubeni International Ltd., the Canadian Boreal Institute, the Alberta Parks, Sport, Recreation and Wildlife Foundation and NSERC. In particular, we wish to thank and acknowledge the support of Brock Allison Flying Services Ltd., Dolors Planas, Ian Campbell, James Hurley, Johanna Pierre, John Glew, Kara Powell, Paula Siwik, Roland Hall and Stéphanie Nicopoulos.

Introduction

Boreal forests represent the largest forested ecoregion in Canada, accounting for forty percent of the world's boreal forests (Natural Resources Canada 1998). Since forestry is such a prominent force in the boreal forests of Alberta, there is a need to establish the levels of impact that will allow the preservation of long-term boreal ecosystem health. To these ends, a new approach to minimize the human impact of clear-cutting looks at a large-scale natural disturbance, fire, as a model for logging (Hunter Jr. 1993). Fire is the most prevalent and widespread disturbance in the Boreal Plain, and it is important as it structures vegetation composition and patterns (Tilman 1996). However, the impact of fire on the environment remains to be fully understood.

Forest fire can cause an increase the amount of nutrients transported in runoff from the drainage basin to aquatic systems (Schindler et al. 1980). Furthermore, phosphorus (P) and nitrogen (N) concentrations can increase in aquatic systems through direct deposition of smoke and ash (Spencer and Hauer 1991). Fire typically releases a greater amount of nitrogen relative to phosphorus in upland-dominated systems, causing lake N:P ratios to increase (Bayley et al 1992). Whereas lowland-dominated systems tend to show the opposite (McEachern et al. 2000).

Phytoplankton are very sensitive to such short-term fluxes in nutrients because of quick generation times, making them good indicators of watershed disturbance (Schindler 1987). Phytoplankton abundance typically grows with increased phosphorus loading to lake systems (Schindler 1977). Conversely, the composition of phytoplankton communities reacts to changes in N:P ratios. A greater ratio of nitrogen relative to phosphorus concentrations, gives competitive advantages to algal species that do not fix atmospheric nitrogen because of the abundance of nitrogen (Zhang and Prepas 1996). Under such a scenario, non-nitrogen-fixing green algae, chrysophytes and diatoms would be favored over nitrogen-fixing cyanobacteria (*Anabaena*, *Aphanizomenon*).

The boreal landscape can be thought of as a mosaic of watersheds so that every square inch of forest drains into some form of freshwater. As such, any evidence of disturbance in the Boreal Plain will inevitably end up in lakes or streams. The advantage of studying lakes rather than streams, is that paleolimnological techniques can be applied to lakes to reconstruct past conditions from the remains of organisms preserved in lake sediments. Ecosystem change due to fire implies a response to fire in some way that is outside its natural range of variation (Schindler 1990). Because knowledge of baseline conditions of such an unpredictable event as forest fire is not available, paleolimnology offers the only feasible approach to infer reference conditions in lakes (Smol 1991). The remains of many organisms are preserved in lake sediments and it is possible to use these to reconstruct long-term variations in aquatic assemblages and their surrounding environment. The historical abundance of major phytoplankton groups is estimated as the amount of taxa-specific photosynthetic pigments buried in lake sediment (Leavitt 1993). Unlike terrestrial plant pigments, phytoplankton pigments preserve well after cell death, especially when deposited in the cold, low-light, anoxic conditions often found in the sediments of deep lakes (depth > 10m; Leavitt 1993).

The chronology of a sediment core is estimated using a model that best describes the distribution of ^{210}Pb radioactivity in the sedimentary column. The most popular model is the Constant Rate of Supply model (c.r.s.). This model assumes a constant influx of ^{210}Pb to sediment and is independent of changing sediment accumulation rates. The accuracy of the ^{210}Pb method has been proven in some cases (von Gunten and Moser 1993), but not in others (Anderson et al. 1987). The atmospheric ^{210}Pb-flux may vary significantly from year to year but it is reasonably constant on a 100-200 year timescale (Krishnaswamy and Lal 1978). However, internal processes such as slumping and sediment resuspension and focussing can significantly alter the ^{210}Pb activity in a sediment profile (Anderson et al. 1987). Therefore, independent measures of age determination are required to verify the ^{210}Pb profile (Oldfield and Appleby 1984).

Objectives

The objective of this research project is twofold: 1) To verify the ^{210}Pb dating accuracy of high-resolution (yearly) chronology of unvarved sediments in four lakes in the Boreal Plain of Alberta using charcoal analysis, 2) To detect and describe changes in phytoplankton community composition, as determined by fossil pigments, following fire in boreal lake watersheds. I expect an increase of total phytoplankton abundance shortly after fire due to increased nutrient loading to the system and then a decrease within five years of the fire event. Furthermore, since the study area is mostly upland, I expect the relative number of non-nitrogen fixing phytoplankton to increase (due to increased N:P ratio) the year after a fire, and then to decrease within five years after the fire event.

Materials and Methods

Study area

The study sites are located within the Boreal Uplands Region (Vitt et al. 1997) in the Buffalo Head Hills of Northern Alberta (surface area = 0.08-1.12 km^2, z_{mean} = 2.7-4.5 m, watershed area/surface area = 4.7-27.7). Typical overstory vegetation is composed mainly of white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*) and Jackpine (*Pinus strobus*) in uplands, and black spruce (*Picea mariana*) and larch (*Larix sp.*) in lowlands. A large (630 km^2) forest fire swept through the area in 1982, surrounding dozens of lakes. Alberta Lands and Forest Service historical fire records going back to the 1930s show no other major fire activity in the area (Information can be obtained from http://www.gov.ab.ca/env/forests/fpd/). Six lakes with greatest depth and accessible by float-plane were selected. All lakes lie within a 30 km radius. Out of the six lakes, four were completely surrounded by the 1982 fire and are all found within a 6.5 km radius. Over 93% of the watersheds of these four study lakes were burned, right up to the lakeshore. The other two reference lakes are separated by 5 km and are approximately 15 km NE of the burnt lakes.

Sediment sample collection

Lakes were accessed by float-plane in September 1999. Lake sediments were collected with a short hand-held gravity corer provided by Dr. Ian Campbell, Canadian Forest Service. Three cores (core length between 35 and 45 cm) were collected from the deepest part of each lake, filled with lake-water, capped and kept cool until arrival at Meanook Biological Research Station. Only two of the three cores were used for analysis. On the evening of the collection day, one core was extruded under low-light, sealed in plastic Whirl-Pak$_{®}$ bags and immediately frozen. This core was later used for ^{210}Pb analysis, organic matter content, charcoal analysis and pigment analysis. The other core was extruded in daylight, sealed in plastic Whirl-Pak$_{®}$ bags and kept cool. This second core was sent to Aline Phillibert (Université du Québec à Montréal) for diatom analysis. High temporal resolution of sediment cores (~1 year intervals) was achieved by slicing sediment cores at 2.5 mm intervals using a vertical, close-interval extruder (Glew 1988). Frozen samples were transferred to urine cups and lyophilized.

Pb-210 analysis preparation and modeling

Sub-samples (0.5g) for ^{210}Pb activity were taken from every second centimeter for the first half of the cores and from the middle and the end of the second half of the cores. ^{210}Pb activity of sub-samples was measured by Flett Research Ltd. (http://www.mbnet. mb.ca/ flett_ research/). The accumulation rate of sediments was estimated using the Constant Rate of Supply (c.r.s.) model originally proposed by Goldberg (1963), and revised by Eakins and Morrison (1978).

Charcoal analysis

Samples for charcoal analyses were prepared according to Rhodes (1998) which consists of bleaching sediment material with 6% hydrogen peroxide. Charcoal fragments were identified at 375X on gridded petrie dishes using a stereomicroscope. Charcoal particles with a diameter >80µm on the longest axis were counted (Clark 1988). The beginning rather than the maxima of a charcoal peak was chosen to indicate a fire event since previous studies have shown charcoal maxima can occur up to 5 years after fire (Whitlock and Millspaugh 1996). Most cores were analysed back to the early 1930s. The selection of core length to study was made to include natural charcoal variability and all charcoal from the 1982 fire.

HPLC apparatus

Sediment pigments were identified and quantified using methods similar to Descy et al. (1999) and with equipment from the Water Science and Engineering Laboratory at the University of Wisconsin, under the supervision of Dr. James P. Hurley. Pigments were separated with a Waters 712B autosampler and three detectors: a Shimadzy L-4200 H absorbance detector set at 440 nm, a Milton Roy/LDC Fluoromonitor fluorescence detector, a Waters 991M diode array detector and Millenium 32 data analysis software. Pigments were extracted (around 50mg. dry wt.) by soaking in 90% acetone for 24 hrs. and sonication for 15minutes in the dark, at 4°C. Sediment extracts were then filtered through 0.2µm Mandel Scientific membrane seringe filters and injected in the HPLC system. Separation was achieved using a binary gradient that combines a 10 cm Waters Nova-Pak C18 column, followed by two Vydac 201TP54 polymeric columns. Standard procedure consisted of the injection of 50-200 µl of extract through a 50 minute gradient (A: 80:20 methanol:ammonium acetate 0.5 M; B: 70:30 methanol:acetone). Calibration was achieved with diode array and fluorescence detection of a mixed standard of chlorophyll *a*, chlorophyll *b*, lutein, fucoxanthin, zeaxanthin, echinenone and β-carotene and a separate pheophytin *a* standard.

Identification and quantification of sediment pigments

Pigment identifications were based on comparisons of the column retention time of pigments isolated from sediments with those from the standards and on the comparison between the visible absorption spectra of sediment and standard and on-line pigment absorption spectra library. Peak areas were manually integrated using Millenium 32 data analysis software. Pigment concentrations were determined by peak area from the respective standard curves and are expressed as ng pigment/g organic matter. Carotenoids with no standards (myxoxanthophyll, canthaxanthin) were quantified against fucoxanthin, using as relative response the ratio of extinction coefficients at 440nm in acetone. Phaophorbide *a* was quantified against phaeophytin *a*. Pigments identified and quantified include pigments characteristic of total algae (chlorophyll *a*, *b*-carotene), a chlorophyll *a* degradation product (phaeophytin *a*), total cyanobacteria (echinenone, zeaxanthin, myxoxanthophyll), nitrogen-fixing cyanobacteria (canthaxanthin), green algae (lutein), chromophytic algae (diatoms, chrysophytes and dinoflagellates: fucoxanthin) and herbivory (phaeophorbide *a*). Organic content was determined by dry sediment weight loss after combustion at 550°C for one hour.

Preliminary results and discussion

Charcoal profiles

The lake B3 charcoal profile agrees with fire history data, as derived from the c.r.s. model of ^{210}Pb accumulation in sediments. Since the 1930s, lake B3 sediment shows the presence of two charcoal peaks, indicating two fire events. The first peak starts in the ^{210}Pb-year 1947 and spans 15 years. This fire is undocumented in Alberta Lands and Forest Service historical records because of the remoteness of the area and of the limited budget for forest fire detection at that time (Murphy 1985). The other peak begins in 1982, the year of the documented fire, and also spans a period of 15 years. Furthermore, there is a two-fold decrease in baseline (peakless) charcoal concentrations beginning at around 1970. This drop in background charcoal corresponds to increased fire prevention and suppression efforts during the 1960s (Tymstra et al. 1998). Forest fire fighting costs tripled by 1968 and remained high after this time (Murphy 1985).

The lake B4 sediment charcoal profile does not match ^{210}Pb chronology. Similarly to lake B3 sediments, lake B4 sediments show the presence of two large peaks, indicating two large local fires since the 1930s. The first peak begins at around 1963 and spans six years. The last peak begins during the years 1983-1984 and spans approximately seven years. A two-fold decrease in baseline charcoal concentrations is also observed for lake B4, occurring at 1979. The sediment profile is fairly accurate from the year 1982 to present. The beginning of the 1982 charcoal peak is only 1-2 years later than the ^{210}Pb dated year of the fire. However, the first charcoal peak and the decrease in the charcoal baseline occur much later than historical and lake

B3 events. The c.r.s. model assumption of a constant influx of ^{210}Pb to sediment was likely violated by an increase in stream inflow of ^{210}Pb caused by the 1982 fire.

The chronology of lakes B5 and B19 are not accurate. In both cases, the charcoal maxima occurs before the 1982 c.r.s. derived year. Lakes B5 and B19 likely violate the c.r.s. model assumption of constant influx of ^{210}Pb to lake sediment. These two lakes are very shallow and do not form summer stratification and therefore, are subject to sediment resuspension, and focussing. These processes would cause a sediment profile to have ^{210}Pb activity that is divergent from the model estimate, given a constant influx to the sediment. Lake B5 is especially vulnerable to sediment mixing because of its large surface area and greater exposure to wind.

Preliminary pigment data

The data for this section is currently being worked up. However, certain trends can be extracted. Two lakes show a response to the 1982 fire. Lake B3 shows an increase in total algal abundance. More specifically, phytoplankton such as cryptophytes , diatoms, chrysophytes and dinoflagellates responded positively to the fire event. Lake B19 shows increases in the abundance of total algae after fire. Both nitrogen fixing and non-nitrogen fixing cyanophytes show a response. Chromophytic phytoplankton such as diatoms, chrysophytes and dinoflagellates also react positively to the 1982 fire. Lake B5 shows no response in phytoplankton abundance due to the 1982 fire. However, the pigment profile of lake B5 sediments is difficult to interpret because of the large amount of sediment mixing. Results on lake R1, R3 and B4 cannot be reported at this time.

Literature cited

Anderson, R.F., S.L. Schiff, and R.H. Hesslein. 1987. Determining sediment accumulation and mixing rates using ^{210}Pb, ^{137}Cs, and other tracers: problems due to postdepositional mobility or coring artifacts. Canadian Journal of Fisheries and Aquatic Sciences. 44(Suppl. 1): 231-250.

Bayley, S.E., D.W. Schindler, K. Beaty, B.R. Parker, and M.P. Stainton. 1992. Effects of multiple fires on nutrient yields from streams draining boreal forest and fen watersheds: nitrogen and phosphorus. Can. J. Fish. Aquat. Sci. 49: 584-96.

Descy, J.-P. T.M. Frost, and J.P. Hurley. 1999. Assessment of grazing by the freshwater copepod *Diaptomus minutus* using carotenoid pigments: a caution. J. Plankton Res. 21: 127-45.

Eakins, J.D., and R.T. Morrison. 1978. A new procedure for the determination of lead-210 in lake and marine sediments. Int. J. Appl. Radiat. Isot. 29: 531-536.

Goldberg, E.D. 1963. Geochronology with 210Pb, In Radioactive Dating. Proceedings of a Symposium, International Atomic Energy Agency, Vienna., pp. 121-131.

Glew, J.R. 1988. A portable extruding device for close interval sectioning of unconsolidated core samples. J. Paleolimnol. 1: 235-9.

Hunter Jr, M.L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biol. Conservation . 65: 115-20.

Krishnaswami, S., and D. Lal. 1978, Radionuclide limnochronology. In Lakes, Chemistry, Geology and Physics, A. Lerman (ed.), Springer-Verlag New York Inc., pp. 153-177.

Leavitt, P.R. 1993. A review of factors that regulate carotenoid and chlorophyll deposition and fossil pigment abundance. J. Paleolimnol. 9: 109-27.

McEachern, P., E.E. Prepas, J.J. Gibson, and W.P. Dinsmore. 2000. Forest fire induced impacts on phosphorus, nitrogen, and chlorophyll *a* concentrations in boreal subarctic lakes of northern Alberta. Can. J. Fish. Aquat. Sci. 57: 73-81.

Murphy, P.J. 1985. History of Forest and Prairied Fire Control Policy in Alberta. Alberta Energy and Natural Resources, Report number T/77.

Natural Resources Canada, 1998. The state of Canada's forests: The people's forests 1997-1998, Canada, p.4.

Oldfield, F., and P.G. Appleby. 1984. Empirical testing of 210Pb-dating models for lake sediments. In Lake Sediments and Environmental History, E.Y. Haworth and J.W.G. Lund (eds.), Leicester University Press, pp 93-124.

Rhodes, A.N. 1998. A method for the preparation and quantification of microscopic charcoal from terrestrial and lacustrine sediment cores. The Holocene.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science. 195: 260-2.

Schindler, D.W., R.W. Newbury, K.G. Beaty, J. Prokopowich, T. Ruszczynski, and J.A. Dalton. 1980. Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the quality of receiving streams. Can. J. Fish. Aquat. Sci. 37: 328-334.

Schindler, D.W. 1987. Detecting ecosystem responses to anthropogenic stress. Can. J. Fish. Aquat. Sci. 44: 6-25.

Schindler, D.W. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystems structure and function. Oikos . 57: 25-41.

Smol, J.P. 1992. Paleolimnology: an important tool for effective ecosystem management. J. Aquat. Ecosystem Health. 1: 49-58.

Spencer, C.N., and F.R. Hauer. 1991. Phosphorus and nitrogen dynamics in streams during a wildfire. J. North Am. Benth. Soc. 10(1): 24-30.

Tilman, D. 1996. The benefits of Natural Disasters. Science. 273: 1518.

Timstra, C., C. McGregor, D. Quintilio, and K. O'Shea. 1998. Is fire a wildcard in Alberta's protected areas strategy for forest conservation? In: Proceedings of the Third International Conference on Science and Management of Protected Areas, May 12-16, 1997, Calgary, Alberta, N.W.P. Munro and J.H.M. Willison (eds.), pp 542-551, Wolfville, Nova Scotia.

Vitt, D.H., L.A. Halsey, M.N. Thormann, and T. Martin. 1997. Peatland Inventory of Alberta. SFM Publication.

Von Gunten, H.R., and R.N. Moser. 1993. How reliable is the 210Pb dating method? Old and new results from Switzerland. J. Paleolimnol. 9: 161-178.

Whitlock, C., and S.H. Millspaugh. 1996. Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. The Holocene 6(1): 7-15.

Zhang, Y., and E. E. Prepas. 1996. Regulation of the dominance of planktonic diatoms and cyanobacteria in four eutrophic hardwater lakes by nutrients, water column stability, and temperature. Can. J. Fish. Aquat. Sci. 53: 621-33.