



Contents lists available at SciVerse ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Recent palaeolimnological change recorded in Lake Xiaolongwan, northeast China: Climatic versus anthropogenic forcing

Virginia N. Panizzo^{a,*}, Anson W. Mackay^a, Neil L. Rose^a, Patrick Rioual^b, Melanie J. Leng^{c,d}^a Environmental Change Research Centre, Department of Geography, University College London, Pearson Building, Gower Street, London WC1E 6BT, UK^b Key Laboratory of Cenozoic Geology & Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, P.O. Box 9825, Beijing 100029, People's Republic of China^c Department of Geology, University of Leicester, Leicester LE1 7RH, UK^d NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK

ARTICLE INFO

Article history:

Available online 5 August 2012

ABSTRACT

Lake Xiaolongwan is a closed maar lake located in the Long Gang Volcanic Field, northeast China. Core XLW2 was collected in 2007 from the central region of the lake and provides a palaeoecological reconstruction over the past ca. 130 years (dated using radiometric methods: ²¹⁰Pb and ¹³⁷Cs). Diatom floristic changes and catchment productivity (carbon isotope ratios) were analysed within the core. Indicators of atmospheric pollution (XRF and SCP inventories) were also measured. Results show a marked transition from a dominant benthic assemblage to a planktonic one (increasing P:B ratios) starting after ca. 1940 AD, becoming most prominent after ca. 1980 AD (P:B > 1). Most notable floristic changes result from the increase in the planktonic species *Discostella woltereckii*. These changes are concomitant with increased temperature trends from the region and reconstructed temperature anomalies of the Northern Hemisphere. SCP concentrations and flux rates also increase after ca. 1950 AD, with highest values seen at ca. 1980 AD after which values decline. Normalised elemental geochemistry (e.g. Pb/Ti) also show marked changes after ca. 1970 AD, most likely derived from atmospheric deposition of Pb. The recent increase in *D. woltereckii* precedes anthropogenic contamination (Pb/Ti) at the site and persists after the decline in SCP concentrations. This suggests that the recent increases are driven by increased mean annual temperature trends. These temperature trends may be manifested as changes in ice cover persistence, a longer growing season and/or increased DOC at Lake Xiaolongwan: conditions for which planktonic species have a more competitive advantage.

© 2012 Elsevier Ltd and INQUA. All rights reserved.

1. Introduction

It is now well established that lakes, particularly in heavily polluted regions, have been impacted by anthropogenic contamination over the past ca. 150 years, e.g. through acidification (e.g. O'Dwyer and Taylor, 2010; Battarbee and Bennion, 2011) and heavy metal pollution (e.g. Thevenon et al., 2011). Many of these studies have focused on the regions of North America and Europe, where ecological thresholds are frequently crossed due to the sheer scale of atmospheric deposition and anthropogenic nutrient loading (e.g. nitrogen hotspots such as the Rocky Mountains, North America, Saros et al., 2003; western North America, western Canada and the Arctic, Holtgrieve et al., 2011). Increasingly, impacts upon lakes in remote regions, including increased mercury (Hg) accumulation in Arctic Canada (Kirk et al., 2011) and Svalbard (Drevnick et al., 2012)

and lead (Pb) deposition in European Arctic and alpine lakes (Camarero et al., 2009; Liu et al., 2012), have been detected. Contamination in remote, continental regions such as the Tibetan Plateau have also been reported (e.g. Pb and Hg deposition; Wang et al., 2010; Yang et al., 2010a; persistent organic pesticides (POPs) and polychlorinated biphenyls (PCBs); Yang et al., 2010b), at least some of which may be deposited after long-range transport (Yang et al., 2010a). Atmospheric transport and deposition of Hg has resulted in widespread contamination (Fitzgerald et al., 2005; Lindberg et al., 2007), potentially impacting sensitive ecosystems, as well as yielding concerns over its toxicity (Hylander and Meili, 2005). However, despite such marked pollution (e.g. Wang et al., 2010; Yang et al., 2010a, 2010b), evidence suggests that over the 20th century, in the remote region of the Tibetan Plateau, and in the context of this paper, diatom community changes have been modest. Wischniewski et al. (2011) highlight that lake geochemistry changes are more apparent than those of diatom species, with the latter showing only muted changes. This is thought to be most likely a response to localized and/or negative climate feedbacks and

* Corresponding author.

E-mail address: virginia.panizzo@nottingham.ac.uk (V.N. Panizzo).

highlights that pollution effects do not have a clear, coherent impact upon lakes in this region (Wischniewski et al., 2011).

The 20th century global air temperature rise north of 60°N is well documented with warming in the order of 1.5 °C being observed in the periods between ca. 1915 and 1940 AD and from the late 1960s until 2010 AD (e.g. Moritz et al., 2002; Jones and Moberg, 2003; Mann et al., 2008; Manabe et al., 2011). In the context of the past ca. 150 years, temperature rise over the past two to three decades has been particularly prominent (Jansen et al., 2007). This recent warming, and subsequent increases in the length of the ice-free season, has been found to affect algal assemblages in circum-Arctic lakes and ponds (Smol et al., 2005) as well as alpine and temperate lakes (Rühland et al., 2008). Similar ecosystem responses have also been shown from sites in northeastern China, based on analyses of regional time-series data, where the length of the spring season has increased by more than 10 days and the summer season by up to 40 days, over the period 1951–2000 AD (Dong et al., 2010; Liu et al., 2010).

Rühland et al. (2008) provide a coherent picture that climate-driven, taxon-specific changes, especially increases in planktonic diatoms such as *Discostella* taxa (previously named *Cyclotella*) are now evident across large regions of the Northern Hemisphere (NH), representing a wide spectrum of non-acidified/non-enriched lake ecosystems. Many of these lake ecosystems have crossed ecological thresholds, with changing climate, initiated in the 19th century in Arctic and alpine regions, but which typically only occurred in the mid-20th century in lakes from mid-latitude regions of North America and Europe (Rühland et al., 2008). Rapid changes in other algal populations (e.g. chrysophytes) have also been shown to occur since the latter part of the 20th century (e.g. in Canadian high and mid Arctic regions; Wolfe and Perren, 2001) implying that such biological changes are now apparent in different algal groups. However, evidence of 20th century warming is not spatially coherent across the Arctic (e.g. northern Québec; Laing et al., 2002). In particular regions of northern Labrador, in the Canadian Arctic, these trends have not been found. For example, at Saglek Lake-15, Paterson et al. (2003) highlight that minimal evidence of 20th century warming exists, compared with other regions of the Arctic and sub-Arctic. They discuss that only muted changes are seen in diatom and chrysophyte assemblages, at both Saglek Lake-15 (reference site) and neighbouring Saglek Lake-2, with the latter also documenting high values of PCB contamination since the mid-20th century. Paterson et al. (2003) further outline that recent warming documented across the Arctic is most likely driving diatom regime shifts (e.g. increase in planktonic *Discostella* species) rather than long distance transport of pollutants, documented in lake sediments from other regions of the Arctic and sub-Arctic, outside of northern Labrador and northern Québec (Finney et al., 2004). This argument is being increasingly supported (e.g. Rühland et al., 2003a, 2008; Smol et al., 2005). In northeast China, similar diatom floristic changes have now been identified, where abundances in *Discostella pseudostelligera* increased in tandem with records of increased summer temperatures (Wang et al., 2012), which result in longer lake thermal stratification periods (and weaker wind driven mixing) in summer months (Sorvari et al., 2002; Rühland et al., 2003a). Contemporary monitoring at Lake Tahoe shows that with intensified lake stratification, abundances of small celled phytoplankton (namely the diatom genus *Discostella*) increased due to their competitive advantage over larger sized cells (e.g. *Stephanodiscus*), which is believed to be a result of their ability to survive in more nutrient deplete conditions following reduced lake mixing and/or as a result of reduced lake water clarity, as these valves have a lower sinking velocity (Winder and Hunter, 2008; Winder et al., 2009). Other evidence has shown that benthic assemblages decline as a response to reduced periods of lake ice

cover duration, another response to increasing trends in mean annual temperatures (e.g. Lotter and Bigler, 2000).

As well as causing problems of aquatic contamination, fossil fuel combustion has made a significant contribution to global warming over the past century (Oreskes, 2004). Direct interactions between pollutants and climate change are also increasingly being recognized. Indeed, there is also a strong relationship between 20th century climate trends and byproducts of anthropogenic combustion (e.g. nitrogen, sulphur and heavy metal deposition) (Curtis et al., 2009; Pla et al., 2009). For example, in parts of the Tibetan Plateau, You et al. (2009) describe the clearly weakened effect in diurnal temperature ranges (important in regulating precipitation and circulation) due to anthropogenic emissions. In northeast China, Yu et al. (2011) investigated atmospheric deposition in response to industrialisation, and in particular the role that deposited pollutants may play in influencing sensitive ecosystems. Instrumental data from regions affected by the East Asian Summer Monsoon (EASM) document considerable decadal variability during the second part of the 20th century, displayed as persistent moisture anomalies (Li et al., 2009). In order to aid in the discussions of forcing factors triggering this change (e.g. natural versus anthropogenic), particularly in regions where data are sparse, this study provides a detailed investigation of recent floristic changes in diatom species composition from a small, remote crater lake in northeast China. The analysis of pollutants (trace metals and spheroidal carbonaceous particle (SCPs)) as well as lake and catchment productivity (as measured by $\delta^{13}\text{C}$), enable a detailed discussion of environmental change over the past ca. 150 years.

2. Regional setting

Lake Xiaolongwan is one of eight maar lakes present in the Long Gang Volcanic Field (LGVF), Jilin Province, NE China (Fig. 1). Mean annual temperature for the region (between 1999 and 2001), based on the data from Changchun (Fig. 1) is 5.9 °C, with temperatures falling below a mean monthly value of 0 °C from November to the end of March. Highest mean monthly temperatures are in July (25.5 °C) and lowest in January (−16.7 °C). Total mean annual precipitation for the years 1999–2001 inclusive was 444 mm and more than 65% of this rain falls during the monsoon period (June to August). The geology of the lake region is mostly composed of alkali basaltic rocks of Quaternary age (Liu et al., 2009). Lake Xiaolongwan is the smallest of the eight lakes (maximum water depth 16.2 m in August 2007, area of 0.1 km²) and is a closed basin. The lake in August 2007 had a pH of 6.7, dissolved organic carbon (DOC) of 12.3 mg l⁻¹ and surface water temperature of 22.3 °C. The catchment of Lake Xiaolongwan is covered with broadleaf (predominantly *Betula costata*) and mixed conifer vegetation. The lake is dimictic with overturn in spring (April–May) and autumn (late September–October) and a period of ice cover between November and April when regional temperatures are lowest. Stratification occurs between May and mid-September. These limnological characteristics are very sensitive to the climate of the region, making it a suitable location for investigating climate (and anthropogenic) forcing over the 20th century.

3. Materials and methods

3.1. Field methodology

On 18th August 2007 core XLW2 was collected from the central region of Lake Xiaolongwan (42°17'59.8"N; 126°21'34.3"E) using an UWITEC-gravity corer. A Plastimo hand-held Echo Sounder II was

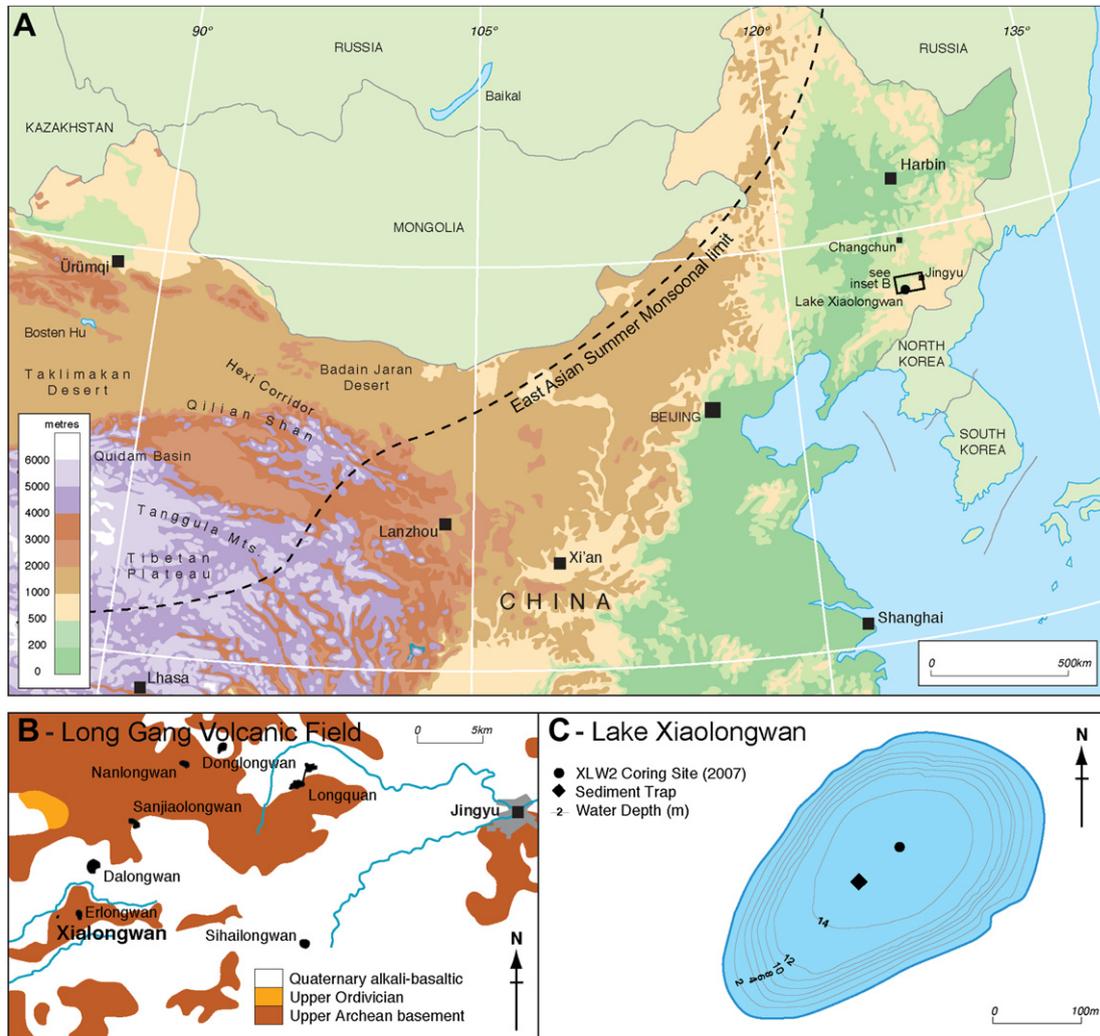


Fig. 1. A) A map of northeast China detailing the present day East Asian Summer Monsoon limit and the location of the Long Gang Volcanic Field (LGVF); B) the area of the LGVF, with the eight lakes located in the park and the main geology of the region; C) The basin of Lake Xiaolongwan, with sediment trap and XLW2 core locations detailed. Images redrawn from Mingram et al. (2004) and Chu et al. (2008).

used to locate the deepest position for coring, 16.2 m. Surface sediments were carefully sampled from the core using a syringe and transferred into labelled Whirlpack bags. Core XLW2 was extruded in the field: at every 0.5–20 cm and thereafter every 1 cm to the base at 64 cm. These sediments were very soft with a high water content and account for the long sediment record collected by the gravity corer. Samples were then stored in a dark and cool (<4 °C) environment. Only the upper 19 cm form the basis of this study because of its well-constrained chronology.

3.2. Analytical methods

3.2.1. Chronology

Radiometric techniques (^{210}Pb and ^{137}Cs) were used to date sediments from the XLW2 core. Sediment samples were dated by non-destructive gamma spectrometry (Appleby and Oldfield, 1992) at the Centre for Environmental Research, University of Sussex, UK. Ten core sub-samples were counted for at least eight hours on a Canberra well-type ultra-low background HPGc gamma ray spectrometer to determine the activities of ^{137}Cs , ^{210}Pb and other gamma emitters. The constant rate of supply (CRS) (Appleby and Oldfield, 1978) model was used here in order to generate an age model for the XLW2 record.

3.2.2. Diatom sample preparation

A total of 20 samples (0–19 cm) were analysed within core XLW2. Approximately 0.1 g of wet sediment was digested in 5 ml 5% H_2O_2 using the water bath technique (Battarbee et al., 2001). Diatom counting was conducted using a Zeiss light microscope at $\times 1000$ magnification under oil immersion and phase contrast.

A minimum of 300 valves were counted per slide. Diatom floras such as Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), Lange-Bertalot and Metzeltin (1996), Lange-Bertalot and Genkal (1999), and Vyverman (1991) were used for identification. In addition, Krammer (1992), Lange-Bertalot (2001), and Lange-Bertalot and Moser (1994) for the identification of the species *Pinnularia*, *Navicula* and *Brachysira* respectively. The work of Haworth and Hurley (1986) was used to aid the identification of *Discostella woltereckii*. For the distinction between the species *Punctastriata discoidea* and the newly identified *Punctastriata glubokoensis*, both Williams et al. (2009) and Flower (2005) were used. Diatom planktonic:benthic (P:B) ratios were calculated by grouping species based on contemporary sampling at the site. Ratios of *D. woltereckii*:*Fragilariaceae* benthic and Planktonic:*Fragilariaceae* benthic taxa were also calculated.

3.2.3. Organic isotope geochemistry

Sediment sub-samples were prepared for organic geochemical analyses ($^{13}\text{C}/^{12}\text{C}$, %Total Organic Carbon (TOC) and %Total Nitrogen (TN)) to determine possible sources of organic matter within the lake sediments (Leng and Marshall, 2004). Bulk organic carbon samples were prepared by placing 2 g of wet sediment in 5 ml of 5% HCl overnight in order to remove carbonates. A resolution of every 0.5 cm was selected between 0 and 20 cm after which every 1 cm was sampled to the base of the core. Samples were washed four times with de-ionised water through Whatman 41 filter papers using manifolds and dried overnight at 40 °C. Bulk sediment samples were ground to a fine powder using a marble pestle and mortar, $^{13}\text{C}/^{12}\text{C}$ analyses were performed by combustion using a Carlo Erba NA1500 on-line to a VG Triple Trap and Optima dual-inlet mass spectrometer at NERC Isotope Geosciences Laboratory (NIGL). Carbon isotope composition ($\delta^{13}\text{C}_{\text{Organic}}$) was calculated to the Vienna Pee Dee Belemnite (VPDB) scale using within-run laboratory standards calibrated against NBS-18 and NBS-19. %TOC and %TN, from which weight C/N is calculated, were determined simultaneously by reference to an Acetanilide standard. Replicate analyses of well-mixed samples for both $\delta^{13}\text{C}$ and C/N were conducted in order to obtain a precision of $\pm 0.1\%$ and 0.1 respectively.

3.2.4. X-ray fluorescence (XRF) spectrometry analysis

Up to 2 g of accurately weighed (4 decimal places) freeze dried sediment was finely ground and compressed into 25 mm deep polythene sample pots for XRF analysis. A total of 50 samples were analysed throughout the 64 cm core, although only the upper 19 cm are presented within this study. Samples were analysed using a Spectro Xlab 2000 energy dispersive X-ray fluorescence spectrometer. Certified reference material (Buffalo River Sediment: reference material 8704) was run every 6th sample.

In order to determine the anthropogenic component of trace elements in the sediments, the data were normalised to titanium (a conservative geochemical element) as follows (e.g. here for Pb):

$$\text{Pb}_{a(x)} = \text{Pb}_{\text{total}(x)} - \left(\text{TiO}_{2(x)} / \text{TiO}_{2(b)} \right) (\text{Pb}_b)$$

Norton and Kahl (1987); where a = anthropogenic, (x) is sample depth and b = background. This method is appropriate when total element concentrations are firmly bound in mineral lattices. Although for elements such as Cu, Ni and Pb, the labile fraction is generally greater and reduces the value of the method (Boyle, 2001). Its use permits discussion of anthropogenic contamination in the recent sediments of Lake Xiaolongwan.

3.2.5. Spheroidal carbonaceous particle (SCP) analysis

Spheroidal carbonaceous particle (SCP) analysis followed the procedure described in Rose (1994). Sequential treatments using nitric, hydrofluoric and hydrochloric acids removed organic, siliceous and carbonate fractions respectively. A known fraction of the resulting suspension was then evaporated onto a coverslip and the number of SCPs counted using a light microscope at $\times 400$ magnification. The criteria for SCP identification followed Rose (2008). Sediment SCP concentrations were calculated in units of 'number of particles per gram dry mass of sediment (or soil)' (gDM^{-1}). Analytical blanks and SCP reference material (Rose, 2008) were included in each batch of sample digestions. Reference concentrations agreed closely with expected values, while no SCPs were observed in the blanks. The detection limit and accuracy for the technique are typically $\sim 100 \text{ gDM}^{-1}$ and $\pm 45 \text{ gDM}^{-1}$ respectively.

3.2.6. Multivariate statistics

Detrended correspondence analysis (DCA) was undertaken on diatom relative abundances $>2\%$ in order to establish the

magnitude of species turnover along the first axis (i.e. the gradient length of the dataset). Relative abundance data were square root transformed in order to stabilise species variance and rare species were down-weighted. The DCA axis 1 gradient length was relatively short (1.952), so trends in diatom assemblage data were subsequently investigated using the linear ordination technique of Principal Components Analysis (PCA) (Lepš and Šmilauer, 2003). The number of significant PCA axes was determined using a broken stick model (Jolliffe, 1986).

Detrended canonical correspondence analysis (DCCA) was undertaken upon the complete dataset (with square root transformation and detrending by segments) in order to investigate species turnover (a measure of the total diatom floristic change), with the diatom data constrained using dates obtained from the age model (Birks, 2007). In order to establish the significance of turnover (standard deviation (SD) units) from the Lake Xiaolongwan core, it was compared with turnover established for a number of non-impacted, reference sites (sensu Smol et al., 2005). Smol et al. (2005) indicate that diatom turnover (beta diversity) >1 SD unit at circumpolar lakes can be used to indicate sites where taxonomic change is greater than that measured at non-impacted temperate lakes (e.g. reference sites). As reference sites were not sampled as part of this project, the SD value of >1 presented by Smol et al. (2005) was applied to gauge the significance of compositional turnover at Lake Xiaolongwan. This is appropriate, as the average time interval analysed by Smol et al. (2005) is comparable (ca. 150 years) and identical multivariate methods were applied. Diatom zones were delimited by optimal partitioning (OPTIMAL) using the program Zone v. 1.2 (Birks and Gordon, 1985; Juggins, 1992).

4. Results

4.1. Core chronology

The chronology of the core was calculated using the CRS model (based on a constant flux of ^{210}Pb) and corrected by the ^{137}Cs concentration peak at 8.5 cm (Fig. 2) which was assigned the date 1963, associated with peak atmospheric nuclear

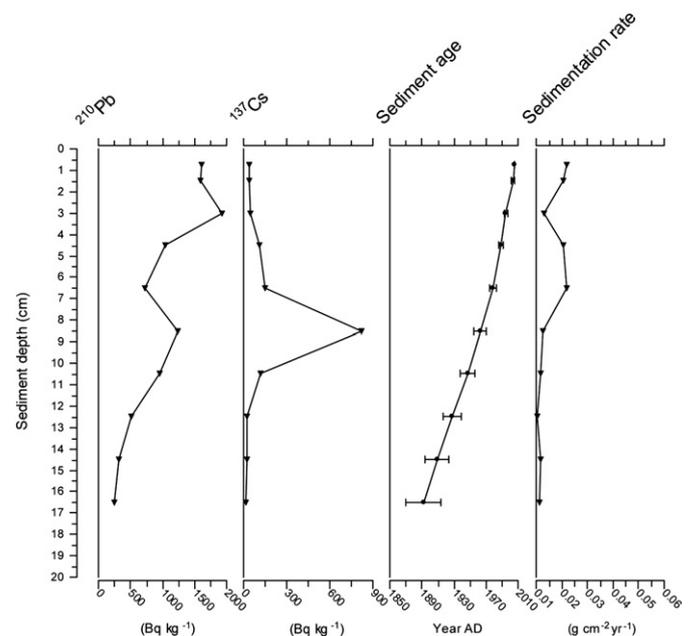


Fig. 2. The ^{210}Pb downcore activity (Bq kg^{-1}) and ^{137}Cs activity (Bq kg^{-1}) for the core XLW2 against depth (cm). The derived chronology, with standard errors (age against depth) for the core and sedimentation rates ($\text{g cm}^{-2} \text{ yr}^{-1}$) are also displayed.

weapons testing. There are two decreases in ^{210}Pb activity between 8.5 and 3 cm and after 1.5 cm. The first event corresponds with an increased mineral component and lower %TOC, and the later event after ca. 2000 AD, corresponds with increased geochemical elements (e.g. Si and Al). As such, both may reflect a dilution of the sediments with increased catchment in-wash. The resulting age-depth model is shown in Fig. 2 with the start of the chronology (1892 ± 22 AD) at 16.5 cm. The sediment accumulation rates are also displayed, and show an increase over the last ca. 30 years. This chronology is used in all subsequent stratigraphic analyses.

4.2. Diatom results from XLW2

Diatom preservation was good with little frustule dissolution and a total of 55 species were identified. Three zones were delimited using optimal partitioning and applied to the diatom stratigraphy. Zone 1 is dominated by a benthic assemblage (P:B ratios close to 0) (Fig. 3). At the beginning of the record, after ca. 1885 AD, there was a mixed floristic assemblage of *Staurosira construens* var *venter*, *P. discoidea* and *Achnanthisidium minutissimum*. This assemblage persisted for the duration of Zone 1, with *P. discoidea* and *S. construens* var *venter* decreasing after ca. 1920 AD. PCA axis 1 scores show an increasing trend throughout this zone.

The start of Zone 2 is marked by the first notable appearance of planktonic diatoms, with a distinct increase in both *D. woltereckii* (ca. 5–35%) and P:B ratios. *S. construens* var *venter* and *P. discoidea* fluctuate between 15–30% and 10–30% respectively. *A. minutissimum* and *T. flocculosa* fluctuate between ca. 10–15% and 0–10% respectively. PCA axis 1 scores are greater than in Zone 1, remaining close to 0 for the entirety of Zone 2.

After ca. 1985 AD (Zone 3), planktonic assemblages increase further. However at ca. 1985 AD there is a short lived increase in the abundance of *Fragilaria delicatissima*, to ca. 45%, concomitant with a decrease in *D. woltereckii*, following which, this planktonic species returns and dominates. At ca. 1985 AD, abundances of *S. construens* var *venter* and *P. discoidea* further decline along with *T. flocculosa*. The floristic assemblage at this time, and for the first time in the record, is dominated by a planktonic composition of *D. woltereckii*, *Fragilaria nanoides*, and *F. delicatissima*. Benthic assemblages of *A. minutissimum* and *Brachysira neoexilis* were also present, with the latter having its first sustained period of appearance in the core after ca. 1990 AD. After 1995 AD abundances of *Encyonopsis descripta* increase and remain between ca. 5–10% until the top of the core while *T. flocculosa* increases to 3–6%. P:B ratios increase during Zone 3, fluctuating between 1.3 and 2 as does the ratio of *D. woltereckii*:*Fragilariaceae* benthic taxa. PCA axis 1 scores also increase steadily to values close to 2.

4.3. Bulk organic isotope geochemistry

For the duration of the record, %TOC varies between 18 and 40% (Fig. 4). After ca. 1940 AD, there is a small increase in values until ca. 1960 AD. A later increasing trend is seen in Zone 3 with a peak in values occurring at ca. 1990 AD. C/N oscillates between ca. 11 and 16. There is a declining trend in values until ca. 1965 AD. During this period values are greater than 12 (mixed macrophyte source of carbon) until ca. 1920 AD after which they decline to <12. These lower values are maintained for Zone 2 and most of Zone 3, increasing at ca. 1990 AD and in surface samples. $\delta^{13}\text{C}$ has a small range of values over the XLW2 record, between -30 and -27‰ . Increases in values occur between ca. 1900 to 1945 AD (to ca. -27‰) and later between ca. 1945 and ca. 1970 AD (to ca. -27‰), after which values declined towards the top of the core.

4.4. XRF analyses

Selected elements show an increasing trend after ca. 1925 AD, with Fe increasing to ca. 4% and Pb to $50 \mu\text{g g}^{-1}$, although changes in Ti are minimal over this period (<0.1%) (Fig. 4). The higher values in Fe and Pb continue during Zone 2, when Ti begins to decline after ca. 1970 AD. Within Zone 3 concentrations of Pb increase further to $165 \mu\text{g g}^{-1}$ at ca. 2000 AD while %Ti continues to decline towards the top of the record. Contamination indices (Pb/Ti, Zn/Ti, Cu/Ti and Ni/Ti) show little variation throughout Zone 1 with values close to 1. After ca. 1970 AD, ratios of Cu, Zn and Pb enrichment increase and reach peak values at ca. 2000 AD (Zone 3). However, despite this, values for Cu/Ti, Zn/Ti and Ni/Ti all remain close to 1. Pb/Ti, by contrast reaches a peak enrichment of >3.

4.5. Spheroidal carbonaceous particles (SCPs)

The first presence of SCPs is detected in ca. 1910 AD and concentrations increase slowly to ca. 1955 after which they increase rapidly to a peak in ca. 1980 AD when concentrations exceed $13,500 \text{ (gDM}^{-1}\text{)}$ (Fig. 4). After this date, concentrations decline towards the surface sediments. SCP fluxes (Fig. 5) also show an increasing trend after ca. 1920 AD to a peak of $300 \text{ cm}^{-2} \text{ yr}^{-1}$ in ca. 1980 AD. Fluxes decrease from this time to the top of the core (2007 AD).

4.6. Multivariate statistics

Broken stick analysis reveals that the first two PCA axes are significant and together explain 45% of species data. Axis 1 sample scores summarise the principal floristic change (30.8%), and these are plotted alongside other proxy data in Figs. 3 and 5. As discussed in Section 3.2.6, the value of 1 beta diversity (SD) unit, identified by Smol et al. (2005) as being a significant level above which species beta diversity has changed at non-impacted, temperate sites has been applied to this study (in the absence of its own independent reference sites). DCCA shows that diatom compositional turnover was significant (1.78 SD units); Table 1).

5. Discussion

This study provides a reconstruction of palaeolimnological changes from Lake Xiaolongwan over the past ca. 130 years. We focus on this period because we can securely date the upper sediments using radiometric dating, and these place any changes seen in the core into an historical context.

5.1. Evidence of human impact

There is documented evidence for anthropogenic disturbance to the LGVF (over the past ca. 150 years at Lake Sihailongwan), based on pollen reconstructions (Li et al., in review; Mingram et al., 2004). In the catchment of Lake Sihailongwan (location on Fig. 1B), there has been increased evidence of human induced forest thinning, based on total pollen counts (Mingram et al., 2004). Furthermore, during the past ca. 70 years there has been an indication of agricultural activity within the region. Pollen analyses conducted on cores from Lake Erlongwan (ca. 1 km from Lake Xiaolongwan: Fig. 1B) also show support for these vegetation trends over the late Holocene (Mingram et al., 2004). In particular, human induced vegetation changes are seen during the 1930s at this site (changing vegetation to a deciduous forest with mixed shrub and grassland) as a result of Japanese occupation in the region, which prompted the selective felling of *Pinus koraiensis* (Liu, 1989; Li et al., in review). Charcoal deposits in Lake Erlongwan sediments further highlights human induced forest clearance,

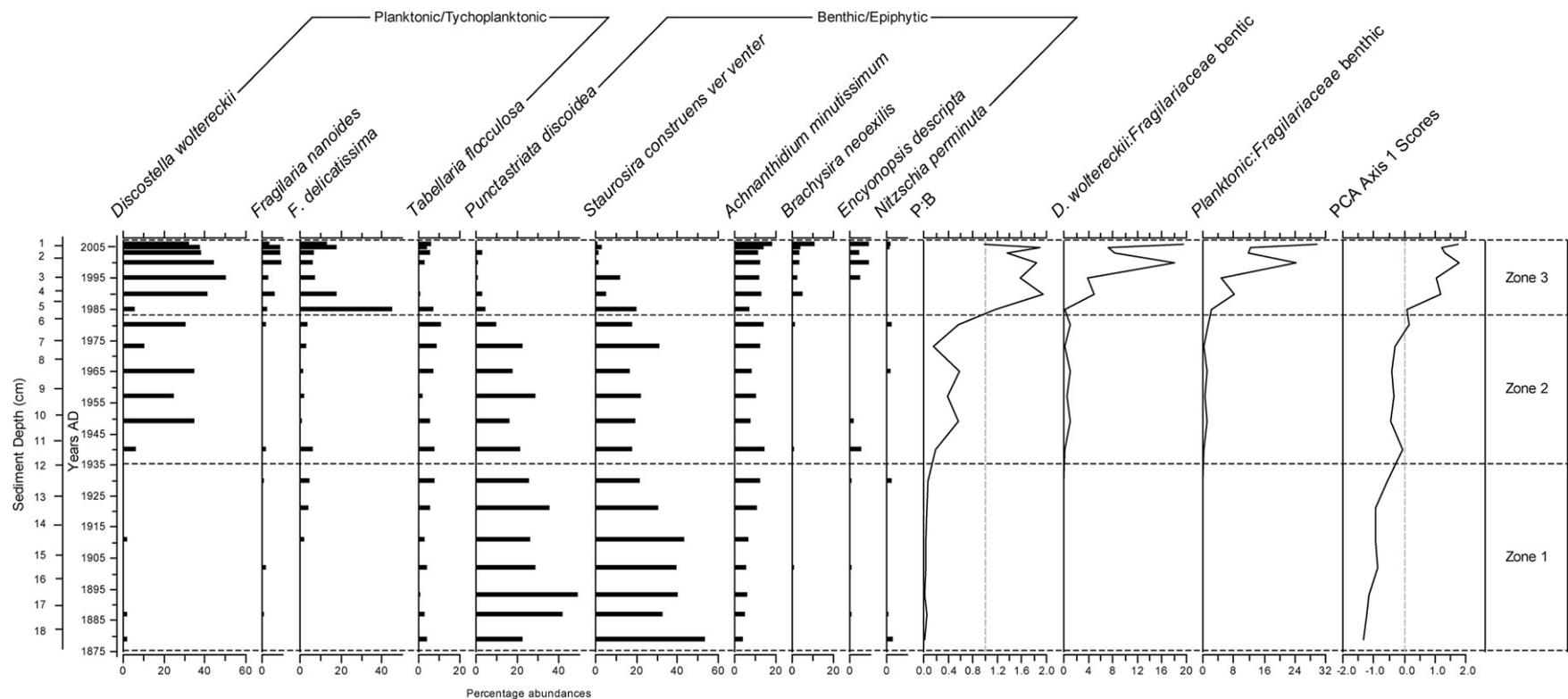


Fig. 3. Diatom floristic assemblages for core XLW2 displayed in years AD and sediment depth (cm). Species with most dominant abundances were selected to view in the stratigraphy. Planktonic:Benthic (P:B) species ratios, along with *D. woltereckii*:*Fragilariaceae* benthic and *Planktonic:Fragilariaceae* benthic (based on age model) ratios are shown. Summary scores of PCA analyses (Axis 1) are displayed to highlight main floristic changes. OPTIMAL zonation applied to the diatom species data, where three zones were delimited, is also displayed.

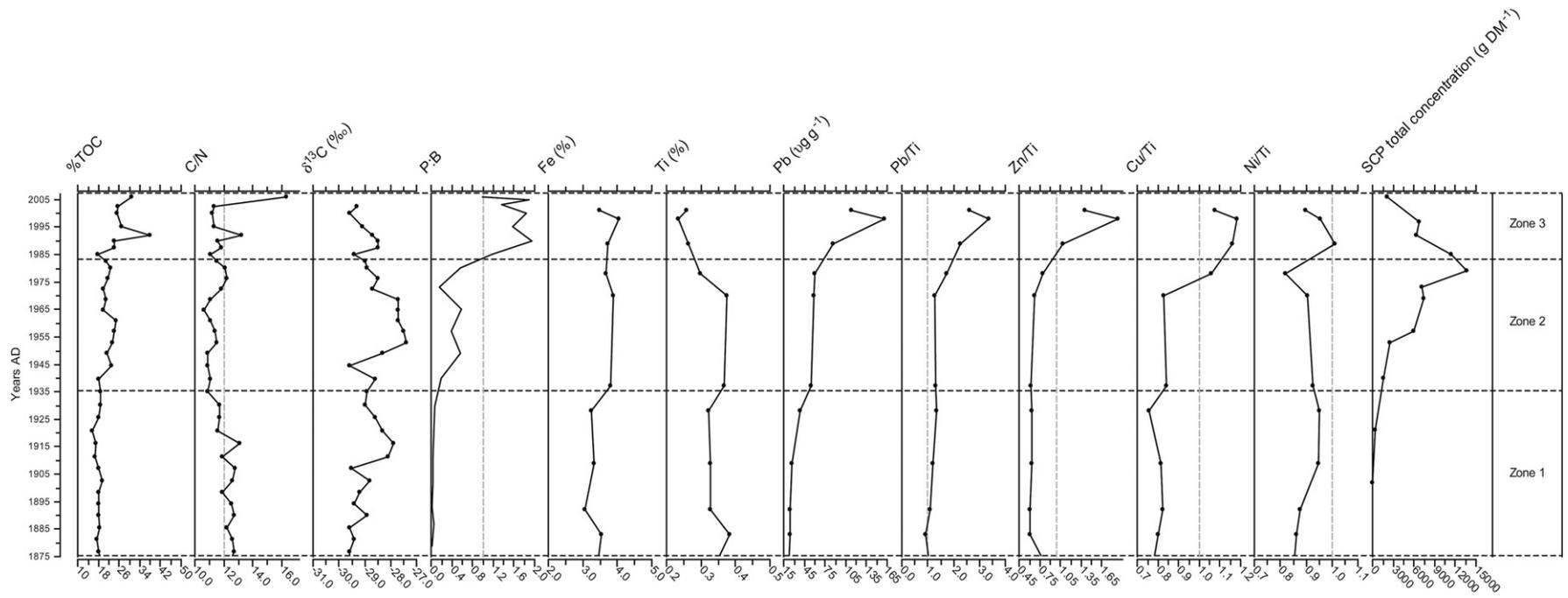


Fig. 4. Stable organic isotope analyses conducted on XLW2: %TOC, C/N, $\delta^{13}\text{C}$ (‰). The reference line on the C/N plot corresponds to the threshold for an aquatic source of carbon (<12). Trace element results from XRF analyses (Fe, Ti, Pb) and their respective units, are also displayed. Pollution indices, which show largest shifts are also shown (Pb/Ti, Zn/Ti, Cu/Ti, Ni/Ti) as are SCP concentrations (g DM^{-1}). Chronology is in Years AD and the diatom zonation is applied to the stratigraphy.

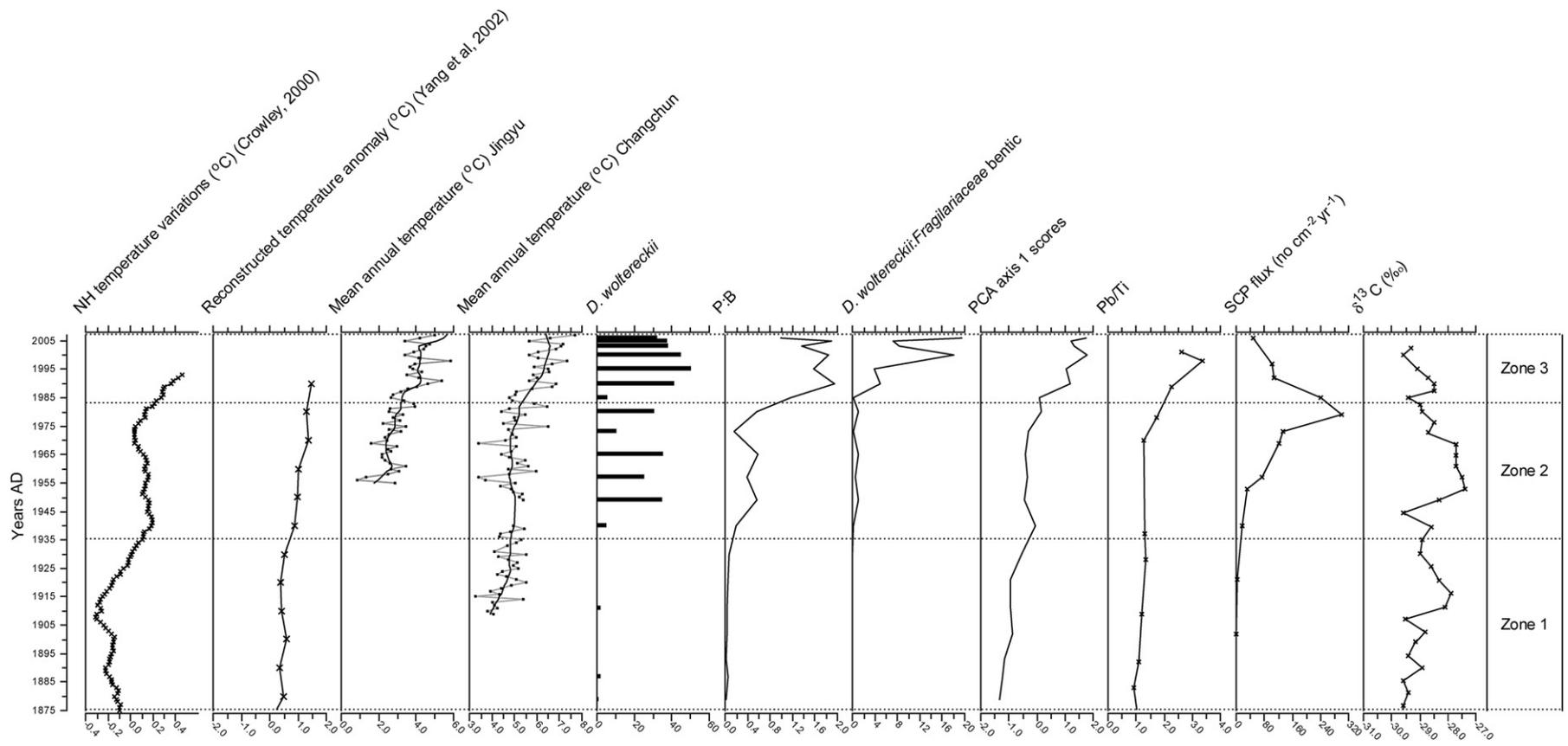


Fig. 5. Temperature anomalies for the NH derived by Crowley (2000) are shown along with reconstructed temperature anomalies from northern China (Yang et al., 2002). Mean annual temperature time-series (°C) from Changchun and Jingyu meteorological stations are also displayed. A composite of XLW2 data is also displayed, including percentage abundances of *D. woltereckii*, P:B ratios, *D. woltereckii*:Frugiliariaceae benthic (based on age model) ratios and diatom PCA Axis 1 scores. $\delta^{13}\text{C}$ (‰), Pb/Ti and SCP flux rates ($\text{no. cm}^{-2} \text{ yr}^{-1}$) are also displayed.

Table 1

Results of DCCA on diatom species data from the core XLW2. As SD for core XLW2 is >1 , results are classified as significant. The SD from this study is presented in bold italics. Data from Wischniewski et al. (2011) are also presented, acting as reference sites for Lake Xiaolongwan. Lakes cited in Smol et al. (2005), which show diatom species compositional changes similar to those presented in this paper, are also shown (Lakes Saanajarvi, Finnish Lapland; Birgervatnet, Spitsbergen; CF-11, Baffin Island and Slipper Lake, Northwest Territories). Reference site PC4, northern Québec, presented in Smol et al. (2005) is also displayed.

| Site name | Location | Author | Turnover (SD) |
|------------------|---------------------------------|----------------------------|---------------|
| Lake Xiaolongwan | Temperate northeast China | This study | 1.78 |
| Wuxu Lake | Montane-boreal, Tibetan Plateau | Wischniewski et al. (2011) | 0.36 |
| LC6 Lake | Montane-boreal, Tibetan Plateau | Wischniewski et al. (2011) | 0.94 |
| Saanajarvi | Finnish Lapland, Arctic | Smol et al. (2005) | 1.19 |
| Birgervatnet | Spitsbergen, Arctic | Smol et al. (2005) | 1.40 |
| CF-11 | Baffin Island, Arctic | Smol et al. (2005) | 1.20 |
| Slipper Lake | Northwest Territories, Arctic | Smol et al. (2005) | 1.25 |
| PC4 | Northern Québec, Arctic | Smol et al. (2005) | 0.84 |

although these have declined since ca. 1980 AD as a result of government policy to restore the reclaimed land to forested regions (Li et al., in review). Despite regional evidence, we argue that forest clearance and agriculture, in the LGVF, has had minimal impact upon the small catchment of Lake Xiaolongwan, over the past ca. 130 years (Panizzo, unpublished data).

However, to further look at the degree of catchment disturbance at Lake Xiaolongwan and to investigate in more detail natural versus anthropogenic contamination signals in the catchment (via in wash or atmospheric deposition), trace element analyses were conducted. Enrichment factors in trace elements after ca. 1980 AD (e.g. Zn/Ti, Cu/Ti and Ni/Ti; Fig. 4) are very close to 1 and do not exceed pre-industrial values (Panizzo, unpublished data). However, Pb concentrations do show a marked increase on entering Zone 3 and Pb/Ti increases after 1970 AD. These exceed pre-industrial values and indicate atmospheric contamination at Lake Xiaolongwan. Evidence of atmospheric deposition is corroborated by increasing SCP concentrations at Lake Xiaolongwan, although the timing of highest values for both proxies differs (SCP concentrations decrease after ca. 1980 AD, when Pb/Ti increase; Fig. 4). These data demonstrate anthropogenic contamination from a fossil-fuel source, most likely high temperature coal combustion (e.g. Farmer et al., 1999), has occurred at Lake Xiaolongwan since the mid-20th century.

Very little literature documents the increase in industrialisation in this region of China to independently corroborate these data. However, one source does state that after 1945 AD and with the advent of the People's Republic of China, Jilin Province became the "industrial heartland of China", with coal-fired power stations rapidly increasing in number (Hays, 2009). Another study by Kang et al. (2009) investigating contemporary pollution aerosol transport over northeast China, South Korea and Japan, found that dust and pollution aerosols (including Cu, Zn, P and Ni) are transported east, by westerly winds. In drawing comparisons with the Lake Xiaolongwan pollution record, Pb aerosols were largely transported to the Japan East Sea from the Asian continent during the autumn, winter and early spring months (Kang et al., 2009). Although the dominant source of Pb (leaded petrol) has been reduced over the past decade on the Asian continent (Kang et al., 2009), their findings imply that other sources must be contributing to regional atmospheric Pb. Such sources may include metallurgic dust, coal combustion and cement manufacturing (Chen et al., 2005; Kim, 2007).

The shift to higher Pb/Ti after ca. 1970 AD is coincident with a further increase in planktonic communities in the lake (Fig. 5). However, it is clear that the most notable increase in planktonic species (*D. wolvereckii*) is seen much earlier in the record and predates this evidence of atmospheric contamination (after ca. 1940 AD). Furthermore this is concomitant with increased mean annual temperature and reconstructed NH temperature trends (Crowley, 2000: Fig. 5), regarded to be ecologically consistent changes with predicted limnological responses to climatic warming (Smol et al., 2005). This suggests that evidence of atmospheric deposition (Pb/Ti) post dates main floristic assemblage changes at Lake Xiaolongwan.

However, the boundary between Zones 3 and 2 shows the increase in P:B occurs at the same time as an initial increase in SCP concentrations (Fig. 4). SCP flux rates (Fig. 5) further demonstrate the increase in SCP deposition after ca. 1950 AD. To our knowledge there are no other SCP data for this region with which to compare our Lake Xiaolongwan fluxes. However, some comparisons can be made with records from other regions of Asia and southern China. For example, SCP fluxes from the more contaminated southern basin of Lake Baikal (Rose et al., 1998) reach ca. $50 \text{ cm}^{-2} \text{ yr}^{-1}$ (Rose, unpublished data) whereas at Lake Xiaolongwan, SCP fluxes reach a peak of ca. $300 \text{ cm}^{-2} \text{ yr}^{-1}$, suggesting considerably higher levels of contamination. However, these values are still an order of magnitude less than records from Lake Taihu, close to Shanghai, east China, where fluxes exceed $4000 \text{ cm}^{-2} \text{ yr}^{-1}$ after 1990 AD (Rose et al., 2004). Furthermore, flux values at Lake Xiaolongwan remain close to Lake Baikal background levels until after ca. 1955 AD (when they reach ca. $75 \text{ cm}^{-2} \text{ yr}^{-1}$).

There is a notable decrease in SCP concentrations and flux rates after ca. 1980 AD (Fig. 4), while abundances of *D. wolvereckii* continue to dominate the Lake Xiaolongwan record. This suggests that, although evidence of anthropogenic contamination from fossil fuel combustion has been recorded at the once perceived pristine lake, it may not be the dominant driving force for high compositional (beta diversity) change at the site in the 20th century. As highlighted earlier, the shift from benthic to planktonic assemblages has been identified in Arctic, alpine and increasingly in non-acidified, non-enriched temperate lakes due to longer ice free periods and warming-induced changes in water column properties induced by warming climate trends (Smol et al., 2005; Rühland et al., 2008). On the basis of the data presented in this study, we argue that positive temperature anomalies/trends are trigger factors for significant species turnover during the late 20th century at Lake Xiaolongwan, particularly prior to ca. 1950 AD. After which, anthropogenic contamination (SCPs) may also be acting in tandem, although concentrations of these pollutants are considerably lower than highly impacted sites in southern China (Rose et al., 2004) and are close to background levels in northern Europe (e.g. Rose, 1995). However, it is increasingly recognised that the interplay between atmospheric aerosols and changing climate are complex, and their dual impact on freshwater ecosystems is poorly understood. Use of palaeoecological records can further our understanding, at least of the timing of potential impacts from different drivers.

5.2. Species turnover at Lake Xiaolongwan

The DCCA results of estimated compositional turnover (SD units) are summarised in Table 1. When compared to DCCA results from an unpublished, longer (ca. 2000 years) diatom record from the same site, it is clear to see that species turnover for the 20th century is greater (SD unit of 1.17 versus 1.78 presented here; Table 1) (Panizzo, unpublished data). This is similarly highlighted at other regions in central Asia, e.g. the East Sayan Mountains, where Holocene beta diversity changes (SD = 1.194) are lower than those

presented here for Lake Xiaolongwan (Mackay et al., 2012). However, such trends are not so clear-cut in the southeastern Tibetan Plateau (Wischniewski et al., 2011), which had very stable species (diatom and pollen) compositional change over the past 200 years (Table 1). Wischniewski et al. (2011) argued that both lakes and catchments in this region were resilient to current rates and magnitude of climate change and that as a result, ecological species thresholds have not yet been crossed. This is interesting as it could suggest the use of these lakes as reference sites for the Lake Xiaolongwan (sensu Smol et al., 2005). Furthermore, they highlight that only muted regime shifts (<1 SD) are seen in this region, despite evidence of long-range atmospheric deposition and contamination in the Tibetan Plateau (e.g. Wang et al., 2010; Yang et al., 2010a, 2010b). Our data is also compared with Arctic lakes presented by Smol et al. (2005) where, as at Lake Xiaolongwan (Fig. 3), an increase in planktonic diatoms can be seen at the expense of benthic genera (e.g. *Fragilaria* and *Achnanthyidium* species) (Table 1).

Beta diversity values are on a par with those from sites in northern Labrador, at Saglek Lake-2 and -15 (1.10 SD units and 0.79 SD units respectively: Table 1), where the absence of recent warming (despite evidence of PCB deposition at Saglek-2) and minimal diatom assemblage change are seen (Paterson et al., 2003). In particular, it may highlight the negligible effects of pollution in driving such compositional changes (compared to clear temperature trends). Smol et al. (2005) concluded that diatom changes (e.g. beta diversity) in Arctic lakes (notably those cited in Table 1, which document species assemblage changes comparable with Lake Xiaolongwan: Fig. 5) show dramatic, unidirectional regime shifts within the past ca. 130 years (e.g. SD > 1). Furthermore, these ecological shifts are consistent with the predicted limnological responses that would be expected due to climatic warming (e.g. increased competitiveness of planktonic, *Discostella*, species due to reduced ice cover duration and/or enhanced thermal stratification) (Sorvari et al., 2002; Rühland et al., 2003a; Winder and Hunter, 2008; Winder et al., 2009) and in the absence of anthropogenic impacts (e.g. increased nutrients, heavy metal deposition) which are often found to postdate the observed initiation of algal changes (Smol et al., 2005).

5.3. Palaeoecological changes and natural variability

The beginning of the diatom record at Xiaolongwan is dominated by *S. construens* var *venter* and *P. discoidea* (Fig. 3). These species, based on sediment trap data from Lake Xiaolongwan (Rioual et al., unpublished data), are more abundant at the end of summer thermal stratification and during autumn lake turnover. After ca. 1920 AD *A. minutissimum* and *T. flocculosa* increase in relative abundance, which at the site today are also most abundant during periods of lake stratification and autumn turnover. After ca. 1935 AD (Zone 2) *D. woltereckii* appears for the first time. Contemporary sediment trap data show that this species is most abundant during spring and autumn turnover and is also present during summer stratification (Rioual et al., unpublished). Regional time-series data has demonstrated a clear increase in spring and summer growing seasons over the past 50 years (Dong et al., 2010; Liu et al., 2010). We argue that the increase in *D. woltereckii* since ca. 1950 AD is reflecting this increased growing season trend (resulting from earlier/late ice off/on dates). These small-sized species (*D. woltereckii* ranges between 5 and 8 μm in diameter) have been found to have high growth rates, low nutrient requirements and a low sinking velocity (a high surface area/volume ratio (SA/V)), a competitive advantage with prolonged periods of stratification and nutrient deplete conditions (Winder et al., 2009). However, as at Lake Xiaolongwan, the species is today also found to dominate during spring and autumn turnover, we argue that this relationship

is more complex at this site and the increase in the species also reflects an increase in the duration of the growing season as a whole.

However, trap data from neighbouring Lake Sihailongwan (Rioual, unpublished data) shows that the closely related *D. pseudostelligera* species is more abundant during summer stratification. When looking at the main floristic changes driving species turnover in the Lake Xiaolongwan record, it is clear to see a shift from a benthic to planktonic assemblage. This is clearly summarised by P:B ratios and PCA Axis 1 scores (Fig. 5). P:B ratios and *D. woltereckii* abundances increase on entering Zone 2, after ca. 1935 AD. Instrumental records from Changchun and Jingyu meteorological stations (Fig. 1) have shown that after ca. 1900 AD there have been increasing trends in mean annual temperatures (Fig. 5). These trends are concomitant with increased reconstructed temperature anomalies for northern China (>0 °C) and the NH (>0 °C) (Fig. 5; Crowley, 2000, respectively; Gong et al., 2011). Furthermore, the greatest increase seen in mean annual temperatures, at Changchun, after ca. 1980 AD is concomitant with the increase in *D. woltereckii*: *Fragilariaceae* benthic ratios.

%TOC showed only small increases between ca. 1885–1985 AD, but increased to highest values during the past 20 years, perhaps related to increased lake productivity. Because $\delta^{13}\text{C}$ values fluctuate between -27‰ and -30‰ , we can rule out any significant contribution of routinely higher $\delta^{13}\text{C}$ values (ca. -8‰ to -15‰) from C_4 land vegetation. Moreover, there is no pollen evidence of C_4 plants from nearby maar lake sediments deposited over the past ca. 150 years (e.g. Li et al., in review; Mingram et al., 2004). It is likely therefore that C_3 plants are the main source of terrestrial carbon to Lake Xiaolongwan. C/N ratios are used to help discriminate between autochthonous and allochthonous sources of carbon to lake sediments, especially vascular and aquatic plants (algae) (Leng et al., 2006). At Lake Xiaolongwan, the importance of autochthonous sources of carbon to the lake is highlighted due to low C/N ratios (C/N <12 indicates a phytoplanktonic source of carbon; Meyers and Teranes, 2001), although continuous delivery of allochthonous matter cannot be ruled out either (Meyers, 1994), especially at the very top of the core where values increase >16. Interpretation of changing $\delta^{13}\text{C}$ values in lake sediments is complex. While increasing values can be used to infer primary production in lakes (e.g. Leng and Marshall, 2004), burial of ^{12}C -enriched organic matter into bottom sediments can also result in less negative $\delta^{13}\text{C}$ values (Meyers and Lallier-Vergès, 1999). Changes to catchment vegetation and associated soil respiration can also alter $\delta^{13}\text{C}$ values in lakes (Reuss et al., 2010), although being a maar lake, the catchment of Lake Xiaolongwan is small and may not be a significant factor. The ratio of planktonic to benthic species (P:B) may also influence $\delta^{13}\text{C}$ values in lake sediments because planktonic algae have on average lower $\delta^{13}\text{C}$ values (-32‰) than benthic species (-26‰) (France, 1995) due to the diffusive boundary layer effect. This is a result of the difference in the turbulence of water surrounding benthic and planktonic valves, benthic diatoms can have a diffusive layer around them of >1 mm, while phytoplankton only ca. 10 μm (Smith and Walker, 1980; Jorgensen and Revsbech, 1985; Ribber and Wetzel, 1987). This diffusive layer affects the potential for CO_2 or HCO_3^- to exchange with the valves.

In Lake Xiaolongwan $\delta^{13}\text{C}$ values increased from approximately -29.5‰ at ca. 1885 AD to -27.5‰ by ca. 1955 AD, concurrent with a small increase in %TOC and decline in C/N ratios, which may suggest that $\delta^{13}\text{C}$ values were influenced by a small increase in lake productivity. The decline in $\delta^{13}\text{C}$ values from ca. 1970 AD to ca. 2000 AD however, also occur at the same time as an increase in % TOC (particularly after 1985 AD), and therefore their relationship to primary production is not straightforward. The decline in $\delta^{13}\text{C}$

values occurs at the same time as very large increases in the proportion of planktonic taxa in the lake and therefore might be indicative of a shift in productivity from littoral to pelagic regions. These changes are also coincident with the notable increase in the planktonic *F. nanoides* and *F. delicatissima* further supporting this argument. However, increases are also seen in the epiphytic species *B. neoexilis* and *E. descripta*, which are today found on the macrophytes *Phragmites*, *Typha* and *Utricularia*. These emergent macrophytes are found in large populations, in the extensive littoral regions of the lake (Fig. 1C). The increase in the epiphytic diatoms may suggest a shift to a larger macrophyte population in response to longer summer seasons, although C/N values remain for the most part <12, apart from a brief increase at ca. 1990 AD and in surface sediments, suggesting small changes may have occurred. Nevertheless, it does demonstrate a regime shift to different species after ca. 1980 AD when temperature trends increase further.

The reduction in benthic assemblages after ca. 1975 AD, may also be reflecting an increase in DOC (increased %TOC) and therefore increased light attenuation in these habitats. Laird et al. (2011) have detailed that changes in DOC can have significant impacts on light transparency and lake thermal structure (Fee et al., 1996; Snucins and Gunn, 2000; Keller et al., 2006) which in turn can influence algal productivity and dominant assemblage structure (Adrian et al., 2009; Heino et al., 2009; Karlsson et al., 2009). Evidence has shown the favourable increase of planktonic diatoms (predominantly *D. pseudostelligera*: a species which belongs to the same species complex) over benthic assemblages (due to their high growth rates and small cell size: Winder et al., 2009) with values of increased %TOC and DOC concentrations, from boreal North American lakes (e.g. Laird et al., 2011). Such increases in planktonic assemblages have been noted after 1990 AD at these sites. As a result, it is possible that *D. woltereckii* increases at Lake Xiaolongwan (percentage abundances and *D. woltereckii*:*Fragilariaceae* benthic ratios), as well as other planktonic species (P:B ratios >1) after ca. 1985 AD, are also responding to similar increased DOC conditions (greatest increase in %TOC). Currently the presence of *D. woltereckii* at the site is associated with DOC concentration values between 7 and 12 mg l⁻¹. *Discostella stelligera* complex has high DOC species optima (ca. 14 mg l⁻¹) (Enache and Prairie, 2002), although other authors have identified this group as generalists in terms of DOC optima (Rühland et al., 2003b). Following detailed monitoring of contemporary diatoms from other sites in the LGVF, Rioual (unpublished) outlines that *D. woltereckii* is found at sites with higher DOC values (e.g. Lake Xiaolongwan) compared with the other *Discostella* species such as *D. pseudostelligera* and *D. stelligera*.

It is clear that further investigation into this argument is needed as variations in DOC concentrations in lakes are very complex and largely driven by climatic processes (Pace and Cole, 2002). Evidence has looked at the effects of precipitation and ice cover variations (Pace and Cole, 2002), changes in residence times (Curtis and Schindler, 1997), catchment changes (e.g. peat formation; Dillon and Molloy, 1997) and changes in sulphur and chloride deposition (Monteith et al., 2007; Keller, 2009). Indeed, the discussion that increased DOC at Lake Xiaolongwan is in fact acting in tandem with other forcing factors could be quite important. While increased % TOC is seen after ca. 1940 AD, concomitant with the large increase in *D. woltereckii*, these changes are <10% (Fig. 4), and the greatest increase is seen much later in Zone 3. Temperature trends however, show an increasing trend concomitant with the increase of *D. woltereckii*. As such, this is likely a response to increased warming at the site, which shows increasing trends prior to the largest increase in %TOC.

6. Conclusions

Significant species turnover in Lake Xiaolongwan over the 20th century is concomitant with positive temperature anomalies over the NH and China, and positive trends in regional mean annual temperature records since ca. 1900 AD. Most notable floristic changes in diatoms are seen after ca. 1940 AD when an increase in P:B ratios and a notable increase in *D. woltereckii* occurs, coincident with increasing trends in mean annual temperature. However, this study also provides one of the first detailed reconstructions of anthropogenic contamination in northeast China. Our results show that after ca. 1940 AD there is an increase in contamination as indicated by SCP fluxes (until ca. 1980 AD) and Pb enrichment (from ca. 1970 AD). Nevertheless, following the decrease in SCP fluxes and the later increase of Pb/Ti ratios (appearing after ca. 1970 AD) the dominance of *D. woltereckii* remains and epiphytic assemblages increase, concomitant with even greater regional warming trends after ca. 1985 AD. We conclude that recent warming, over the 20th century, has led to increased beta diversity (namely a significant increase in the planktonic species *D. woltereckii*) at Lake Xiaolongwan since ca. 1940 AD. This is comparable with other studies of Arctic, alpine and non-acidified, non-enriched temperate lakes across the NH, where with evidence of recent warming, has led to planktonic assemblages dominating lacustrine ecosystems.

Acknowledgements

This project was funded by the National Environmental Research Council (NERC) (NER/S/A/2006/14046) and the work was conducted at University College London, UK, through a tied CASE studentship with the NERC Isotope Geosciences Laboratory (NIGL). Thanks go to NIGL for carbon isotope analyses, Dr. Andy Cundy, University of Sussex, for radiometric measurements, and Dr. Handong Yang for age model advice. Gratitude also is extended to Prof. Wang Luo for fieldwork assistance and Prof. Chu Guoqiang for his collaboration with this project.

References

- Adrian, R., O'Reilly, C.M., Zagarese, H., Baines, S.B., Hessen, D.O., Keller, W., Livingstone, D.M., Sommaruga, R., Straile, D., Van Donk, E., Weyhenmeyer, G.A., Windler, M., 2009. Lakes as sentinels of climate change. *Limnology and Oceanography* 54, 2283–2297.
- Appleby, P.G., Oldfield, F., 1978. The calculation of ²¹⁰Pb dates assuming a constant rate of supply of unsupported ²¹⁰Pb to the sediment. *Catena* 5, 1–8.
- Appleby, P., Oldfield, F., 1992. Application of ²¹⁰Pb to sedimentation studies. In: Ivanovich, M., Harmon, R.S. (Eds.), *Uranium-Series Disequilibrium: Applications to Earth, Marine and Environmental Sciences*. Oxford University Press, Oxford, pp. 731–778.
- Battarbee, R.W., Bennion, H., 2011. Palaeolimnology and its developing role in assessing the history and extent of human impact on lake ecosystems. *Journal of Paleolimnology* 45 (4), 399–404.
- Battarbee, R.W., Jones, V.J., Cameron, N.G., Carvahlo, L., Juggins, S., 2001. Diatoms. In: Smol, J.P., Birks, H.J.B., Last, W.M. (Eds.), *Tracking Environmental Change Using Lake Sediments*, vol. 3. Kluwer Academic Publishers, Dordrecht, pp. 155–203.
- Birks, H.J.B., Gordon, A.D., 1985. *Numerical Methods in Quaternary Pollen Analysis*. Academic Press, London, 317 pp.
- Birks, H.J.B., 2007. Estimating the amount of compositional change in Late-Quaternary pollen-stratigraphical data. *Vegetation History and Archaeobotany* 16 (2–3), 197–202.
- Boyle, J.F., 2001. Inorganic geochemical methods in palaeolimnology. In: Last, W.M., Smol, J.P. (Eds.), *Tracking Environmental Change Using Lake Sediments: Physical and Geochemical Techniques*, vol. 2. Kluwer Academic, Dordrecht, pp. 83–143.
- Camarero, L., Botev, I., Muri, G., Psenner, R., Rose, N., Stuchlik, E., 2009. Trace elements in alpine and arctic lake sediments as a record of diffuse atmospheric contamination across Europe. *Freshwater Biology* 54 (12), 2518–2532.
- Chen, J.M., Tan, M.G., Li, Y.L., Zhang, Y.M., Lu, W.W., Tong, Y.P., Zhang, G.L., Li, Y., 2005. A lead isotope record of shanghai atmospheric lead emissions in total suspended particles during the period of phasing out of leaded gasoline. *Atmospheric Environment* 39 (7), 1245–1253.

- Chu, G., Sun, Q., Rioual, P., Boltovskoy, A., Liu, Q., Sun, P., Han, J., Liu, J., 2008. Dinocyst microlaminations and freshwater "red tides" recorded in Lake Xiaolongwan, northeastern China. *Journal of Paleolimnology* 39, 319–333.
- Crowley, T.J., 2000. Causes of climate change over the past 1000 years. *Science* 289 (5477), 270–277.
- Curtis, P.J., Schindler, D.W., 1997. Hydrologic control of dissolved organic matter in low-order Precambrian Shield Lakes. *Biogeochemistry* 36, 125–138.
- Curtis, C.J., Juggins, S., Clarke, G., Battarbee, R.W., Kernan, M., Catalan, J., Thompson, R., Posch, M., 2009. Regional influence of acid deposition and climate change in European mountain lakes assessed using diatom transfer functions. *Freshwater Biology* 54 (12), 2555–2572.
- Dillon, P.J., Mollot, L.A., 1997. Effect of landscape form on export of dissolved organic carbon, iron and phosphorous from forested stream catchments. *Water Resource Research* 33, 2591–2600.
- Dong, W.J., Jiang, Y.D., Yang, S., 2010. Response of the starting dates and the lengths of seasons in Mainland China to global warming. *Climatic Change* 99 (1–2), 81–91.
- Drevnick, P.E., Yang, H., Lamborg, C.H., Rose, N.L., 2012. Net atmospheric mercury deposition to Svalbard: estimates from lacustrine sediments. *Atmospheric Environment* 59, 509–513.
- Enache, M., Prairie, Y.T., 2002. WA-PLS diatom-based pH, TP and DOC inference models from 42 lakes in the Abitibi clay belt area (Québec, Canada). *Journal of Paleolimnology* 27 (2), 151–171.
- Farmer, J.G., Eades, L.J., Graham, M.C., 1999. The lead content and isotopic composition of British coals and their implications for past and present releases of lead to the UK. *Environmental Geochemistry and Health* 21, 257–272.
- Fee, E.J., Hecky, R.E., Kasian, S.E.M., Cruikshank, D.R., 1996. Effects of lake size, water clarity and climatic variability on mixing depths in Canadian Shield Lakes. *Limnology and Oceanography* 46, 912–920.
- Finney, B.P., Rühland, K., Smol, J.P., Fallu, M.-A., 2004. Paleolimnology of the North American Subarctic. In: Pienitz, R., Douglas, M.S.V., Smol, J.P. (Eds.), *Long-Term Environmental Change in Arctic and Antarctic Lakes*, vol. 8. Springer, Dordrecht, The Netherlands.
- Fitzgerald, W.F., Engstrom, D.R., Lamborg, C.H., Tseng, C.M., Balcom, P.H., Hammerschmidt, C.R., 2005. Modern and historic atmospheric mercury fluxes in northern Alaska: global sources and arctic depletion. *Environmental Science & Technology* 39 (2), 557–568.
- Flower, R.J., 2005. A taxonomic and ecological study of diatoms from freshwater habitats in the Falkland Islands, South Atlantic. *Diatom Research* 20, 23–96.
- France, R.L., 1995. Carbon-13 enrichment in benthic compared to planktonic algae: foodweb implication. *Marine Ecology Progress Series* 124, 307–312.
- Gong, Z.Q., Zhi, R., Feng, G.L., Zhang, Q., 2011. Dry/wet changes and their standing characteristics in China during the past 531 years. *Acta Meteorologica Sinica* 25 (2), 142–155.
- Haworth, E.Y., Hurley, M.A., 1986. Comparison of the stelleroid taxa of centric diatom genus *Cyclotella*. In: Ricard, M. (Ed.), *Proceedings of the 8th International Diatom Symposium*. Koeltz Scientific Books, Koenigstein, pp. 43–53.
- Hays, J., 2009. Facts and Details: Jilin Province. <http://factsanddetails.com/china.php?itemid=451&catid=15&subcatid=98>.
- Heino, J., Virkkala, R., Toivonen, H., 2009. Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. *Biological Reviews* 84, 39–54.
- Holtgreve, G.W., Schindler, D.E., Hobbs, W.O., Leavitt, P.R., Ward, E.J., Bunting, L., Chen, G.J., Finney, B.P., Gregory-Eaves, I., Holmgren, S., Lisac, M.J., Lisi, P.J., Nydick, K., Rogers, L.A., Saros, J.E., Selbie, D.T., Shapley, M.D., Walsh, P.B., Wolfe, A.P., 2011. A coherent signature of anthropogenic nitrogen deposition to remote watersheds of the Northern Hemisphere. *Science* 334 (6062), 1545–1548.
- Hylander, L.D., Meili, M., 2005. The rise and fall of mercury: converting a resource to refuse after 500 years of mining and pollution. *Critical Reviews in Environmental Science and Technology* 35 (1), 1–36.
- Jansen, E., Overpeck, J., Briffa, K.R., Duplessy, J.-C., Joos, F., Masson-Delmotte, V., Olago, D., Otto-Bliesner, B., Peltier, W.R., Rahmstorf, S., Ramesh, R., Raynaud, D., Rind, D., Solomina, O., Villalba, R., Zhang, D.N., 2007. Paleoclimate. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Climate Change 2007: the Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- Jolliffe, I.T., 1986. *Principal Component Analysis*. Springer Verlag, New York, 271 pp.
- Jones, P.D., Moberg, A., 2003. Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001. *Journal of Climate* 16 (2), 206–223.
- Jorgensen, B.B., Revsbech, N.P., 1985. Diffusive boundary-layers and the oxygen-uptake of sediments and detritus. *Limnology and Oceanography* 30, 111–122.
- Juggins, S., 1992. *Zone v. 1.2*. Environmental Change Research Centre.
- Kang, J., Choi, M.S., Lee, C.B., 2009. Atmospheric metal and phosphorus concentrations, inputs, and their biogeochemical significances in the Japan/East Sea. *Science of the Total Environment* 407 (7), 2270–2284.
- Karlsson, J., Bystro, P., Ask, J., Persson, L., Jansson, M., 2009. Light limitation of nutrient-poor lake ecosystems. *Nature* 460, 506–510.
- Keller, W., Heneberry, J., Leduc, J., Gunn, J., Yan, N., 2006. Variations in epilimnion thickness in small boreal shield lakes: relationships with transparency, weather and acidification. *Environmental Monitoring and Assessment* 115, 419–431.
- Keller, W., 2009. Limnology in northeastern Ontario: from acidification to multiple stressors. *Canadian Journal of Fisheries and Aquatic Sciences* 66, 1189–1198.
- Kim, K.-H., 2007. Airborne lead concentration levels on the Korean Peninsula between 1991–2004. *Atmospheric Environment* 41, 809–824.
- Kirk, J.L., Muir, D.C.M., Antoniadou, D., Douglas, M.S.V., Evans, M.S., Jackson, T.A., Kling, H., Lamoureux, S., Lim, D.S.S., Pienitz, R., Smol, J.P., Stewart, K., Wang, X., Yang, F., 2011. Climate change and mercury accumulation in Canadian high and Subarctic Lakes. *Environmental Science & Technology* 45 (3), 964–970.
- Krammer, K., Lange-Bertalot, H., 1986. *Bacillariophyceae*. I. Teil. *Naviculaceae*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K., Lange-Bertalot, H., 1988. *Bacillariophyceae* 2. Teil. *Bacillariaceae*, *Epithemiaceae*, *Surirellaceae*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K., Lange-Bertalot, H., 1991a. *Bacillariophyceae*. 4. Teil. *Achnanthes*, *Navicula*, *Gomphonema*, *Kritische Nachtraege*, *Literatur*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K., Lange-Bertalot, H., 1991b. *Bacillariophyceae*. 3. Teil. *Zentrische Diatomeen*, *Diatoma*, *Meridion*, *Asterionella*, *Tabellaria*, *Fragilaria*, *Eunotia* und *Verwandte*, *Peronia* und *Actinella*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K., 1992. *Pinnularia*: eine Monographie der europäischen taxa. In: *Bibliotheca Diatomologica*, vol. 26. Cramer, Stuttgart.
- Laing, T.E., Pienitz, R., Payette, S., 2002. Evaluation of limnological responses to recent environmental change and caribou activity at Riviere George region, northern U. Canadian Arctic, Antarctic and Alpine Research 34, 424–464.
- Laird, K.R., Kingsbury, M.V., Lewis, C.F.M., Cumming, B.F., 2011. Diatom-inferred depth models in 8 Canadian boreal lakes: inferred changes in the benthic: planktonic depth boundary and implications for assessment of past droughts. *Quaternary Science Reviews* 30, 1201–1217.
- Lange-Bertalot, H., Genkal, S., 1999. Diatoms from Siberia. I. Islands in the Arctic Ocean (Yugorsky-Shar Strait). In: Lange-Bertalot, H. (Ed.), *Iconographica Diatomologica*. Koeltz Scientific Books, Königstein.
- Lange-Bertalot, H., Metzeltin, D., 1996. Indicators of oligotrophy. 800 taxa representative of three ecologically distinct lake types. Carbonate buffered – oligodystrophic – weakly buffered soft water. In: Lange-Bertalot, H. (Ed.), *Iconographica Diatomologica*. Koeltz Scientific Books, Königstein.
- Lange-Bertalot, H., Moser, G., 1994. *Brachysira*: monographie der Gattung und *Naviculadicta* nov. genus. In: Lange-Bertalot, H. (Ed.), *Bibliotheca Diatomologica*, vol. 29. Cramer, Stuttgart, p. 212.
- Lange-Bertalot, H., 2001. *Navicula sensu stricto* 10 genera separated from *Navicula sensu lato Frustulia*. In: Lange-Bertalot, H. (Ed.), *Diatoms of Europe: diatoms of the European inland waters and comparable habitats*. A.R.G. Gantner Verlag K.G. Ruggell G.
- Leng, M., Marshall, J., 2004. Palaeoclimate interpretation of stable isotope data from lake sediment archives. *Quaternary Science Reviews* 23 (7–8), 811–831.
- Leng, M.J., Lamb, A.L., Heaton, T.H.E., Marshall, J.D., Wolfe, B.B., Jones, M.D., Holmes, J.A., Arrowsmith, C., 2006. Isotopes in lake sediments. In: Leng, M.J. (Ed.), *Isotopes in Palaeoenvironmental Research*, vol. 10. Springer, Dordrecht.
- Lepš, J., Šmilauer, P., 2003. *Multivariate Analysis of Ecological Data Using CANOCO*. University Press, Cambridge, 269 pp.
- Li, Y., Wang, N., Cheng, H., Long, H., Zhao, Q., 2009. Holocene environmental change in the marginal area of the Asian monsoon: a record from Zhuye Lake, NW China. *Boreas* 38 (2), 349–361.
- Li, J., Mackay, A.W., Zhang, Y., Li, J. A high-resolution pollen and charcoal record from Lake Erlongwan in the Long Gang region (northeast China) since the last millennium. *Quaternary International*, in review.
- Lindberg, S., Bullock, R., Ebinghaus, R., Engstrom, D., Feng, X.B., Fitzgerald, W., Pirrone, N., Prestbo, E., Seigneur, C., 2007. A synthesis of progress and uncertainties in attributing the sources of mercury in deposition. *Ambio* 36 (1), 19–32.
- Liu, J., Chu, G., Han, J., Rioual, P., Jiao, W., Wang, K., 2009. Volcanic eruptions in the Longgang volcanic field, northeastern China, during the past 15,000 years. *Journal of Asian Earth Sciences* 34 (5), 645–654.
- Liu, B.H., Henderson, M., Zhang, Y.D., Xu, M., 2010. Spatiotemporal change in China's climatic growing season: 1955–2000. *Climatic Change* 99, 93–118.
- Liu, X.D., Jiang, S., Zhang, P.F., Xu, L.Q., 2012. Effect of recent climate change on arctic Pb pollution: a comparative study of historical records in lake and peat sediments. *Environmental Pollution* 160, 161–168.
- Liu, M.Y., 1989. *Huinan Country Annals*. Shenzhen Haitian Press, Shenzhen, 500 pp.
- Lotter, A.F., Bigler, C., 2000. Do diatoms in the Swiss Alps reflect the length of ice-cover? *Aquatic Sciences* 62 (2), 125–141.
- Mackay, A.W., Bezrukova, E.V., Leng, M.J., Meaney, M., Nunes, A., Piotrowska, N., Self, A., Shchetnikov, A., Shilland, E., Tarasov, P., Wang, I., White, D., 2012. Aquatic ecosystem responses to Holocene climate change and biome development in boreal, central Asia. *Quaternary Science Reviews* 41, 119–131.
- Manabe, S., Ploshay, J., Lau, N.-C., 2011. Seasonal variation of surface temperature change during the last several decades. *Journal of Climate* 24, 3817–3821.
- Mann, M.E., Zhang, Z., Hughes, M.K., Bradley, R.S., Miller, S.K., Rutherford, S., Ni, F., 2008. Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences of the United States of America* 105 (36), 13252–13257.
- Meyers, P.A., Lallier-Vergès, E., 1999. Lacustrine sedimentary organic matter records of Late Quaternary paleoclimates. *Journal of Paleolimnology* 21 (3), 345–372.
- Meyers, P.A., Teranes, J.L., 2001. Sediment organic matter. In: Last, W.M., Smol, J.P. (Eds.), *Tracking Environmental Change Using Lake Sediments*. Physical and Geochemical Methods, vol. 2. Kluwer Academic Publishers, London, pp. 239–270.

- Meyers, P.A., 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemical Geology* 144, 289–302.
- Mingram, J., Allen, J., Brüchmann, C., Liu, J., Luo, X., Negendank, J., Nowaczyk, N., Schettler, G., 2004. Maar- and crater-lakes of the Long Gang Volcanic Field (NE China)—overview, laminated sediments, and vegetation history of the last 900 years. *Quaternary International* 123, 135–147.
- Monteith, D.T., Stoddard, J.L., Evans, C.D., de Wit, H.A., Forsius, M., Hogasen, T., Wilander, A., Skjelkvale, B.L., Jeffries, D.S., Vuorenmaa, J., Keller, B., Kopacek, J., Vesely, J., 2007. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature* 450 (7169), 537–539.
- Moritz, R.E., Bitz, C.M., Steig, E.J., 2002. Dynamics of recent climate change in the Arctic. *Science* 297 (5586), 1497–1502.
- Norton, S.A., Kahl, J.S., 1987. A comparison of lake sediments and ombrotrophic peat deposits as long term monitors of atmospheric pollution. In: Boyle, T.P. (Ed.), *New Approaches to Monitoring Aquatic Ecosystems (ASTM STP)*, vol. 940. American Society for Testing and Materials, Philadelphia, pp. 40–57.
- O'Dwyer, B., Taylor, D., 2010. Variations in levels of deposition of atmosphere-borne industrial pollutants at three oligotrophic lakes in Ireland over the last 50–150 years: sediment-based archives of sources, levels and ecological sensitivity. *Journal of Paleolimnology* 44 (1), 123–142.
- Oreskes, N., 2004. The scientific consensus on climate change. *Science* 306 (5702), 1686. <http://dx.doi.org/10.1126/science.1103618>.
- Pace, M.L., Cole, J.J., 2002. Synchronous variation of dissolved organic carbon and color in lakes. *Limnology and Oceanography* 47, 333–342.
- Paterson, A.M., Betts-Piper, A.A., Smol, J.P., Zeeb, B.A., 2003. Diatom and chrysophyte algal response to long-term PCB contamination from a point-source in northern Labrador, Canada. *Water, Air and Soil Pollution* 145, 377–393.
- Pla, S., Monteith, D., Flower, R., Rose, N., 2009. The recent palaeolimnology of a remote Scottish loch with special reference to the relative impacts of regional warming and atmospheric contamination. *Freshwater Biology* 54, 505–523.
- Reuss, N.S., Hammarlund, D., Rundgren, M., Segerstrom, U., Eriksson, L., Rosen, P., 2010. Lake ecosystem responses to Holocene climate change at the subarctic tree-line in Northern Sweden. *Ecosystems* 13 (3), 393–409.
- Riber, H.H., Wetzel, R.G., 1987. Boundary-layer and internal diffusion effects on phosphorus fluxes in lake periphyton. *Limnology and Oceanography* 32 (6), 1181–1194.
- Rose, N.L., Appleby, P.G., Boyle, J.F., Mackay, A.W., Flower, R.J., 1998. The spatial and temporal distribution of fossil-fuel derived pollutants in the sediment record of Lake Baikal, eastern Siberia. *Journal of Paleolimnology* 20, 151–162.
- Rose, N.L., Boyle, J.F., Du, Y., Yi, C., Dai, X., Appleby, P.G., 2004. Sedimentary evidence for changes in the pollution status of Taihu in the Jiangsu region of eastern China. *Journal of Paleolimnology* 32, 14–51.
- Rose, N.L., 1994. A note on further refinement to a procedure for the extraction of carbonaceous fly-ash particles from sediments. *Journal of Paleolimnology* 11, 201–204.
- Rose, N., 1995. Carbonaceous particle record in lake sediments from the Arctic and other remote areas of the Northern Hemisphere. *Science of the Total Environment* 160, 487–496.
- Rose, N.L., 2008. Quality control in the analysis of lake sediments for spherical carbonaceous particles. *Limnology and Oceanography: Methods* 6, 172–179.
- Rühland, K., Priesnitz, A., Smol, J.P., 2003a. Paleolimnological evidence from diatoms for recent environmental changes in 50 lakes across Canadian arctic treeline. *Arctic Antarctic and Alpine Research* 35 (1), 110–123.
- Rühland, K., Smol, J.P., Pienitz, R., 2003b. Ecology and spatial distributions of surface-sediment diatoms from 77 lakes in the subarctic Canadian treeline region. *Canadian Journal of Botany* 81, 57–73.
- Rühland, K., Paterson, A., Smol, J., 2008. Hemispheric-scale patterns of climate-related shifts in planktonic diatoms from North American and European lakes. *Global Change Biology* 14 (11), 2740–2754.
- Saros, J.E., Interlandi, S.J., Wolfe, A.P., Engstrom, D.R., 2003. Recent changes in the diatom community structure of lakes in the Beartooth Mountain Range, USA. *Arctic Antarctic and Alpine Research* 35 (1), 18–23.
- Smith, F.A., Walker, N.A., 1980. Photosynthesis by aquatic plants – effects of unstirred layers in relation to assimilation of CO₂ and HCO₃⁻ and to carbon isotopic discrimination. *New Phytologist* 86 (3), 245–259.
- Smol, J., Wolfe, A., Birks, H., Douglas, M., Jones, V., Korhola, A., Pienitz, R., Rühland, K., Sorvari, S., Antoniades, D., Brooks, S., Fallu, M., Hughes, M., Keatley, B., Laing, T., Michelutti, N., Nazarova, L., Nyman, M., Paterson, A., Perren, B., Quinlan, R., Rautio, M., Saulnier-Talbot, E., Siitonen, S., Solovieva, N., Weckstrom, J., 2005. Climate-driven regime shifts in the biological communities of arctic lakes. *Proceedings of the National Academy of Sciences of the United States of America* 102, 4397–4402.
- Snucins, E., Gunn, J., 2000. Interannual variation in the thermal structure of clear and coloured lakes. *Limnology and Oceanography* 45, 1639–1646.
- Sorvari, S., Korhola, A., Thompson, R., 2002. Lake diatom response to recent Arctic warming in Finnish Lapland. *Global Change Biology* 8 (2), 171–181.
- Thevenon, F., Graham, N.D., Chiaradia, M., Arpagaus, P., Wildi, W., Poté, J., 2011. Local to regional scale industrial heavy metal pollution recorded in sediments of large freshwater lakes in central Europe (lakes Geneva and Lucerne) over the last centuries. *Science of the Total Environment* 412–413, 239–247.
- Vyverman, W., 1991. Diatoms from Papua New Guinea. *Cramer, Berlin*, 224 pp.
- Wang, X., Yang, H., Gong, P., Zhao, X., Wu, G., Turner, S., Yao, T., 2010. One century sedimentary records of polycyclic aromatic hydrocarbons, mercury and trace elements in the Qinghai Lake, Tibetan Plateau. *Environmental Pollution* 158 (10), 3065–3070.
- Wang, L., Rioual, P., Panizzo, V.N., Lu, H., Gu, Z., Chu, G., Yang, D., Han, J., Liu, J., Mackay, A.W., 2012. A 1000-year record of environmental change in NE China, indicated by diatom assemblages from maar lake Erlongwan. *Quaternary Research* 78, 24–34.
- Williams, D.M., Chudaev, D.A., Gololobova, M.A., 2009. *Punctastriata glubokoensis* spec. nov., a new species of “fragilarioid” diatom from Lake Glubokoe, Russia. *Diatom Research* 24 (2), 479–485.
- Winder, M., Hunter, D.A., 2008. Temporal organization of phytoplankton communities linked to physical forcing. *Oecologia* 156 (1), 179–192.
- Winder, M., Reuter, J.E., Schladow, G.S., 2009. Lake warming favours small-sized planktonic diatom species. *Proceedings of the Royal Society of London (Series B)* 276, 427–435.
- Wischniewski, J., Kramer, A., Kong, Z.C., Mackay, A.W., Simpson, G.L., Mischke, S., Herzsich, U., 2011. Terrestrial and aquatic responses to climate change and human impact on the southeastern Tibetan Plateau during the past two centuries. *Global Change Biology* 17 (11), 3376–3391.
- Wolfe, A.P., Perren, B.B., 2001. Chrysophyte microfossils record marked responses to recent environmental changes in high- and mid-arctic lakes. *Canadian Journal of Botany* 79, 747–752.
- Yang, B., Braeuning, A., Johnson, K.R., Yafeng, S., 2002. General characteristics of temperature variation in China during the last two millennia. *Geophysical Research Letters* 29 (9), 1324. <http://dx.doi.org/10.1029/2001GL014485>.
- Yang, H.D., Battarbee, R.W., Turner, S.D., Rose, N.L., Derwent, R.G., Wu, G.J., Yang, R.Q., 2010a. Historical reconstruction of mercury pollution across the Tibetan Plateau using lake sediments. *Environmental Science & Technology* 44 (8), 2918–2924.
- Yang, R., Wang, Y., Li, A., Zhang, Q., Jing, C., Wang, T., Wang, P., Li, Y., Jiang, G., 2010b. Organochlorine pesticides and PCBs in fish from lakes of the Tibetan Plateau and the implications. *Environmental Pollution* 158 (6), 2310–2316.
- You, Q., Kang, S., Flugel, W.-A., Sanchez-Lorenzo, A., Yan, Y., Xu, Y., Huang, J., 2009. Does a weekend effect in diurnal temperature range exist in the eastern and central Tibetan Plateau? *Environmental Research Letters* 4, 045202.
- Yu, W.T., Jiang, C.M., Ma, Q., Xu, Y.G., Zou, H., Zhang, S.C., 2011. Observation of the nitrogen deposition in the lower Liaohe River Plain, Northeast China and assessing its ecological risk. *Atmospheric Research* 101 (1–2), 460–468.