HISTORY OF WAHLEACH AND STAVE RESERVOIRS: A PALEOLIMNOLOGICAL PERSPECTIVE

Submitted to

BC Hydro
Environmental Services
Burnaby, BC

Prepared by

John Stockner PhD
&
[1]Darren Bos PhD

Eco-Logic Ltd.
2614 Mathers Avenue
West Vancouver, B.C. V7V 2J4

[1]Current Address:
Parks Canada
300-300 W. Georgia Street
Vancouver, B.C. V6B 6B4

March 12, 2002

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Executive Summary

Wahleach Reservoir. Historic reconstruction of events that have affected Wahleach Lake/Reservoir production over the past century were made more difficult by an intrusive layer caused by either one major or several smaller depositional events that introduced large amounts of sediment over the span of a decade or two in the latter half of last century. Nonetheless, examination of the sediment has revealed several interesting events that brought change to the ecosystem. Our analyses suggest that the 'original' Wahleach Lake was a small, perched, fishless lake that was relatively shallow with growth of emergent macrophytes within an extensive littoral zone. It is likely that annual littoral production exceeded pelagic production. Introduction of fish in 1928 and other anthropogenic impacts within the catchment, e.g. mining, fishing, subtly changed the nutrient dynamics of the ecosystem. Impoundment of the lake in the 1950s brought nutrient enrichment from flooded landscape and increases in pelagic production. But by far the most profound changes came from logging and road construction in the 1960s and 70s. Forest removal and roads must have resulted in slope failures and debris torrents during heavy rain events that introduced large quantities of silt and debris into the small reservoir (+/-13 cm of sediment accrual). The commencement of a reservoir fertilization program in 1995 to restore fisheries potentials of Wahleach has markedly enhanced pelagic production and shifted ecosystem carbon production from an 'original' littoral to a present pelagic predominance.

Stave Reservoir. Stave's historic reconstruction is not puzzled by large depositional events as was the case for Wahleach, and our analyses clearly show that impoundment of the Stave River in the late 1920s changed an unproductive, ultra-oligotrophic fast-flushing lake into a larger and more productive pelagic driven ecosystem. Nutrient releases from flooded landscapes enhanced pelagic carbon production, but this increase was transient lasting only a few decades and then began to decline only to be enhanced again when discharges of hypolimnetic water from Alouette Reservoir were diverted to Stave in the early 1950s. The C/N data indicates that the continued discharge of Alouette water to Stave Reservoir has stabilized pelagic production at higher levels than occurred in the 'parent' low production Stave Lake. Very high C/N values in the most recent sediment suggest that the current Alouette Reservoir fertilization program for fisheries restoration may also be enhancing the carbon production of Stave. Low ^{15}N values in deep lake sediment from 'original' Stave Lake indicate that that the old lake did not support a run of anadromous salmon due to an effective migration blockage at Stave Falls. Distribution and abundance of fossil littoral and pelagic diatoms indicate that pelagic production has dominated the system throughout the past 2 centuries and in the last decade has attained highest levels.

Introduction

Background

Paleolimnology is a sub-discipline of limnology that reconstructs lake and drainage basin history by examining the distribution and abundance of microfossils and geo-chemical remains laid down within the deep-water sediments of the lake. Lake sediment cores yield a plethora of information about past lake/reservoir conditions, including the impacts of man and climate upon the drainage basin, e.g. logging, road and dam construction, (impoundment, water diversion), landslides, and volcanic eruptions. Deep-water sediments of lakes and reservoirs chronicle these events occurring within the drainage basin and provide an invaluable time-series of the impact of each major event and how they have affected production, including fisheries over several centuries and/or millennia (depending on core length and sedimentation rate). Collectively these variables provide clues to interpreting how the past impacts of climate, landscape intervention and even over-fishing have influenced sedimentation rates and lake productivity over many centuries. Profiles of stable ^{15}N isotopes of marine origin provide good evidence of historic anadromous salmon and steelhead escapements prior to and after first white-European contact and the advent of the commercial fisheries.

There are many tools used to discriminate past lake productivity and food web structure, and these include the enumeration of diatoms, macro-zooplankton microfossils and the estimation of amounts of phytoplankton pigments, e.g. decomposition products of chlorophyll and other algal pigments. Further, by examining the patterns of fossil pollen in cores one can document changes in vegetation within the basin drainage caused by climate changes, logging and fire. These drainage basin interventions (land clearance, road construction, landslides) leave coarse sediment markers that indicate the frequency of major storm events and associated turbidity plumes within lakes and how these have affected sedimentation rate and lake productivity.

Using several of these techniques, we can determine whether Wahleach and Stave lake productivities were higher during the previous century *before* European contact. That is, has drainage basin habitat degradation and river impoundment affected ecosystem productivity including fisheries?

Objectives

In February 2001 Eco-Logic was awarded a contract from BC Hydro to provide paleolimnological studies of lake sediments in Wahleach and Stave reservoirs. Studies were to include analysis of profiles of sediment cores for:

- Carbon (C) & Nitrogen (N) content
- ^{15}N stable isotope (marine derived nutrients)
- Fossil phytoplankton pigments
- Fossil diatoms (Bacillariophytes)
- Fossil macro-zooplankton (Cladocera)

- Core dating by ^{210}Pb decay curves

Since both Stave and Wahleach were existing lakes prior to impoundment, some specific questions were to be addressed:

- Did changes in lake production occur after initial impoundment of outflows?
- Did impoundment of Stave Lake at Stave Falls block passage of anadromous salmon?
- Are present levels of reservoir ecosystem production lower than in pre-impoundment lake conditions because of oligotrophication?

Study limitations

As a caveat it should be noted that limited funding did not permit detailed, high-resolution examination of the cores and this restricted our ability to make fine-scale interpretations of changes beyond a 3 - 5 yr time horizon. Thus we provide our best interpretation of past events in the Wahleach and Stave lake/reservoir drainage basins, but caution that our discussion, by necessity, must remain somewhat speculative.

Study area

Wahleach

Wahleach is a 'perched' lake/reservoir (elevation 640m) ecosystem located approximately 15 km west of Hope, BC. It has a maximum depth at full pool of 28 m and surface area 410 ha, but declines to 125 ha at full drawdown. The reservoir was created (impounded) in 1952 and is 6.1 km long, but the original lake was only 3.3 km in length (Fig. 1). It was fishless prior to 1926 when it was stocked with rainbow trout (*Oncorhynchus mykiss*) and kokanee salmon (*Oncorhynchus nerka*). A fertilization program commenced in 1995 to restore declining fisheries and the reservoir was stocked in 1997 and 1999 with kokanee, rainbow and cutthroat trout.

Stave

The original Stave Lake was a classic coastal 'fiord-type' lake in a deep, steep-sided basin carved by retreating glaciers over 10,000 yrs ago. Stave Reservoir was formed in 1928 by construction of a hydroelectric dam at Stave Falls, and is located approximately 45 km east of Vancouver, BC. At full pool maximum depth is about 101 m and surface area 5,858 ha (Fig. 2). The hydrologic input to Stave was supplemented by the addition of Alouette Reservoir hypolimnetic water beginning in 1952. Early anecdotal information suggests that Stave Falls was impassable for anadromous salmon, and thus the original lake was likely ultra-oligotrophic without the input of marine derived nutrients from carcass decomposition. However the number of early aboriginal settlements around the original Stave Lake has raised questions as to whether salmon may in fact have been present throughout the system.

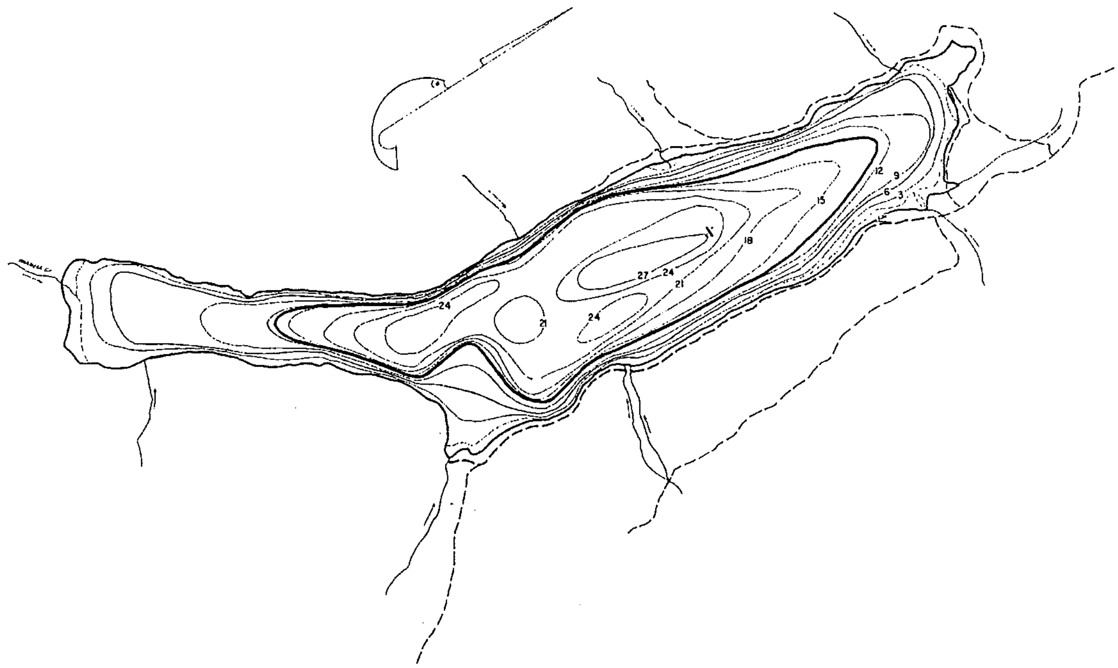


Fig. 1 Bathymetric map of Wahleach reservoir. The approximate coring location is shown by an "X". The dark isocline shows the outline of the original lake. Coordinates of the coring site were N 49° 14.000' W 121° 36.622'. One core was taken off the west side of the boat, the other from the east side.

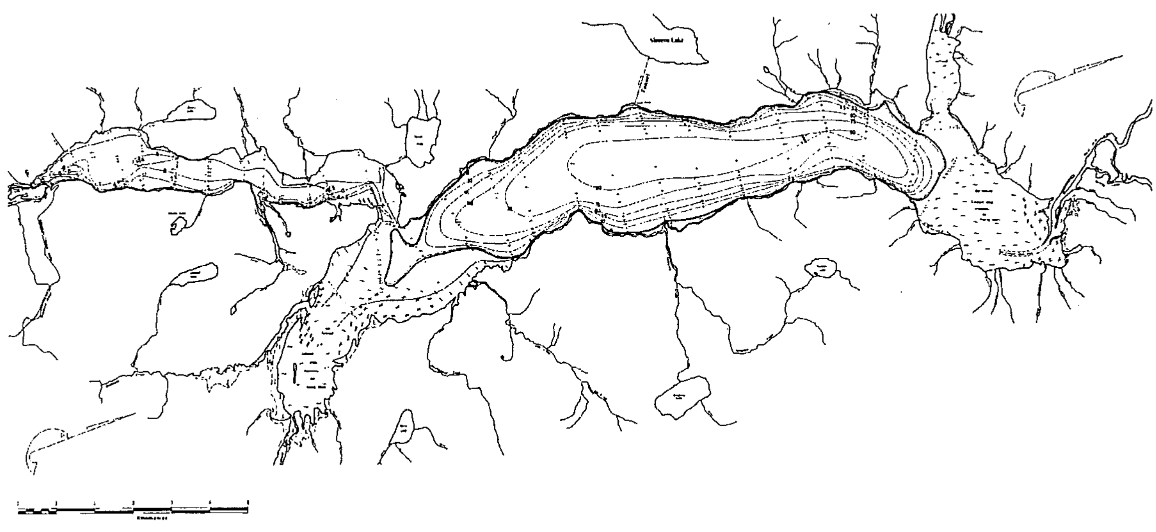


Fig. 2 Bathymetric map of Stave reservoir. The approximate coring location is shown by an "X". The dark isocline shows the outline of the original lake. Coordinates of coring site one were N 49° 24.704' W 122° 16.965'. Coordinates of coring site two were N 49° 24.643' W 122° 16.961'.

Methods

Sampling locations & sectioning

Both reservoirs were cored using a modified KB-type gravity corer with tube diameter of 6.35 cm. Two cores were taken from the deepest part of each reservoir at a point that corresponded to the profundal zone of the parent (original) lake (see Photos 1 & 2). Cores were taken where bathymetric maps and echo sounding showed the bottom to be level and at a maximal distance from any steep slopes in the basin (Figs. 1&2). The cores for Wahleach reservoir were sectioned on shore, while the cores from Stave were transported back to Vancouver for sectioning. The cores from Stave were kept cool with ice during transport and were sectioned approximately two hours after sampling. For Wahleach Reservoir, the first core (core one) was sectioned at 0.25 cm intervals, while the second core was sectioned at 1 cm intervals. For Stave Reservoir, core one was sectioned at 0.25 cm intervals for the first 20 cm and at 1 cm intervals from 20 cm to the bottom of the core, core two was sectioned at 1 cm intervals throughout. All cores were sectioned into Whirlpack® bags and stored at 4° C until further analysis. All analyses were conducted on core 1 for each lake, with the exception of carbon and nitrogen analyses.

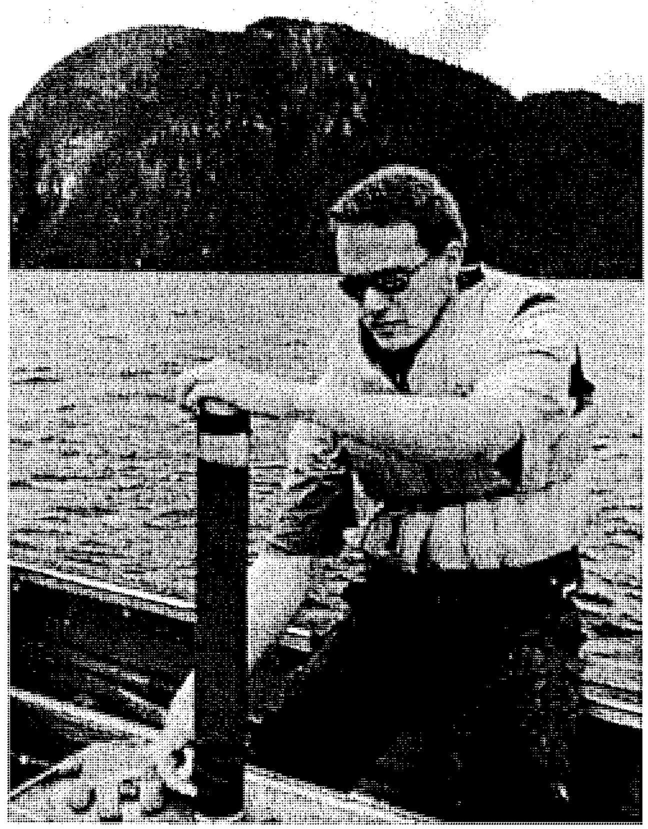


Photo 1 D. Bos with sediment Core 1 from Stave Reservoir, May 2001.

Photo 2 D. Bos on shore with sediment Core 1, Stave Reservoir May 2001.

Dating

Sixteen sediment intervals were selected for ^{210}Pb dating in each reservoir, and in both reservoirs only ***core 1*** was dated. For both reservoirs it was necessary to combine sediment from the 0 to 0.25 cm interval and the 0.25 to 0.5 cm interval in order to have a sufficient mass of dry sediment for dating. All other samples used sediment from a single interval for dating. Samples were prepared for ^{210}Pb analysis by drying a known weight of homogenized sediment. Samples were dried at 105° C for 24 hrs. After drying samples were re-weighed, ground to a uniform fine powder, placed in 50 mL plastic centrifuge tubes and shipped to MYCORE Ltd., Deep River, Ontario, for analysis. ^{210}Pb activity for each sample was measured using Alpha Spectroscopy and a ^{209}Po tracer of known activity. Supported ^{210}Pb was estimated following Binford (1990). Dates were calculated from unsupported ^{210}Pb using the constant rate of supply (CRS) model (Appleby and Oldfield 1978).

Carbon and Nitrogen

Elemental carbon and nitrogen concentrations were determined for all sediment intervals in Core 1 from each reservoir. Samples were prepared and analyzed at the Soils Science Laboratory, University of British Columbia, Vancouver. Analyses were conducted on a Leco CN-2000® with infrared detection of carbon (as CO_2) and thermal conductivity analysis for nitrogen. Samples were combusted at 1050° C.

Pigments & ^{15}N

Fossil phytoplankton pigments and their degradation products and ^{15}N values were analyzed on dry sediment by Dr. Peter Leavitt, at the Limnology Laboratory, University of Regina, Sask., using high-pressure liquid chromatography (HPLC) for pigments and mass spectrometry for ^{15}N.

Cladocera

Samples for cladoceran analyses were taken every 5 cm along the sediment core, with the exception of the top 5 cm in Wahleach reservoir that was sampled every 1 cm to track changes of the recent fertilization of the reservoir. Cladoceran samples were prepared by deflocculating a known mass of wet sediment (~ 2 g) in 200 mL of 10% KOH solution at 70° C for 1 hr. Samples were then sieved through a 34 μm Nytex® mesh. Material retained on the mesh was washed into a vial and the volume was adjusted to 5 mL. 200 μL of this solution was plated onto microscope slides/cover-slips with glycerin jelly as a mounting medium. Slides were enumerated at 400X magnification. The entire sample under each cover slip was enumerated to avoid bias that could result from an uneven distribution of remains. Taxonomy follows that outlined in Bos (2001).

Diatoms

Identical intervals were sampled for diatom and cladoceran analyses. Diatom samples were prepared by treating a known mass of wet sediment (~ 1g) with concentrated nitric acid in 60 mL beakers. Samples were heated for 4 hrs on a hot plate to remove organic debris. Following acid digestion the samples were allowed to settle overnight, the acid was then decanted off the top and the samples were transferred to scintillation vials filled with distilled water. Subsequently, samples were decanted and refilled with water daily, allowing 24 hrs for diatoms to settle between decanting. This was repeated 10 times until the sample pH became neutral. Sub-samples (1 mL) were dried on cover slips and sides prepared using Permount© mounting medium. Slides were enumerated at 560X magnification using a Zeiss Inverted phase-contrast microscope. Taxonomy was based on Stockner and Costella (1980) and Canter-Lund and Lund (1995). Approximately 250-300 frustules were enumerated/slide.

Results

Wahleach Reservoir

Dating. ^{210}Pb data from Wahleach Reservoir do not show a typical exponential decline with increasing depth in the core (Fig. 3). Instead, after a near linear decline between the surface and 6.75 cm, the activity remains low for several centimeters and then increases again to a maximum at 18.75 cm. Thereafter it follows a normal exponential decay once again returning to low values.

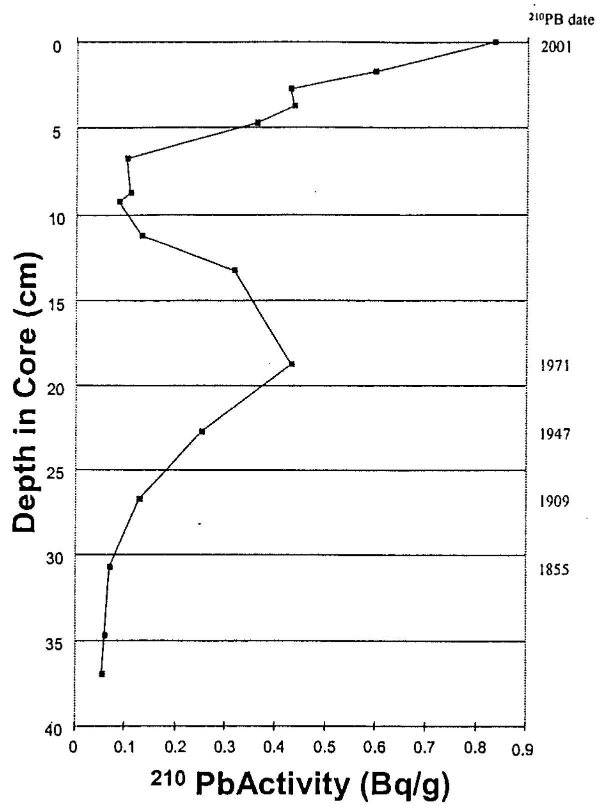


Fig. 3 ^{210}Pb activity in the Wahleach Reservoir sediment core. Dates are for ^{210}Pb-analyzed intervals.

Similar to the ^{210}Pb profile, the sedimentary matrix observed during both the diatom and cladoceran counts changed between 17 cm and 5 cm. Starting at the bottom of the core and moving forward through time, the bottom of the core consisted of a diffuse mixture of fine and coarse organic debris. However, at 15 cm large amounts of fine organic debris appeared in the core, and at 10 cm this changed to abundant coarse, plant material along with coarse (>34 μm) unworn (jagged) clastic material. By 5 cm the organic debris decreased to levels similar to those seen below 20 cm and the unworn, clastic material was much reduced.

C/N analyses. Carbon and nitrogen values tracked each other closely from 35 cm to 18 cm. Percent carbon and nitrogen remained low and stable from 35 cm to 26 cm, but after 26 cm both increased, peaking at 21cm before declining somewhat in the period between 21 cm and 18 cm (Fig. 4). Coinciding with the disturbance seen in 210Pb and with observations of un-weathered clastic material, beginning at 17 cm the carbon and nitrogen values moved out of phase and became more variable. Gradually, the two indicators moved back into phase beginning around the 13 cm sediment depth level. However, the C:N ratio during this period remained higher than pre-disturbance levels. By 5 cm the C:N ratio was consistent with pre-disturbance conditions. However, over the top 5 cm of the core the sediments become increasingly nitrogen enriched relative to carbon.

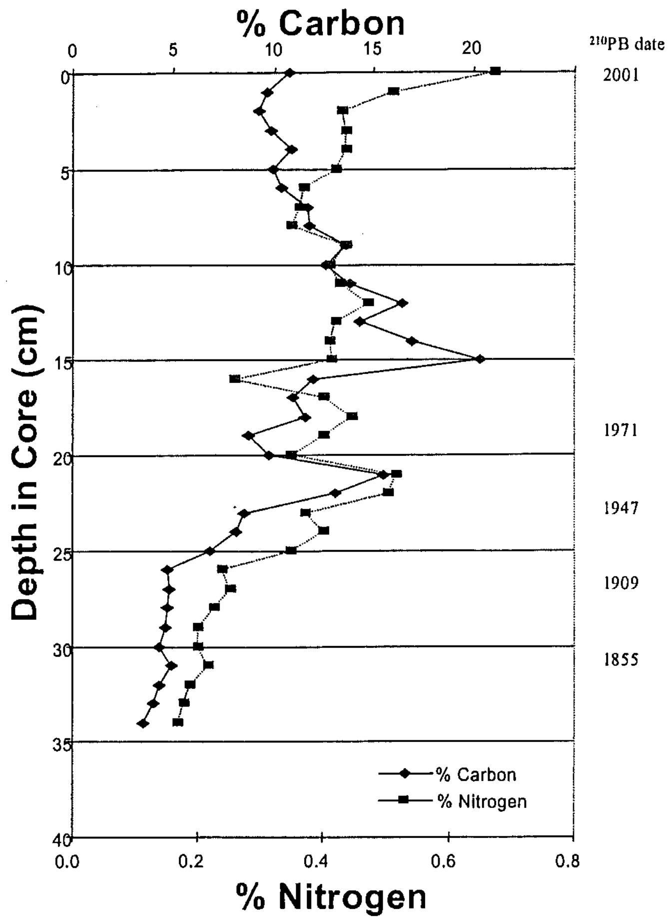


Fig. 4 Carbon and Nitrogen content of the Wahleach reservoir sediment core. Dates shown are for ^{210}Pb analyzed intervals.

Zooplankton. Like many low nutrient, coastal lakes the cladoceran species composition in the sediment core is strongly dominated by *Bosmina*. Initially, *Bosmina* accounts for greater than 60% of the assemblage, with *Chydorus brevilabris, Chydorus biovatus* and *Daphnia* accounting for much of the rest of the population (Fig. 5). The macrophyte associated species *Acroperus harpae* and *Alonella excisa* are only found in samples below 25 cm depth. Between 35 and 25 cm depth there is a gradual increase in the relative abundance of planktonic taxa (*Daphnia* and *Bosmina*) and a decrease in littoral taxa (Fig. 5). By 20 cm the macrophyte associated species *Acroperus harpae* and *Alonella excisa* entirely disappeared, while species such as *Chydorus brevilabris, Chydorus biovatus* and *Alona quadrangularis,* that also use other benthic habitats, continue to persist but at lower abundances. The 15 cm and 10 cm intervals had insufficient remains to calculate meaningful relative abundances (Fig. 6). From 5 cm to the surface the community is strongly dominated by *Bosmina*, all other taxa are at lower relative abundance than was seen at the bottom of the core, with the exception of the *Alona quadrangularis* and *Alonella nana* (Fig. 5). Concentration data for the top 5 cm showed a rise and fall in productivity of *Bosmina,* although all five intervals are higher than those seen at the base of the core (Fig. 6). *Daphnia* productivity increased over the top 5 cm of the core to levels that were slightly above those seen earlier in the core.

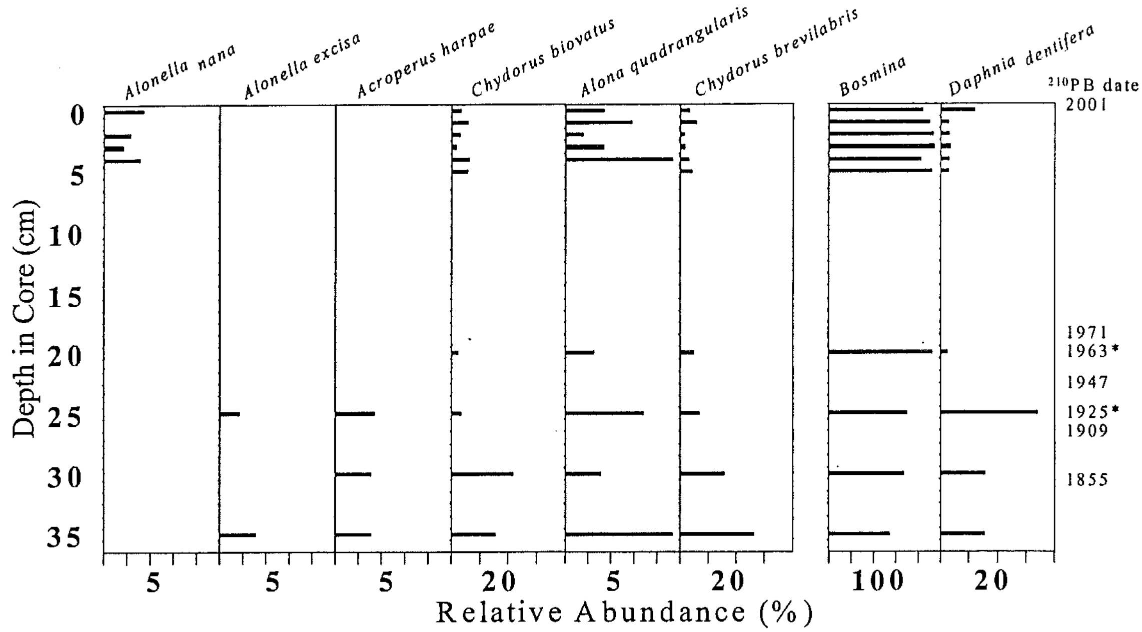


Fig. 5 Relative abundance of cladoceran remains in Wahleach core. Littoral taxa are grouped on the left; planktonic taxa are grouped on the right. * Denotes an interpolated ^{210}Pb date.

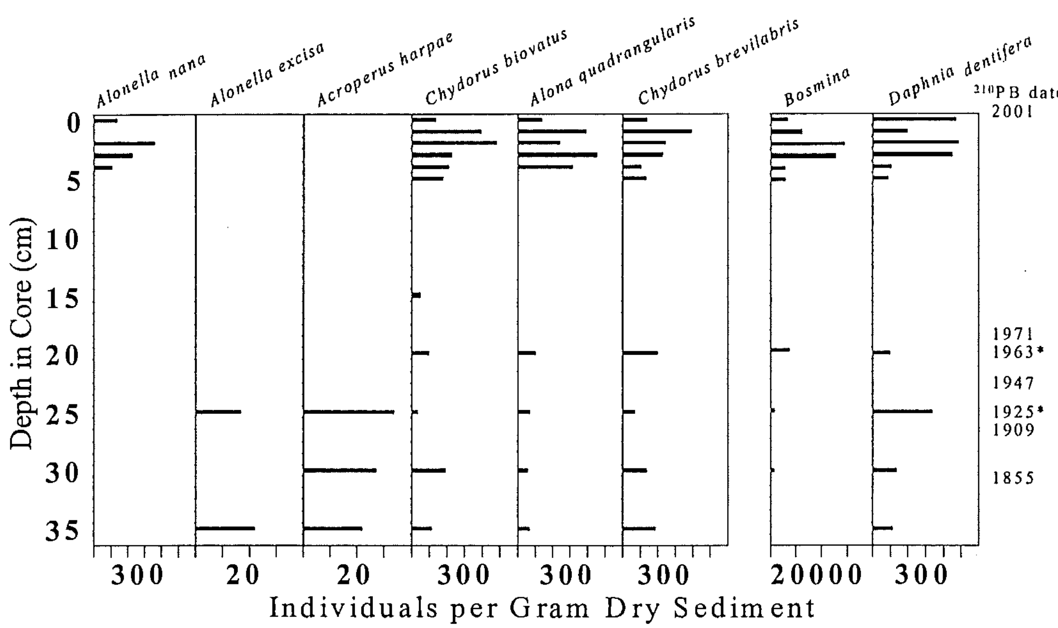


Fig. 6 Concentration of cladoceran remains in Wahleach core. Littoral taxa are grouped on the left; planktonic taxa are grouped on the right. * Denotes an interpolated ^{210}Pb date.

Diatoms. The diatom data from Wahleach Reservoir showed remarkable stability throughout the core with most species present in all intervals. The earliest three intervals (original lake sediment) show stability with little change in the relative abundance (Fig. 7) or concentration (Fig. 8). At 20 cm depth the community changes slightly, planktonic taxa with relatively higher TP optima, such as *Fragilaria acus, Cyclotella glomerata, Asterionella formosa,* become more abundant. At the same time many species associated with benthic habitats decrease slightly in relative abundance (Fig. 7). However, concentration data for the same intervals suggest most of this trend is created by increases in planktonic taxa at 20 cm rather than decreases in littoral taxa (Fig. 8). Similar to other indicators, the diatoms show a disturbance at the 15 and 10 cm intervals. At this time planktonic taxa disappeared almost entirely, while littoral taxa persisted, but at a low abundance (Fig. 8). Over the top 5 cm of the core there is a pulse in many planktonic species, first increasing and then falling back slightly. Over the same period many littoral species maintain similar concentrations. As a result there is an increase in the planktonic/littoral ratio, and the relative abundance of many littoral species decreases. Much of this change is driven by *Cyclotella glomerata*, which often has greater than 60% relative abundance. Although a few species disappear in the top five centimeters, *Suriella spp.* and *Fragilaria vaucheriae,* most changes are within species abundance rather than a switching of species.

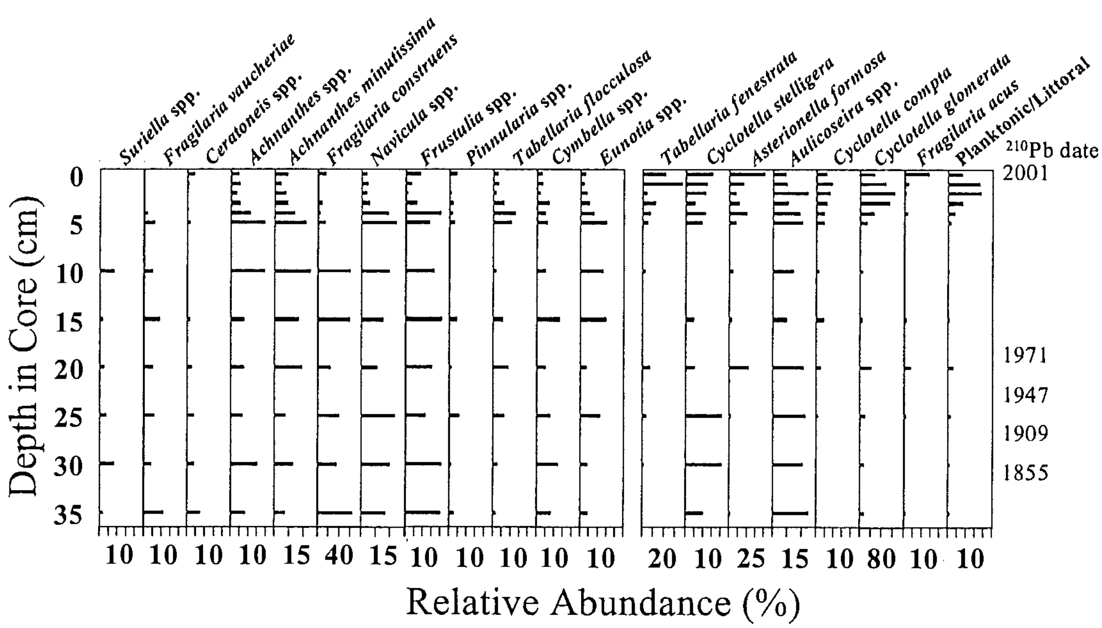


Fig. 7 Relative abundance of diatom species in the Wahleach Reservoir sediment core 1. Littoral taxa are grouped on the left and pelagic taxa are grouped on the right.

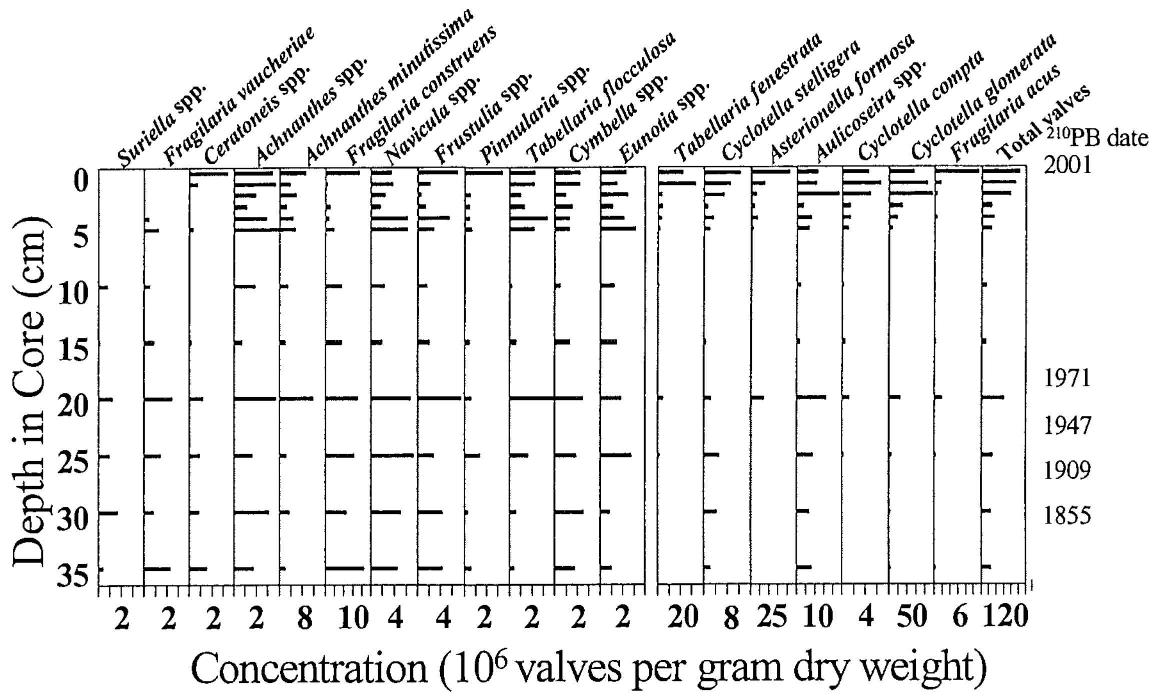


Fig. 8 Concentration of diatom species in the Wahleach Reservoir sediment core. Littoral taxa are grouped on the left and pelagic taxa are grouped on the right.

Pigments. Algal pigment data in the core showed a very similar trend to that seen in the diatom data (Fig. 9). In general shifts were seen within an algal group, rather than a switching between groups. Shifts in pigment concentration

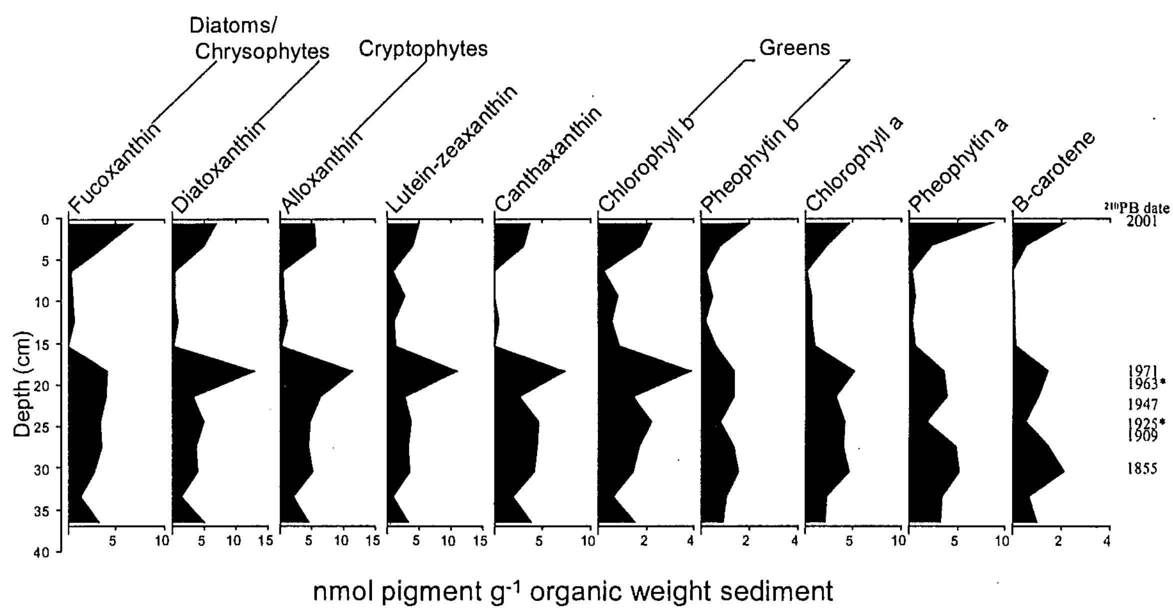


Fig. 9 Fossil phytoplankton pigment concentrations in Wahleach Reservoir.

are synchronous across a wide group of algae, indicating that the algal community was largely responding in concert. Pigment concentrations are generally low in the early part of the core with peaks in many groups at 18.25 cm. Most notable are the increases in pigments related to diatoms, cryptophytes, blue-green and green algae. As noted in other indicators there were very low levels of pigments between 18 and 5 cm in the core. After 5 cm pigment concentrations increased in all groups.

Stave Reservoir

C/N analyses Carbon and Nitrogen analyses on the Stave Reservoir core show a period of sustained low concentration prior to 16 cm

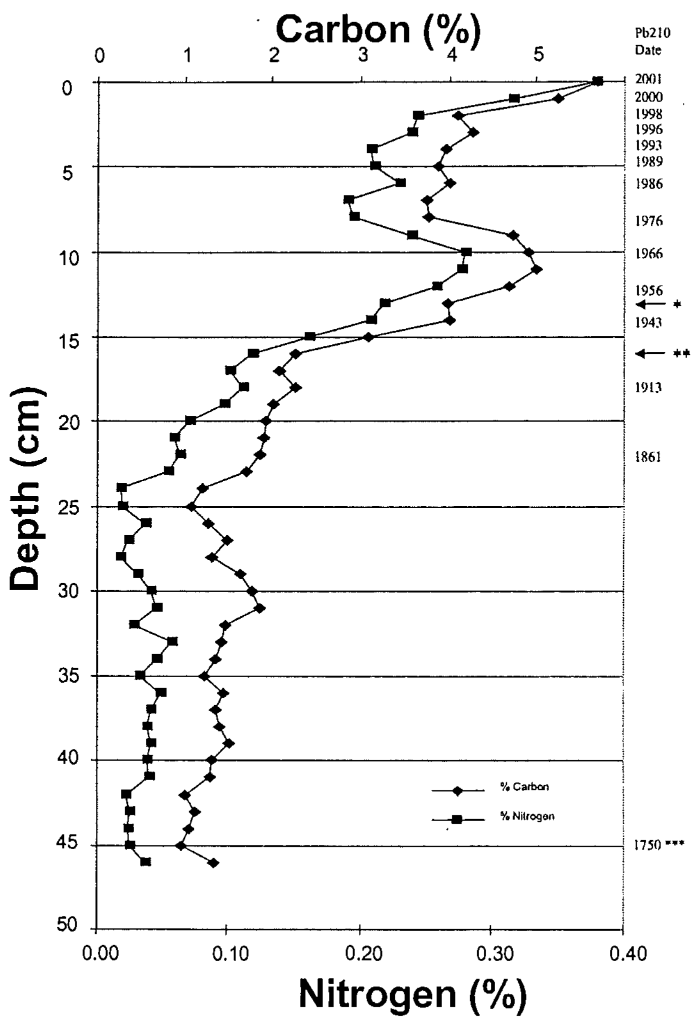
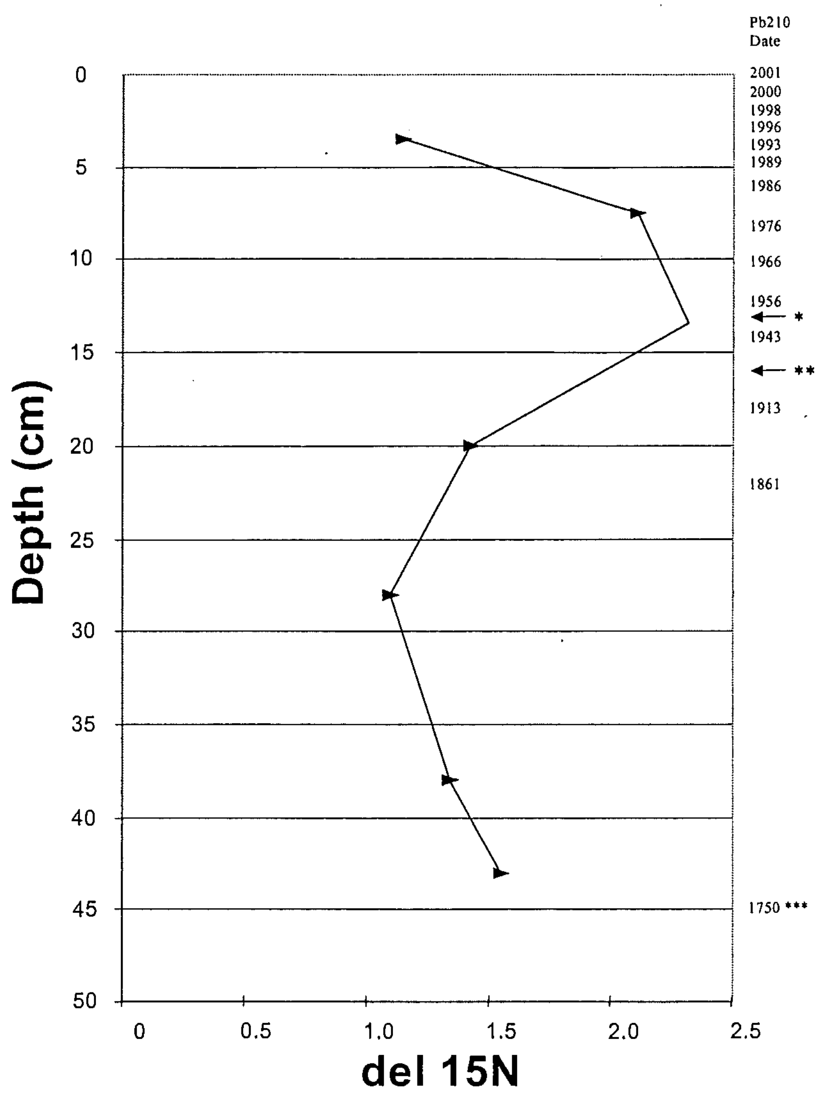


Fig. 10 Carbon and Nitrogen content of the Stave Reservoir sediment core. Dates are shown for interval analyzed for ^{210}Pb. * Initiation of diverting hypolimnetic water from Alouette Reservoir into Stave. ** The 1928 impoundment of the lake to form the reservoir. *** Extrapolated date using sedimentation rate between 18.5 and 22.5cm in the core.

(1929±5 yrs) (Fig.10). After 16 cm C and N content of the core steadily increases to a peak at 13 cm (1950±3 years), at which point values are nearly double levels seen at 16cm. C and N content then declines again stabilizing by 8cm (1976±1 year). Following 8 cm, C and N levels remain relatively stable through to 2 cm in the core (1998±1 year), after which they increase dramatically at the 1 cm and surface interval.

^{15}N analyses Unlike C and N, ^{15}N did not show a trend with depth. Throughout the core ^{15}N levels remain low (Fig. 11).



<u>Fig. 11</u> ^{15}N analysis of the Stave Reservoir sediments. Dates are shown for interval analyzed for ^{210}Pb. * Initiation of diverting hypolimnetic water from Alouette Reservoir into Stave. ** The 1928 impoundment of the lake to form the reservoir. *** Extrapolated date using sedimentation rate between 18.5 and 22.5cm in the core.

Zooplankton. Cladoceran remains from the Stave core show a similar pattern to that seen with C and N. Initially the accumulation rate was very low in the core, in fact for the bottom four intervals, the density of zooplankton remains was so low that it was impossible to reach the minimum cut-off of 40 individuals, even after counting 1 mL (5 cover-slips) of the sediment slurry. During this period the assemblage is almost completely comprised of *Bosmina,* with very low numbers of littoral cladocera also present (Fig. 12). Consistent with the increase in C and N seen after reservoir formation, the accumulation rate of cladocera also increased dramatically at 15 cm in the core. Maximum cladoceran abundance is seen at 10 cm, which coincides with the peak in C and N content of the core. *Daphnia* also appears in the assemblage at this time. Following this peak levels drop somewhat for the 5 cm and surface interval of the core. However, the accumulation rate of *Daphnia* actually increases further during this period, and the accumulation rate of 4 other species remains higher than noted in the lowest part of the core. Counts for the surface interval of the core were somewhat low due to the high water content of this portion of the core.

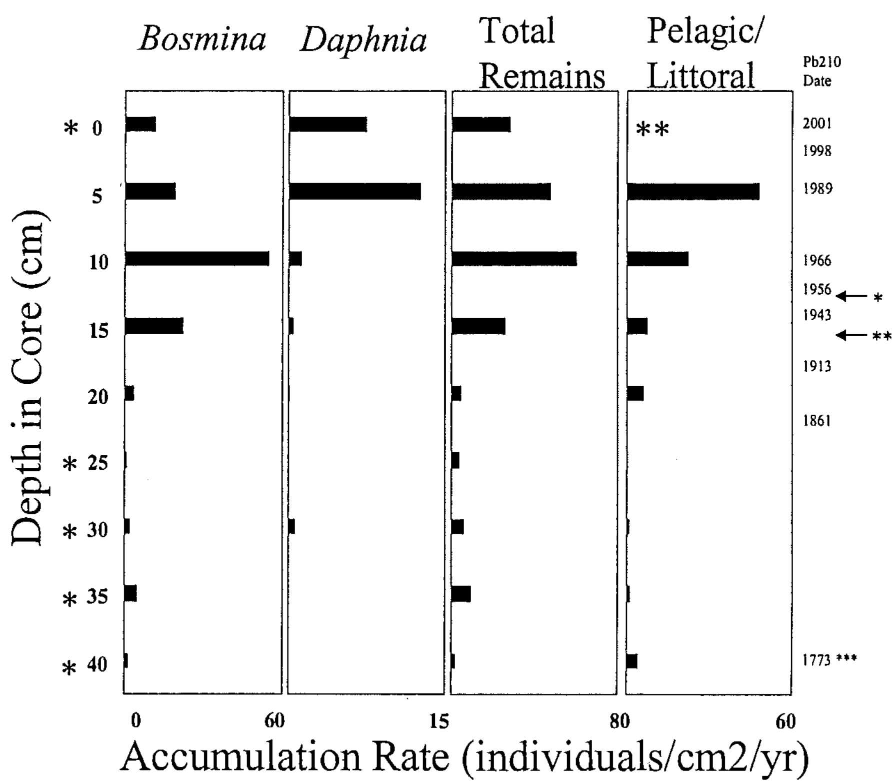


Fig. 12 Cladoceran remains from the Stave Lake sediment core. Dates are shown for interval analyzed for ^{210}Pb. * Initiation of diverting hypolimnetic water from Alouette Reservoir into Stave. ** The 1928 impoundment of the lake to form the reservoir. *** Extrapolated date using sedimentation rate between 18.5 and 22.5cm in the core.

Diatoms. The diatom assemblage in Stave Reservoir shows very little change over the approximately 230 yr history of the core. Most changes that occur are within the abundance of individual species rather than changes in the species composition of the assemblage. Across almost all species there is a pattern of low accumulation rates for the bottom five samples of the core (Fig. 13). After reservoir formation, the accumulation rate of most species increases slightly. After diversion of water from Alouette Reservoir into Stave, the accumulation rates for all species increase again and remain elevated compared to pre-impoundment levels. Only two taxa are not present throughout the core - *Fragilaria acus* and *Pinnularia* spp. and both do not appear in the core until after the diversion of water from Alouette Reservoir into Stave.

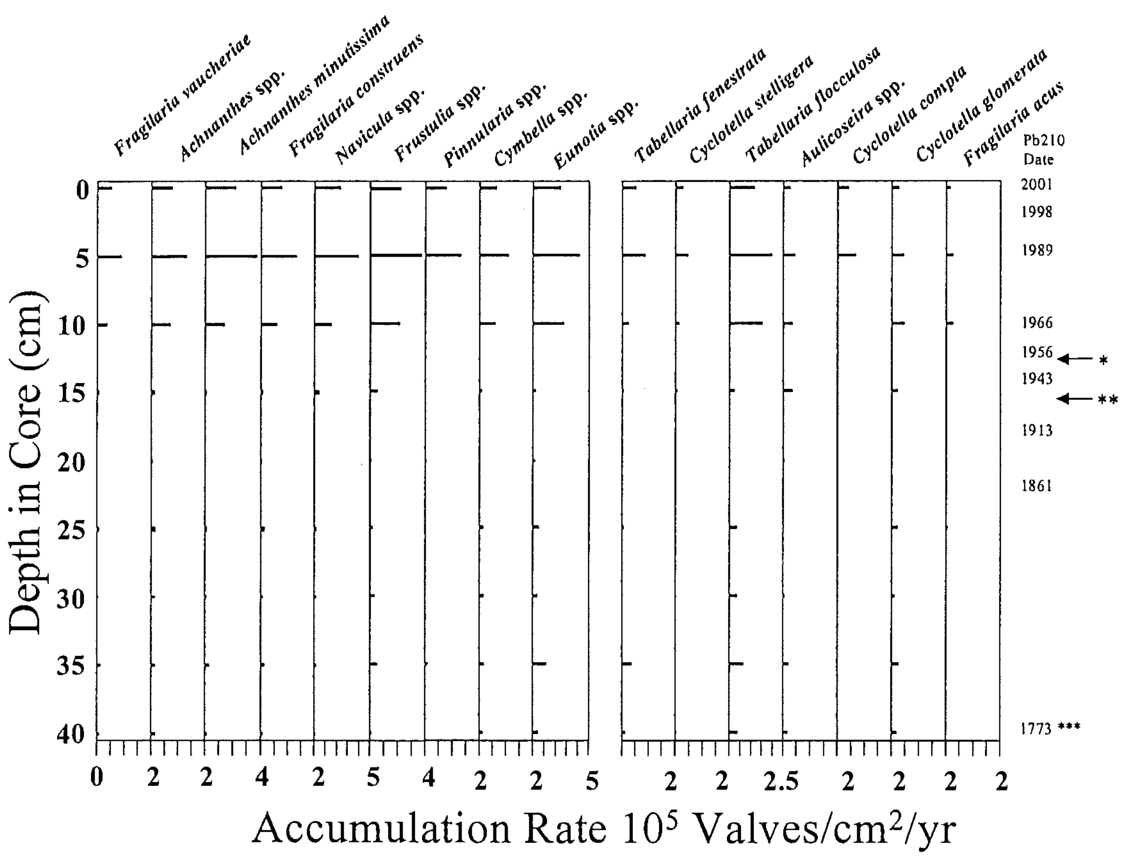


Fig. 13 Diatom species assemblage from the Stave Reservoir sediment core. Dates are shown for interval analyzed for ^{210}Pb. * Initiation of diverting hypolimnetic water from Alouette Reservoir into Stave. ** The 1928 impoundment of the lake to form the reservoir. *** Extrapolated date using sedimentation rate between 18.5 and 22.5cm in the core.

Pigments. Generally, the concentrations of pigments in the Stave Reservoir core are low, about one tenth that seen in a mesotrophic lake (Peter Leavitt, Univ. Regina, personal communication). Overall algal productivity for the

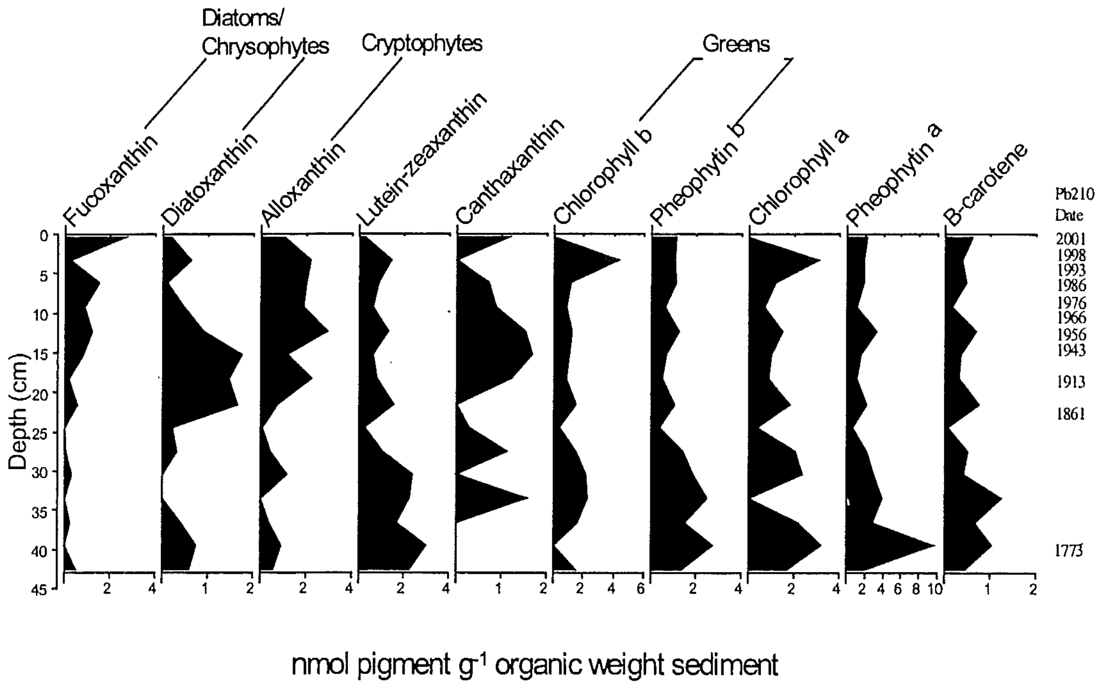


Fig. 14 Fossil phytoplankton pigment concentrations in Stave Reservoir sediment.

system, as indicated by chlorophyll a, pheophytin a and B-carotene, is highest at the base of the core, although the changes over the entire core are modest (Fig. 14). Decreases in the algal pigments associated with green algae (lutein-zeaxanthin and phoephytin b) are seen after 25 cm depth, while Cyanobacteria (canthaxanthin) diatoms, Chrysophytes and Cryptophytes generally increase after this period.

Discussion

Wahleach Reservoir

Core Disturbance

The pattern of ^{210}Pb activity in Wahleach is unusual and is consistent with allochthonous (and perhaps autochthonous) material low in ^{210}Pb being re-deposited at the coring site, i.e. caused by debris torrent, slope failure, etc. This material low in ^{210}Pb was probably deposited in the lake between 18.75 and 5 cm in the core. The high levels of coarse and unworn clastic material seen in relatively high-power microscopic cladoceran and diatom counts at 15 cm and 10 cm also confirm that there were large inputs of terrestrial material into the lake/reservoir at this time. All of the other indicators used also show disturbance during this period. Pigment concentrations become very low across all groups of algae, which is consistent with a large disturbance that either introduced terrestrial material, or well oxygenated existing pigments thus destroying them. Cladoceran remains also disappear during this period, again supporting the hypothesis that large amounts of terrestrial material were deposited on top of existing sediment during this time. Diatoms show almost a complete loss of pelagic species during this period, while littoral species show decreases but remain present. Taken together, these data support the hypothesis that large amounts of terrestrial material have been washed into the lake, likely as a result of intense erosion associated with logging roads and associated slope failures during heavy rain events.. As this material was swept into the lake the suspended terrestrial material would have increased the density of the incoming water making it more likely to incorporate some littoral sediments in a turbidity plume. This effect would have been exacerbated if the reservoir were at a low level during periods of heavy rain. Inclusion of material from the littoral zone of the lake would explain why littoral species of diatoms remain present in the core throughout the disturbed period, although at lower levels, while planktonic species disappear almost entirely. Although cladoceran and pigment remains are commonly deposited in the littoral zone, both would likely be destroyed by exposure (desiccation) during periods of reservoir drawdown.

Whether the introduction of terrestrial material took place as a single event (a slope failure and associated turbidity plume and currents in the lake), several smaller events, or a combination therein is unknown. A likely explanation is that one or a few large events were responsible for the massive deposition between 18.75 cm and 5 cm in the core. One likely source for the terrestrial material is slope failure related to logging in the basin. Both the removal of the trees and poor logging road construction would have contributed to destabilizing the steep slopes of the Wahleach drainage basin. Logging began in the basin in 1958 and in 1973 Whonnock Lumber was fined for sediment transport into Jones creek due to road failure (Perrin and Stables 2000). Thus, samples found immediately below the disturbed layer in the sediment core likely represent the post-impoundment period of the reservoir. Lower levels of erosion may *still* be occurring in these areas as suggested by the continued presence of unworn clastic material from 5 cm to the top of the core

Dating

The irregular sediments of the Wahleach core make ^{210}Pb dating difficult. Dates are most reliable when cores show little or no signs of disturbance, little or no change in sedimentation rate, and an exponential decrease in ^{210}Pb activity with accumulated sediment. None of these characteristics are seen in the Wahleach core above 18 cm. However, given the very low activity seen between 12 and 6 cm it is reasonable to assume that the material entering the lake during the disturbance did not contain excess ^{210}Pb (Jack Cornett, Mycore Inc., personal communication). Thus the peak in ^{210}Pb at 18cm may be interpreted as undisturbed and dates maybe be assigned from that level downward using the surface sample to determine the initial activity.

Environmental Historic Reconstruction

Carbon (C) and Nitrogen (N) data are both low and stable in the earliest part of the core (below 25 cm, 'original' lake sediment), and indicate a condition of low to moderate productivity at the turn of the century in Wahleach Lake. Consistent with this data, the cladoceran assemblage is dominated by *Bosmina*, but also has *Daphnia,* a combination that is common in coastal lakes with moderate to low productivity (Stockner 1987). Similarly, the concentration of diatom valves and algal pigments in the sediment is low and stable. During this period the diatoms are dominated by oligo- to mesotrophic taxa such as *Fragilaria construens* (TP_{optima} = 16.5 ug/L) (Cumming et al. 1998) and *Aulicoseira* spp.

Starting at 25 cm C and N concentrations begin to increase in the sediments. However, little response can be seen in the biological indicators at this time. Fish stocking also began in the reservoir around this time and it is likely that adding fish to the barren lake may have changed nutrient cycling in the lake. The continued presence of *Daphnia* at 25 cm suggests that the lake maintained a favorable environment for the introduced fish. Because of its larger size, *Daphnia* is the preferred zooplankton prey of most planktivorous fish (e.g. Brooks and Dodson 1965, Kerfoot 1981, Mills et al. 1987, Jeppeson 1986).

While the cause of the initial increases in productivity around 25 cm is unclear, the dramatic increase in C and N at 22 cm and 21 cm corresponds to the years 1952 and 1958 and is almost certainly the result of reservoir formation and the introduction of nutrients during flooding and subsequent decomposition of vegetation and organic matter in surficial soils ('boom' cycle). However this increase in productivity in Wahleach was short-lived, and by 1963 (20cm) productivity had dropped off appreciably ('bust' cycle). Unfortunately, right after this period the disturbance in the core prohibits interpretation until we get to the 5 cm depth. At this point C and N content are similar to that seen at 20 cm. This is consistent with contemporary research on reservoirs in which a relatively short-lived increase in productivity is followed by a protracted decrease in productivity (Stockner et al. 2000). The considerable increase in N over the top five centimeters of the core is likely a direct of result of its addition during lake fertilization experiments that began in 1995. The modest increases in C content in top layers are likely the result of enhanced primary productivity commensurate with nutrient addition.

Comparing the pre-flooding stage (samples below 23 cm) to the post-flooding, pre-fertilization conditions (5 cm), there is a shift to a cladoceran assemblage strongly dominated by *Bosmina* with few *Daphnia* suggesting a decrease in the productivity of the lake. While *Chydorus biovatus* and *Chydorus brevilabris*, which are normally associated with more productive conditions, also decrease over this period, it is difficult to separate this decline from decreased productivity or from loss of macrophyte vegetation in the reservoir, which is one of their primary habitats. Because of it larger size, *Daphnia* is the preferred prey for many fish species. It's disappearance after flooding of the reservoir is likely related to its greater physiological requirement for higher phosphorus levels, and the ability of planktivorous fish to graze its population down to low levels more effectively when productivity is low. The appearance of *Alonella nana* over the top 5 cm of the core is most likely related to it ability to utilize benthic substrates with finer structures due to its small size. Unlike many of the macrophyte-associated species, *Alonella nana* can utilize the fine sediment and debris of the reservoir littoral zone.

The top five centimeters of the core confirm that Wahleach reservoir has been responding favorably to fertilization. The 5cm interval is likely from the early 1990's and represents the pre-fertilization state. Following this interval, dramatic increases in the concentration of all cladoceran species present can be seen. These results are similar to those observed by Perrin and Stables (2001) during lake fertilization. Initially, they observed increases in *Bosmina* concentration in 1995 through 1998, which began to fall-off in 1999 and 2000. They also observed *Daphnia* appearing in 1998 and becoming most abundant in 2000. In this case, our record differs slightly in that we show that *Daphnia* was always present, just at low abundance, however the increase in 1998 parallels those seen at 3cm and 4cm, while a slight decrease in 1999 is seen at 1cm, and the top-most section again shows very high levels of *Daphnia*, as were seen by Perrin and Stables in 2000.

The diatom assemblages indicate that 'original' Wahleach Lake was shallow and must have had extensive littoral development with submergent macrophytes, because attached epiphytic and epipelic diatoms dominate the earliest sediment horizon, e.g. *Achnanthes minutissima*, *Frustrulia* spp., *Navicula* spp., *Cymbella* sp. and *Fragilaria construens*. The major pelagic species were *Cyclotella stelligera* and *Aulicoseira* spp. but they were in low abundance indicating oligotrophic conditions in the original lake. Following the initial impoundment of the lake and creation of the larger Wahleach reservoir there was a slight rise in both pelagic and littoral species that was sustained for more than a decade. However, the most striking change in diatom assemblages coincides with the commencement of reservoir fertilization in 1995, and is highlighted by the predominance of pelagic species in moderate abundance, most notably *Cyclotella glomerata, Tabellaria fenestrata* and *Fragilaria acus*, species quick to respond to nutrient pulses and commonly observed in fertilized BC coastal oligotrophic lakes (Stockner et al. 1980, Shortreed & Stockner 1990).

Stave Reservoir

Environmental Historic Reconstruction

Carbon and nitrogen content of the sediment core increase dramatically after 1928, which coincides with the flooding of Stave Lake to form the reservoir. This response is consistent with the increase in productivity that has been seen in other reservoirs after impoundment releases nutrients from the flooded terrestrial material (Stockner et al. 2000). Throughout the core the ratio of carbon to nitrogen in the core remains relatively constant, which suggests that the increases in carbon and nitrogen seen are from increased within lake production rather than material being re-deposited from the terrestrial catchment basin. The further increases in C and N concentration seen after 1952 are likely the result of diverting nutrient enriched hypolimnetic water from Alouette Reservoir into Stave Reservoir. This water likely contained sufficient nutrients to prevent the bust phase of oligotrophication that is commonly seen after an initial pulse in productivity. The increases in C and N seen in the two most recent sections of the sediment core (approx. 1998 to 2001) suggest that recent nutrient additions to increase productivity in Alouette Reservoir are being mirrored in Stave Lake, again due to the large inputs of hypolimnetic water from 'fertilized' Alouette Reservoir.

Changes in cladoceran and diatom abundance in the core are consistent with the changes seen in C and N profiles. The low accumulation rates and dominance of *Bosmina* in the bottom four intervals of the core indicate that the 'original' Stave Lake was relatively unproductive pre-impoundment. Following reservoir formation the accumulation rates of Cladocera and diatoms both increase, which is consistent with the pulse in productivity seen in many reservoirs shortly after impoundment. However, Stave seems to diverge from the usual trend of decreasing productivity due to nutrient loss to sedimentation and increased outflow that is common in many hydroelectric reservoirs. Both cladoceran and diatom accumulation rates increase even further after the diverting water from Alouette were introduced to Stave. This increase is not transient, but continues to the top of the core. Although both of these reservoirs are warm monomictic lakes, it would appear that the hypolimnetic water from Alouette reservoir is sufficiently nutrient enriched to increase productivity in Stave.

^{15}N analyses of the sediment core shows that levels have been very low throughout the last 250-275 years. The small increase seen after 15 cm in the core may be the result of reservoir flooding causing groundwater enriched with ^{15}N to be mixed into the lake (Daniel Schindler, University of Washington, personal communication). The low levels of ^{15}N found in Stave are comparable to the levels found in most lakes that have no anadromous salmon returns. The observed shift to slightly higher ^{15}N levels *after* reservoir formation and dam construction, an event that would have effectively blocked *all* entry of salmon into Stave, indicates that Stave Lake prior to impoundment did not have large or significant returns of anadromous salmon over the last 2-3 centuries.

Summary

Wahleach Reservoir. Historic reconstruction of events that have affected Wahleach Lake/Reservoir production over the past century were made more difficult by an intrusive layer caused by either one major or several smaller depositional events that introduced large amounts of sediment over the span of a decade or two in the latter half of last century. Nonetheless, examination of the sediment has revealed several interesting events that brought change to the ecosystem. Our analyses suggest that the 'original' Wahleach Lake was a small, perched, fishless lake that was relatively shallow with growth of emergent macrophytes within an extensive littoral zone. It is likely that annual littoral production exceeded pelagic production. Introduction of fish in 1928 and other anthropogenic impacts within the catchment, e.g. mining, fishing, subtly changed the nutrient dynamics of the ecosystem. Impoundment of the lake in the 1950s brought nutrient enrichment from flooded landscape and increases in pelagic production. But by far the most profound changes came from logging and road construction in the 1960s and 70s. Forest removal and roads must have resulted in slope failures and debris torrents during heavy rain events that introduced large quantities of silt and debris into the small reservoir (+/-13 cm of sediment accrual). The commencement of a reservoir fertilization program in 1995 to restore fisheries potentials of Wahleach has markedly enhanced pelagic production and shifted ecosystem carbon production from an 'original' littoral to a present pelagic predominance.

Stave Reservoir. Stave's historic reconstruction is not puzzled by large depositional events as was the case for Wahleach, and our analyses clearly show that impoundment of the Stave River in the late 1920s changed an unproductive, ultra-oligotrophic fast-flushing lake into a larger and more productive pelagic driven ecosystem. Nutrient releases from flooded landscapes enhanced pelagic carbon production, but this increase was transient, lasting only a few decades and then began to decline only to be enhanced again when discharges of hypolimnetic water from Alouette Reservoir were diverted to Stave in the early 1950s. The C/N data indicates that the continued discharge of Alouette water to Stave Reservoir has stabilized pelagic production at higher levels than occurred in the 'parent' low production Stave Lake. Very high C/N values in the most recent sediment suggest that the current Alouette Reservoir fertilization program for fisheries restoration may also be enhancing the carbon production of Stave. Low ^{15}N values in deep lake sediment from 'original' Stave Lake indicate that that the old lake did not support a run of anadromous salmon due to an effective migration blockage at Stave Falls. Distribution and abundance of fossil littoral and pelagic diatoms indicate that pelagic production has dominated the system throughout the past 2 centuries and in the last decade has attained highest levels.

Acknowledgements

We are grateful to Ms Carol Lamont, BC Hydro and Power Authority, and Ross Newman, Ministry of Water Land & Air Protection (MWL&AP) for initiating the contract and to Ms. Janice Doane, BC Hydro and Ross Newman for acting as contract authorities. We appreciate the help of Kiyo Masuda and Chris Perrin of Limnotek for assistance in obtaining the Wahleach cores, and thank Bob Land and Greg Wilson (MWL&AP) for their assistance in obtaining Stave cores. We greatly appreciate the assistance of Dr. Peter Leavitt, University of Regina, Laboratory of Limnology, for doing the pigment and ^{15}N analyses, and offering expert opinion on interpretations of profiles. Jack Cornett, Mycore Scientific, Dunrobin, Ontario did the ^{210}Pb dating and helped with the difficult chronology of the Wahleach core. We thank Drs. Les Lavkulich and Hans Schreier, Institute for Resources and Environment, UBC, for use of the C/N analyzer at the Soil Science Lab, and wish to extent our thanks to Carol Dyck and Keren Ferguson for doing the core C/N sample analyses. We are also grateful for additional ^{15}N analyses provided by Erland MacIsaac, DFO – Science Branch Pacific, SFU, Vancouver.

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