Lake sediment archives of late Holocene climate variability in Lützow-Holm Bay, East Antarctica

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

THESIS ABSTRACT

Large fluctuations in year-to-year climate variability have been observed at southern high latitudes over the last 60 years, however short instrumental records make the identification and interpretation of long-term trends difficult. In the Antarctic region, the need for a longer term perspective on climate variability can be addressed using natural archives including ice cores and lake and marine sediments. Lakes in coastal ice-free regions sit at the boundary of the continent and the oceans, and provide an opportunity to fill a spatial gap between the ice core records constrained to the interior of the continent, and the more extensively studied lower latitudes.

This thesis presents records of environmental change spanning 3000 years inferred from the sediments of two lakes, Lake Hamagiku and Lake Naga, in the Lützow-Holm Bay region of East Antarctica. These records of past environmental change are supported by an investigation into the modern relationship between diatom assemblages and their habitats and lake water chemistry. Specific conductivity was found to be the primary factor explaining variations in diatom assemblage, consistent with previous studies. Diatom assemblages were also observed to differ significantly between the lake littoral region and the lake floor deeper than two metres water depth. These modern observations are used in the interpretation of the fossil diatom records to reflect changes in ice cover as a result of regional temperature variations, where longer ice-free conditions result in a greater relative abundance of the taxa inhabiting the lake floor region. Fossil diatom assemblages revealed a coherent and sustained shift in the relative abundance of key taxa at ~1800 cal. yr BP in both lakes, which is interpreted to reflect regional warming, and an associated increase in the duration of ice-free conditions at these sites. Diatom valve concentration, organic carbon and nitrogen concentrations and carbon and nitrogen stable isotope ratios suggest that the climatic shift at this period was not associated with changes in lake productivity, which is attributed to the limitations imposed by the low nutrient conditions of these lakes.

Periodicities in the variability archived in the sediments of both lakes are identified, in the fluctuations in key diatom taxa and to a lesser extent in the organic geochemistry records. This shared periodicity is observed with a wavelength of ~250 years from 2500 to 1000 cal. yr BP, after which a periodicity of closer to 128 years is observed across the records. These periodicities are consistent with those reported from a range of Southern Hemisphere palaeoclimate records and reconstructions, influenced by the Southern Hemisphere westerly airflow, and also solar activity in the Southern Hemisphere. The results presented in this thesis are a valuable addition to our knowledge of Southern Hemisphere climate throughout the late Holocene.

THESIS DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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PUBLICATIONS DURING THE COURSE OF THIS THESIS

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Conference presentations:

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Rudd, R.C., Tyler, J.J., Tibby, J., Yokoyama, Y., Tavernier, I., Verleyen, E., Fukui, M & Takano, Y. (2016). Lake variability in Lützow-Holm Bay, East Antarctica, inferred from fossil diatoms. Australian Earth Sciences Convention, Adelaide

Rudd, R.C., Tyler, J.J., Tibby, J., Yokoyama, Y., Tavernier, I., Verleyen, E., Fukui, M & Takano, Y. (2016). Late Holocene ecological variance from two lakes in Skarvsnes, East Antarctica. NIPR Seventh Symposium on Polar Science, Tokyo

CHAPTER 1

Introduction and thesis outline

Introduction

Dramatic climatic changes have been observed in the Antarctic region since records began. Between the 1950s and 1990s, the Antarctic Peninsula recorded some of the largest increases in surface air temperature in the Southern Hemisphere (Turner *et al.*, 2016; Stenni *et al.*, 2017) and 87% of glaciers on the Antarctic Peninsula have retreated over the last 60 years (Cook *et al.*, 2005). Since the 90s however, temperatures at most Antarctic Peninsula stations have not shown a warming trend (Turner *et al.*, 2016). In West Antarctica, temperatures have cooled slightly over recent decades, and for East Antarctica, significant temperature change has not been observed since the 1950s (Nicolas & Bromwich, 2014). The discrepancies in spatial coherency of recent trends (Mulvaney *et al.*, 2012) make understanding their context in the history of climatic change in the region critical.

The effects of a warming climate on the Antarctic region are of particular interest, due to the global consequences of potential sea level rise. The Antarctic Ice Sheet comprises around 90% of continental ice on earth (Lythe & Vaughan, 2001; Vaughan & Spouge, 2002) and has the potential to contribute around 70 metres of sea level rise (Huss & Farinotti, 2014), compared to the 7.2 metres calculated for the Greenland Ice Sheet (Aschwanden *et al.*, 2019). Regardless of current trends, even short-term warming may have lasting effects, due to positive feedback processes, for example via decreased albedo. Warming oceans also have effects on ocean-terminating glaciers (Cook *et al.*, 2016). The Southern Ocean is an important sink of anthropogenic CO_2, although the rate of uptake over decadal timescales is influenced by changes in ocean circulation, sea-surface temperature and stratification (Gruber, Landschützer & Lovenduski, 2019). This rate of uptake has declined with a southward trend of the westerly winds around Antarctica, a trend that is predicted to continue in a warming world (Gillett & Thompson, 2003; Gruber *et al.*, 2019). Changes in the Antarctic region have further global implications as the spatial extent of polar sea ice influences atmospheric temperatures, ocean thermohaline circulation, and atmospheric thermal gradients which regulate Earth's climate and weather (Hodgson & Smol, 2008). Understanding these processes in the context of contemporary and future climatic change requires detailed and high quality records of the past. The last two to three millennia (i.e. the late Holocene) has been widely identified as being an ideal period of focus, since the global climatic and tectonic boundary conditions are analogous to the modern world, and due to the plethora of available palaeoclimate evidence for this period (Pages 2K Consortium, 2013).

Antarctic climate regime

The current climate regime of the Antarctic region is largely controlled by its isolation from other land masses (Martinson, 2012). Forced by the Southern Hemisphere westerly winds, the Antarctic Circumpolar Current (ACC) in the Southern Ocean flows around the continent and thermally isolates it from other continents and oceans at lower latitudes (Martinson, 2012). Large natural variability in the strength and position of the westerly winds is observed, which can alter the ACC fronts, with implications for Southern Ocean circulation and surface mixing (Ferster, Subrahmanyam & Arguez, 2019). The Southern Ocean has global influence, in the transport of heat, nutrient and gases (Ferster *et al.*, 2019), as well as being an important carbon dioxide sink (Gruber *et al.*, 2019). Recent warming and freshening of the Southern Ocean have been observed, and has been attributed to greenhouse gas emissions and ozone depletion (Swart *et al.*, 2018; Ferster *et al.*, 2019). The Southern Ocean and the Antarctic region are also influenced by several modes of climate variability in the Southern Hemisphere, including the Southern Annular Mode, El Niño Southern Oscillation and the Indian Ocean Dipole.

The leading mode of atmospheric circulation variability in the Southern Hemisphere is the Southern Annular Mode (SAM, also known as the Antarctic Oscillation), which is a measure of the atmospheric pressure gradient across the southern mid-high latitudes. A positive SAM phase describes a poleward contraction of the westerly winds circling Antarctica, and is associated with colder temperatures across most of Antarctica (Thompson & Wallace, 2000; Gillett, Kell & Jones, 2006). There is some spatial variability however, as over the 1957–2004 period, and across four seasons, near-surface temperatures across most of the Antarctic continent showed a strong negative correlation to SAM, while the Antarctic Peninsula showed a positive correlation (Marshall, 2007). Records from the subantarctic islands have been used to identify an increase in intensification of the westerly winds during the late Holocene, between 2000 and 1000 years ago (Turney *et al.*, 2016; Browne *et al.*, 2017). Recent trends indicate more positive phases of the SAM which are believed to lie outside natural variation (Thompson & Solomon, 2002; Abram et al., 2014) and are thought to be heightened by the depletion of ozone and anthropogenic increase of greenhouse gases (Marshall *et al.*, 2004; Perlwitz *et al.*, 2008).

Beyond the Southern Ocean, the El Niño Southern Oscillation (ENSO) describes the largest ocean-atmospheric cycle on decadal and sub-decadal timescales, with global impacts (Diaz, 1992). Although it is difficult to relate meteorological conditions across the entire Antarctic continent to ENSO, as the relationships do not appear to be constant through time or space (Turner, 2004), it has been shown that ENSO may have a strong effect on the height and mass of ice shelves in West Antarctica (Paolo et al., 2018). During strong El Niño years, the rates of accumulation and basal melting are both observed to increase, with ice shelf height increasing, but overall net mass decrease due to dense ice being lost from the base (Paolo *et al.*, 2018). The spatial expression of ENSO influence on Antarctic ice shelves remains uncertain, due to spatial inconsistencies in observed response (Paolo *et al.*, 2018). Climate model simulations have found a generally negative correlation between ENSO and SAM although further research into their interactions over longer timescales is necessary to determine the stability of teleconnections in the Southern Hemisphere (Dätwyler *et al.*, 2019).

Another mode of climate variability with possible impacts on the Antarctic region is the Indian Ocean Dipole (IOD), which is defined by the difference in sea surface temperature across the Indian Ocean (Abram *et al.*, 2007). Over recent decades, an increase in extreme positive IOD events has been observed, where the eastern Indian Ocean is cooler, and the western Indian Ocean is warmer (Cai, Cowan & Sullivan, 2009; Cai *et al.*, 2014). These extreme positive IOD events may be induced by greenhouse warming, ENSO and positive phases of the SAM (Cai *et al.*, 2009). It has been proposed that the IOD coupled with ENSO may affect Antarctic sea ice, although the influence of ENSO is stronger (Nuncio & Yuan, 2015). While the IOD and ENSO have been shown to be linked (Cai, Sullivan & Cowan, 2011), the way in which the IOD interacts with SAM is an ongoing area of research, and the extent of their influence on one another is currently unclear (Cai *et al.*, 2011; Cleverly *et al.*, 2016).

Palaeoclimate research in Antarctica – ice cores

Compared to the Northern Hemisphere, multi-centennial records are sparse in the Southern Hemisphere due to uninhabited areas, the dominance of oceans and limited instrumental records (Neukom & Gergis, 2012). This problem is heightened at southern high latitudes, where logistics in reaching the remote continent of Antarctica also play a role. Instrumental records in Antarctica are short and sparse, with most only extending as far back as the international geophysical year in 1957 (IPCC, 2014; Nicolas & Bromwich, 2014; Stenni *et al.*, 2017). Antarctic climate exhibits a large magnitude of year to year variability, which makes discerning longer-term trends difficult (Jones *et al.*, 2016; Stenni *et al.*, 2017). In order to interpret these trends in the context of longer records, natural archives must be utilised.

At lower latitudes, instrumental records extend back further in some regions, and natural archives including tree rings, marine sediments, lake sediment, corals and speleothems have all been used as a means of understanding past climate (Neukom & Gergis, 2012). In the Antarctic region, marine sediments, lake sediments and ice cores are the most commonly used natural archives. Ice core records provide an unparalleled insight into past temperature, precipitation amount, atmospheric gas concentration and particulate deposition for the interior of the continent (Leuenberger & Siegenthaler, 1992; Petit *et al.*, 1999; EPICA community members, 2004; Spahni *et al.*, 2005; Vance *et al.*, 2012; Mulvaney *et al.*, 2013).

Ice core measurements include isotope analysis of the water molecules themselves, measurement of both soluble and insoluble chemical impurities (eg. volcanic sulphate, terrestrial dust and sea salts) and analysis of the composition of the air trapped within the ice (Wolff, 2005). In areas of high accumulation, annual snow accumulation rates may be calculated provided that snowfall is high enough to resolve annual layers, and that these layers are preserved over time. Higher accumulation rates are more common in coastal zones and West Antarctica, while for the dry regions of the central Antarctic plateau, annual layering is less commonly observed yet longer records can be collected (Stenni *et al.*, 2017).

Past temperatures have been inferred from ice cores using the isotopic composition (δD and/or $\delta^{18}O$) of water molecules (Jouzel *et al.*, 1997), and have been used to create high resolution records across the continent. Borehole temperature measurements have also been used in conjunction with ice core isotope records to help constrain past temperature (eg. Cuffey *et al.*, 2016), however this method is restricted to sites of high snow accumulation rate. For the last 2000 years, a synthesis of 11 ice cores identified a relatively warmer period from ~1783 to ~750 calendar years before present (herein referred to as cal. yr BP, where BP is 1950), after which, temperatures became more variable yet cooler overall (Pages 2K Consortium, 2013). Further composite reconstructions have been made, for seven Antarctic regions, as well as for the East Antarctic, West Antarctic and the whole Antarctic region. These reconstructions show regional variability, but overall, a long-term cooling trend is inferred for the East, West, and whole Antarctic from 1950 to 0 cal. yr BP (Stenni *et al.*, 2017). The warmest temperatures were inferred to have occurred between 1650 and 950 cal. yr BP, and the coldest period was between 750 and 50 cal. yr BP (Stenni *et al.*, 2017). Significant warming trends were identified for the Antarctic Peninsula, West Antarctic Ice Sheet and Dronning Maud Land Coast since 50 cal. yr BP (Stenni *et al.*, 2017).

One of the limitations of ice core records is that they are geographically constrained to the interior of the continent, with the exception of a few locations where accumulation rates are high enough to preserve layers near the coast (eg. Law Dome). Lakes along the coastline in rocky, seasonally ice covered regions can provide an alternate perspective to complement ice core records. A coastal perspective is particularly valuable as the two leading modes of large scale atmospheric circulation affecting southern high latitudes – namely the SAM and ENSO – act primarily across the oceans, and since ice-free coastal regions sit at the interface of the oceanic circulation patterns and the continents, they are ideally placed to track such processes. Studying lake sediments also has the advantage of capturing catchment level variability rather than an integrated signal over a wider region (Oldfield, 1977; Noon *et al.*, 2001). Lake sediments from coastal Antarctic regions have proven to be a valuable palaeoclimate archive to complement ice core records (eg. Jones, Hodgson & Chepstow-Lusty, 2000; Roberts *et al.*, 2004; Hodgson *et al.*, 2016), however the number of detailed late Holocene Antarctic lake sediment records remains few and these are geographically restricted.

Lake systems in Antarctic ice-free regions

Only 3.5% of the Antarctic continent is ice free, and only 1-2% of this is comprised of coastal ice-free regions exposed through glacial retreat and isostatic uplift, the majority of ice-free areas being comprised of mountain peaks protruding from the polar ice cap (Fox, Paul & Cooper, 1994; Hodgson *et al.*, 2004). The McMurdo Dry Valleys in Victoria Land is the largest coastal ice-free area, and there are many smaller regions including the Vestfold Hills, Larsemann Hills, Bunger Hills, Schirmacher Oasis and Syowa Oasis (Figure 1.1). These ice free regions along the coastline provide opportunity for life despite the harsh environment of the continent and are sometimes referred to as oases (Tanabe *et al.*, 2016). Whilst Antarctica receives very little precipitation, water may accumulate in these regions where solar radiation and advected heat promote melting (Hodgson *et al.*, 2004). Lakes which form in depressions in the landscape provide an opportunity for palaeolimnological studies (Figure 1.2).

Antarctic coastal lakes and ponds remain frozen for much of the year, and may lose ice cover briefly during the summer months, exposing the lake system to the atmosphere (Spaulding *et al.*, 2010). Some lakes maintain permanent ice cover over most of their surface area with moats forming around their perimeter where ice melt is focused (eg. Lake Bonney in the McMurdo Dry Valleys, Fritsen & Priscu, 1999), while many other lakes lose ice cover completely for up to several months. The thickness of ice cover usually ranges from 1.5 to 6 m, and this ice acts to insulate the water underneath so that only very shallow, unprotected lakes freeze to their base (Hodgson *et al.*, 2004).

The ice cover of these lakes has implications for their chemistry and biology, limiting light penetration, wind-generated currents and gas exchange with the atmosphere (Wharton *et al.*, 1993). Whilst photosynthetically available radiation is limited during winter, in the summer the transparency of the water column and prolonged periods of daylight promotes a high degree of illumination which may inhibit phytoplankton and photoautotrophs in shallow littoral regions (Goldman, Mason & Wood, 1963; Tanabe *et al.*, 2008). In perennially frozen Arctic lakes, ice cover duration and extent has been reported to be a key driver of ecological change (Douglas & Smol, 1999; Griffiths *et al.*, 2017). The timing and duration of the ice-free season predominantly reflects the temperature of the region, but is also influenced by wind strength and cloud cover (Douglas & Smol, 1999). The prolonged period of ice cover also acts to inhibit wind-induced mixing, which in turn limits sediment focusing within the lake basin (Spaulding *et al.*, 1997). An example of ice cover melt and ice rafting over the summer months at Lake Naga and Lake Hamagiku is shown in Figure 1.3a and b.

With the exception of a few locations in East Antarctica, most Antarctic coastal regions which are now ice-free were overridden by continental ice sheets during the Last Glacial Maximum (LGM), and sediments preserved are typically of Holocene age and post-date the last deglaciation (Hodgson *et al.*, 2004). Many lakes in coastal Antarctica, particularly those at low altitudes, were formed during isostatic uplift and lake isolation associated with glacial retreat (Miura *et al.*, 1998; Matsumoto *et al.*, 2010; Takano *et al.*, 2012). Lakes at higher altitudes formed in depressions in the landscape where meltwater has accumulated following their exposure during glacier retreat. Both of these lakes types are common in the ice-free regions around the Antarctic continent. Lakes have also been observed along ice shelf or glacier fronts (epishelf/epiglacier lakes), in depressions on glaciers (supraglacial lakes), and beneath glaciers (subglacial lakes) (Hodgson *et al.*, 2004).

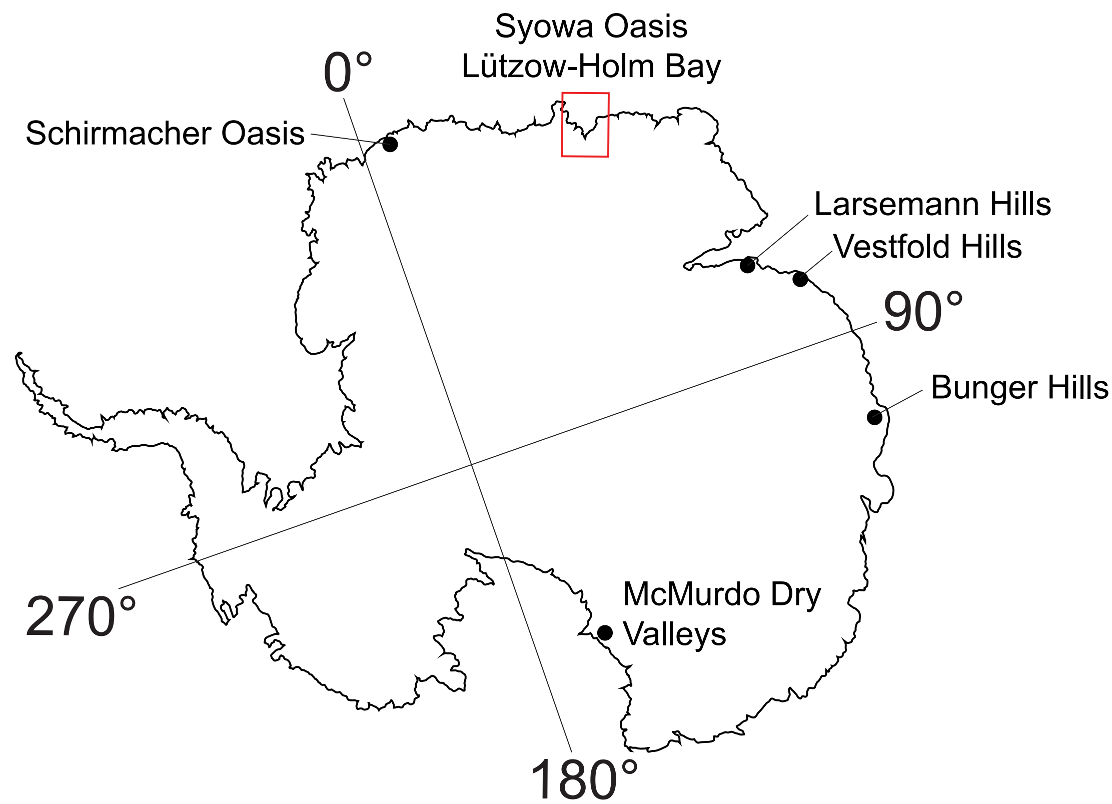

Figure 1.1 Location of ice-free areas in Antarctica.

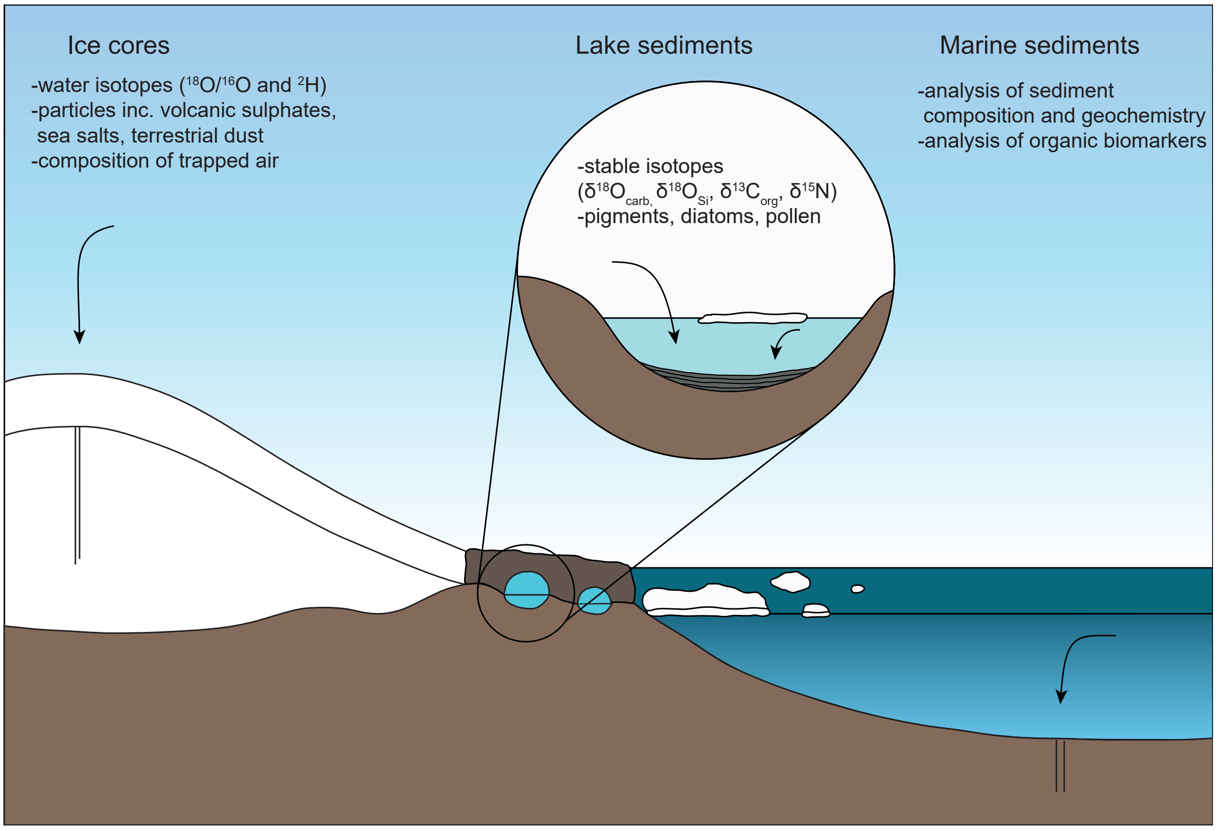

Figure 1.2 Schematic of natural climate archives in the Antarctic region.

In contrast to the barren conditions across much of the continent, the lakes and ponds of coastal Antarctica host a relatively large species diversity. Across the different ice-free regions, benthic microbial mats have been observed in lakes, composed of cyanobacteria, diatoms and green algae (Gibson *et al.*, 2006). These lakes are mostly oligotrophic, and dissolved inorganic nitrogen and phosphate concentrations in the surface sediments of lakes have been observed to be substantially higher than concentrations measured in the water column (Tanabe *et al.*, 2016). As a result, nutrient cycling occurs largely in the surface sediments favouring benthic cyanobacteria and diatoms, and an absence of plankton in many lakes is observed (Gibson *et al.*, 2006). Lake primary productivity is usually modulated by temperature, as a result of its effect on the ice-free duration of Antarctic lakes (Quayle *et al.*, 2002). As such, proxies including organic matter accumulation, fossil pigments and total diatom concentrations have been used as tools for inferring past temperature variability from Antarctic lake sediments (Hodgson *et al.*, 2005; Cremer *et al.*, 2007; Verleyen *et al.*, 2011; Sterken *et al.*, 2012).

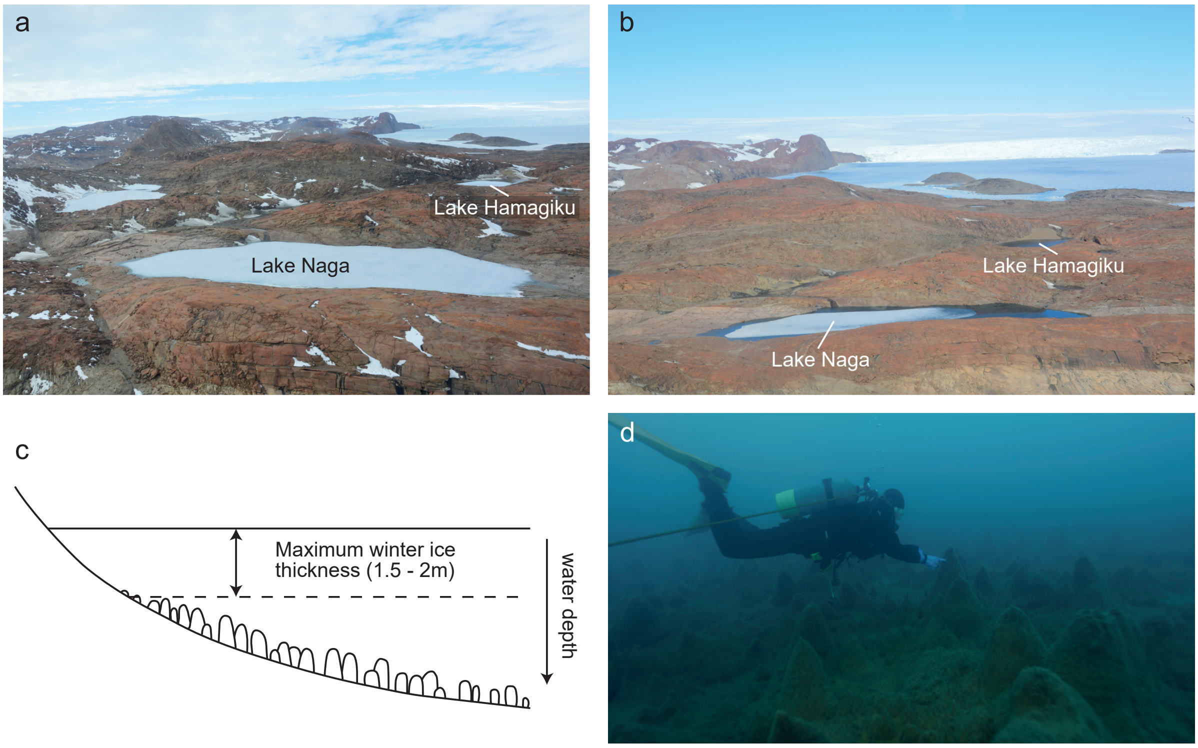

Figure 1.3 a) Aerial photograph of Lake Naga and Lake Hamagiku, Skarvsnes, taken on the 20th of December 2017, b) aerial photograph of Lake Naga and Lake Hamagiku, on the 13th of January 2018, c) schematic diagram of moss pillars found in lakes in Lützow-Holm Bay, adapted from Imura *et al*. (1999), d) underwater photograph of moss pillars and a diver, taken in a lake in the Lützow-Holm Bay area.

Diatoms as indicators of climate in Antarctic lakes

The preservation potential in lake sediments of the silica frustules of diatoms, coupled with their sensitivity to changes in water chemistry and lake morphology have made them a popular proxy for palaeoclimate research in Antarctic lakes (Spaulding & McKnight, 1999; Hodgson *et al.*, 2004). Diatom species diversity is low when compared to temperate regions (Jones, 1996) believed to be the result of geographic isolation (Vyverman *et al.*, 2007; Spaulding *et al.*, 2010). The distribution of diatoms from waterbodies in various regions have been described, and pronounced differences in diatom assemblages have been observed between the Sub-Antarctic Islands (Van de Vijver & Beyens, 1999), maritime Antarctica (Zidarova, Kopalová & Van de Vijver, 2016) and Continental Antarctica (Sabbe *et al.*, 2003; Esposito *et al.*, 2008).

An important driver of lake diatom composition is lake water salinity, usually reported as specific conductivity (Spaulding & McKnight, 1999; Battarbee *et al.*, 2001). The role of specific conductivity has been highlighted in the Sub-Antarctic Islands (Saunders *et al.*, 2015), Antarctic Peninsula (Kopalová *et al.*, 2013, 2019) and East Antarctica (Verleyen *et al.*, 2003; Tavernier *et al.*, 2014), which has led to the development of conductivity transfer functions for interpreting past climate variability (Roberts & McMinn, 1996; Verleyen *et al.*, 2003; Tavernier *et al.*, 2014; Saunders *et al.*, 2015). Changes in conductivity in Antarctic lakes are generally interpreted to be the result of temperature changes affecting the moisture balance through precipitation and evaporation, although this has been interpreted in different ways (Spaulding *et al.*, 2010). In some studies, when lakes have become less saline, warmer temperatures have been inferred, associated with increased precipitation and snow accumulation (Roberts & McMinn, 1999; Roberts *et al.*, 2004; Verleyen *et al.*, 2004; Hodgson *et al.*, 2005). In other cases, increases in salinity have been associated with warmer temperatures, as reduced snow cover has led to increased evaporation through albedo loss (Hodgson *et al.*, 2006a). For the Sub-Antarctic Islands, increases in conductivity are used to infer periods of increased wind strength blowing sea salt spray into lakes (Saunders *et al.*, 2015). In the Antarctic region, diatom based transfer functions have also been used to reconstruct chlorophyll-*a* concentrations in maritime Antarctic lakes (Jones & Juggins, 1995) and to reconstruct water depth based on preferences of diatoms in the surface sediments from fjords in the Vestfold Hills (Whitehead & McMinn, 1997). Transfer functions in Antarctic have generally been considered to be region specific, due to discrepancies in taxonomy (Hodgson *et al.*, 2004) and the evidence of significant regional differences in diatom species composition and ecology between regions due to local adaption (Elie Verleyen, pers. comm.; Tavernier, 2014).

The model described for Arctic lakes (Smol, 1983, 1988), whereby the duration and extent of ice cover can be inferred from the composition of the fossil diatom assemblages has been applied to Antarctic lakes. Fluctuations in the abundance of large pennate diatoms in cores from Lake Mondsee and Lake Tiefersee on King George Island were attributed to the extent of the ice-free moat which develops during summer periods (Schmidt, Mäusbacher & Müller, 1990). Furthermore, a greater diatom abundance and in particular a greater abundance of periphytic diatoms was observed for Lake Tiefersee relative to Lake Mondsee due to more persistent ice cover at Lake Mondsee (Schmidt *et al.*, 1990). During the last glacial maximum, perennial ice cover at Lake Reid in the Larsemann Hills was inferred from the very low diversity observed, with a near monospecific assemblage of *Stauroforma inermis* observed during this time period (Hodgson *et al.*, 2005).

There are limitations surrounding the use of diatoms as an indicator of palaeoenvironmental conditions, which also apply to their use in transfer functions. One of these limitations is that diatom dissolution may occur in saline or alkaline lakes, and bias the preserved assemblage towards more robust taxa (Ryves, Battarbee & Fritz, 2009). Another limitation is the potential for a lack of modern analogues for past lake conditions and diatom species (Birks, 1998). Where modern analogues do exist, the assumption is made that the diatom-environment relationships are consistent through time. The study of fossil diatom records also requires the assumption that the diatom assemblage in lake sediments at the location of coring is representative of the whole lake which, due to the limited wind disturbance while there is ice covering the lakes, may be a less efficient process in Antarctic lakes than is assumed for other locations (Spaulding *et al.*, 1997).

Studies from both Antarctic lakes and others worldwide have observed substrate to be a key control on diatom assemblages (Lim, Kwan & Douglas, 2001; Pla-Rabés & Catalan, 2018). For lakes on James Ross Island off the Antarctic Peninsula, diatom communities were found to differ significantly between different substrate types within the lakes, particularly between submerged and exposed habitats (Kopalová *et al.*, 2019). Specific diatom-substrate associations were used to infer warmer and wetter conditions during MIS5e, from the sediments of Lake Reid and Progress Lake in the Larsemann Hills (Hodgson *et al.*, 2005, 2006b). The diatom assemblage observed in the MIS5e sediments were similar to those found in sub- and maritime-Antarctic lakes in the present day, including species associated with mosses which are not currently found in the Larsemann Hills or other East Antarctic oases (Hodgson *et al.*, 2005, 2006b). As the focus of Antarctic diatom sampling has largely been for the development of transfer functions, there have only been a limited number of studies which examine diatom-substrate associations. There is scope to improve knowledge of diatom-substrate associations for Antarctic lakes, to aid in the interpretation of paleoclimate records.

Paleolimnological studies from Antarctica covering the late Holocene are limited, with many studies not covering the past 2000 years. Paleolimnological studies have been used in conjunction with other archives to identify two warm periods during the Holocene, one 11,500–9000 years ago and one in the mid-Holocene known as the mid-Holocene hypsithermal (MHH) (Bentley *et al.*, 2009). For the MHH, warm conditions have been interpreted from a variety of lake sediment proxies, including increased sedimentation rates, increased rates of organic productivity and increased species diversity (Bentley & Hodgson, 2009). The relative timing and duration of this warm period varies greatly across the continent, but is believed to have been most marked in the Antarctic Peninsula and maritime Antarctic regions, and to have occurred between ~4000 and 2700 cal. yr BP (Bentley & Hodgson, 2009). In continental Antarctica, increased biogenic production in lakes has been associated with this event (Hodgson *et al.*, 2004), as well as increased salinity in the Bunger Hills between 4000 and 2000 ^{14}C yr BP (Roberts, McMinn & Zwartz, 2000).

Study region: Lützow-Holm Bay

The study area of this thesis is Lützow-Holm Bay in Dronning Maud Land, East Antarctica. There are eight ice-free regions along the coast of Lützow-Holm Bay, the largest of which is Skarvsnes, followed by Langhovde and Skallen (Figure 1.4). At the southern end, the Shirase glacier enters the bay. The Japanese research station, Syowa Station, is located on East Ongul Island in the northern end of Lützow-Holm Bay. Syowa Station (69°00'16.0"S, 39°34'54.0"E) was established in 1957 and meteorological observations have been recorded since this time (Sato & Hirasawa, 2007). Over the period 1957–2007, the mean temperature recorded was -10.5°C, sea level pressure was 986 hPa and wind speed was 6.6 m/s, predominantly in a northeasterly direction (Sato & Hirasawa, 2007).

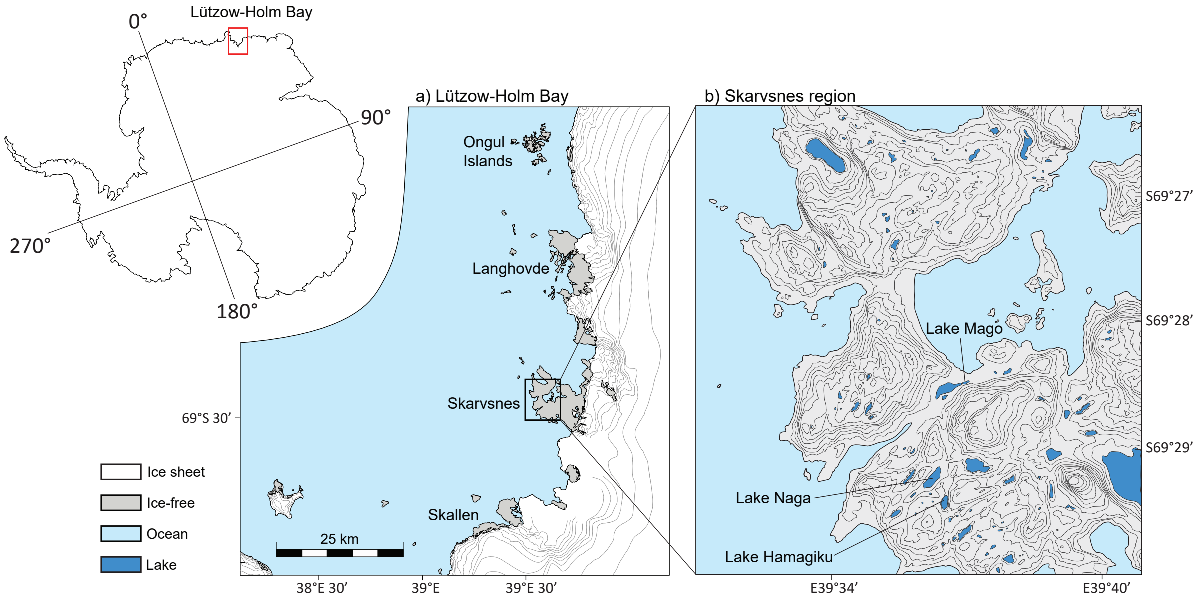

Figure 1.4 Location of Lützow-Holm Bay in East Antarctica a) ice-free areas in Lützow-Holm Bay, b) lakes mentioned in the text in the Skarvsnes region. Maps adapted from a Geographical Survey Institute map (Geospatial Information Authority of Japan, 1987) and Takano et al. (2012). Contour intervals for the ice sheet in a) are 100m and for the ice-free region in b) is 10m

The ice-free regions in Lützow-Holm Bay, also known as the Syowa Oasis, are considered to have been largely exposed from ca. 20,000 years ago (Kimura *et al.*, 2010). There are more than 100 lakes in this area, ranging in size and limnological characteristics (Tanabe *et al.*, 2016). Lakes in this region have been observed to host luxuriant benthic mats of cyanobacteria, green algae and diatoms amongst aquatic mosses, which in this region also form pillar-like structures in some lakes (Imura *et al.*, 1999; Kudoh *et al.*, 2003). A schematic and photograph of the moss pillars are shown in Figure 1.3c and d. Diatoms and algae in these lakes have been described in a number of studies (eg. Hirano, 1983; Ohtsuka *et al.*, 2006).

The lakes in Lützow-Holm Bay were formed in a similar way to those in other Antarctic regions, either with the exposure of depressions in the landscape following glacial retreat or the uplift of basins from under the ocean through isostatic rebound (Verleyen *et al.*, 2017). For lakes which formed through the uplift of ocean basins, the age at which they were isolated from the ocean has been studied using lake sediments, and used to determine the relative sea level of the region through time (Tavernier *et al.*, 2014; Verleyen *et al.*, 2017). Major elemental concentrations and stable isotope ratios have also been used to track these marine to lacustrine transitions in several lakes, with fluctuations in the lacustrine part of the records found to be low (Matsumoto *et al.*, 2006, 2010, 2014; Takano *et al.*, 2012). Verleyen *et al.* (2017) determined that the minimum marine limit for the Skarvsnes region was 32.7 m, higher than previously anticipated, and higher than the other ice-free regions in Lützow-Holm Bay. Differences in the deglaciation history of the region have been attributed to differences in bedrock geomorphology and the reactivation of faults in the region (Verleyen *et al.*, 2017).

A diatom-conductivity transfer function was developed for the Lützow-Holm Bay region, and applied to the sediments of Lake Mago (Figure 1.4) in the Skarsvnes region (Tavernier *et al.*, 2014). This study found that the lake was isolated from the ocean at ~1500 cal. yr BP, as reflected by a transition from marine to brackish to freshwater diatom assemblages. Diatom inferred specific conductivity did not show any major fluctuations above the prediction error throughout the record. Furthermore, the Lake Mago sediments did not archive any evidence of warming associated with the Medieval Climate Anomaly observed in the Northern Hemisphere, or any evidence of twentieth century warming (Tavernier *et al.*, 2014).

Thesis aims and objectives

This thesis aims to contribute to the knowledge of Antarctic climate through the late Holocene, via the addition of new, high resolution records for the coastal region. The overarching aim of the research is to better constrain the spatial homogeneity of decadal scale climate variability in Antarctica over the last ~3000 years, and the underlying drivers of change in this globally significant region. These aims are achieved by (a) developing two decadal scale palaeoclimate records from lakes in Lützow-Holm Bay, and (b) augmenting those records by investigating the modern controls over diatom species assemblages in these lakes. The results of these studies are interpreted in the context of paleoclimate records from around the Antarctic region and also across the Southern Hemisphere.

Thesis outline

Chapter 2 – A diatom-inferred record of lake variability during the last 900 years in Lützow-Holm Bay, East Antarctica

In Chapter 2 a 900-year, decadal scale record of fossil diatoms from sediments in Lake Hamagiku in East Antarctica is presented as a preliminary study exploring the potential of these lakes for paleoclimate research. This lake was previously known as Lake Abi and is referred to as such in this chapter. Variability in diatom relative abundances are tentatively interpreted to reflect subtle variations in specific conductivity, water depth and nutrient availability, although the paper highlights the need for further research into modern lake ecology in order to make more confident interpretations. The variability observed in this record contrasts to the overall stability reported for eastern Antarctica yet is reminiscent of the Interdecadal Pacific Oscillation as reconstructed from the Law Dome ice core (Vance *et al.*, 2015).

Chapter 3 – Ecological and habitat preferences of diatoms in Lützow-Holm Bay, East Antarctica

In Chapter 3, diatom species assemblages were studied from lake edge samples and surface sediments across varying water depths from nine lakes in Lützow-Holm Bay, with the aim of developing an understanding of diatom-environment relationships to assist in the interpretation of lake sediment records. Using multivariate regression tree and non-metric multidimensional scaling analyses, associations between measured physical and chemical lake variables and diatom assemblages are identified. Diatom assemblages are shown to vary subtly along gradients of these environmental variables, with specific conductivity, position in lake and maximum lake depth all identified as significant variables in explaining the diatom assemblages observed. The results of this study have implications for the interpretation of sedimentary diatom assemblages in the region.

Chapter 4 – Coherent patterns of late Holocene environmental change inferred from two lake diatom records in Lützow-Holm Bay, East Antarctica

Chapter 4 presents an extended fossil diatom record from Lake Hamagiku, together with a new record from neighbouring Lake Naga, both covering around 3000 years. These two high resolution records archive past variability of these lake systems and are interpreted using the results from Chapter 3 of this thesis alongside other studies of diatoms in the region. The diatom records from each lake exhibit a significant and objectively defined change point at approximately 1800±150 cal. yr BP, with a more dramatic shift observed at Lake Hamagiku interpreted as a freshening of the lake system. Significant ~250 year periodicity, common in both lakes, was also identified. Variability in key taxa are interpreted to reflect changes to nutrient input into the sites, and the extent and duration of ice cover during the summer months is inferred to have been a key control on these lakes as a result of regional temperature change. This study adds to the knowledge of Antarctic and Southern Hemisphere climate during the late Holocene.

Chapter 5 – Stable lake productivity throughout the late Holocene inferred from organic carbon and nitrogen isotopes in two East Antarctic lakes

In chapter 5, in order to further investigate the variability archived at Lake Hamagiku and Lake Naga, two high resolution carbon and nitrogen stable isotope records are presented, alongside carbon and nitrogen elemental concentrations. These independent proxies give further insight into productivity and nutrient cycling at these sites and are interpreted in relation to the fossil diatom records presented in Chapter 4. These records show large fluctuations over short timescales, but do not archive a change point to coincide with the change point identified in the fossil diatom records. These discrepancies suggest that the changes in diatom species composition were not accompanied by changes to lake productivity, and may be due to a smaller change in lake ecology and a threshold response which did not alter lake productivity.

Chapter 6 – Discussion – synthesis of Southern Hemisphere climate over the last 3000 years

In chapter 6, the findings of this thesis are summarised and interpreted in the context of palaeoclimate records from the Antarctic region and the Southern Hemisphere. The regional warming interpreted in this thesis for the ~1800 cal. yr BP shift in fossil diatoms is compared to, and bears strong similarities with, ice core and marine sediment temperature reconstructions. The periodicities observed in the fossil diatom assemblages of Lake Hamagiku and Lake Naga are compared to the ~250 year periodicity observed in numerous palaeoclimate records from the Southern Hemisphere, and also to a reconstruction of total solar irradiance. The records developed from Lake Hamagiku and Lake Naga in Lützow-Holm Bay in this thesis are significant in linking records of higher and lower latitudes across the Southern Hemisphere.

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CHAPTER 2

This chapter is published as:

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The published article has been re-formatted to match the rest of the thesis. The text remains the same, except for the figure and table numbers, which are now prefaced with the chapter number e.g. Table 1 is now Table 2.1. The published version of the chapter is provided in Appendix 1. Note that species names have been revised since publication of this chapter and are amended in subsequent chapters.

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Overall percentage (%)	85		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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A diatom inferred record of lake hydrological variability during the last 900 years in Lützow-Holm Bay, East Antarctica

Abstract

Decadal-centennial scale climate variability in coastal Antarctica remains poorly understood due to the limited number of highly resolved, well-dated records. Here we present a 900 year, decadal-scale reconstruction based on sedimentary diatoms from Lake Abi in Lützow-Holm Bay, East Antarctica. Hydrological change is inferred from diatom ecological preferences in conjunction with an existing regional training set and implies that lake water specific conductivity, depth and nitrogen availability are the key drivers of diatom assemblage change. Lake Abi underwent a series of subtle environmental changes related to these environmental variables, possibly driven by changes in catchment snow melt and the duration of seasonal ice cover. Ordination is used to trace the major patterns of change in the diatom community, with notable shifts identified between 470 and 400 and at ~370 cal a BP (where present=CE 1950). The frequency of environmental variability at Lake Abi is broadly consistent with a record of the Interdecadal Pacific Oscillation during the last millennium, but contrasts with the apparent climate stability elsewhere in eastern Antarctica. Further research is required to constrain the limnological and ecological responses of lakes in coastal Antarctica to obtain more rigorous palaeoclimate reconstructions from these sites of immense potential.

Introduction

Antarctic ice-shelf collapse and glacial retreat are highly publicised climatic trends of recent decades. An understanding of natural climate variability on decadal to centennial timescales is paramount, to discern the extent to which trends are within the bounds of natural variability, or are anthropogenically forced (Pages 2K Consortium, 2013; Abram *et al.*, 2014; IPCC, 2014; Schmidt *et al.*, 2014). Southern Hemisphere climate and oceanography plays an important feedback role in the global climate system (Rintoul, Hughes & Olbers, 2001; Russell *et al.*, 2006; Toggweiler, Russell & Carson, 2006). Furthermore, hemisphere-wide climate oscillators result in marked variability in regional hydroclimates, which have a substantial impact upon the economic and environmental prosperity of South America, Africa and Australia. Most notably, the Southern Annular Mode (SAM) - which tracks the inter-annual position of the westerly jet (Kidson, 1988; Gillett, Kell & Jones, 2006; Abram *et al.*, 2014) - and the El-Niño Southern Oscillation (ENSO) play a major role in short-term climate variability in the Southern Hemisphere (Karoly, 1989; Garreaud & Battisti, 1999). However, uncertainties remain concerning many aspects of low-frequency and long-term climate variability, such as the drivers of ENSO variability (Emile-Geay *et al.*, 2013), linkages between ENSO and SAM, and the stationarity of teleconnections between these phenomena and climates in the Southern Hemisphere (Gallant *et al.*, 2013).

Highly resolved, multi-centennial palaeoclimate records are sparse in the Southern Hemisphere, relative to the Northern Hemisphere, reflecting the dominance of ocean and sparsely populated continents (Neukom & Gergis, 2012). Information from Antarctica is heavily weighted towards ice core records, which provide an unparalleled record of climate and atmospheric gas and particulate composition (Leuenberger & Siegenthaler, 1992; Petit *et al.*, 1999; EPICA community members, 2004; Spahni *et al.*, 2005; Vance *et al.*, 2012; Mulvaney *et al.*, 2013). Antarctic ice core records for the past 2000 years indicate that the majority of the continent warmed during the Medieval Climate Anomaly (800 – 1300 AD) and was cooler during the Little Ice Age (1300 – 1850 AD) with some spatial variation in extent (Bertler, Mayewski & Carter, 2011; Mulvaney *et al.*, 2012; Pages 2K Consortium, 2013; Neukom *et al.*, 2014). Since 1850, Antarctic ice core records exhibit less temporal variability, with the exception of the Antarctic Peninsula, which over the past 50 years has been warming rapidly compared to moderate warming in West Antarctica and moderate cooling in East Antarctica (Mulvaney *et al.*, 2012; Bromwich *et al.*, 2013). However, despite the benefits of ice core records, the extent to which they afford a complete picture of regional/continental climate variability is uncertain. Ice core records are inherently constrained geographically and do not provide information on surface hydrological processes, such as melting and evaporation. Therefore, lake sediment records from coastal ice-free regions of Antarctica which reflect local hydrological balance can provide complementary information (Roberts *et al.*, 2001; Tavernier *et al.*, 2014).

Lake sediments archive chemical, biological and physical characteristics of lakes, which in turn reflect changes in past climate (Battarbee, 2000; Jones, Hodgson & Chepstow-Lusty, 2000; Hodgson, Vyverman & Sabbe, 2001). Fossil diatoms preserved in lake sediment are particularly useful, due to their sensitivity to chemical and physical lake conditions, as well as their prevalence and high preservation potential in sediments (Birks *et al.*, 1990; Battarbee *et al.*, 2001; Round, Crawford & Mann, 2007). Diatoms are particularly sensitive to salinity (Battarbee *et al.*, 2001; Fritz, 2007; Spaulding *et al.*, 2010; Stager *et al.*, 2012), which in closed basins or lakes with long residence times is primarily the function of the hydrological balance between precipitation and evaporation (Verleyen *et al.*, 2003; Hodgson *et al.*, 2006; Spaulding *et al.*, 2010). The nexus between climate, salinity and diatom response is modulated by several factors such as basin shape and size (Fritz, 2008), landscape position (Webster *et al.*, 1996) and water chemistry variables other than salinity (Saros & Fritz, 2000). As a result, replication of fossil diatom studies is important but rare in Antarctica due to the challenges of research in this remote region.

The aquatic ecosystems within the Skarvsnes Foreland, East Antarctica, have been the subject of several studies. Diatoms and blue-green algae sampled from lakes and streams in the region are documented by Hirano (1983) and Ohtsuka *et al.* (2006). Takano *et al.* (2012) analysed sediments from two lakes in Lützow-Holm Bay, including Lake Skallen in Skarvsnes, and used diatoms and sediment geochemistry to document the transition from marine to lacustrine conditions during glacial-isostatic uplift. Most recently, Tavernier *et al.* (2014) studied a sediment core from Lake Mago (Mago Ike) in Skarvsnes. Tavernier *et al*. (2014) developed and applied a regional diatom-based transfer function for lake water salinity, from which they concluded that there is no evidence for distinct climatic change between the Medieval Climate Anomaly and the Little Ice Age in East Antarctica. Here we present a new record of environmental change in East Antarctica for the past 900 years based on a study of diatoms within the uppermost 45 cm of sediment from Lake Abi, in the Skarvsnes Foreland, approximately 2 km from Lake Mago. Palaeoclimate inferences are based on previous observations of diatom autecological preferences (Hirano, 1983; Sabbe *et al.*, 2003; Verleyen *et al.*, 2003), a regional surface sediment training set and associated salinity transfer function (Tavernier *et al*., 2014). The data provide a new perspective on climate change and variability in coastal Antarctica, while highlighting some of the challenges facing palaeoclimate and palaeolimnological research in the region.

Site description

The Skarvsnes Foreland is one of several ice-free regions along the coast of Lützow-Holm Bay in East Antarctica (Figure 2.1). Lakes in Antarctica are restricted to these ice-free regions and range from hypersaline to freshwater (Tavernier *et al*., 2014). The climate across most of Antarctica, including Showa Station in Lützow-Holm Bay (location shown in Figure 2.1b), is classified as an ice cap climate, with no months where the average daily temperature is above 0 °C (Kottek *et al.*, 2006). Monthly climate data for the Showa Station is provided in Supplementary Information Table S2.1.

Lake Abi is seasonally ice-free, and located within the Skarvsnes Foreland (69°29’26.2”S, 39°36’04.9”E), 100m above sea level. The lake is fed by snowfield melt and most volume loss is by evaporation. The lake is at maximum 4m deep, with a surface area of 2000 m^2 (Ohtsuka *et al.*, 2006). As with many lakes in the region, the lake floor of Lake Abi is dominated by microbial mats composed of cyanobacteria, green algae and diatoms, with occasional aquatic moss and little allochthonous sediment input (Hirano, 1983; Ohtsuka *et al.*, 2006).

Methods

Sample collection and subsampling

The Ab5S core from Lake Abi was collected in January 2006 during the 47th Japanese Antarctic Research Expedition, using a piston-operated coring device. An Ekman grab sample of the sediment-water interface was also collected and a visual comparison of this and the top of the core taken with the piston corer led to the firm conclusion that the uppermost core samples are representative of an undisturbed sediment-water interface. During the same expedition, the water column profile of the lake was determined using a multiple water quality sensor (YSI 6600EDS/YSI Nanotech, Inc.) for water temperature, pH, conductivity, dissolved oxygen, oxidation–reduction potential, turbidity and concentration of chlorophyll. Sediment was sampled from the core using contiguous 22x22x22 mm cubes. These samples were further subsampled for diatom analysis.

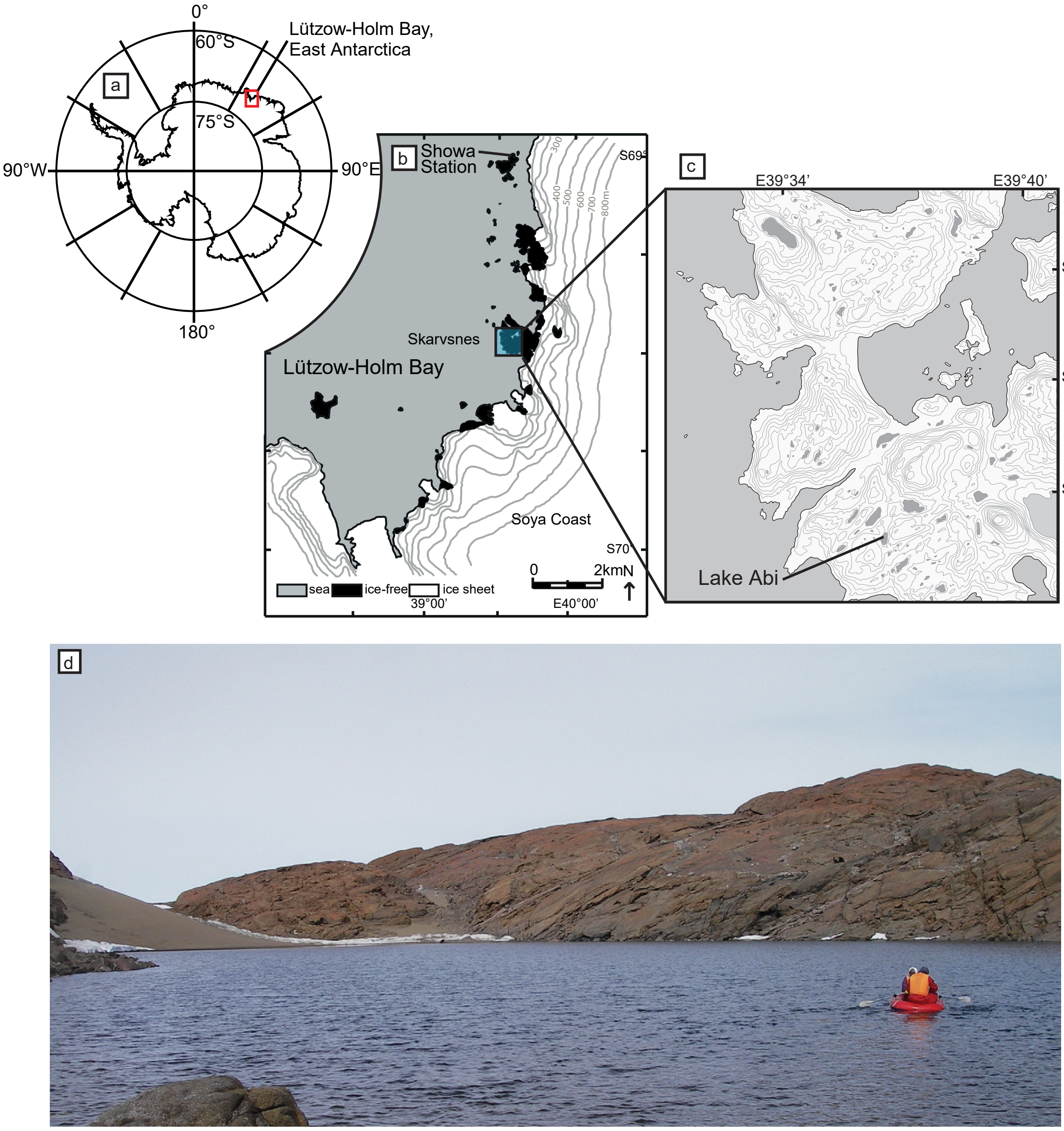

Figure 2.1 a) Location map of Lützow-Holm Bay in East Antarctica; b) ice-free areas and ice sheet extent within Lützow-Holm Bay, as well as the location of Showa Station (contour interval is 100 m) (adapted from Takano *et al.,* 2012); c) detailed map of the Skarvsnes ice-free regions highlighting the location of Lake Abi (contour interval is 10 m) (adapted from Geographical Survey Institute, 1987) - the grey areas on this figure are ocean; d) landscape of Lake Abi at Skarvsnes. Photo taken in January 2006.

Due to dehydration during storage and transport, most of the sediment samples had shrunk within the storage cubes. Therefore, subsamples were taken at intervals proportional to the size of the sediment cube at the time of sampling, by cutting the sample in half, then in half again. The sediments were subsampled parallel to the orientation of the pervasive sediment laminations. Due to the shrinking, some samples may have rotated within their boxes. In these instances, the same sampling strategy was followed, cutting the sediment perpendicular to laminations, but there are uncertainties with regards to precise sample orientation in these instances. This uncertainty is indicated in the figures where relevant.

Diatom analysis

Samples were prepared using a method adapted from Battarbee *et al*. (2001) involving HCl and H_2O_2 digestion. Diatom frustules were mounted onto slides using Naphrax. Slides were analysed at a magnification of 1000x using a Nikon Eclipse E600 microscope, and taxonomic assignments were aided by scanning electron microscopy. Due to the high prevalence of one species, *Diadesmis australis*, slides were counted for 200 valves counting all valves, and then another 200, not counting the *D. australis* valves to better characterize the variation of other species (following a method suggested by Battarbee *et al*., 2001). Diatom data are reported and subsequently analysed as percentage relative abundance for all taxa, as is common practice. Species were identified with floras derived from studies of lake surface sediments in the Skarvsnes region (Hirano, 1983; Ohtsuka *et al.*, 2006) as well as other lake sediment diatom studies from East Antarctica, namely the Amery Oasis (Cremer *et al.*, 2004), and the Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003).

Age modelling and nitrogen isotope analysis

A chronology for the Lake Abi core was established using 19 radiocarbon dates from bulk organic material. Following acid–alkali–acid pretreatment, samples were converted to graphite following Yokoyama *et al*. (2007), which was analysed by accelerator mass spectrometry (AMS) at the University of Tokyo or at Beta Analytic, Inc. (Miami, FL, USA). Radiocarbon ages were calibrated to calendar years using BACON (Blaauw & Christen, 2011) combined with the Southern Hemisphere atmospheric calibration curve (Hogg *et al.*, 2013). A coring date of -56 years (AD 2006) before present (cal a BP, where present is 1950) was used to constrain the age of the uppermost sediments.

To assess whether the sediments were deposited in freshwater, we determined sediment nitrogen isotopic composition using an elemental analyser (Costech 4010 or Flash 2000) - isotope ratio mass spectrometer (ThermoFinnigan, Delta Plus or ThermoFinnigan Delta V Advantage) as described by Takano *et al.* (2015). Nitrogen isotopic compositions are expressed as per mil (‰) deviations as:

$$\delta^{15}N = [(^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{standard} - 1] \square 1000 \text{ (‰ vs. Air)}$$

The standard deviations for nitrogen isotopic compositions using authentic working standard reagents (cf. Tayasu *et al.*, 2011) were: BG-A (n = 12, $\delta^{15}N < \pm 0.25$‰), BG-P (n = 6, $\delta^{15}N <$

±0.24‰), and BG-T (n = 9, $\delta^{15}N$ < ±0.26‰) in the first validation, and BG-A (n = 10, $\delta^{15}N$ < ±0.26‰), BG-P (n = 6, $\delta^{15}N$ < ±0.18‰), and BG-T (n =7, $\delta^{15}N$ < ±0.38‰) in the second validation.

Numerical analysis and diatom conductivity reconstruction

To identify major patterns of ecological change in diatom assemblages, detrended correspondence analysis (DCA) was used, reducing the species data to a limited number of principal vectors (Hill & Gauch, 1980). DCA was conducted with square-root transformation of diatom percentage data to reduce the influence of the highly abundant taxa (sensu Mills *et al.*, 2014). The relationship between diatom species assemblages in the Lake Abi core and the diatoms and environmental variables in the modern Lützow-Holm Bay training set of Tavernier *et al*. (2014) was explored by performing canonical correspondence analysis (CCA) upon the modern data and plotting the Lake Abi diatoms passively within the ordination space. CCA was also conducted using square-root-transformed diatom data, with the exclusion of two training set samples from site SK4 which were marked outliers in the ordination. Both DCA (DECORANA) and CCA were carried out using VEGAN for R (Oksanen *et al.*, 2018).

Lake water conductance was inferred using the transfer function of Tavernier *et al*. (2014), namely a two-component weighted averaging partial least squares model, with a jackknifed r^2 between diatom-inferred and measured specific conductance of 0.85 and a root mean squared error of prediction of 0.10 mS cm^{-1}. The Lake Abi fossil flora is well represented in the calibration set, with >99% of the diatoms found in each sample represented in Tavernier *et al*. (2014). Furthermore, each of the species found in the Lake Abi core are well represented in Tavernier *et al*. (2014). Each species has an N_2 value (Hill, 1973) exceeding four, with the exception of *Hantzschia* c.f. *amphioxys*, which is not abundant in the Lake Abi record.

Results

Limnology, lithology and geochronology

Water temperature at Lake Abi varied between 3.7 and 4.1 °C in the vertical profile (Figure 2.2). Other parameters such as pH, electrical conductivity, dissolved oxygen, oxidation–reduction potential and chlorophyll concentration did not fluctuate markedly with depth, suggesting that there was no significant chemocline in the water column at the time of sampling. The benthic microbial mat (maximum water depth: 4 m) could be observed during sampling, indicating low turbidity.

The Ab5S core consists of green–grey laminated algal biofilm, including some mosses and medium- to coarse-grained sands within the organic layers (Figure 2.3). There are few to no discernible changes in lithology throughout the 1.2 m of sediment. The nitrogen isotopic composition of the entire Ab5S sequence exhibits typical freshwater limnological characteristics (depth 0–130 cm, n=20; δ15N from -1.6 to +1.5‰ vs. Air), similar to the freshwater sedimentological stages in Lake Oyako at

Skarvsnes and Lake Skallen in the Skallen area (Takano *et al.*, 2012).

Nineteen radiocarbon dates, reported in Supplementary Information Table S2.2, are all in stratigraphic order, with no evidence for age reversals within the radiocarbon measurement and calibration error. The radiocarbon dates suggest a relatively constant sediment accumulation rate of approximately 40 cm per 1000 years (Figure 2.3). The extrapolated age of the radiocarbon dates to the present day does not entirely overlap with the estimated age of the sediment surface, based on coring date. This implies that the uppermost 5 cm of sediment represents an approximate period between 300 and 150 years, the upper end of which is around half the sediment accumulation rate of the rest of the core.

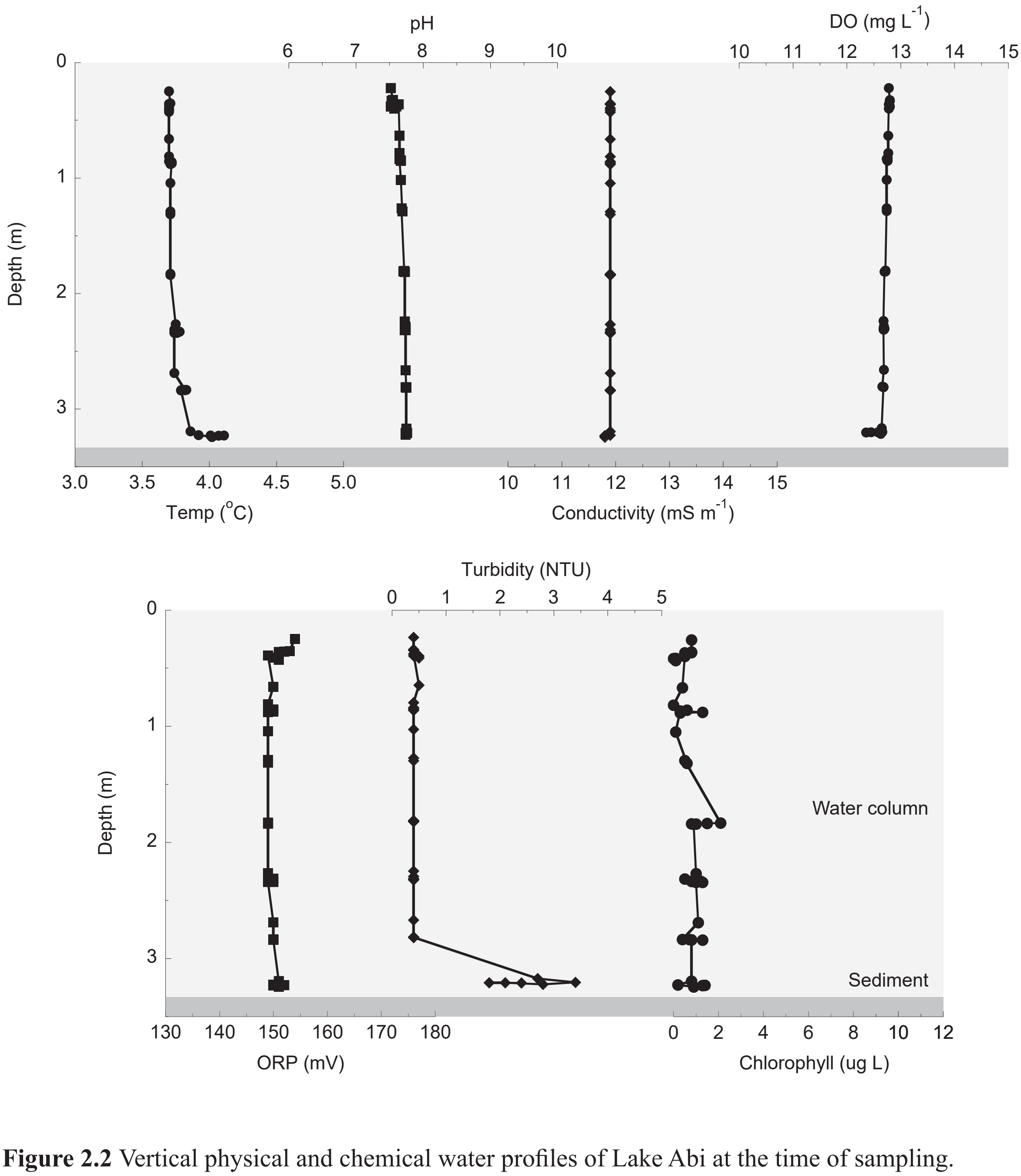

Figure 2.2 Vertical physical and chemical water profiles of Lake Abi at the time of sampling.

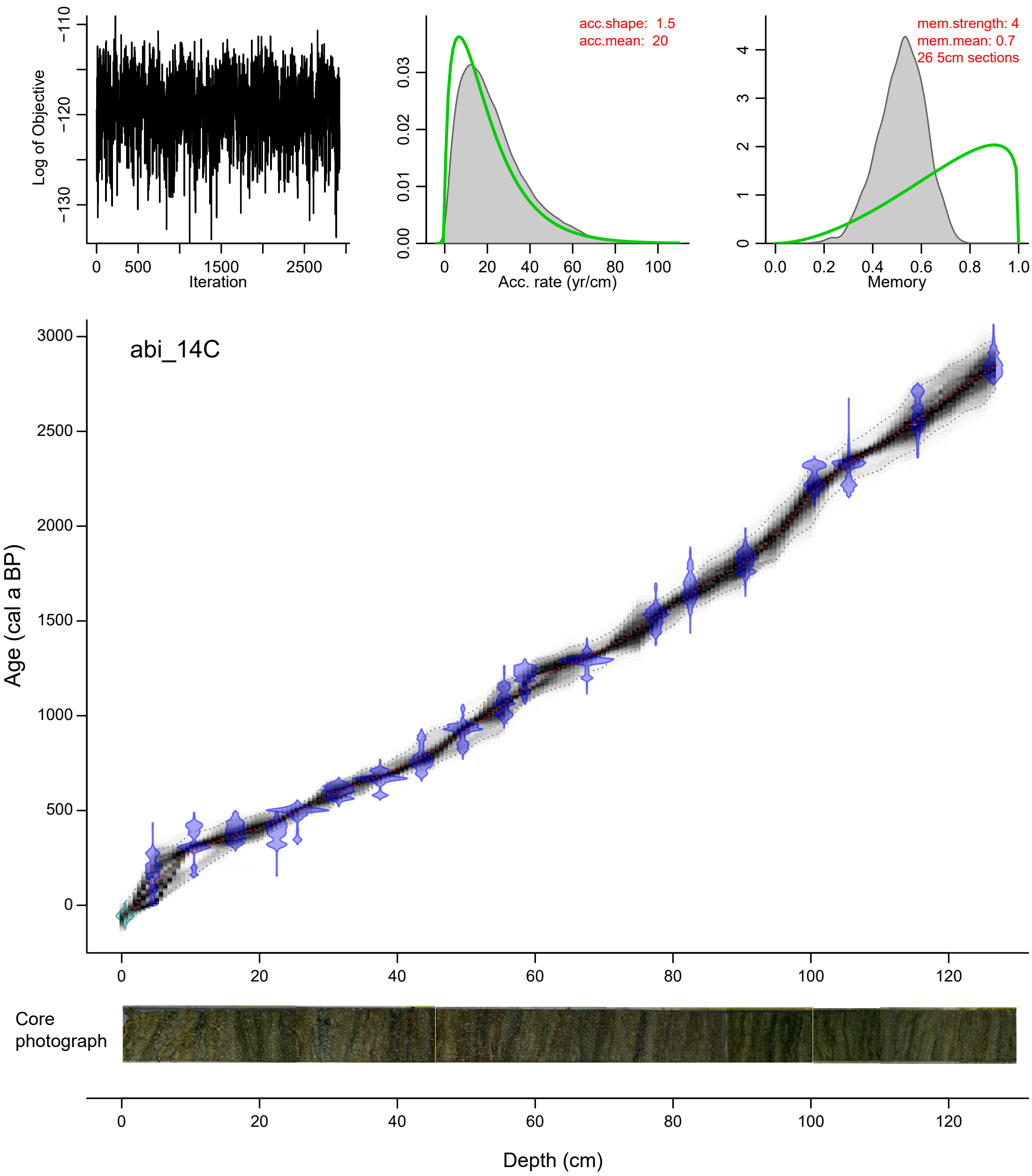

Figure 2.3 Bacon age model for the Lake Abi sediment core, where probability density functions for each calibrated age are shown in blue, the grey curve indicates the age-depth model and the red curve is the best fit model. Upper panels indicate the iterations performed, accumulation rate and memory used to construct the model. Beneath the age model is a photograph of the core.

Diatom species abundances

Eighty-four contiguous samples over the uppermost 45 cm section from Lake Abi core Ab5S were analysed for diatoms at 5 mm intervals. Seven species dominated, with several others observed, represented by only occasional valves. There were no distinct arrivals or disappearances in the section analysed, covering 900 years (Figure 2.4). Nevertheless, changes in relative abundance did occur, and these are documented below.

Diadesmis australis was the most abundant diatom species observed. It is considerably more abundant than any other throughout the core, and is the second most abundant in only seven of the 84 samples. *D. australis* has an almost oscillatory pattern of abundance, varying around 80–90%, with a maximum abundance of 99.5% in three samples, at 820, 810 and 400 cal a BP. Aside from at these times, there are local maxima at 780, 720, 665, 605, 580, 525, 490, 430, 360, 265, 195, 120 and -40 cal a BP (Figure 2.4). *Navicula gregaria* is the second most abundant species in the core section and has a highest relative abundance at 595 cal a BP of 76.9%. *N. gregaria* also has many local maxima, at 790, 740, 645, 540, 500, 455, 410, 360, 320, 305, 160 and 30 cal a BP, with small variations around these peaks (Figure 2.4).

The third most abundant species is *Craticula antarctica*. This species has very low abundance in samples older than ~470 cal a BP, where there is a notable increase peaking at 450 cal a BP to 18.4%, and followed by another larger increase in abundance peaking at 220 cal a BP to 34.9% (Figure 2.4).

Psammothidium papilio has a notable increase in abundance from 485 to 470 cal a BP, peaking at 475 cal a BP to 13.8%. Other small peaks of 5–7% occur at 790, 720, 560, 360 and 95 cal a BP. *P. papilio* otherwise shows low variation, with a particularly low abundance from 690 to 605 cal a BP.

Stauroneis latistauros has a maximum abundance at 460 cal a BP of 1.5%. There are three other smaller peaks in abundance at 790, 330 and 90 cal a BP, each around 0.8–1%. This species also shows a distinctly lower relative abundance around 665–595 cal a BP, similar to *P. papilio*.

Halamphora veneta is observed at very low abundance in some samples. Eight samples have an abundance of over 0.5%, and the maximum is 0.9% at 560 cal a BP. *Hantzschia* cf. *amphioxys* is the least common of the seven species in Figure 2.4, and only observed in 16 samples. The largest peak in abundance (0.25%) occurs near the base of the studied section of core, at 790 cal a BP.

Ordination of diatom data

Changes in the diatom species assemblages at Lake Abi are summarized using DCA (Figure 2.5a), as well as CCA (Figure 2.5b) to relate patterns in species assemblages within contemporary ecosystems to environmental parameters. The first DCA axis, which explains 36.3% of the variance in the dataset, is characterized by positive weighting of *C. antarctica*, *S. latistauros* and *N. gregaria*. The other four major taxa exhibit a negative association with DCA axis 1, in particular *Halamphora veneta* and *Hantzschia* cf. *amphioxys* (Figure 2.5a). The second DCA axis explains 26.0% of the total variance. It is characterized by positive weighting by *C. antarctica* and also, to a lesser extent, by *D. australis*. The other five major taxa exhibit a negative weighting, in particular *N. gregaria* (Figure 2.5a). Plotted against time in Figure 2.6(e), the first DCA axis shows a shift from negative to positive values at around 450 cal BP, a decline between 400 and 350 cal a BP, followed by a subsequent return to positive DCA scores after 350 cal a BP (Figure 2.6e).

As seen in Figure 2.5(b), CCA axis 1 is strongly associated with lake water salinity, whilst CCA axis 2 corresponds to changes along a nutrient gradient, with sites positively loaded against CCA axis 2 associated with lakes with high total nitrogen, high oxidation–reduction potential, and low pH and lake depth (Tavernier *et al*., 2014). When plotted passively within this CCA biplot, the diatom species from Lake Abi closely associate with other lakes in Lützow-Holm Bay, namely samples collected in Skarvsnes, West Ongul Islands and East Ongul Islands (Figure 2.5b). The passive Lake Abi timetrack varies along a fairly linear gradient that most strongly associates with CCA axis 2, and hence is interpreted to relate to changes in lake depth, total nitrogen concentration and, to a lesser extent, with the salinity gradient of CCA axis 1. The Lake Abi passive scores for CCA axis 2 particularly correlate negatively with the relative abundance of *Navicula gregaria* (r^2=0.60, p<0.001).

Diatom-inferred lake water conductivity

Using the diatom transfer function based on the Lützow-Holm Bay calibration dataset (Tavernier *et al.*, 2014), a record of conductivity change over time for Lake Abi is presented in Figure 2.6(f). Diatom-inferred conductivity exhibits a low amplitude of variability which falls well within the ±0.1 mS cm^{-1} reconstruction uncertainty, thus implying that there was no significant change in conductivity. However, diatom-inferred conductivity positively correlates with DCA axis 1 (r^2=0.66, p<0.001) suggesting that although subtle, the pattern of change in the diatom-inferred conductivity does represent environmental changes at Lake Abi. As expected, diatom-inferred conductivity also correlates positively with the passive CCA axis 1 scores (r^2=0.61, p<0.001).

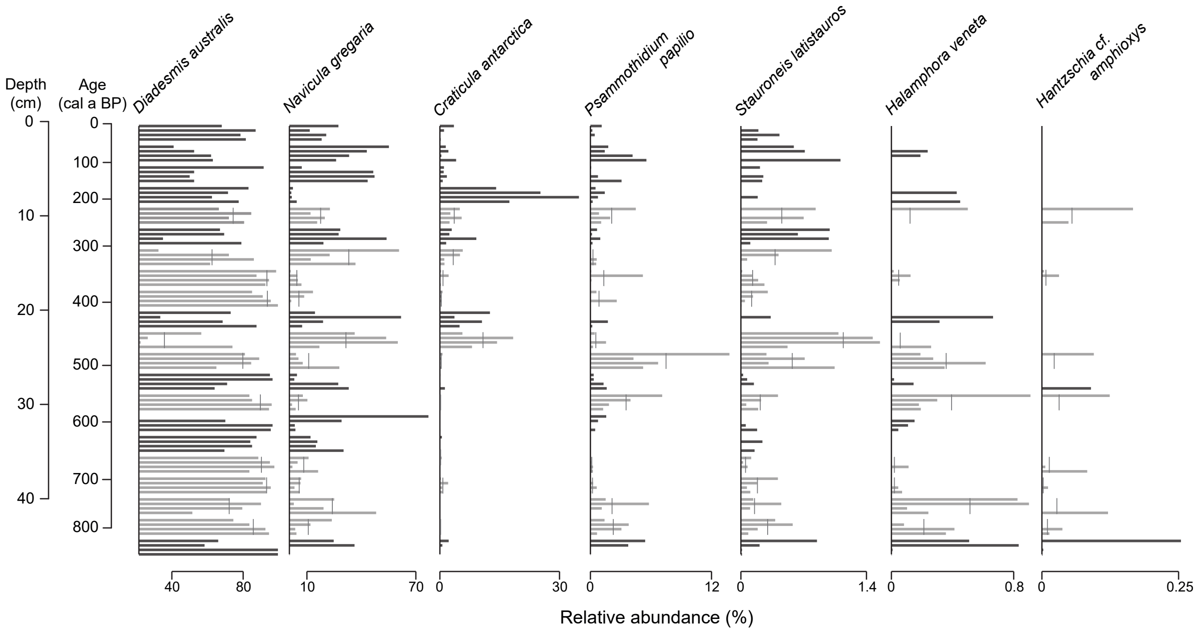

Figure 2.4 Stratigraphic diagram of all diatom species above 0.25% in at least one sample in the Lake Abi record. Lighter bars indicate where sediment realignment may have occurred within the sediment cubes, and average bars are calculated and included for these samples. Note that scales vary for relative abundance between species.

Discussion

Chronology

The 19 radiocarbon dates from the Ab5S core indicate a near constant rate of sediment accumulation throughout the last 3000 years, providing confidence in the age model despite some limitations. Radiocarbon dating is best conducted using terrestrial organic matter, where the source of the fixed carbon can be unequivocally assigned to atmospheric CO_2 (Lowe, Walker & Walker, 1997). In the case of Lake Abi, this was not possible due to an absence of terrestrial plant macrofossils in the sediments, reflecting an absence of vegetation in the lake catchment. Although this situation is not optimal, we have confidence in the Lake Abi age model, firstly because there is not likely to be any source of aged, detrital organic carbon from the lake catchment, which is also bereft of soil. Secondly, the shallow lake depth of Lake Abi (<4 m) is likely to allow a constant mixing of lake water and the maintenance of isotopic equilibrium with atmospheric CO_2 (sensu Björck & Wohlfarth, 2001). These factors, plus the overall consistency of radiocarbon dates, support the assumption that bulk organic matter is a suitable medium for radiocarbon dating at this site.

One source of uncertainty in the Lake Abi radiocarbon chronology relates to the change in sediment accumulation rate near to the top of the core, whereby the coring date does not intersect an extrapolation of the radiocarbon-only age model (Figure 2.3). This disagreement may relate to a number of factors, including a reservoir effect, the loss of some material from the top of the core or compaction during coring.

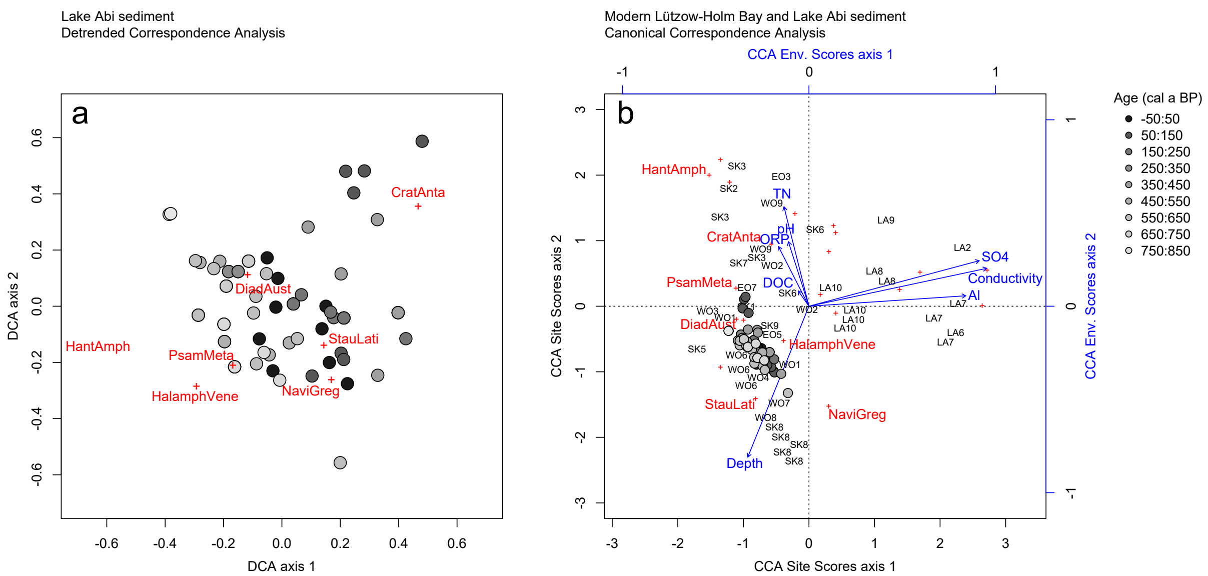

Figure 2.5 (a) DCA ordination biplot for the first two axes of the Lake Abi samples, with major diatom species labelled. (b) CCA plot of modern diatom samples and environmental variables in Lützow-Holm Bay within the training set of Tavernier *et al*. (2014), excluding two outlier sites as described in the text. Lake Abi diatom data plotted passively within the CCA ordination space (grey points). In both plots, the age of the Lake Abi samples is indicated by the grey shading, as depicted in the key.

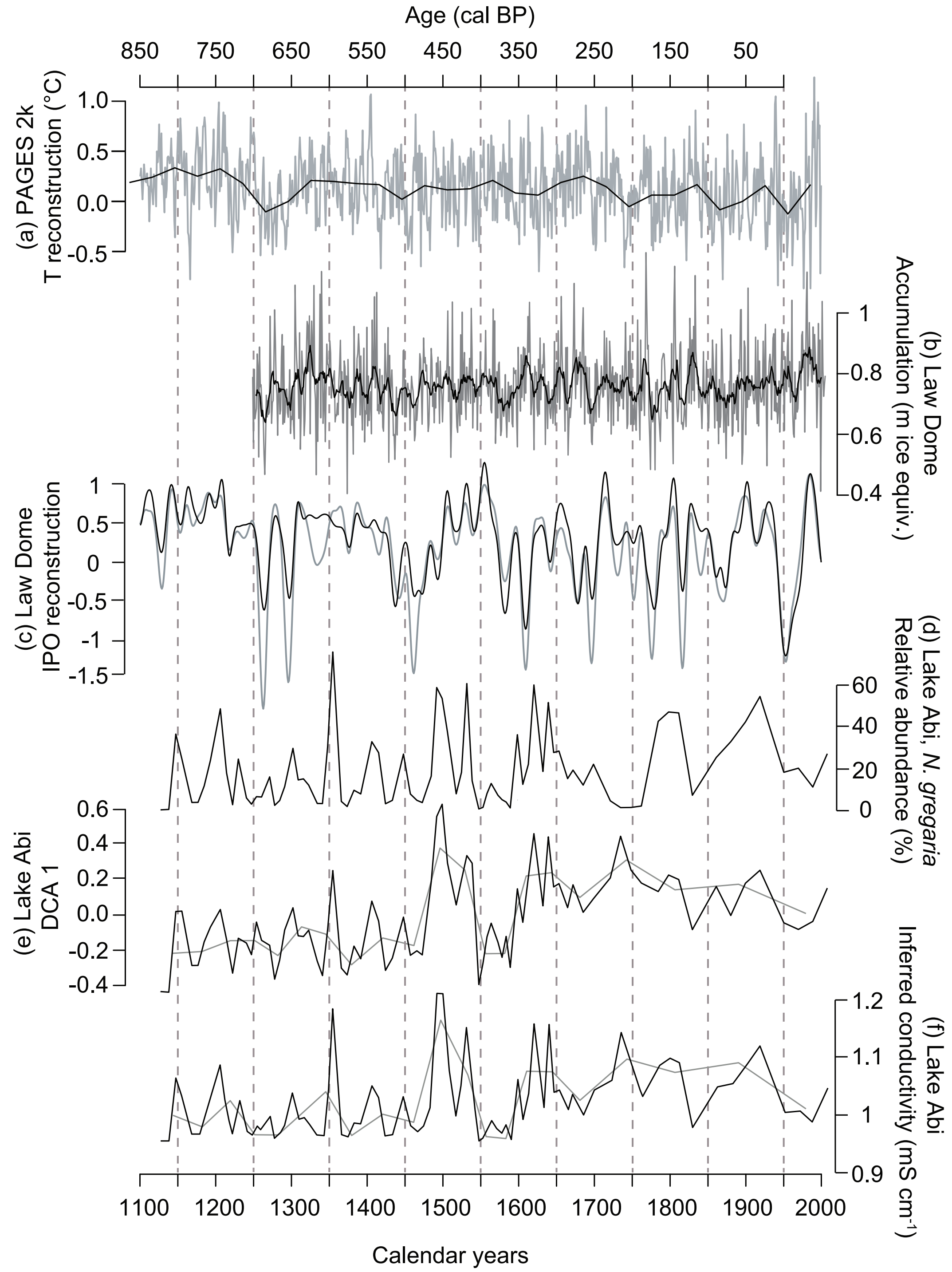

Figure 2.6 Compilation of climate and hydroclimate reconstructions for the past 900 years. (a)Antarctic regional temperature reconstruction - the black line indicates a 30-year average (PAGES 2k Consortium, 2013); (b) ice accumulation rate at Law Dome in East Antarctica - black line indicates a nine-sample moving average (Vance *et al.*, 2012); (c) Interdecadal Pacific Oscillation index reconstruction from the Law Dome ice core record, where the grey line indicates a piecewise linear fit model and black is a decision tree model reconstruction (Vance *et al.*, 2015); (d) relative abundance in the lake record of *N. gregaria*; (e) DCA axis 1 scores for Lake Abi species data; (f) inferred conductivity reconstructed for Lake Abi species data (root mean square error of prediction=0.1 mS cm^{-1}). In (e) and (f), grey lines indicate four-sample averages.

Changes in groundwater-derived inorganic carbon (a freshwater reservoir effect) can lead to alterations in the apparent ^{14}C age of aquatic carbon (Björck & Wohlfarth, 2001). A reservoir effect from old carbon is a possibility in a lake with high organic content from the microbial mats, and limited lake water mixing due to low inflow and outflow, as well as ice cover for part of the year. However, the laminated nature of the sediments suggests macro-scale bioturbation is limited, and this coupled with low temperatures, resulting in slow breakdown and respiration, could result in limited transfer of carbon from the sediment to the water column. Although a reservoir effect cannot be ruled out, at such low temperatures, with perennially frozen soil and groundwater, a significant groundwater influence is unlikely. Furthermore, reservoir effects are rarely observed in freshwater lakes in coastal Antarctica (Hodgson *et al.*, 2001).

Loss of surficial sediment during coring is another possible explanation for the apparent reduction in accumulation rate in the uppermost section of the core. However, as described above, the mucilaginous nature of the surficial sediments at Lake Abi, and the strong similarity between the sediment-water interface observed in both the Ekman grab and in the uppermost sediments collected by the piston corer, suggests limited sediment loss or disturbance during coring. As with reservoir effects, although we cannot comprehensively rule out sediment loss as being the explanation for the lower accumulation rate in the uppermost sediments, we deem this explanation unlikely.

Compaction is a common problem when using piston corers to sample soft, surficial sediments (Glew, Smol & Last, 2001). At Lake Abi, the spongy nature of the sediments lends them to compaction, particularly in the well-hydrated uppermost sediments. We therefore conclude that compaction is the most likely explanation for the change in sediment accumulation rate depicted in Figure 2.3, whereby the uppermost sediments expelled water and air during coring. A range of low-impact gravity corers have been developed to counter this (e.g. Renberg & Hansson, 2008); however, such methods were not employed when coring Lake Abi. Furthermore, limited sample availability precluded the application of additional dating techniques (e.g. ^{210}Pb) to constrain the sediment accumulation rate in the uppermost sediments. Due to the uncertainties with respect to the age and accumulation rate of the top 5 cm of sediment, we have deliberately avoided interpreting the timing and significance of changes in the uppermost sediment record.

Ecological preferences of diatom taxa found in the sediments of Lake Abi

The diatom species within the analysed section of the Lake Abi core have a very low diversity, characteristic of lakes at higher latitudes, with diversity in lakes found to decrease southward on the Antarctic continent (Jones, 1996). The value of diatoms as palaeoenvironmental tracers is limited by what is known about their physical and chemical preferences, a problem that is particularly marked in Antarctica due to inherent practical challenges of field collection and observation. Nevertheless, despite these uncertainties, it is still possible to make informed interpretations on the basis of diatom species assemblages. Ohtsuka *et al.* (2006) found that diatom composition in lakes within the Skarvsnes Foreland was not affected by the presence or absence of mosses within the lakes, and that the main environmental gradient was electrical conductivity (a measure of salinity). Ohtsuka *et al.* (2006) suggest *D. australis*, *P. papilio* and *H. veneta* may have very low phosphate optima, but also conclude that most lakes in the region are likely to be oligotrophic (low in nutrients), so it is likely that many of the species observed are tolerant of low phosphate conditions.

Diadesmis australis, the most common species in the sediments of Lake Abi (Figure 2.4), is characteristic of small ponds (Hodgson *et al.*, 2005), and has been observed throughout Antarctica and East Antarctic lakes (Sabbe *et al.*, 2003; Cremer *et al.*, 2004; Van de Vijver *et al.*, 2010). This small species was reclassified by Van de Vijver *et al*. (2010) from *Diadesmis* cf. *perpusilla*. *D. australis* was observed as *Navicula arcuata* in Skarvsnes lakes (Hirano, 1983), and as *D*. cf. *perpusilla* in saline lakes in East Antarctica. It has been suggested that *Diadesmis australis* may be halophobic (salt intolerant) and have a low phosphate optimum, but from its abundance in a range of locations may have a much larger tolerance than previously documented (Ohtsuka *et al*., 2006). The species has been found on moist rocks, mosses and soils as an aerophilic species, meaning it tolerates being exposed to air (Krammer & Lange-Bertalot, 1986), but its distribution suggests it is not limited to these habitats.

Craticula antarctica, *Navicula gregaria* and *Stauroneis latistauros* are all Naviculoids, a morphological type which is often associated with motile diatoms that inhabit biofilms and sediment surfaces (Round *et al.*, 2007). *Navicula gregaria* is believed to be a cosmopolitan and common species (Lange-Bertalot, 2001), but is rare in continental Antarctica (Kellogg & Kellogg, 2002). *N. gregaria* is, however, reported from several Skarvsnes lakes at the sediment surface, including in Lake Abi (Ohtsuka *et al*., 2006). *Craticula antarctica* was described as a new species by Van de Vijver *et al*. (2010). *C. antarctica* has been previously reported from Antarctica under several other names, including from the East Antarctic Vestfold Hills, Larsemann Hills and Rauer Islands as *C. molesta* (Roberts & McMinn, 1999; Sabbe *et al*., 2003), and from Skarvsnes as *Craticula* sp. (Ohtsuka *et al*., 2006). *Stauroneis latistauros* was also described as a new species in 2005 (Van de Vijver, Gremmen & Beyens, 2005). This species and several other new species were separated from *S. anceps*, which was believed to have a very widespread distribution across Antarctica (Kellogg & Kellogg, 2002). The distribution of *S. latistauros* is now unclear due to taxonomic reorganization, but the species has been reported from East Antarctica as *S. anceps* (Sabbe *et al.,* 2003) and from Skarvsnes lakes (Ohtsuka *et al*., 2006). *S. latistauros* has a low specific conductance optimum (Van de Vijver *et al.*, 2005), as do *N. gregaria* and *C. antarctica*, in the context of the Lützow-Holm Bay training set (Figure 2.4b; Tavernier *et al*., 2014). However, while *S. latistauros* and *N. gregaria* associate most closely with the deeper, nutrient-poor lakes within the training set, *C. antarctica* exhibits positive loading on CCA axis 2, demonstrating a greater affiliation with shallower, relatively nutrient-rich and moderately more saline lakes (Figure 2.4b; Tavernier *et al*., 2014).

Psammothidium papilio is believed to be prevalent across Antarctica, but has previously been reported under other names (Sabbe *et al.*, 2003; Kopalová *et al.*, 2012). *P. papilio* has been documented from freshwater lakes in the Larsemann Hills and Rauer Islands (Sabbe *et al*., 2003) and the Amery Oasis Cremer *et al*., 2004) in East Antarctica as well as from Skarvsnes lakes (Ohtsuka *et al.,* 2006). Although commonly affiliated with sand substrates (epipsammic), the genus *Psammothidium* has also been observed growing attached to rocks (epilithic) in other locations (Flower *et al.*, 2007) and may also be epilithic in Antarctica. As with *C. antarctica*, *P. papilio* was also commonly collected from shallow depths in the Lützow-Holm Bay training set (Tavernier *et al.,* 2014). *H. veneta* is found around Antarctica, including lakes in the Vestfold Hills, the Larsemann Hills and Rauer Islands of East Antarctica (Roberts & McMinn, 1999; Sabbe *et al.*, 2003).

Diatom species change at Lake Abi in the context of regional environmental conditions

DCA of the Lake Abi diatom assemblages results in species groupings that agree well with the ecological preferences of those taxa (as described above). *H. veneta*, *P. papilio* and to a lesser extent *D. australis*, all non-motile, periphytic taxa, exhibit negative loading on DCA axis 1. By contrast, the naviculoids *N. gregaria*, *S. latistauros* and *C. antarctica* all exhibit positive loading on DCA axis 1 (Figure 2.5a). Changes in the DCA axis 1 scores therefore reflect shifts between these groups, a pattern which is clear from the raw diatom data, where periods of high *N. gregaria* relative abundance, for example, correspond with lower concentrations of *H. veneta* (Figure 2.4). DCA axis 2 predominantly reflects the offset between *C.antarctica*, which is positively loaded on DCA axis 2, and the other naviculoids: *N. gregaria* and *S. latistauros*. The most common taxon, *D. australis*, is situated centrally in the DCA biplot. It follows that the major patterns of change in the diatom assemblages result from changes in the relative abundance of the additional taxa (Figure 2.5a).

CCA axis 1 is positively associated with lake water conductivity (salinity) in Lützow-Holm Bay (Figure 2.5b). CCA axis 2 is positively linked to lake water total nitrogen concentrations, oxidation-reduction potential and pH, and negatively associated with water depth at the sampling site (Figure 2.5b). The distribution of species found at Lake Abi within the regional CCA plot (Figure 2.5b) mimics that in the Lake Abi-specific DCA biplot (Figure 2.5a), with *C. antarctica* in particular lying separate from the other species found in Lake Abi. All taxa found at Lake Abi are negatively loaded upon CCA axis 1, suggesting that the lake sits among the least saline lakes in the region. When plotted passively within the CCA plot, the diatom assemblages from Lake Abi cluster closely to other lakes in Skarvsnes (note that Lake Abi was not part of the training set) as well as water bodies in West Ongul Island, and are situated along CCA axis 2. Hence, an important component of change in the diatom species assemblage at Lake Abi reflects a pattern of fluctuating nitrogen availability and/or lake water depth. This pattern of change is illustrated in Figure 2.6 through the concentration of *Navicula gregaria*.

Diatom-inferred conductivity exhibits only very moderate change through the record, well within the reconstruction uncertainty, and hence should be treated with caution (cf. Tavernier *et al.*, 2014). These small changes are probably related to the lake water being freshwater with only a minor sensitivity to changes in evaporative salt concentration or dilution. However, the correlation between diatom-inferred salinity and both DCA axis 1 and the passive CCA axis 1 scores suggests that these patterns of change represent real changes in the diatom assemblage alongside an additional effect of changing lake water nutrient status over shorter timescales (Figure 2.6e,f).

Lake water depth, nitrogen availability and salinity can all be related to climate-driven changes in catchment snow melt and seasonal lake ice cover. The water balance of Antarctic lakes is, however, complicated, particularly in systems where wind-blown snow is a major contributor to water input. However, due to the low temperatures it is logical to infer that changes in catchment snow melt have an important influence upon lake water depth. Water depth in turn affects lake ice cover, with lakes <2.5 m deep commonly freezing entirely during the winter (Verleyen *et al*., 2012). Because of this freezing, shallow lakes in Lützow-Holm Bay are commonly characterized by an absence of cyanobacterial mats, a higher percentage of epipsammic and aerophilous diatoms and an increase in the mobilization of nutrients from the sediments (Figure 2.5b; Tavernier *et al*., 2014). By contrast, increases in snow melt and lake water depth promote the development of microbial mats, which in turn draw down available nutrients into the sediment. Such changes in snow melt and lake level will also result in changes in lake water conductivity, depending on the initial solute concentration in the lake water (Verleyen *et al*., 2012). The current water depth at Lake Abi is ~4 m, which is close to the threshold of complete freezing on a seasonal basis under conditions of lower temperature and reduced snow melt. Consequently, the palaeolimnological records from Lake Abi and similar lakes in the region potentially provide sensitive archives of climate-driven environmental changes. Of course, this hypothetical interpretation requires significant further research, both in the form of contemporary limnological monitoring as well as through the analysis of complementary sediment properties, both sedimentological and geochemical (e.g. Noon *et al.*, 2001; Noon, Leng & Jones, 2003; Hodgson *et al.*, 2005). These questions represent major goals for ongoing research.

Regional significance of the Lake Abi record

Irrespective of the mechanisms behind the diatom species change at Lake Abi, the record exhibits low amplitude variability, which may provide valuable insights into the nature of climate and environmental change in coastal Antarctica and the Southern Hemisphere (Figure 2.6). These shifts include an overall change to higher DCA axis 1 scores and subtly increased conductivity after ~470 cal a BP (Figure 2.6e,f) and marked decadal–centennial-scale variability in nutrient availability and/or lake depth, as indicated by changes in CCA axis 2 and the relative abundance of *N. gregaria* (Figure 2.6d). The changes in *N. gregaria* in particular are comparable to the Interdecadal Pacific Oscillation reconstruction using the Law Dome ice core record (Vance *et al.*, 2015). However, both modes of variability contrast with the apparently stable continent-wide temperature reconstruction (Pages 2K Consortium, 2013) and the record of ice accumulation at Law Dome (Van Ommen, Morgan & Curran, 2004). These patterns of change at Lake Abi, although poorly constrained to date, suggest that significant information can be extracted from lake sediment records in coastal Antarctica that may provide complementary climate records to ice core data, particularly with respect to surface hydrological change, as well as the intrinsic ecological value of such information. In particular, brackish closed lakes should be targeted in future research projects, as the moisture balance in these systems is expected to react more sensitively than freshwater lakes (Verleyen *et al*., 2012).

Conclusion

The 900-year diatom-based reconstruction from Lake Abi, Lützow-Holm Bay, Antarctica, was characterized by relatively moderate changes in species composition. Changes in the diatom assemblage are tentatively inferred to reflect changes in lake salinity, nutrient status and water depth. The lake became moderately more oligotrophic and saline after 450 cal a BP, with notable peaks in oligotrophy and salinity centred on 470 and 200 cal a BP (Figure 2.6f). In addition, the record exhibits decadal-centennial-scale variability, which is reminiscent of the Law Dome Interdecadal Pacific Oscillation reconstruction (Vance *et al*., 2015). It is possible that these changes reflect changes in catchment precipitation and ice melt, although uncertainties associated with our understanding of the limnology and diatom autoecology of Lake Abi prevent a more confident interpretation. Thus, further research into modern day lake ecology, in addition to the further generation of new records, is required to fully resolve the centennial-scale spatiotemporal patterns of climate in this globally important region.

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Table S1 Climate data from the Showa Station in East Antarctica (see Figure 1 for location) sourced from the Japan Meteorological Agency (2010). Climate data was collected over 30 years from 1981-2010, except for wind direction, which was collected over 21 years from 1990-2010.

Month		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Average Temp. (°C)	Max.	2.0	-0.5	-4.3	-7.6	-10.7	-12.1	-14.1	-15.8	-14.9	-10.8	-4.0	1.1	-7.6
	Min.	-3.7	-5.5	-9.2	-13.0	-16.6	-18.7	-20.8	-23.3	-22.0	-17.2	-10.4	-4.6	-13.7
	Avg.	-0.7	-2.9	-6.5	-10.1	-13.5	-15.2	-17.3	-19.4	-18.1	-13.5	-6.8	-1.6	-10.4
Relative humidity (%)		67	68	71	72	67	65	66	64	64	69	68	68	67
Wind (m/s)	Speed	4.8	6.8	8.1	8.8	7.8	7.2	7.2	6.1	6.0	6.4	6.4	5.3	6.7
	Direction	NE	NE	ENE	ENE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Hours of sunshine		375.7	203.2	120.1	58.0	17.7	0.0	4.8	64.1	136.5	191.0	316.0	434.6	1925.9

Table S2 Radiocarbon dates and calibrated age ranges for core Ab5S

Depth (cm)	^{14}C age (yrs BP)	SD	δ^{13}C (‰ PDB)	Calibrated ages (cal. yr BP)		Lab code
				Age range	Weighted mean	
4.5	210	40	-17.9	-49–244	103	Beta-255053
10.5	300	30	-17.3	96–357	275	Beta-387423
16.5	360	30	-18.2	307–428	362	Beta-387424
22.5	340	30	-19.9	397–486	441	Beta-387425
25.5	480	30	-19.3	445–528	490	Beta-315377
31.5	660	30	-19.4	545–643	592	Beta-387426
37.5	770	30	-18.4	634–729	680	Beta-387427
43.6	895	45	-	712–885	784	UT-AMS#12-071114
49.5	1060	30	-19.8	822–1022	921	Beta-387428
55.5	1210	30	-18.0	985–1172	1071	Beta-387429
58.5	1320	30	-17.6	1072–1233	1149	Beta-318040
67.5	1420	30	-18.0	1220–1371	1303	Beta-387430
77.5	1670	30	-17.7	1436–1595	1524	Beta-387431
82.5	1800	50	-18.3	1559–1736	1647	Beta-223650
90.5	1920	30	-18.6	1740–1947	1831	Beta-387432
100.5	2300	30	-17.7	2119–2321	2220	Beta-390637
105.5	2330	30	-16.9	2209–2427	2318	Beta-318041
115.5	2560	30	-17.0	2443–2724	2582	Beta-390638
126.5	2790	40	-17.6	2754–2967	2838	Beta-219369

CHAPTER 3

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Statement of Authorship

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Name of Principal Author (Candidate)	Rachel Rudd		
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Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Ecological and habitat preferences of diatoms in Lützow-Holm Bay, East Antarctica

Abstract

- Lakes and ponds along the Antarctic coastline provide an opportunity for palaeoclimate studies to complement ice core records from the interior of the continent, including via their diatom records.
- Diatom palaeoecological studies, particularly in remote Antarctica, are limited, and one major uncertainty is the relative influence of habitat and substrate on resultant assemblages, compared to the more commonly studied water quality responses.
- The relative abundance and distribution of diatoms across a range of substrates and water depths were analysed from nine lakes in ice-free regions along Lützow-Holm Bay in East Antarctica.
- Specific conductivity and substrate type were identified as significant variables in explaining diatom distribution, using non-metric multidimensional scaling and regression tree analysis to identify statistically significant groupings of diatom assemblages and associated environmental variables.
- There was a significant difference between the diatom assemblages from the littoral region and lake floors at most sites. In contrast, the diatom flora from different substrates in the littoral zone did not exhibit significant differences.
- *Humidophila australis* was the most common species in the lakes with lowest specific conductivity, while *Halamphora vyvermaniana* was associated with lake floor habitats and *Psammothidium papilio* with samples from littoral zones at several sites. The findings of this study have implications for the interpretation of lake sedimentary diatom assemblages in the Antarctic region.

Introduction

Ice free regions along the coastline of Antarctica provide refugia for biota despite the harsh environment of the continent and are sometimes referred to as oases (Tanabe *et al.*, 2016). These regions host an array of lakes and ponds that remain frozen for much of the year, and lose ice cover briefly during the summer months, exposing the lake system to the atmosphere, warmth and sunlight. The diversity and richness of biota found in these water bodies decreases as latitude increases (Gibson *et al.*, 2006b). There are several ice free regions in Lützow-Holm

Bay in East Antarctica, and the lakes and ponds in this area host mats of diatoms, green algae and cyanobacteria which grow amongst aquatic mosses on the lake floor (Imura *et al.*, 1999). These aquatic mosses are not observed in shallow waters, due to winter ice cover which reaches up to two metres in thickness (Imura *et al.*, 2003). Due to low nutrient availability in these lakes, nutrient cycling occurs largely in the surface sediments, favouring benthic species and resulting in a lack of nutrients in the water column and in turn a very low abundance of plankton in many low-nutrient lakes (Gibson *et al.*, 2006b). These microbial sediments accumulate over time, forming organic rich layers up to 2 m thick (Imura *et al.*, 1999).

Diatoms are a valuable paleoclimate indicator in the sediments which accumulate in Antarctic lakes (Jones, Hodgson & Chepstow-Lusty, 2000; Roberts *et al.*, 2004; Hodgson *et al.*, 2016; Rudd *et al.*, 2016), but in order to effectively employ diatoms preserved at these sites for paleoclimate research, detailed ecological information is required. Salinity, as inferred from specific conductivity, is a key control on diatom composition of surface sediments in the Sub-Antarctic Islands (Saunders *et al.*, 2015), Antarctic peninsula (Kopalová *et al.*, 2013, 2019) and East Antarctica (Verleyen *et al.*, 2003; Tavernier *et al.*, 2014), and has allowed for the development of conductivity transfer functions for these regions. However, the application of conductivity transfer functions has been limited to a few studies (eg. Roberts *et al.*, 2004; Hodgson *et al.*, 2006) and in Lützow-Holm Bay, variability in the sediment diatom assemblage at Lake Mago in the Skarvsnes region resulted in very small fluctuations in inferred specific conductivity which fell within the error of the model (Tavernier *et al.*, 2014). This suggests that either salinity alone is not driving the observed changes in the diatom records, or that transfer functions are not sensitive enough to explain the variability observed. Fossil diatoms from the past 900 years at Lake Hamagiku, also in the Skarvsnes region, show large fluctuations in relative abundance of a limited number of species which are tentatively associated with subtle fluctuations in conductivity, depth and nutrient input, although confident interpretations are hindered by a limited knowledge of diatom ecology in the region (Rudd *et al.*, 2016).

In addition to the commonly studied water quality responses, investigating substrate preferences of benthic diatoms has the potential to aid in more informed interpretation of sediment records (McGowan *et al.*, 2018). In North American and Arctic lakes sample substrate has been shown to be a key control on diatom assemblages (Lim, Kwan & Douglas, 2001; Bouchard, Gajewski & Hamilton, 2004), with some diatom species found attached to a variety of substrates, while others having a stronger affinity to a specific substrate type (Reavie & Smol, 1997; Lim *et al.*, 2001). In contrast, few studies of Antarctic lakes have examined the association between diatom assemblages and variation in substrate. Kopalová *et al.* (2019) studied a series of lakes on James Ross Island, and determined that substrate plays a significant role in differentiating diatom communities, particularly whether those substrates are submerged or exposed. Equivalent studies have not been performed in East Antarctica, and as diatom preferences have been thought to vary between regions as different populations become locally adapted (Tavernier, 2014), the lack of such studies in other regions warrants further investigation.

In high latitude lakes, the extent and duration of ice cover is a key variable affecting physical and chemical characteristics which in turn influences lake ecology (Douglas & Smol, 1999; Griffiths *et al.*, 2017). Ice cover can affect the availability of littoral habitats, whereby ice restricts the colonisation of shallow, near-shore surfaces, or scours off existing biomass. In Arctic lakes, ice melt is preferentially focused in the littoral zones during summer months, and depending on the regional temperature and the size of the lake, the lake may be entirely exposed, or a persistent floating ice raft may form, surrounded by a liquid moat, and so littoral taxa dominate the overall lake assemblage (Smol, 1983, 1988; Douglas & Smol, 1999). By comparing the relative abundance of littoral taxa to other species preserved in lake sediment records, past ice cover and in turn temperature variability through time may be inferred. This method has been used for Arctic lakes in a number of instances (Smol, 1983; Lemmen *et al.*, 1988; Paull, Finkelstein & Gajewski, 2017), but requires prior information regarding which species occupy the littoral and deeper regions of lakes.

The degree of endemism of diatoms in Antarctica has been the subject of a number of studies, which challenge reports of cosmopolitan distribution (Toro *et al.*, 2007; Vinocur & Maidana, 2010). Some genera, such as *Luticola,* have been found to have a strong degree of endemism, with nearly 20% of the global *Luticola* species endemic to Antarctica, and of those species, many are endemic to particular regions (Kociolek *et al.*, 2017). Diatom floras in the McMurdo Dry Valleys also have displayed substantial spatial structure (Sakaeva *et al.*, 2016), and diatom floras are believed to reflect the biogeographical regions that have been used to describe the distribution of macroorganisms (Vyverman *et al.*, 2010). The relative simplicity of lake systems in Antarctica also provides an opportunity to untangle the influence of substrate and chemistry on lake ecology, excluding some of the habitat complexity and landscape effects found in more temperate systems, as has been done for Arctic lakes (Griffiths *et al.*, 2017).

The aims of this study are twofold: (1) to evaluate the variability in diatom species distribution within individual lakes both by sampling across water depth gradients, and from different substrate types in the littoral zone; and (2) to assess the relative influence of environmental variables and substrate effects upon the diatom species assemblages. This study therefore adds to the limited knowledge of diatom ecology in Antarctica and provides a foundation from which paleoclimate inferences may be made from lake sediment diatom assemblages.

Methods

Diatom sampling

Nine lakes in the Langhovde, Skarvsnes and Skallen ice free regions in Lützow-Holm Bay, East Antarctica (Figure 3.1), were sampled to examine diatom species distributions and their relationship to the environment in the 2017–2018 austral summer during the 59th Japanese Antarctic Research Expedition. In order to determine species habitat preferences related to substrate type and light availability, diatoms were sampled from different substrates around the perimeter of the lakes in the littoral zone and from surface sediments on the lake floors. The substrates selected for the littoral zone were microbial mats, sands, gravels, cobbles and the surface of larger rocks where present. Lake floor surface sediments were sampled at varying depths in transects across some lakes, and for others a single sample was collected from the deepest point of the lake.

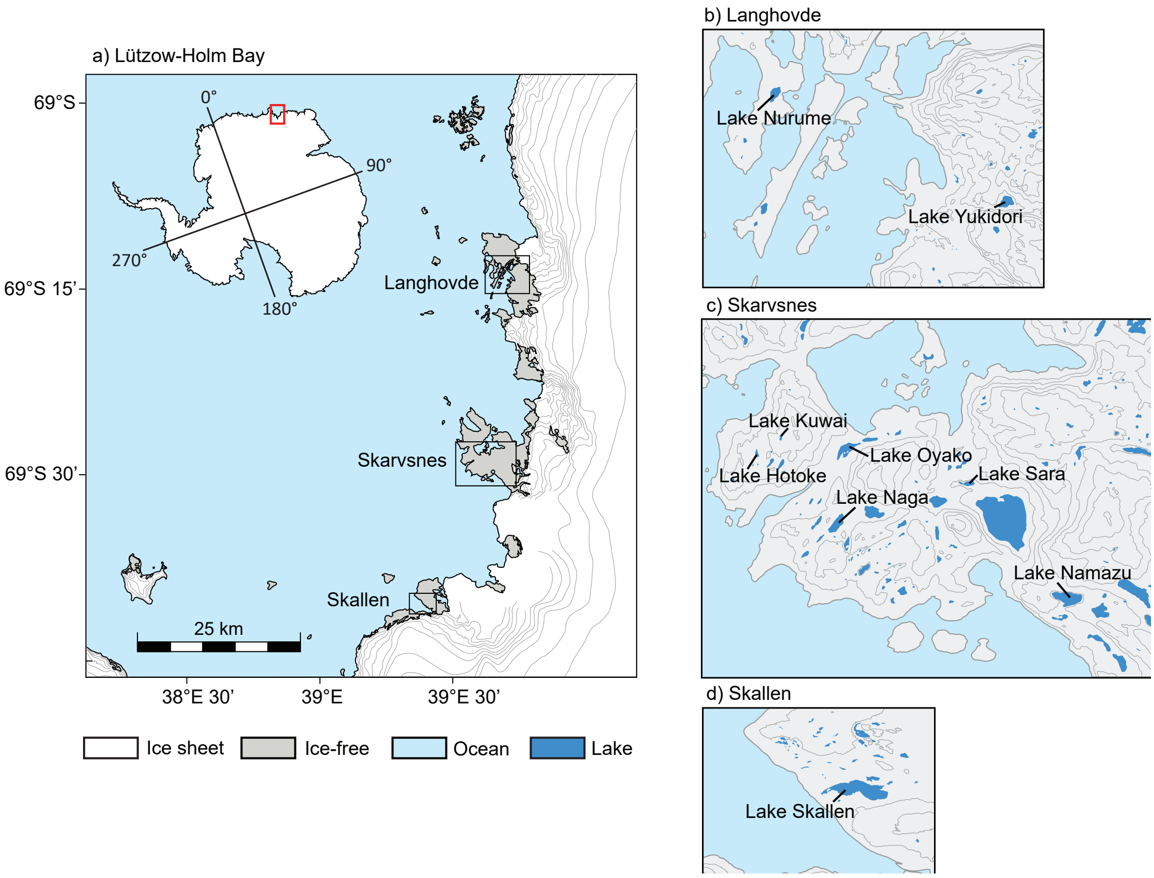

Figure 3.1 Lakes and ponds sampled during this study - a) Lützow-Holm Bay with inset map of Antarctica, where the red rectangle indicates the location of the bay. Ice free regions are shown in light grey, ice sheet contour intervals are 100 metres. b) Langhovde c) Skarvsnes d) Skallen. For b), c) and d) contour intervals are 50 metres. Figure adapted from topographic maps issued by the Geospatial Information Authority of Japan (map numbers 217, 219 and 221).

At each sampling location in the littoral zone, the substrate types present were sampled separately. In order to minimise the effect of small-scale variability, several smaller samples were combined in each sample. For rocks larger than 200 mm in diameter, a purpose-built sampler, modified from Flower (1985), was used which was pushed against the rock surface, and twisted to scrape the surface of the rock with a toothbrush head over a 100 mm diameter circle. This sample, and 15 ml of water was sucked into a 50 mL centrifuge tube. Three of these samples from a 1 m^2 area were combined to make one sample. For cobbles, 20–200 mm in diameter, the cobble was removed from the lake, and two 50 mm^2 areas were scrubbed with a toothbrush into the sample container. For gravel (2–22 mm diameter), sand (<2 mm diameter) and microbial mats, 15 cm^3 of material was collected from a 1 m^2 area and combined. Lake floor samples were either taken from the top of short cores, collected using a 90 mm diameter Pylonex HTH corer, or using an Ekman grab sampler. All samples were frozen until analysis. Due to logistical constraints on fieldwork, at some sites either littoral or deep water sediment surface samples could not be collected. Sampling locations are illustrated in Supplementary Figure 3.1.

Light intensity was measured using a spectral irradiance sensor equipped with a depth sensor (RAMSES-UV/VIS, TriOS) through the water column at Lake Naga. A series of triplicate measurements above the lake surface, just below the surface water and at the lake floor were recorded in five minutes. Water quality measurements (temperature, pressure, dissolved oxygen, specific conductivity, alkalinity, oxidation reduction potential and turbidity) were collected from the centre of the lakes at the time of sampling using a multiparameter water quality logger (YSI-6600V2; YSI). Due to logistical constraints during field work, water quality data was not collected from Lake Namazu. Measurements from Lake Namazu in previous summers (January 2007, February 2008 and February 2012) varied substantially, particularly pH and dissolved oxygen (DO), and hence could not be used as an analogue for the 2018 data. Hence, Lake Namazu was excluded from statistical analyses involving environmental variables.

Slide preparation and diatom analysis

Diatom samples were prepared using a method adapted from Battarbee et al. (2001) involving HCl and H_2O_2 digestion. Diatom frustules were air dried on cover slips before being mounted onto slides using Naphrax. Slides were analysed at 1000x magnification using a Nikon Eclipse E600 microscope. For each sample, 300 valves were counted where possible, with 8 samples counted to a lower target of 200 due to the very limited number of valves. Some samples contained too few valves to count and are not included in the subsequent analysis. Species were identified based on previous studies in the Lützow-Holm Bay region (Hirano, 1983; Ohtsuka *et* *al.*, 2006) and other Antarctic coastal floras (Hodgson, Vyverman & Sabbe, 2001; Sabbe *et al.*, 2003; Cremer *et al.*, 2004; Spaulding *et al.*, 2019). Diatom valve concentration per milligram of sediment was estimated using sediment weight, aliquot volume and transect length of counts (adapted from Davis, 1965; Battarbee & Kneen, 1982). Due to large differences in surface area between different substrates, diatom concentrations are not compared between different substrate types.

Statistical analysis of species diversity

In order to explore and identify the main patterns in species composition across the lakes studied, ordination was employed to view similarities and dissimilarities in the data. A square-root transformation was used to reduce the effect of dominant species, prior to detrended correspondence analysis (DCA) and non-metric multidimensional scaling (NMDS) using the *vegan* package in R (Oksanen *et al.*, 2018; R Core Team, 2018). Both of these methods were conducted in order to compare the results. These analyses were performed with and without the samples from Lake Nurume, as these were notable outliers based on species composition, and are plotted without these samples to better illustrate the remaining data.

Multivariate regression trees (MRT) were used to relate the abundances of diatom species to environmental variables (De'ath, 2002). MRT divide quantitative data into successive partitions, in this case the species relative abundances, where each partition defines a subset of samples. This partitioning occurs under the control of quantitative and categorical variables, namely the geographic (sample region, lake), physical (lake depth, sampling depth, substrate type, turbidity) and chemical variables (pH, specific conductivity, oxidation-reduction potential and dissolved oxygen) measured at each site. With each successive partition, the explanatory variable for which the within-group sum of squares is minimised is selected and associated with the partition. The tree size was selected using the interactive cross validation method, with a 5 branch tree identified as having the smallest estimated predictive error (De'ath, 2002). MRT analysis was conducted in R using the *mvpart* package (archive version 1.6-2). Scatterplots of key species abundances across the lakes against environmental variables are used to highlight the splits associated with the regression tree analysis.

Results

Morphology and chemistry of study sites

The morphology and chemistry of the sites studied is summarised in Table 1. There is little covariance between the physical and chemical variables measured at these sites (Figure 3.2) and most lakes lie within a small range of these variables.

Diatom species assemblage analysis

In total, 35 taxa were observed in 136 samples. Many samples contained fragmented valves that were only identified to a genus level. Some samples also contained occasional fragments of marine diatom species and chrysophyte cysts. The 15 most common diatom species observed are illustrated by photomicrographs in Figure 3.3. Diatom counts for individual samples are presented in Supplementary Figure 3.2. Descriptions, measurements and authorities for the 15 most common taxa are provided in Supplementary Information, part 1.

Some species, such as *Craticula antarctica*, *Halamphora vyvermaniana*, *Navicula gregaria* and *Psammothidium papilio* were observed across most sites and substrates, while other species were confined to a few samples (Figure 3.4). Some species were observed in greater abundances at some locations, while other species, such as *Achnanthes taylorensis*, *Cocconeis* sp., *Paralia sulcata* and *Stauroneis latistauros* were only ever represented by a few valves.

For Lake Nurume, a lake close to the ocean (altitude 0 m, 50 m from ocean) on Langhovde, *Navicula phyllepta* was the most common species across all substrates. *Navicula gregaria* was also present on all substrates, but in low abundance. *Navicula* aff. *directa* was observed on the sand sample and an unidentified *Navicula* sp. was found on the cobble sample and in very low abundance on the sand sample (Figure 3.4). At Lake Yukidori, further inland in the Langhovde area, *Humidophila australis* was dominant in all samples collected. *Psammothidium papilio* was also found on all substrates sampled, but was most common on the sand samples, and to a lesser extent from the lake floor samples. *Psammothidium incognitum* var. *stauroneioides* was observed in the littoral substrates, and of these, was more abundant on the cobbles than in the sand and microbial mats (Figure 3.4).

The samples from littoral substrates at Lake Kuwai in Skarvsnes were dominated by *Psammothidium papilio*. *P. papilio* was also present in the samples collected from the lake floor but was less dominant than *Craticula antarctica* and *Halamphora vyvermaniana* in these samples (Figure 3.4). At Lake Sara, also on Skarvsnes, only littoral samples were collected, and *Navicula gregaria* and *Psammothidium papilio* were abundant in all samples from these substrates. *Craticula antarctica*, *Halamphora vyvermaniana*, *Hantzschia* cf. *amphioxys* and *Luticola pseudomurrayi* were all present at lower abundances (Figure 3.4). The assemblage observed in the samples from Lake Hotoke, also on Skarvsnes, is similar to that of Lake Kuwai.

Table 3.1 Lake locations and surface water chemistry collected during fieldwork. Note that water quality measurements were not collected for Lake Namazu due to logistical constraints. Lake surface area measurements taken from Kimura (2010) and Imura (2003). AMSL = above mean sea level.

Region	Lake	Location	Max. depth (m)	Altitude (m AMSL)	Surface area (m^2)	Conductivity (mS/cm)	pH	Dissolved oxygen (mg/L)	Turbidity (FNU)	Oxidation-reduction potential (mV)
Langhovde	Nurume	S69° 13.472' E039° 39.422'	16.2	0	35,000	4.3	7.85	12.2	7.6	193.5
	Yukidori	S69° 14.375' E039° 45.574'	8.6	125	41,000	0.06	8.65	11.87	6.9	174
Skarvsnes	Hotoke	S69° 28.599' E039° 33.713'	3.0	120	6,000	0.83	8.41	11.97	6.7	87.2
	Kuwai	S69° 28.456' E039° 34.356'	3.6	160	4,000	0.5	8.22	11.85	6.6	164.6
	Naga	S69° 29.261' E039° 35.746'	10.8	70	48,000	1.74	8.57	12.37	6.8	106.2
	Namazu	S69° 29.998' E039° 42.192'	20	95	91,000	-	-	-	-	-
	Oyako	S69° 28.528' E039° 36.147'	8	5	48,000	0.74	8.33	12.25	10.1	91.8
	Sara	S69° 28.871' E039° 39.242'	2.5	0	13,000	0.75	8.75	12.15	7.3	156.9
Skallen	Skallen	S69° 40.330' E039° 25.290'	10	10	209,000	0.27	8.2	12.59	7.1	162.2

Psammothidium papilio is the most common species, observed in samples from cobbles, sand, and the lake floor. *Craticula antarctica* is abundant in the lake floor samples, as for Lake Kuwai, and present in small abundance in the cobble samples. *Halamphora vyvermaniana*, *Luticola pseudomurrayi* and *Navicula gregaria* are also present in low abundance.

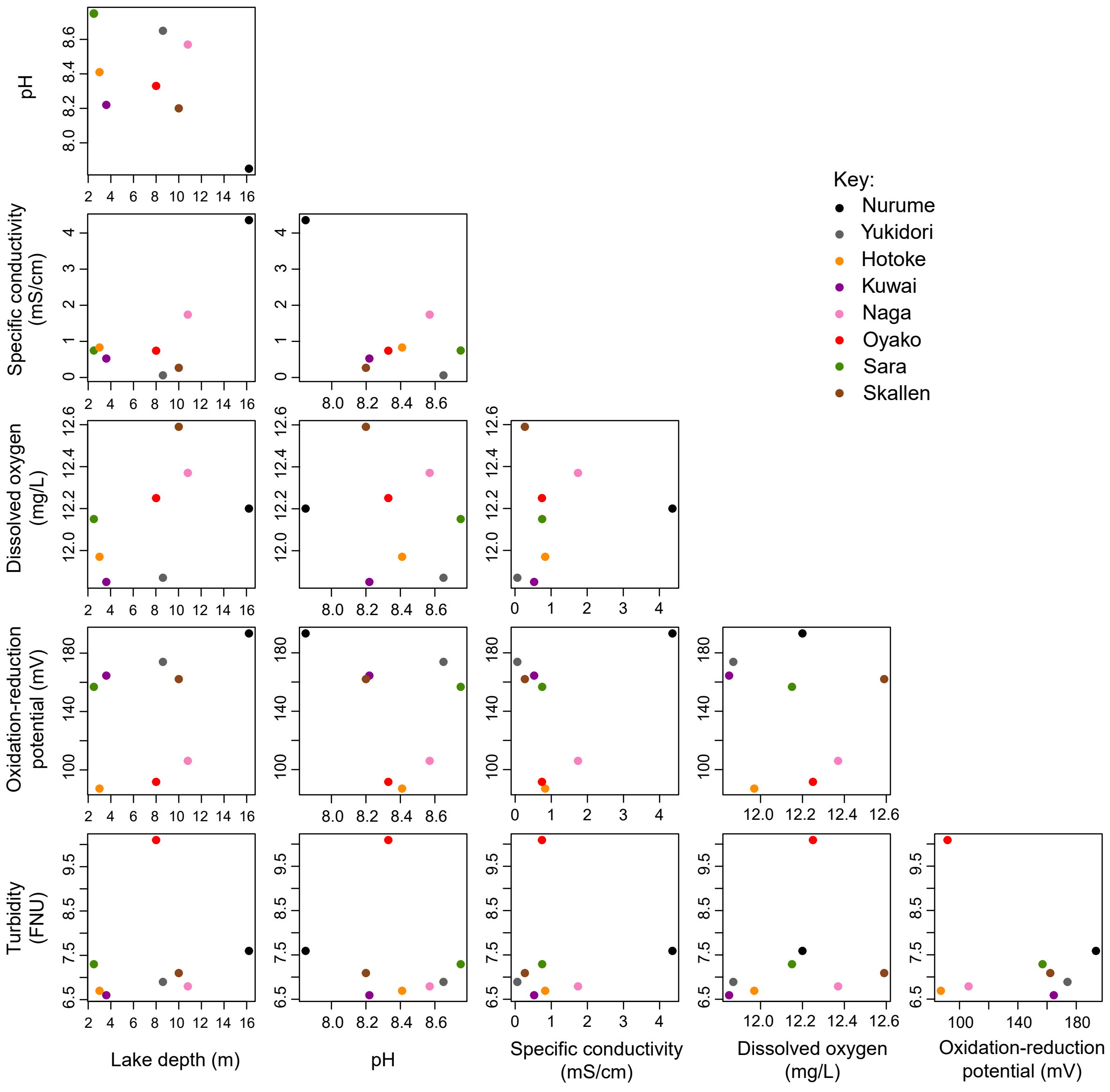

Figure 3.2 Matrix of scatterplots of water quality measurements for the surface of each site. Note that Lake Namazu is not included as no YSI data were collected.

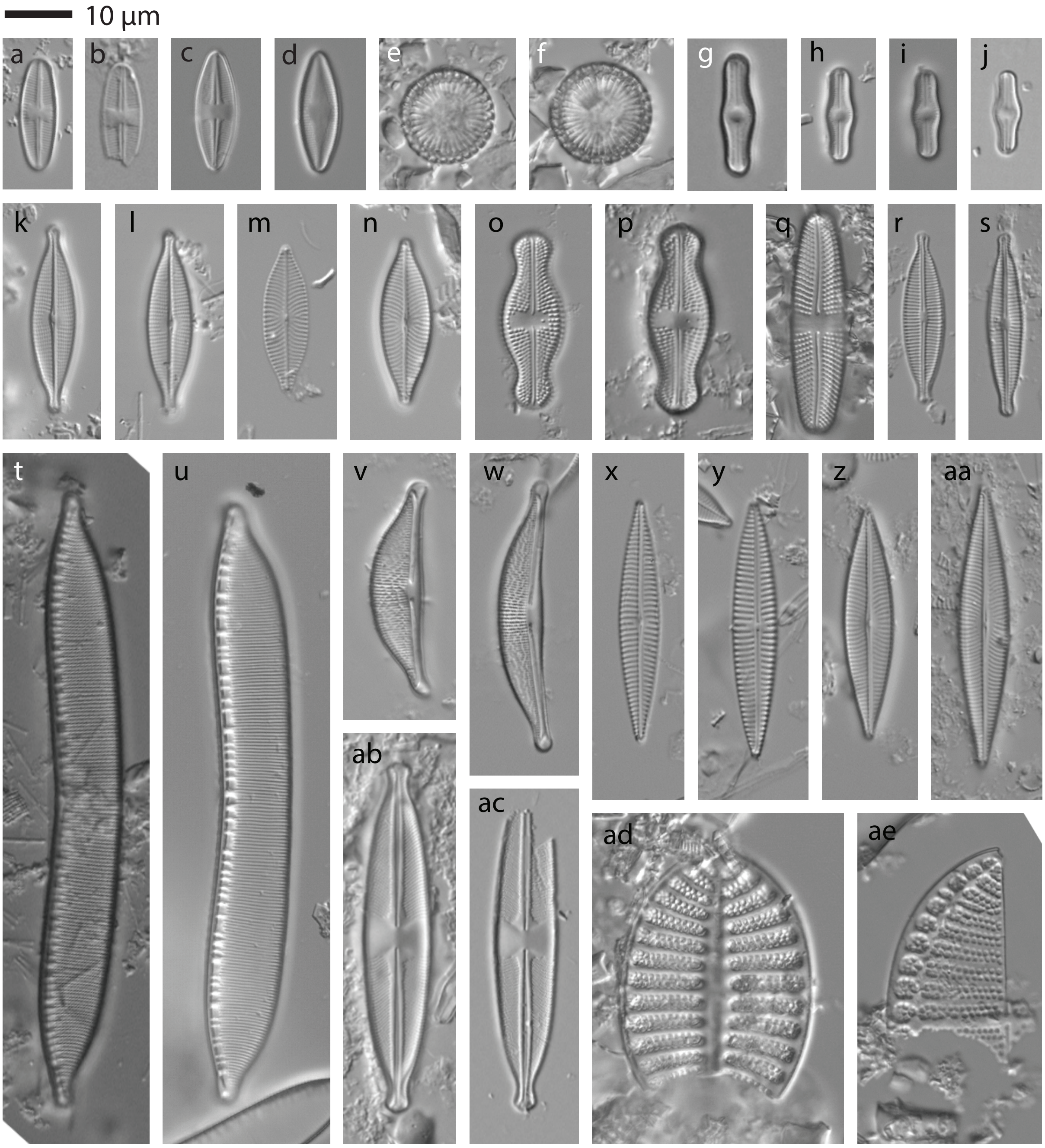

Figure 3.3 Light micrographs of the 15 most abundant diatoms within the samples collected from Lützow-Holm Bay: a-b, *Psammothidium papilio*; c-d, *Psammothidium incognitum* var. *stauroneioides*, same frustule, d is a rapheless valve; e-f, *Paralia sulcata*; g-j, *Humidophila australis*; k-l, *Navicula gregaria*; m-n, *Navicula phyllepta*; o-p, *Luticola pseudomurrayi*; q, A*chnanthes taylorensis*; r-s, *Craticula antarctica*; t-u, *Hantzschia* cf. *amphioxys*; v-w, *Halamphora vyvermaniana*, showing the range in size observed in Lützow-Holm Bay; x-y, *Navicula* sp.; z-aa, *Navicula* aff. *directa*; ab-ac, *Stauroneis latistauros*; ad-ae, *Cocconeis* sp.

At Lake Naga, *Halamphora vyvermaniana* was common across all substrates, but particularly abundant in the samples collected from the lake floor (Figure 3.4). *Psammothidium papilio* was common in the littoral samples; large rock surfaces, cobbles and sands. *Craticula antarctica, Hantzschia* cf. *amphioxys, Luticola pseudomurrayi* and *Navicula gregaria* were observed at lower abundances. For Lake Namazu, samples were only collected from the lake floor, and the most abundant species was *Navicula gregaria*, with *Craticula antarctica*, *Humidophila australis*, *Halamphora vyvermaniana* and *Psammothidium papilio* also common. *Stauroneis latistauros* was also present in low abundances (Figure 3.4). At Lake Oyako, *Navicula gregaria* and *Psammothidium papilio* were observed across all substrates, with *Navicula gregaria* more common in the lake floor samples, and *Psammothidium papilio* more abundant in gravel and sand samples, and less common in the lake floor samples (Figure 3.4). *Halamphora vyvermaniana* was also observed across all substrates yet at a lower relative abundance, and occasional valves of *Achnanthes taylorensis*, *Craticula antarctica*, *Cocconeis* sp., *Humidophila australis*, *Hantzschia* cf. *amphioxys*, *Luticola pseudomurrayi* and *Paralia sulcata* were observed (Figure 3.4).

At Lake Skallen, the only lake sampled from the Skallen area, *Humidophila australis* was the most common species, and was observed at a high relative abundance across all substrates. *Psammothidium papilio* was also observed on all substrates but was the most dominant species observed on sand samples. *Craticula antarctica*, *Halamphora vyvermaniana* and *Navicula gregaria* were also present in lower abundances (Figure 3.4).

Numerical analysis of diatom-environment relationships

The DCA and NMDS analyses returned consistent results, such that only the NMDS analysis is presented here (DCA is presented in Supplementary Figure 3.3). The assemblages from Lake Yukidori were distinct from all other sites, which, in turn, cluster close to each other with respect to their diatom composition. At some sites there is also a distinction between the diatom species associated with different substrate types, particularly at Lake Naga where the lake floor and littoral assemblages differ (Figure 3.5). This distinction is also observed, but to a lesser extent, in Lakes Kuwai, Oyako and Skallen. *Humidophila australis* is strongly associated with samples from Lake Yukidori and Lake Skallen (Figure 3.5b), with *Psammothidium incognitum* var. *stauroneioides* associated with samples from Lake Yukidori and few other samples. The species observed at most sites plot towards the centre of the NMDS (Figure 3.5b) including *Navicula gregaria* and *Craticula antarctica*. Other species, such as *Halamphora vyvermaniana* and *Psammothidium papilio* are more strongly associated with certain substrates and lakes. *H. vyvermaniana* is abundant in Lake Naga lake floor samples while *P. papilio* is an important

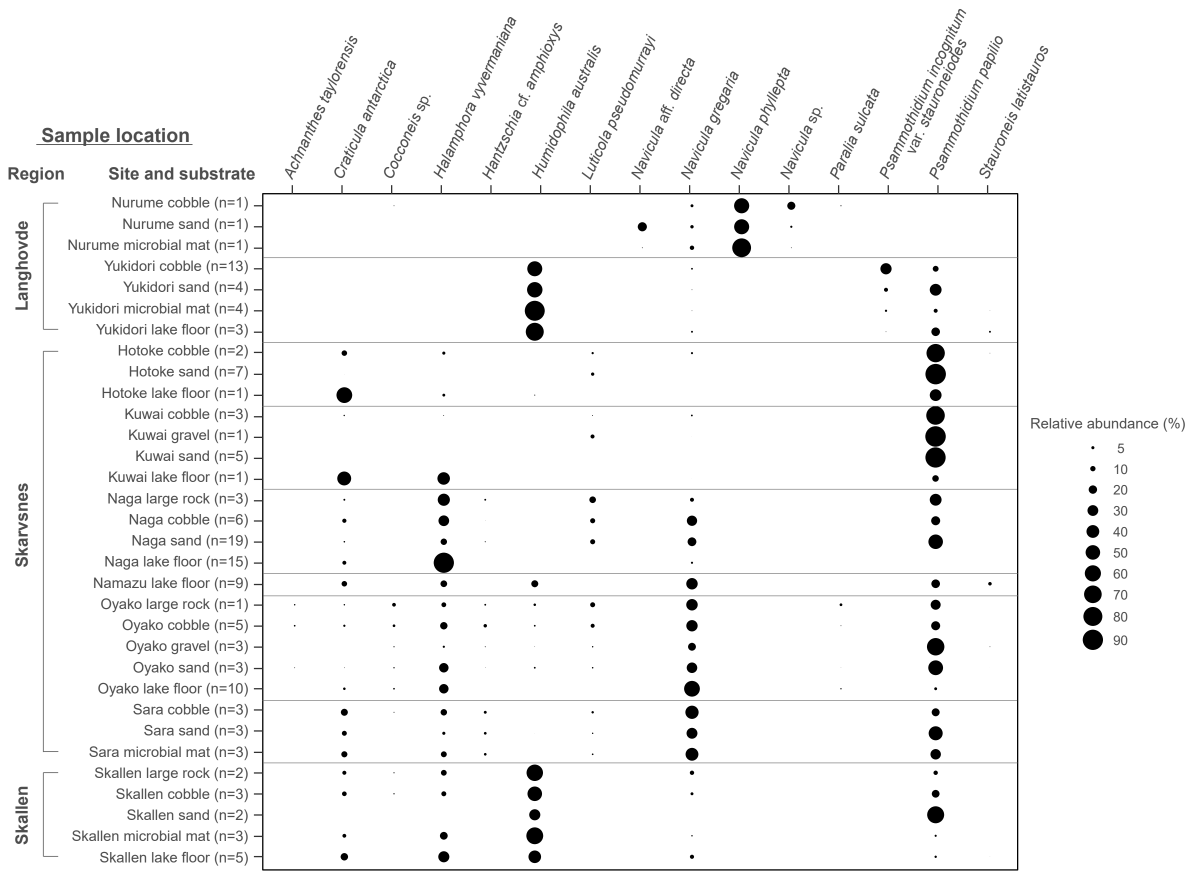

Figure 3.4 Diatom relative abundance for samples collected during this study. Only species with above 5% relative abundance in two samples or above 10% in one sample are displayed here. Samples from the same substrate type and lake have been averaged, and the number of samples comprising each point is indicated by the n value after each sample location.

feature of littoral samples from Lakes Kuwai and Hotoke.

Multivariate regression tree analysis

The multivariate regression tree analysis splits the diatom data according to a range of chemical and habitat preferences (Figure 3.6). The first MRT split of the data is associated with specific conductivity. The group of samples on the left node, with a specific conductivity of less than 0.405 mS/cm, includes samples from the two freshest lakes, Lake Yukidori in the Langhovde region and Lake Skallen in the Skallen area. The bar plot below this node (Figure 3.6a) indicates that the species *Humidophila australis* is strongly associated with these samples, dividing them from the rest of the dataset in which the species is less common, a feature also

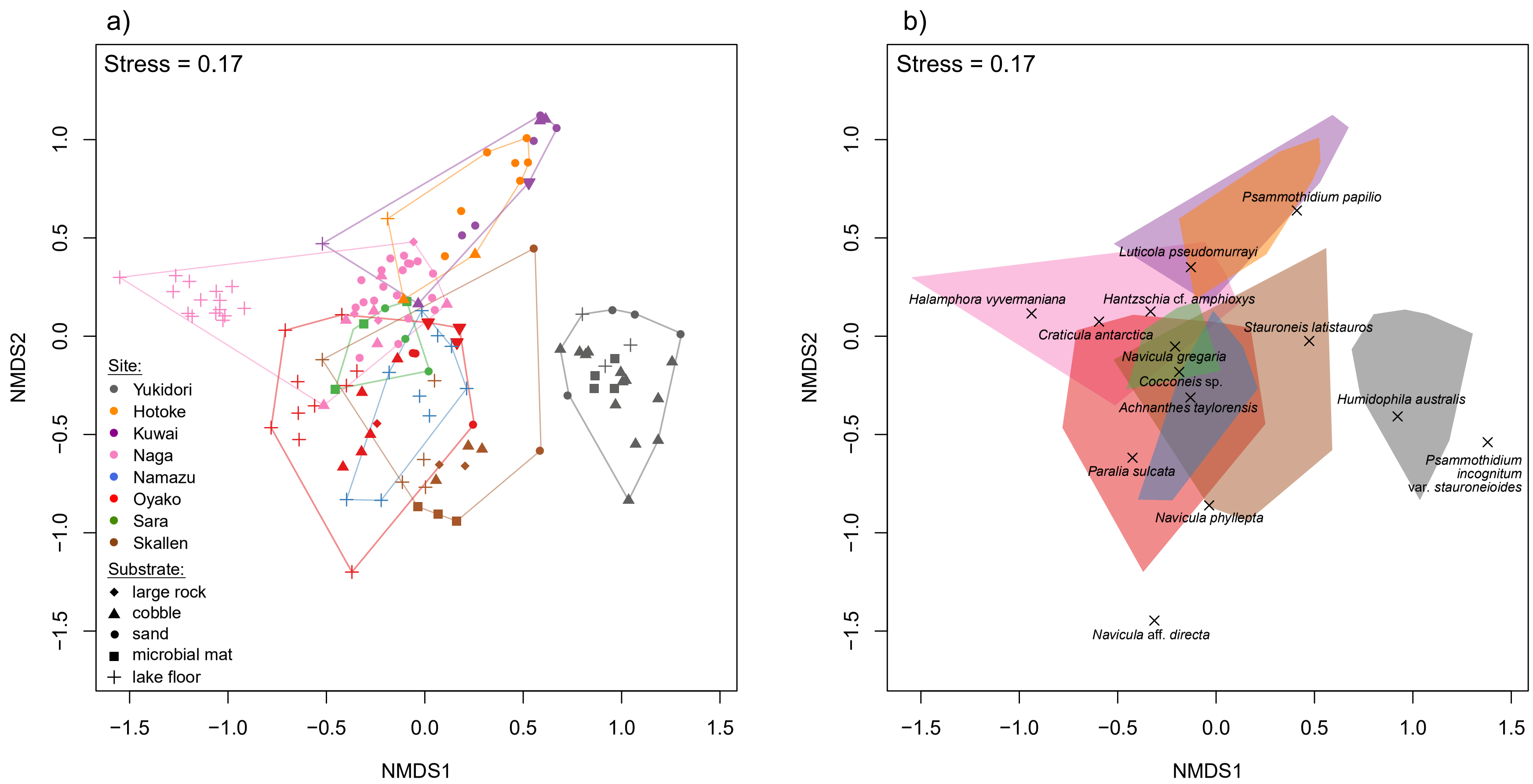

Figure 3.5 Non-metric multidimensional scaling analysis of the diatom data from Lützow-Holm Bay collected during this study. a) the samples and the substrate from which they were collected, with convex hulls bounding samples from the same lake. In b), species names are overlain over the same NMDS plot.

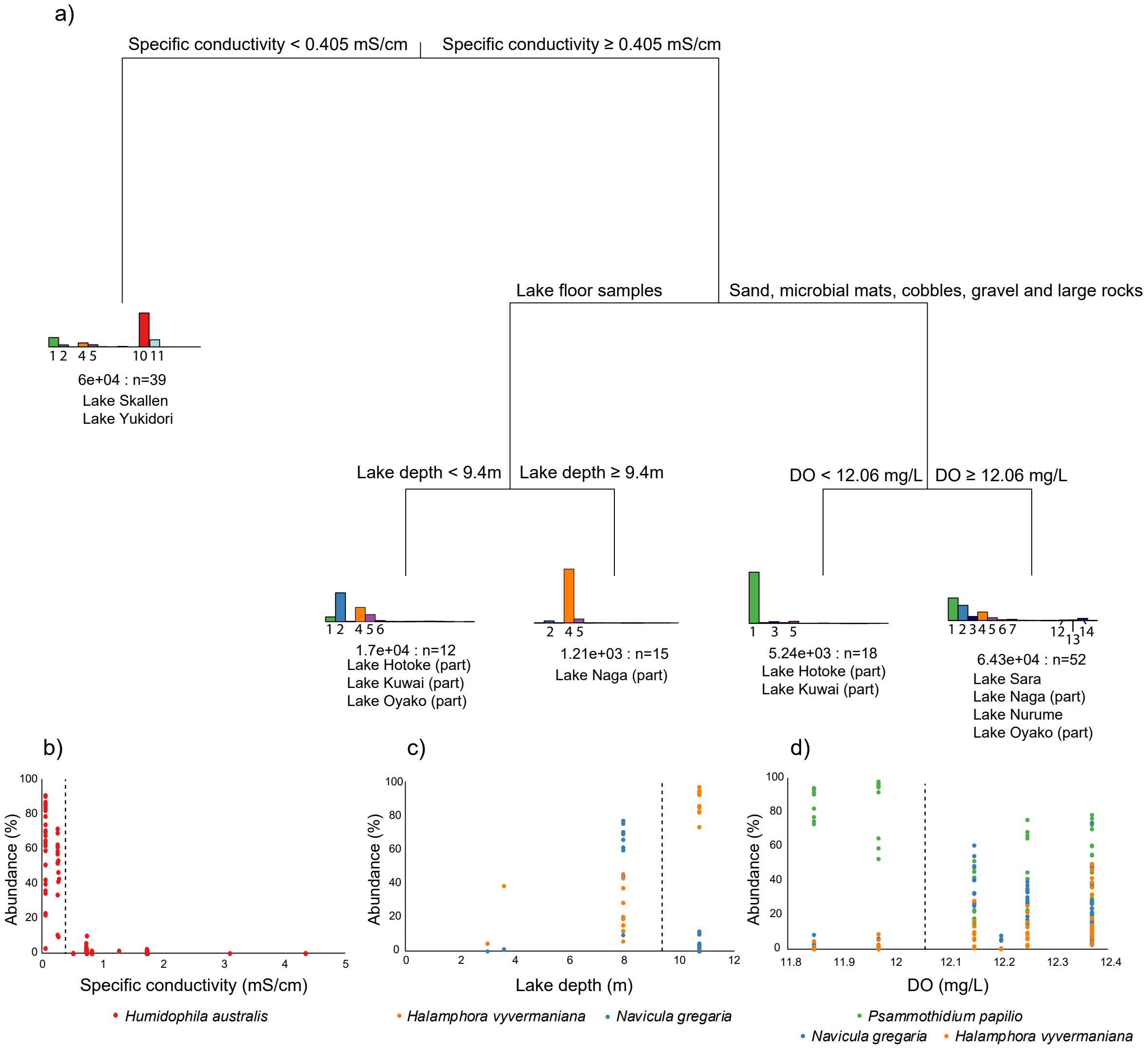

Figure 3.6 Regression tree analysis of the Lützow-Holm Bay diatom data. The regression tree presented has an error of 0.331, cross validation error of 0.372 and a standard error of 0.0477. The bar charts beneath the branches show which species were prominent in the group of samples, numbers indicate species where 1 – *Psammothidium papilio*, 2 – *Navicula gregaria*, 3 – *Luticola pseudomurrayi*, 4 – *Halamphora vyvermaniana*, 5 – *Craticula antarctica*, 6 – *Cocconeis* sp., 7 – *Hantzschia* cf. *amphioxys*, 8 – *Stauroneis latistauros*, 9 – *Achnanthes taylorensis*, 10 – *Humidophila australis*, 11 – *Psammothidium incognitum* var. *stauroneioides*, 12 – *Navicula* sp., 13 – *Navicula* aff. *directa*, 14 – *Navicula phyllepta*, 15 – *Paralia sulcata*. Beneath each branch, the sites which contributed samples are shown, and where samples from a single lake are separated into different branches of the tree, this is indicated in brackets. Scatter plots b), c) and d) illustrate the key diatom abundances at the indicated splits (dashed vertical lines) plotted against the diagnostic environmental variables, as identified by the regression tree analysis.

illustrated in Figure 3.4.

For sites with a specific conductivity > 0.405 mS/cm, the MRT further splits the data according to substrate type. Samples collected from the lake floor at depths of more than 2 m are separated from all those taken in the shallow littoral zone; cobbles, gravels, large rocks, microbial mats and sands (Figure 3.6). Of the samples collected from the lake floor, at lakes with a maximum depth of less than 9.4 m (Oyako, Sara, Kuwai and Hotoke), the assemblages were characterised by a greater abundance of *Navicula gregaria* and to a lesser extent, *Halamphora vyvermaniana*. In lakes deeper than 9.4 m (Lake Naga), *H. vyvermaniana* was the dominant species in the assemblage. The littoral samples are further divided into those from lakes with dissolved oxygen measurements of above or below 12.06 mg/L. In both groups, *Psammothidium papilio* comprises a substantial part of the assemblage. For the sites with a lower dissolved oxygen value, *P. papilio* is highly dominant, while for those sites with a higher value, the assemblage is characterised by a wider range of species, including *Navicula gregaria* and *Halamphora vyvermaniana*.

The splits in the regression tree analysis are associated with explanatory environmental variables, yet there are other variables that covary across these divisions. For example, the MRT analysis associated lake depth with the split of the lake floor samples, separating the samples from Lake Naga from those from Lakes Hotoke, Kuwai and Oyako. In this instance, Lake Naga can also be distinguished by having a higher specific conductivity and for having the lowest pH. The littoral samples are split by dissolved oxygen content, but this division could also be explained by turbidity differences between these lakes. The regression tree analysis did not identify the region from which a sample was collected (Langhovde, Skarvsnes or Skallen) to be an explanatory variable for the differences in diatom assemblages observed.

Light attenuation at Lake Naga

The intensity of ultraviolet and visible light declines with increasing water depth at Lake Naga (Figure 3.7a). Diatom valve concentration generally increases with water depth (Figure 3.7b) from less than 100,000 valves/mg to around 300,000 valves/mg of sediment at the deepest point in the lake (R^2=0.33, p-value=0.025, significant to $p < 0.05$). There is one sample which had more valves than others, with almost 600,000 valves/mg at eight metres water depth. Across this transect, the relative abundance of *Halamphora vyvermaniana* is seen to decline slightly, while the abundance of *Craticula antarctica* increases slightly in the deepest samples collected, however in these cases, the correlations between diatom relative abundance and water depth are not statistically significant to $p < 0.05$.

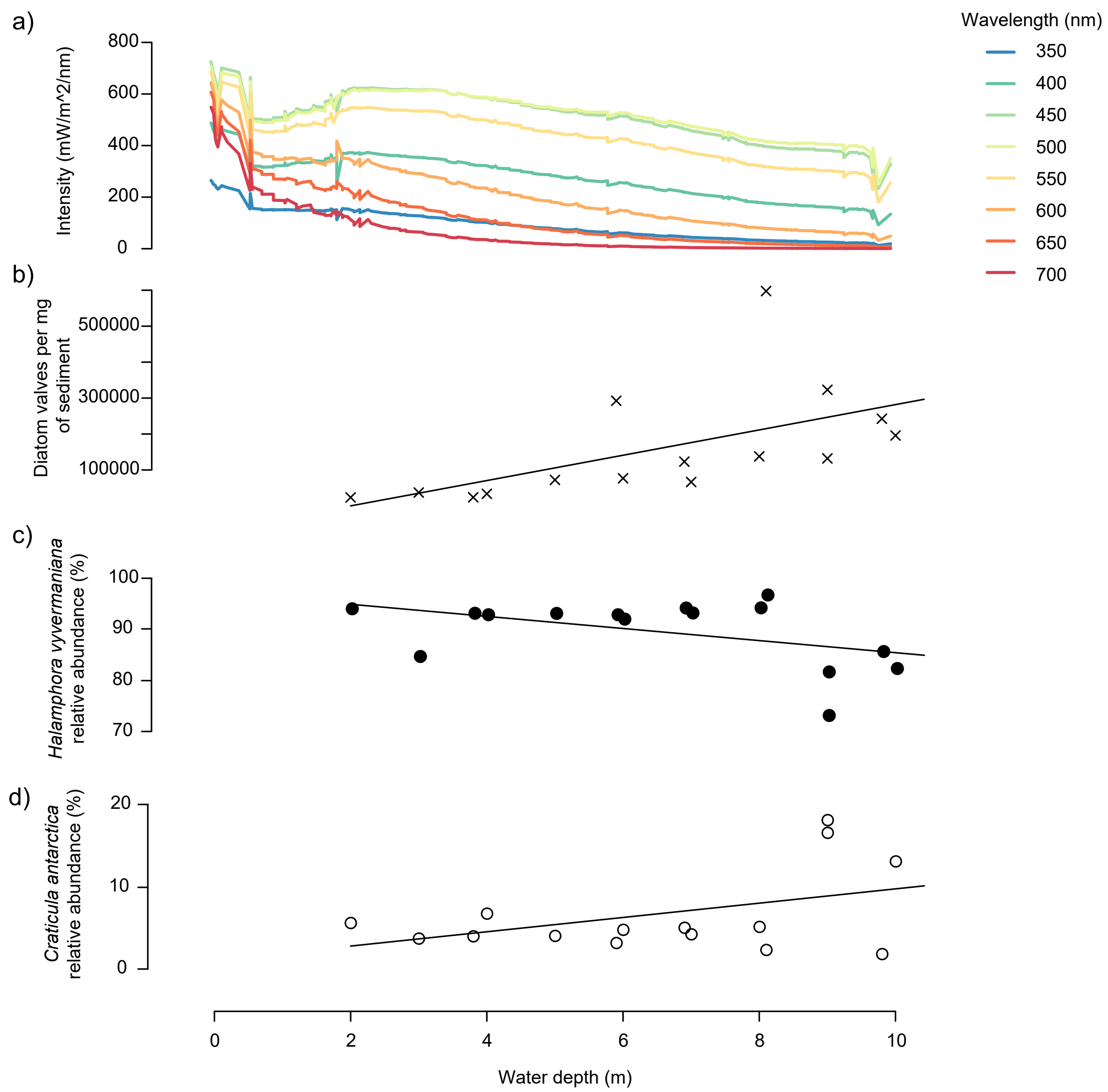

Figure 3.7 Lake Naga light intensity and species relative abundances a) light intensity of various wavelengths plotted against water depth, b) diatom valves per milligram of surface sediment along a water depth transect (linear regression: R^2=0.33, p-value=0.025) c) relative abundances of *Halamphora vyvermaniana* along the depth transect (linear regression: R^2=0.21, p-value=0.087) d) relative abundance of *Craticula antarctica* along the depth transect (linear regression: R^2=0.19, p-value=0.11).

Discussion

The use of diatoms as paleoclimate tracers in Antarctic lakes is limited by uncertainties surrounding diatom-environment relationships. While studies from comparable Arctic lakes have shown that substrate and water chemistry have competing influence on diatom species assemblages, the relative effect of these factors has not been investigated for East Antarctic lakes.

In this study, differences in diatom assemblage were observed, both between the lakes studied and between substrates in a single lake. The overlap of the convex hulls in the NMDS analysis (Figure 3.5) highlights the overlap between the diatom assemblages at most sites, but with species present in varying abundances (Figure 3.4 and Supplementary Figure 3.2). This study suggests that for lakes in the Lützow-Holm Bay region of Antarctica, differences between lakes did not have a large influence on the diatom assemblages observed. The region in which an individual lake is found (Langhovde, Skarvsnes or Skallen) was used as a possible explanatory variable in the MRT yet was not associated with any branches, indicating that at this scale, biogeography did not have a significant effect. The presence of several cosmopolitan species across a variety of lakes and substrates may be a product of the narrow range of water chemistry and substrate types at these sites, or instead, these species may be those which are best adapted to the low temperatures and low light conditions of the region. The subtle changes observed across these smaller gradients, however, provide a valuable tool for interpreting the equally subtle fluctuations in lake sediment records.

The multiple regression tree analysis indicates a hierarchy of factors which influence the composition of the assemblages observed. In Lützow-Holm Bay, specific conductivity is a key physical variable, consistent with other studies of diatom ecology in Antarctica (Verleyen *et al.*, 2003; Kopalová *et al.*, 2013; Saunders *et al.*, 2015). In these lakes, salinity has been linked to the moisture balance between inflow from seasonally melting snow and glaciers, versus output via evaporation (Tavernier *et al.*, 2014). Lakes close to sea level are further influenced by marine-derived salinity, particularly as some basins were beneath sea level prior to isostatic uplift (Takano *et al.*, 2012) and thus retain those salts in the system to varying degrees.

From both the NMDS and the first split of the regression tree analysis (Figures 3.5 and 3.6), *Humidophila australis* is associated more strongly with lakes with the lowest specific conductivity, comprising over 20% of the assemblage in lakes with a specific conductivity < 0.5 mS/cm. These results are consistent with previous research in Antarctica, most of which report it as *Diadesmis australis,* prior to the designation of the *Humidophila* genus (Lowe *et al.*, 2014). For example, *Diadesmis australis* is reported in Monolith Lake on James Ross Island, which has a low specific conductivity (Van de Vijver *et al.*, 2010). Sabbe et al. (2003) report the species, which they named *Diadesmis* cf. *perpusilla,* to be commonly found in the Larsemann Hills in freshwater, but not brackish, lakes. Gibson et al., (2006) observe a *Diadesmis* sp.a associated with a low salinity tolerance in the Bunger Hills in East Antarctica, which also appears to be the same species (Van de Vijver *et al.*, 2010). *Humidophila australis* was also observed with a low relative abundance in several lakes in Taylor Valley, in the McMurdo Dry Valleys, although its distribution does not appear to be associated with specific conductivity (Sakaeva *et al.*, 2016).

On the other end of the specific conductivity gradient of the study sites, Lake Nurume is distinguished by a higher specific conductivity, and a considerably different diatom assemblage, which contrasts with the subtle variations observed between the other sites. While different species are observed at this lake, it is also notable that the species which are highly abundant in other sites are absent, including *Psammothidium papilio*, *Halamphora vyvermaniana* and *Craticula antarctica*. *Navcula phyllepta* was one of the main species observed at Lake Nurume across the littoral substrates sampled, and has been reported to be dominant in two brackish lakes in the Rauer Islands (Hodgson *et al.*, 2001). However it was also observed in two freshwater lakes in the Larsemann Hills (Sabbe *et al.*, 2003), so does not appear to be limited to brackish lakes in East Antarctica. As well as having a higher specific conductivity, Lake Nurume is also deeper and has a lower pH and a slightly higher oxidation-reduction potential than the other sites studied. As there are various chemical and physical differences between Lake Nurume and the others sampled for this study it is not possible to determine conclusively which are the key variables in explaining the diatom assemblage in this lake.

Following specific conductivity, the next branch on the regression tree analysis identifies that diatom assemblage composition was dependant on habitat (lake floor vs. all littoral substrates) (Figure 3.6). The data indicate that littoral substrate type (e.g. rock surface, cobble, gravel, sand) is not as important as whether the sample was collected from the lake floor or the shallow littoral zone. *Halamphora vyvermaniana* was abundant in the lake floor samples from most sites in this study, except for the freshest lakes (Figure 3.4 and Figure 3.6). This species was particularly prevalent in lake floor samples from Lake Naga (Figure 3.4 and Figure 3.5). Regression tree analysis explains this in terms of lake depth, although Lake Naga also has a higher specific conductivity and pH than the other sites, so the reason for the higher abundance of *H. vyvermaniana* is not definitive. Van de Vijver *et al.* (2014) note that most reports of *Halamphora veneta* from the Antarctic continent are likely to represent *H. vyvermaniana.* This species has been reported from the Larsemann Hills and Rauer Islands as *Amphora veneta* in both freshwater and brackish lakes (Sabbe *et al.*, 2003; Van de Vijver *et al.*, 2014). *H. veneta* was also identified in sediment cores in East Antarctic lakes, constituting a large proportion of the diatom assemblage in the sediments of Lake Mago, which has a pH of 8.95 and a specific conductance of 0.48 mS/cm (Tavernier *et al.*, 2014). The association of *H. vyvermaniana* with moderate specific conductivity and alkaline lakes is consistent with this previous study, although the prevalence of this species in lake floor environments over littoral habitats has not been previously reported.

From the regression tree analysis, *Psammothidium papilio* is an important species in both categories of littoral samples, although in some lakes and substrates it is singularly dominant, while in other samples there is a more diverse assemblage, with *Halamphora vyvermaniana* and *Navicula gregaria* also common (Figure 3.6). This species was found in the McMurdo Dry Valleys as *Navicula papilio,* and is thought to be a common freshwater diatom due to reports of the species, as *P. metakryophilum*, in the Maritime Antarctic Region (Kopalová *et al.*, 2012), the Larsemann Hills (Sabbe *et al.*, 2003), the Bunger Hills (Gibson *et al.*, 2006a), and from surface sediments and late Holocene assemblages from Radok Lake and Terrasovoje Lake respectively, in the Amery Oasis, East Antarctica (Cremer *et al.*, 2004). *P. papilio* has also previously been reported in Lützow-Holm Bay (Ohtsuka *et al.*, 2006, as *P. metakryophilum*), although the association with littoral substrates in preference to deeper water substrates inferred from this dataset was not observed in these previous studies.

There are several key differences between the lake floor environment beyond two metres water depth, and the shallow perimeter of these lakes, outside of the mossy nature of the lake floor beyond this depth, and the rocky nature of the littoral region which may contribute to the differences in diatom assemblage observed. One possibility is that, due to the limited nutrients available as observed in similar lakes (Gibson *et al.*, 2006b), much of the nutrient cycling occurs in the surface sediments on the lake floor, so differences in diatom assemblage composition may reflect species responses to nutrient availability, with those adapted to low nutrient conditions around the perimeter. The lake floor of these sites is affected by the ice cover during the winter months, which reduces the light intensity reaching these habitats, such that the diatoms occupying the lake floor may be better adapted to low light conditions. The ice cover of these lakes also has several influences on the littoral habitats, with these areas only available for colonisation after the breakup of ice cover, and their exposure to physical scouring by ice rafts. This may have the implication that these areas are recolonised frequently by species adapted to these influences and low nutrient conditions.

In addition to light availability in the deep-water environment being reduced by ice cover, there is a difference in the light intensity reaching the lake floor to that in the littoral region when the lakes are ice free. At Lake Naga the intensity of light decreases by over 40% from the surface to the lake floor at ten meters depth (Figure 3.7a). Across this same transect, an increase in the concentration of diatom valves in the sediment is observed. This may be a result of the resuspension and transport of diatoms towards the deeper waters of the lake through sediment focusing, however the lack of *Psammothidium papilio* – a prominent species in the littoral zone - in the deeper part of the lake, suggests that sediment focusing is not the primary cause of this pattern. Effective sediment focusing is an assumption commonly made in the study of fossil diatoms, in the development of transfer functions (Battarbee *et al.*, 2001; Hassan, 2018). Basin slope and wind disturbance are key factors affecting the degree to which focusing occurs (Blais & Kalff, 1995), with lakes with shallow basin slopes less likely to have material move into the centre of the lake, and the ice cover at these sites for most of the year limiting wind induced currents and mixing. Inefficient sediment focusing in lakes with similar morphology to Lake Naga may therefore present a further limitation to the development and application of diatom transfer functions, as has been found for shallow, benthic dominated lakes in temperature regions (Bennion, 1994; Sayer, 2001).

The distinction between the species occupying the lake floor in deeper areas, and those in the littoral zone has the potential to assist in the reconstruction of ice duration and extent from lake sediment cores. Smol (1983, 1988) proposed for Arctic lakes that in years of extended ice cover, reduced light penetration to the lake floor would limit productivity for the entire lake, and that the seasonal formation of a moat in the margins of the lake would promote the preferential deposition of littoral diatoms. On the other hand, floating ice can also scour and disturb littoral biofilms, disturbing the accumulation of biomass and promoting epilithic and epipsammic diatoms adapted to rapid colonisation. These competing processes may complicate the interpretation of littoral diatom assemblages in sediment records.

Several other possible mechanisms may explain the absence of littoral diatom species in the lake floor sediments in some of the studied lakes. The intensity of light in the shallow littoral zone of Antarctic lakes can be a physical stressor influencing assemblage differences (Hughes *et al.*, 2006; Tanabe *et al.*, 2008), which may, in combination with the low nutrient availability arising from rock surfaces in the shallow littoral zone, result in the lower proportional representation of littoral diatoms. Seasonal productivity or diatom dissolution are also likely to bias the assemblage archived in the centre of the lakes, with littoral species potentially more susceptible to dissolution due to warmer temperatures, more oxygen or physical breakup by ice scouring due to their position in the lakes (Flower, 1993; Ryves *et al.*, 2001). Nevertheless, the clear distinction between littoral and lake floor diatom assemblages across the nine lakes studied, and the presence of diatom species commonly associated with littoral habitats within lake core samples (Rudd *et al.*, 2016) suggests that there is potential to qualitatively infer changes in lake ice cover from the littoral to lake floor ratio of sedimentary diatoms in Lützow-Holm Bay lakes.

This study has allowed the association between certain diatom species and habitat and lake chemistry parameters to be made, yet limitations remain. Ideally, an even gradient of lake chemical and physical characteristics would be studied, but this is limited by the types of lakes present in the landscape, and by field logistics. This has meant that there are some species for which this study is unable to shed light on chemical or habitat preferences, including *Craticula antarctica*, which is a component in lake sediment diatom records in the region (eg. Tavernier *et al*., 2014; Rudd *et al*., 2016). *C. antarctica* was most abundant in the benthic lake floor samples from Lakes Kuwai and Hotoke in this study and was not observed at Lake Nurume. It is possible that C. antarctica is adapted to low light or soft sediment environments, given the slight increase in abundance with depth at Lake Naga (Figure 3.7), although as the species was also observed in the littoral zone of several lakes, a wider survey may be required to fully constrain its ecology in this region.

Conclusions and future directions

This study suggests that for lakes in the Lützow-Holm Bay region of East Antarctica, diatom species assemblages are principally explained by lake water salinity and by differences between littoral and lake floor habitats. This observation is consistent with that of Kopalová *et al.* (2019), who observed significantly different diatom communities between habitat types on James Ross Island, particularly between submerged and exposed substrates. These observations hold significance for the interpretation of lake sediment diatom assemblages in Lützow-Holm Bay as archives of past climate and environmental change. In particular, surface sediments in the deepest part of the lakes were found to not reflect the whole lake assemblage in several of the lakes studied here, which suggests that transfer functions and other methods which rely on efficient sediment focusing should be applied with caution at these sites.

This study presents several promising avenues for interpreting lake sedimentary diatom assemblages, both in Lützow-Holm Bay and beyond. In particular, the clear distinction between littoral and lake floor diatoms presents the opportunity to infer seasonal lake ice cover, as applied to Arctic lakes (Smol, 1983, 1988). Furthermore, the observation of species adapted to higher or lower salinity, in support of previous studies (Verleyen *et al.*, 2003; Tavernier *et al.*, 2014; Saunders *et al.*, 2015; Kopalová *et al.*, 2019) facilitates at least the qualitative inference of past changes in lake water salinity. Expanding this dataset via further spatial and temporal studies of modern diatom communities in Antarctic lakes is necessary to confirm these conclusions and to develop our understanding of past and future environmental change on the Antarctic continental margin.

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Supplementary Information

Part 1 – taxonomy of species from Lützow-Holm Bay identified in this study

For figures refer to main text.

Achnanthes taylorensis D.E. Kellogg, Stuiver, T.B. Kellogg & G.H. Denton

(Kellogg *et al.*, 1980)

Figure 3.3q

Original description: (Kellogg *et al.*, 1980) *Achnanthes*, not *A. brevipes* var. *intermedia*; similar to *A. coarctata*; valves linear-elliptical with rounded poles; axial area of raphe valve extremely narrow; central area broad and stauroneiform; striae punctate, about 12 radiate striae in 10 µm on the raphe valve, about 13 curving striae in 10 µm on the rapheless valve. Length 31–33 µm; width 8.8–9.3 µm.

LM observations and remarks (this study): valve length 28.0–40.0 µm, valve width 7.5–8.5 µm, 12–14 striae in 10 µm on rapheless valve, 13–15 striae in 10 µm on raphe valve (n=10). The range of valve lengths and widths observed in the Lützow-Holm Bay samples from this study are slightly wider than that of the original description, but is not dissimilar from those observed by Spaulding and Esposito for the McMurdo Dry Valleys (25–38 µm length, 7–10 µm width) (Spaulding *et al.*, 2019).

Distribution: Described from Taylor Valley in the MrMurdo Dry Valleys (Kellogg *et al.*, 1980) and observed in other MDV waterbodies (Spaulding *et al.*, 2019). Widespread in continental Antarctica including the Vestfold Hills, Larsemann Hills and Rauer Islands (West & West, 1911; Kobayashi, 1963; Baker, 1967; Roberts & McMinn, 1999; Hodgson, Vyverman & Sabbe, 2001; Sabbe *et al.*, 2003) and also the sub-Antarctic (Le Cohu & Maillard, 1983). Maritime Antarctic (Zidarova, Kopalová & Van de Vijver, 2016). Reported from the Skarvsnes region (Ohtsuka *et al.*, 2006).

Craticula antarctica Van de Vijver & Sabbe

(Van de Vijver *et al.*, 2010)

Figure 3.3r-s

Original description: (Van de Vijver *et al.*, 2010) Valves elliptical to lanceolate with convex margins and rostrate to capitate apices. Valve dimensions (n=22): length 23.5–36.0 µm, width 6.2-8.0 µm. Axial area narrow, linear, only very slightly widening near the central nodule to form an elliptical to oval central area. Raphe filiform with straight, simple, rather distant central endings. Transapical striae straight to slightly radiate in the centre, becoming convergent and strongly arcuate to even geniculate near the apices, 17–22 in 10 µm (n=23). Areolae almost indistinct in LM. In SEM, external raphe with simple straight to weakly bent central raphe endings and terminal fissures hooked in the same direction. Areolae roundish along the axial area to apically elongate near the margins and towards the apices. Near the apices, areolae rather irregularly organized. Internally, the striae are separated by thickened virgae, they are internally occluded by vela. Internal terminal raphe endings straight, terminating in a slightly swollen hyaline area and is not a helictoglossa as it should be raised above the valve which is not the case here. A small proportion of the population consisted of cells that were entirely coated with a thick layer of silica obscuring entirely the surface structure.

LM observations and remarks (this study): valve length 24.9–26.9 µm, valve width 5.0–6.6 µm, 20–22 striae in 10 µm (n=25). Valve lengths consistent with type description, although widths slightly narrower. Silica covered valves not observed.

Distribution: Described from Naděje Lake on James Ross Island (Van de Vijver *et al.*, 2010). Reported under different names from Bunger Hills (Gibson, Roberts & Van de Vijver, 2006, as *Craticula* sp. a), Vestfold Hills (Roberts & McMinn, 1999, as *Craticula molesta*), Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003, as *C.* cf. *molesta*, Hodgson *et al.,* 2001, as *Craticula molesta*), Amery Oasis (Cremer *et al.*, 2004, as *C.* cf. *molesta*), Skarvsnes (Ohtsuka *et al.*, 2006, as *Craticula* sp.) and Kazumi Iwa (Kobayashi, 1965, as *C. molesta*). Type population from alkaline (pH 8.38), high specific conductance (710 µS/cm), low sulphate and nitrate (Van de Vijver *et al.*, 2010).

Cocconeis sp.

Figure 3.3ad-ae

LM observations (this study): Valves broadly elliptical, valve length 36.4–58.9 µm, valve width 23.2–41.1 µm (n=10).

Distribution: unknown.

Halamphora vyvermaniana B. Van de Vijver, K. Kopalová, R. Zidarova & Z. Levkov

(Van de Vijver *et al.*, 2014)

Figure 3.3v-w

Original description: (Van de Vijver *et al.*, 2014) Frustules broadly elliptical with short protracted and truncated ends. Valves broadly semi-elliptical, dorsi-ventral with a strongly convex dorsal margin and weakly concave ventral margin, sometimes al- most straight to slightly inflated in the middle. Valve ends variable, long protracted and capitate in larger specimens to shortly subrostrate in mid-sized and small-sized specimens. Valve dimensions (n = 22): length 14–47 µm, width 5–10 µm. Axial area narrow, more expressed on the ventral valve side. Central area absent on the dorsal side, longitudinally elongated on the ventral side. Raphe ledge broad, widened at mid-valve tapering towards the valve ends. Raphe biarcuate with slightly expanded, straight to dorsally bent proximal endings. Dorsal striae radiate throughout, distinctly punctate, 24–30 in 10 µm. Areolae in the mid-valve larger. Ventral striae indistinct, hard to resolve with LM, 28–32 in 10 µm. Ghost valves often observed. See Van de Vijver *et al.* (2014) for SEM description.

LM observations and remarks (this study): valve length 22.6–48.6 µm, valve width 5.8–9.3 µm, 22–28 striae in 10 µm (n=25). The species observed in Lützow-Holm Bay during this study resembles both *Halamphora vyvermaniana* and *Halamphora oligotraphenta* (Van de Vijver *et al.*, 2014), but the measurements are consistent with *H. vyvermaniana* which are larger than *H. oligotraphenta*.

Distribution: The type species is from Tarnya Lake in the Vestfold Hills. Van de Vijver *et al.* (2014) note that most observations of *Halamphora veneta* in the Antarctic Continent are likely to represent *Halamphora vyvermaniana. H. veneta* reported from Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003), Skarvsnes region (Ohtsuka *et al.*, 2006), and others noted in Kellogg and Kellogg (2002).

Hantzschia cf. *amphioxys* (Ehrenberg) Grunow

(Cleve & Grunow, 1880)

Figure 3.3t-u

Description: (Sabbe *et al.*, 2003) 78–88 µm length, 9.6–11 µm width, 17.5–21.5 striae in 10 µm, 7–9 fibulae in 10 µm (n = 10). Valves linear/semi- arcuate, asymmetrical, apices rostrate to capitate. Dorsal margin convex, sometimes more or less straight in the central part, ventral margin concave. Valve face flat, at right angles with the deep valve mantle. Raphe situated on the ventral valve face-mantle transition, in a distinct sternum. In the centre, the raphe curves onto the mantle. Whether the raphe is actually continuous across the centre is hard to assess as the CRE may be close together and hidden under the thickened central part of the valve face/mantle margin. The terminal fissures are strongly curved to the dorsal side. Internally, the TRE lie in a distinct helictoglossa. A marginal ridge is usually present on the dorsal valve face/mantle transition. Striae slightly radiate and more widely spaced in the centre, becoming parallel to convergent towards the valve apices. They consist of small round areolae, externally usually lying in transapical grooves sunk beneath the valve face but not the mantle. Internally, the areolae open into narrow slits which extend inbetween the fibulae. The latter are variable in width (spanning up to five or more striae) and spacing, often (but not always) being more widely spaced in the centre of the valve. The cingulum is composed of 7–8 porous copulae.

LM observations and remarks (this study): valve length 53.3–85.1 µm, valve width 5.1–10.7 µm, 20–23 striae in 10 µm (n=25). The valves observed generally fell into two groups, one group significantly smaller in length and width than the other group, and these smaller valves are slightly beyond the measurements described by Sabbe *et al.* (2003).

Distribution: Uncertain. Refer to Sabbe *et al.* (2003) for more discussion on the genus *Hantzschia* in Antarctica. *Hantzschia* species in the Antarctic region are described by Zidarova *et al.* (2010) and Bulínová *et al.*(2018) but the species described in these papers do not resemble the narrow species observed in this study. The species observed in Lützow-Holm Bay most closely resembles the *Hantzschia amphioxys* described by Bulínová *et al.* (2018), which are smaller and narrower than those described by Sabbe *et al.* (2003).

Humidophila australis (Van de Vijver & Sabbe) R.L. Lowe, Kociolek, J.R. Johansen, Van de Vijver, Lange-Bertalot & Kopalová

(Lowe *et al.*, 2014)

Figure 3.3g-j

Original description: (Van de Vijver *et al.*, 2010, as *Diadesmis australis*) Valves linear with a distinctly inflated central part and broadly rounded, sometimes slightly swollen apices. Valve dimensions (n = 40): length 6–19 µm, width 2.0–5.0 µm. Axial area moderately broad, widening towards a round central area, formed by the curving of the striae around the expanded valve mid-region. The raphe is straight filiform with central endings rather distant from each other. Transapical striae usually distinct in LM, especially in the centre of the valve, 32-36 in 10 pm. Striae parallel to slightly radiate, not extending beyond the terminal raphe fissures. For SEM observations refer to text (Van de Vijver *et al.*, 2010).

LM observations (this study): valve length 7.0–16.8 µm, valve width 3.1–5.6 µm (n=25). Striae visible but not distinct in LM, so not counted.

Distribution: Described (as *Diadesmis australis*) from James Ross Island (Van de Vijver *et al.*, 2010). Reported from South Shetland Islands and South Orkney Islands as *Navicula perpusilla* (Jones & Juggins, 1995). From the Antarctic Continent in the Larsemann Hills and Rauer Islands as *D.* cf. *perpusilla* (Sabbe *et al.*, 2003), the Bunger Hills as *Diadesmis* sp. A (Gibson *et al.*, 2006), Amery Oasis (Cremer *et al.*, 2004, as *D.* cf. *perpusilla*) and Skarvsnes region as *Diadesmis* sp. (Ohtsuka *et al.*, 2006). Reported from Livingstone Island, Signy Island and Beak Island (Sterken *et al.*, 2015).

Luticola pseudomurrayi Van de Vijver & Tavernier

(Van de Vijver *et al.*, 2012)

Figure 3.3o-p

Original description: (Van de Vijver *et al.*, 2012) valves broadly lanceolate to broadly elliptical with an almost elliptical central part and clearly constricted, broadly rounded rostrate to capitate apices. Valve length 15.5–50.0 µm, width 7.5–12.0 µm, apex width 4.5–9.0 µm (n=35). Axial area narrow, linear, slightly widening towards the central area and the apices, where a wedge–shaped hyaline area is present. Central area elliptical to rectangular, bordered by several irregularly shortened striae. One isolated stigma present. Raphe filiform, straight. Central raphe endings simple, weakly deflected away from the stigma. Terminal raphe endings short, weakly deflected. Transapical striae radiate near the valve centre to more or less radiate near the apices, 17–20 in 10 µm to 21–22 near the apices. Each stria composed of 4–5 areolae. For SEM observations refer to Van de Vijver *et al.* (2012).

LM observations and remarks (this study): valve length 17.1–38.5 µm, valve width 6.1–10.9 µm, 17–22 striae in 10 µm (n=15). Observations fall in the ranges observed by Van de Vijver *et al.* (2012).

Distribution: Type species described from lake LA9 in the Langhovde region of Lützow-Holm Bay and common in lakes in the region (Van de Vijver *et al.*, 2012).

Navicula aff. *directa* (W. Smith) Ralfs

(Pritchard, 1861)

Figure 3.3z-aa

Original description: (Pritchard, 1861) Slender, narrow-lanceolate, acute; costae fine, parallel, reaching the median line, 20 in .001".

Measurements of *Navicula directa* in King George Island (Al-Handal & Wulff, 2008) - Apical axis, 45–90 mm; transapical axis, 9–11 mm; striae, 8–12 in 10 mm.

LM observations and remarks (this study): valve length 28.7–38.7 µm, valve width 6.6–8.0 µm, 16–18 striae in 10 µm (n=10). The species observed in Lutzow-Holm Bay during this study is smaller than the *N. directa* observed by Al-Handal & Wulff (2008). Visually similar to the *N. ectoris* observed by Ohtsuka *et al.* (2006) in the Skarvsnes region, but measurements are not consistent, and the species observed in this study is more elongate and has coarser striae.

Distribution: *Navicula directa* has been observed on King George Island (Al-Handal & Wulff, 2008), Livingston Island (Zidarova, 2008), in the Vestfold Hills (Roberts & McMinn, 1996, 1998), in a sediment core from the Windmill Islands (Roberts *et al.*, 2004), the Bunger Hills (Gibson *et al.*, 2006)and sediment cores from Lutzow-Holm Bay (Takano *et al.*, 2012; Tavernier *et al.*, 2014)

Navicula gregaria Donkin

(Donkin, 1861)

Figure 3.3k-l

Description: (Van de Vijver *et al.*, 2011) Valves broadly elliptical to broadly lanceolate with rostrate-capitate to capitate-produced apices. Valve length 20–42 µm, valve width 5.5–9.4 µm (n=25). Axial area very narrow. Central area small, typically asymmetric with one side being semi- elliptic and the other almost rectangular. Raphe filiform, situated on a thickened, raised sternum. Central raphe endings deflected to the primary side, slightly expanded. Transapical striae radiate near the valve centre, becoming parallel and strongly convergent towards the apices, 15–17 in 10 µm. Lineolae distinct in LM, 25–30 in 10 µm. Internally, the lineolae are occluded by hymenes. The raphe is situated on a raised raphe sternum with straight central endings and small terminal helictoglossae.

LM observations and remarks (this study): valve length 26.8–30.3 µm, valve width 6.1–7.0 µm, 18–20 striae in 10 µm (n=25). Consistent with the description in Van de Vijver *et al.* (2011).

Distribution: Ile de la Possession and James Ross Island (Van de Vijver *et al.*, 2011), Maritime Antarctica (Sterken *et al.*, 2015; Zidarova *et al.*, 2016), and the Antarctic continent in the Vestfold Hills, (Roberts & McMinn, 1999), Bunger Hills (Gibson *et al.*, 2006), and Skarvsnes region (Ohtsuka *et al.*, 2006).

Navicula phyllepta Kützing

(Kützing, 1844)

Figure 3.3o-p

Description: Sabbe *et al.* (2003) describe a population from the Larsemann Hills which are slightly narrower (width 5.2–6 µm) and have a slightly lower striae density (18–18.5 per 10 µm) than the description by Kobayashi (1965) (width 5–8 µm and 17–22 striae in 10 µm).

LM observations (this study): valve length 14.4–25.6 µm, valve width 5.0–6.4 µm, 20–23 striae in 10 µm (n=25).

Distribution: Also observed from the Rauer Islands (Hodgson *et al.*, 2001), in sediment cores from Prydz Bay (Verleyen *et al.*, 2004; Hodgson *et al.*, 2016) and lake sediments from the Skarvsnes region (Lepot *et al.*, 2014; Tavernier *et al.*, 2014).

Navicula sp.

Figure 3.3x-y

LM observations (this study): valve length 33.7–58.2 µm, valve width 6.0–7.7 µm, 11–14 striae in 10 µm (n=25). Straie near parallel. Central area small, bordered by one shorter striae.

Distribution: unknown.

Paralia sulcata (Ehrenberg) Cleve

(Cleve, 1873)

Figure 3.3e-f

LM observations(this study): valve diameter 12.4–15.6 µm, striae total 26–36 (n=10).

Distribution: The distribution of this species in the Antarctic region is uncertain, but a *Paralia* sp. was identified in the Skarvsnes region by Ohtsuka *et al.* (2006) which may be the same species. *Paralia sulcata* was observed in core material from the Windmill Islands (Roberts *et al.*, 2004) and the Skarvsnes region (Tavernier *et al.*, 2014).

Psammothidium incognitum var. *stauroneioides* (Manguin) Le Cohu

(Le Cohu, 2005)

Figure 3.3c-d

Description: Synonyms – *Achnanthes stauroneioides* Manguin, and *Psammothidium stauroneioides* (Manguin) Bukhtiyarova

From Ohtsuka *et al.* (2006), valves are 13.8–20.4 µm long, 4.9–5.9 µm wide, 27–31 striae in 10 µm (raphid valves), 25–27 striae in 10 µm (araphid valves).

Sabbe *et al.* (2003) describe the species in their study of the Larsemann Hills and Rauer Islands (as *Psammothidium stauroneioides*) as having dimensions: 12–17 µm L, 4.9–6.2 µm W, 27–31 striae in 10 µm (n = 10).

LM observations and remarks (this study): valve length 12.7–19.1 µm, valve width 4.4–6.2 µm, 29–32 striae in 10 µm (n=25). Striae count not observed to vary between raphe and rapheless valves. Largely consistent with the observations by Ohtsuka *et al.* (2006) and Sabbe *et al.* (2003).

Distribution: Described by Le Cohu (2005) from Iles Kerguelen, and observed in the sub-Antarctic (Kellogg & Kellogg, 2002). From Continental Antarctica in the Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003, as *P. stauroneioides*), Amery Oasis (Cremer *et al.*, 2004, as *P. stauroneioides*) and Skarvsnes region (Ohtsuka *et al.*, 2006, as *P. stauroneioides*).

Psammothidium papilio (D.E. Kellogg, Stuiver, T.B. Kellogg & G.H. Denton) K. Kopalová & B. Van de Vijver

(Kopalová *et al.*, 2012)

Figure 3.3a-b

Description: The species revision by Kopalová *et al.* (2012) combines two previously described species — Navicula papilio D.E.Kellogg, Stuiver, T.B.Kel- logg & Denton, and Psammothidium metakryophilum (Rol.Schmidt & Lange-Bert.) Sabbe. Kopalová *et al.* (2012) describe the species to have dimensions of length: 10.5–14.5 µm; width: 4–5 µm; striae: 25–30 in 10 µm (n = 25), for samples from James Ross Island.

LM observations and remarks (this study): valve length 12.7–17.6 µm, valve width 4.2–5.6 µm, 26–29 striae in 10 µm (n=25). The valve lengths of these taxa are slightly longer than those measure by Kopalova *et al.* (2012), but are consistent with those described by Ohtsuka *et al.* (2006) for the Skarvsnes region as *Psammothidium metakryophilum*.

Distribution: In the Maritime Antarctic region – James Ross Island (Kopalová *et al.*, 2012), King George Island (Schmidt, Mäusbacher & Müller, 1990, as *P. metakryophilum*) and Livingston Island (Zidarova, 2008, as *P. metakryophilum*). From the Antarctic Continent in Taylor Valley (Kellogg *et al.*, 1980, as *Navicula papilio* in core material), the Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003, as *P. metakryophilum*), Bunger Hills (Gibson *et al.*, 2006, as *P. metakryophilum*), Amery Oasis (Cremer *et al.*, 2004, as *P. metakryophilum*) and Skarsvnes region (Ohtsuka *et al.*, 2006, as *P. metakryophilum*).

Stauroneis latistauros Van de Vijver & Lange-Bertalot

(Van de Vijver, Beyens & Lange-Bertalot, 2004)

Figure 3.3ab-ac

Description: (Spaulding *et al.*, 2019, as *Stauroneis* cf. *anceps*) Valves elliptical-lanceolate with weakly convex margins and capitate ends (L 35–40 µm, W 6–7,5 µm, 22–26 striae in 10µm). No pseudosepta present. Axial area moderately narrow, linear. Central area a clear fascia, widening towards the margins. No shortened striae present in the middle. Raphe filiform, straight with very weakly deflected central endings. Central pores clearly visible. Transapical striae moderately radiate in the middle, strongly radiate towards the poles.

The population from James Ross Island described by Kopalová *et al.* (2012) had the following dimensions — L: 24–50 mm; W: 6.5–8.0 mm; S: 20–21 in 10 µm (n = 25).

The population from the Skarvsnes region, described by Ohtsuka *et al.* (2006), had the following dimensions — 40.9–47.6 µm long, 7.9–10.4 µm wide, 20–24 striae in 10 µm. Aleorae were visible in LM, 24–28 in 10 µm. The specimens from this region were found to have finer striation than the original description of *Stauroneis latistauros* by Van de Vijver *et al.* (2004).

LM observations and remarks (this study): valve length 36.0–53.8 µm, valve width 8.2–9.1 µm, 22–24 striae in 10 µm (n=10). These measurements also have finer striae than the type specimens, and closely match the measurements by Ohtsuka *et al.* (2006), but some valves were found to be longer than this description.

Distribution: Maritime Antarctic Islands (Van de Vijver *et al.*, 2004; Van de Vijver, Gremmen & Beyens, 2005), Taylor Valley (Kellogg *et al.*, 1980, as *S. anceps*), Larsemann Hills and

Rauer Islands (Sabbe *et al.*, 2003, as *S. anceps*), Bunger Hills (Gibson *et al.*, 2006), Amery Oasis (Cremer *et al.*, 2004, as *S. anceps*) and the Skarvsnes region (Hirano, 1983, as *S. anceps*; Ohtsuka *et al.*, 2006).

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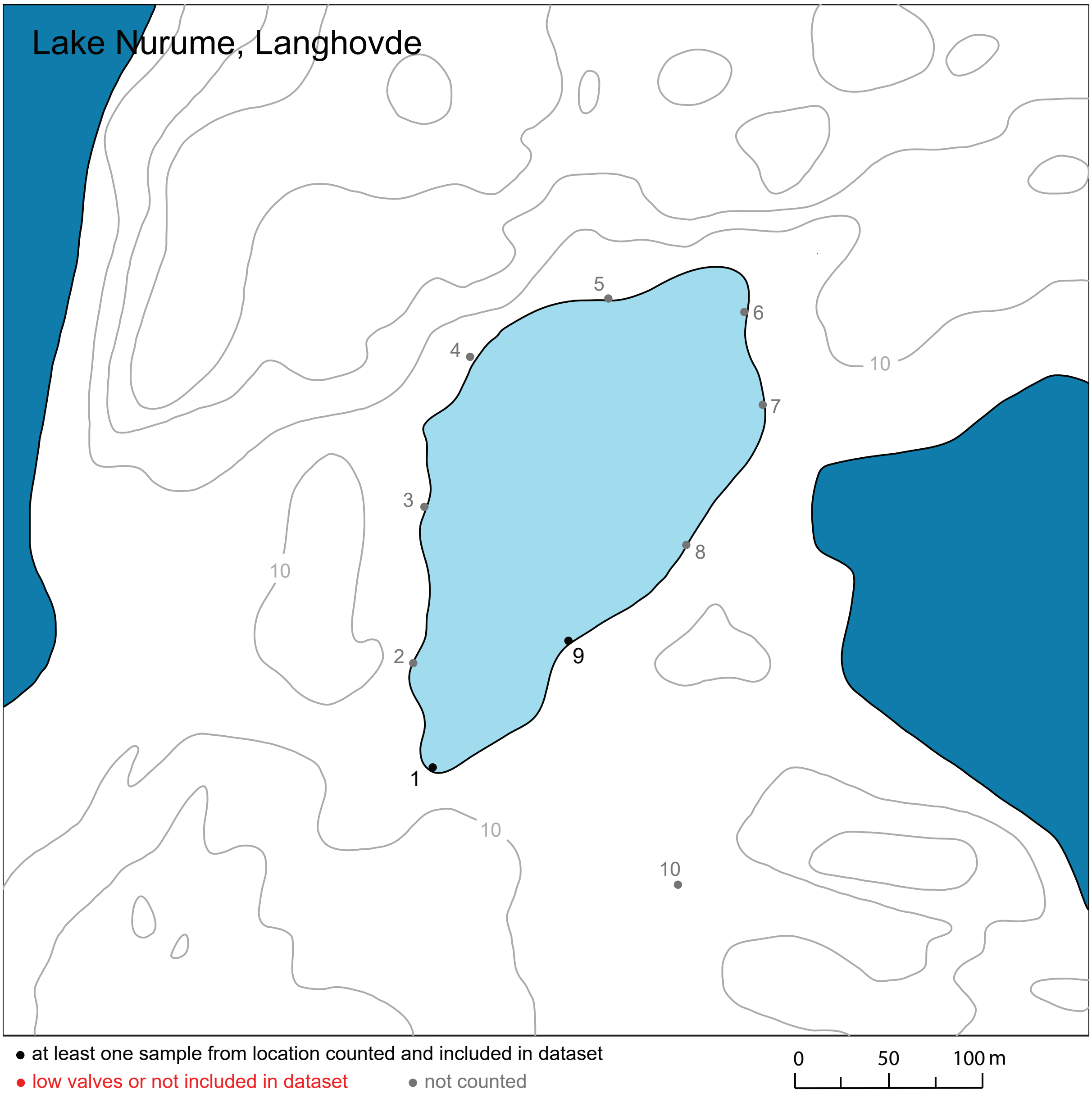
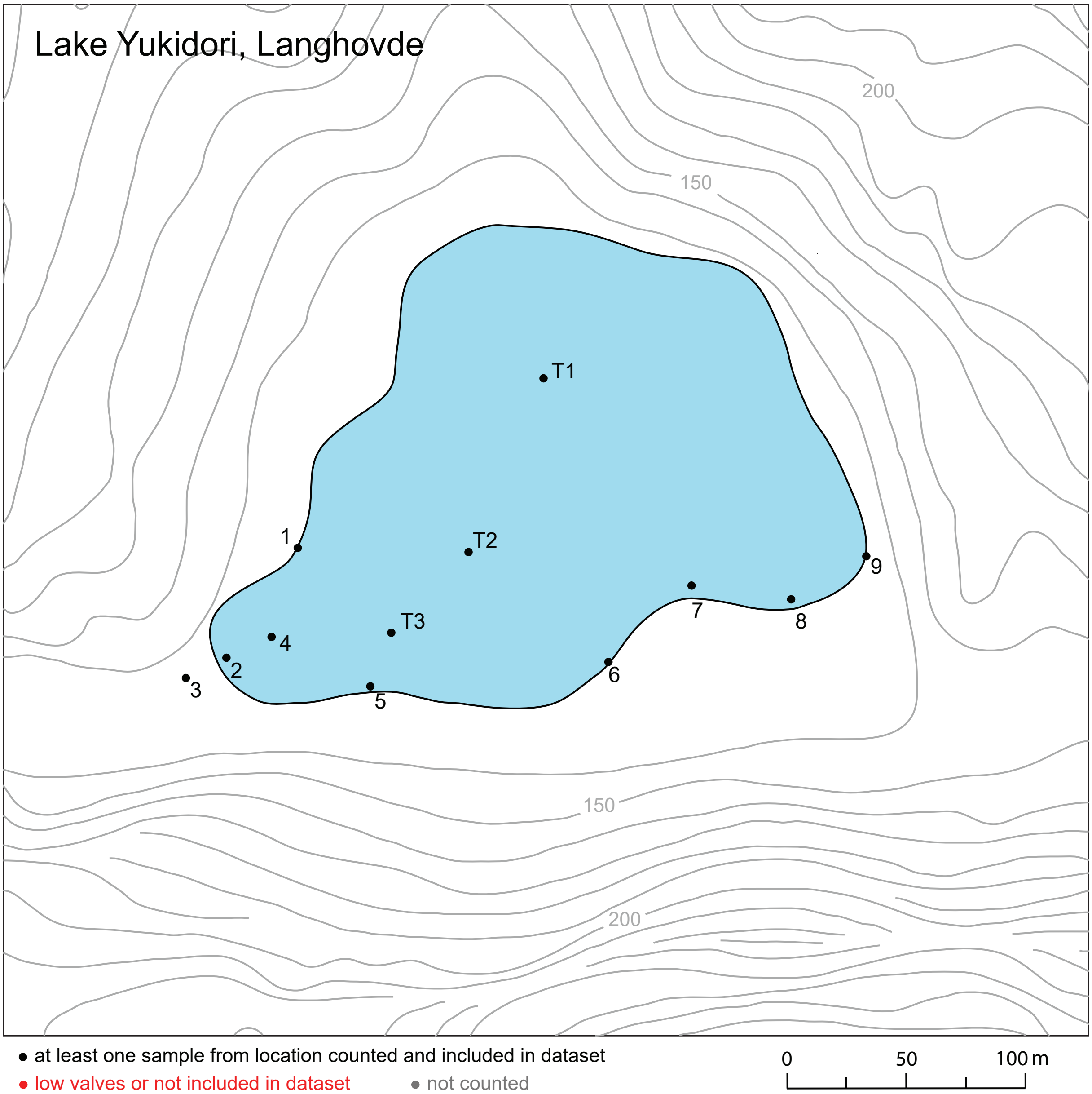
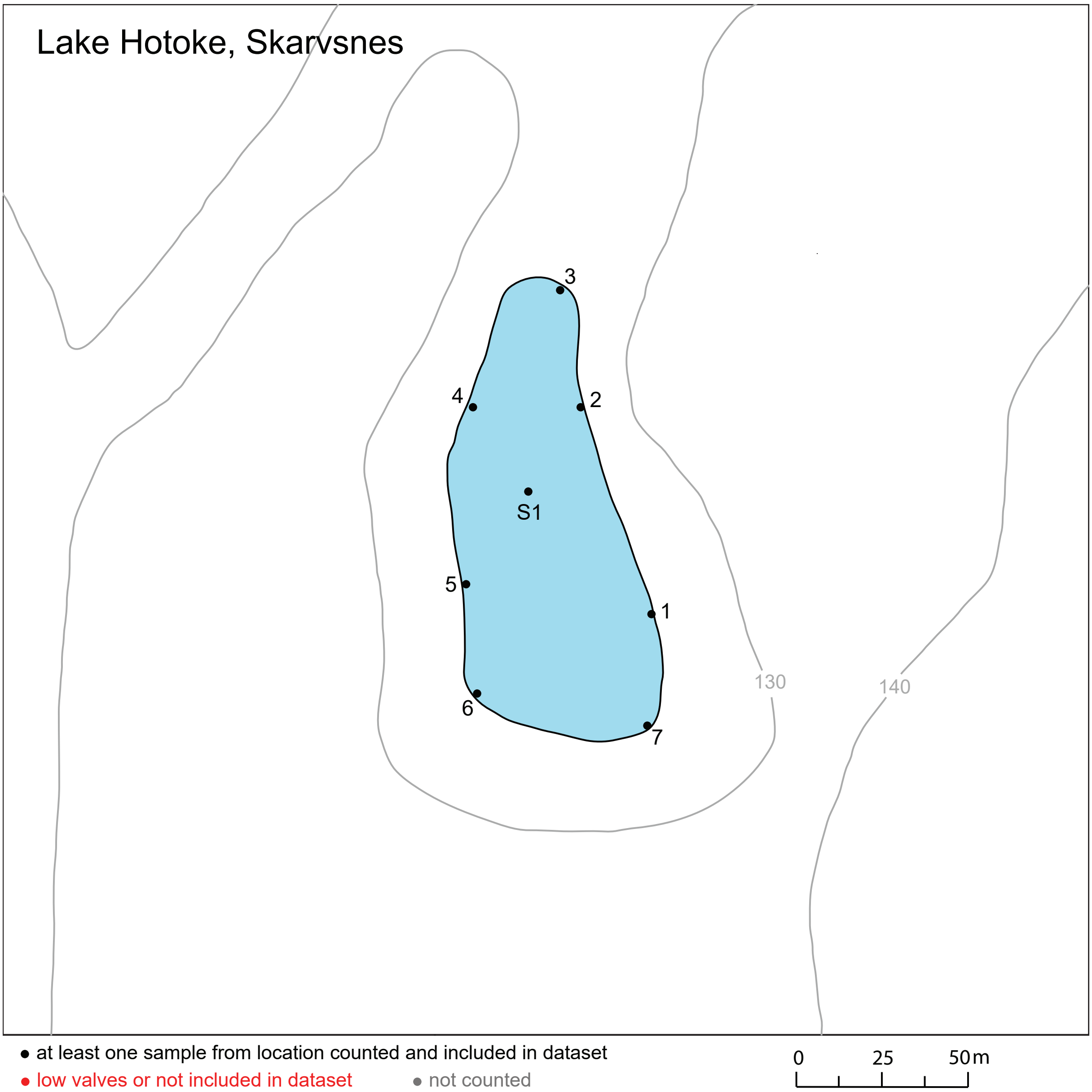


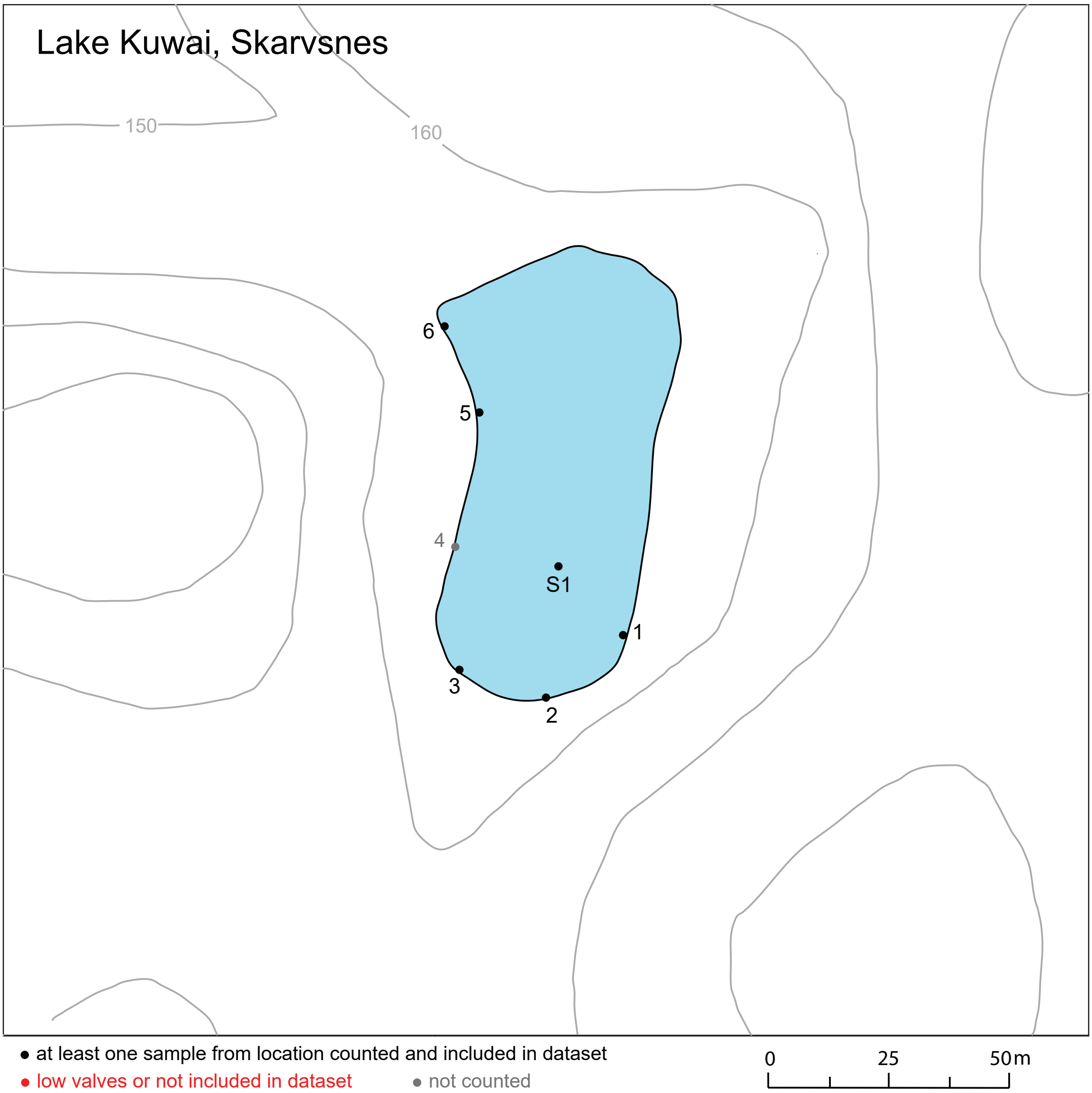
Supplementary Figure 3.1 – sampling locations. Figures adapted from topographic maps issued by the Geospatial Information Authority of Japan (map numbers 217, 219 and 221). Contour interval 10 m for ice free areas, 1 m for bathymetry contours (bathymetry data from Tanabe & Kudoh, 2009). Unlike main text figure 1, dark blue represents ocean and light blue represents lakes.
a) Lake Nurume



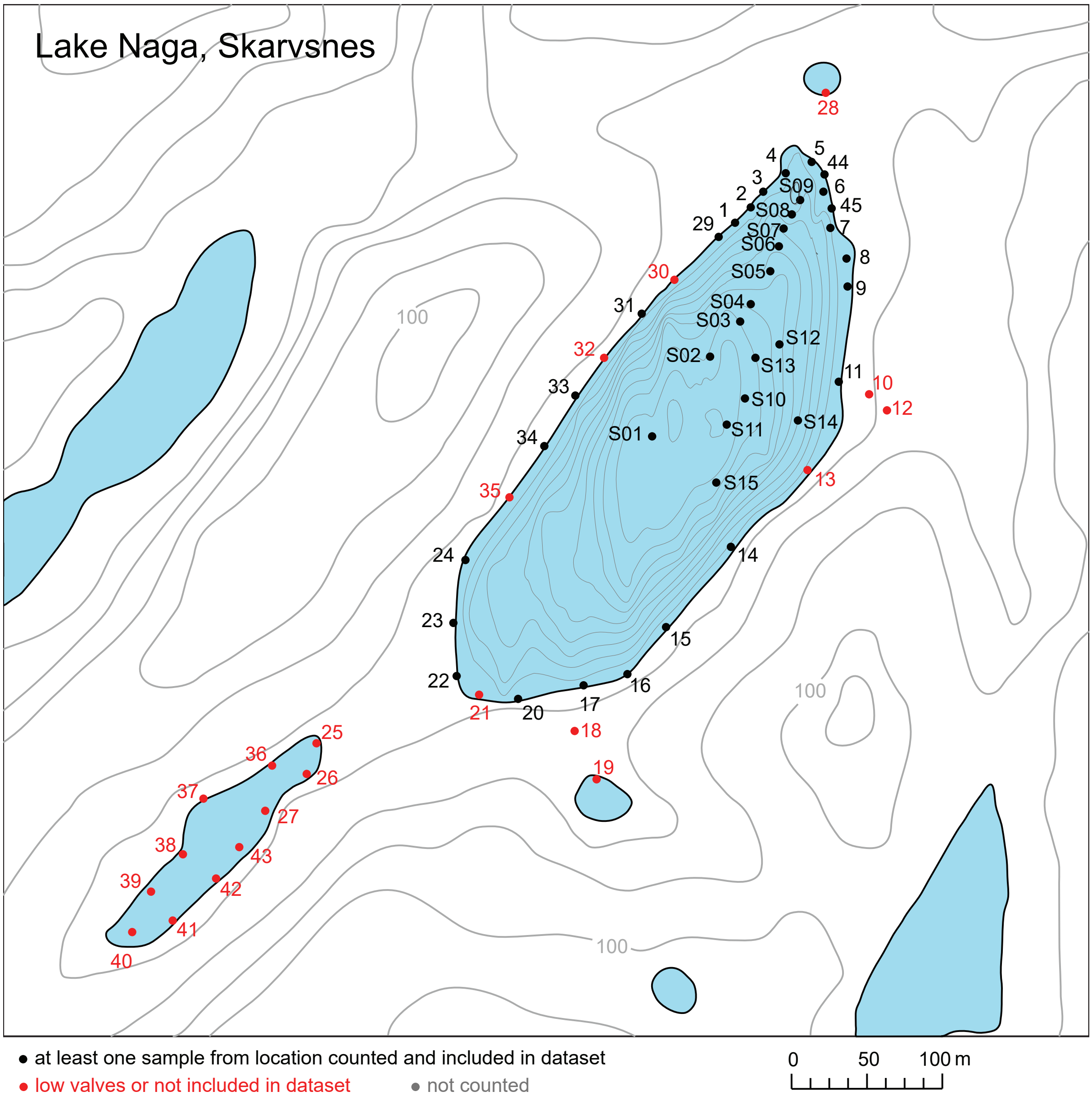
Supplementary Figure 3.1 cont. b) Lake Yukidori



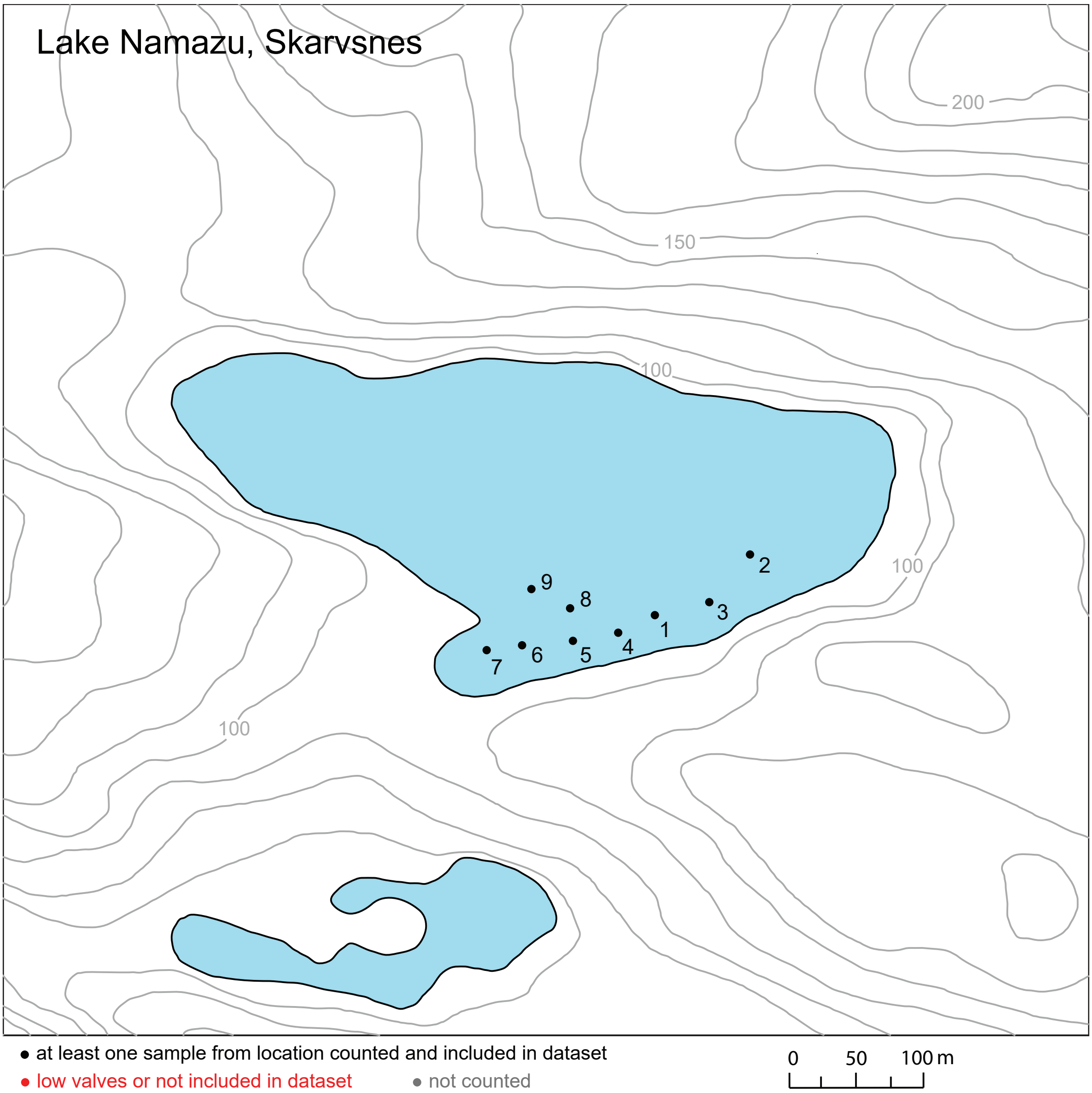
Supplementary Figure 3.1 cont. c) Lake Hotoke



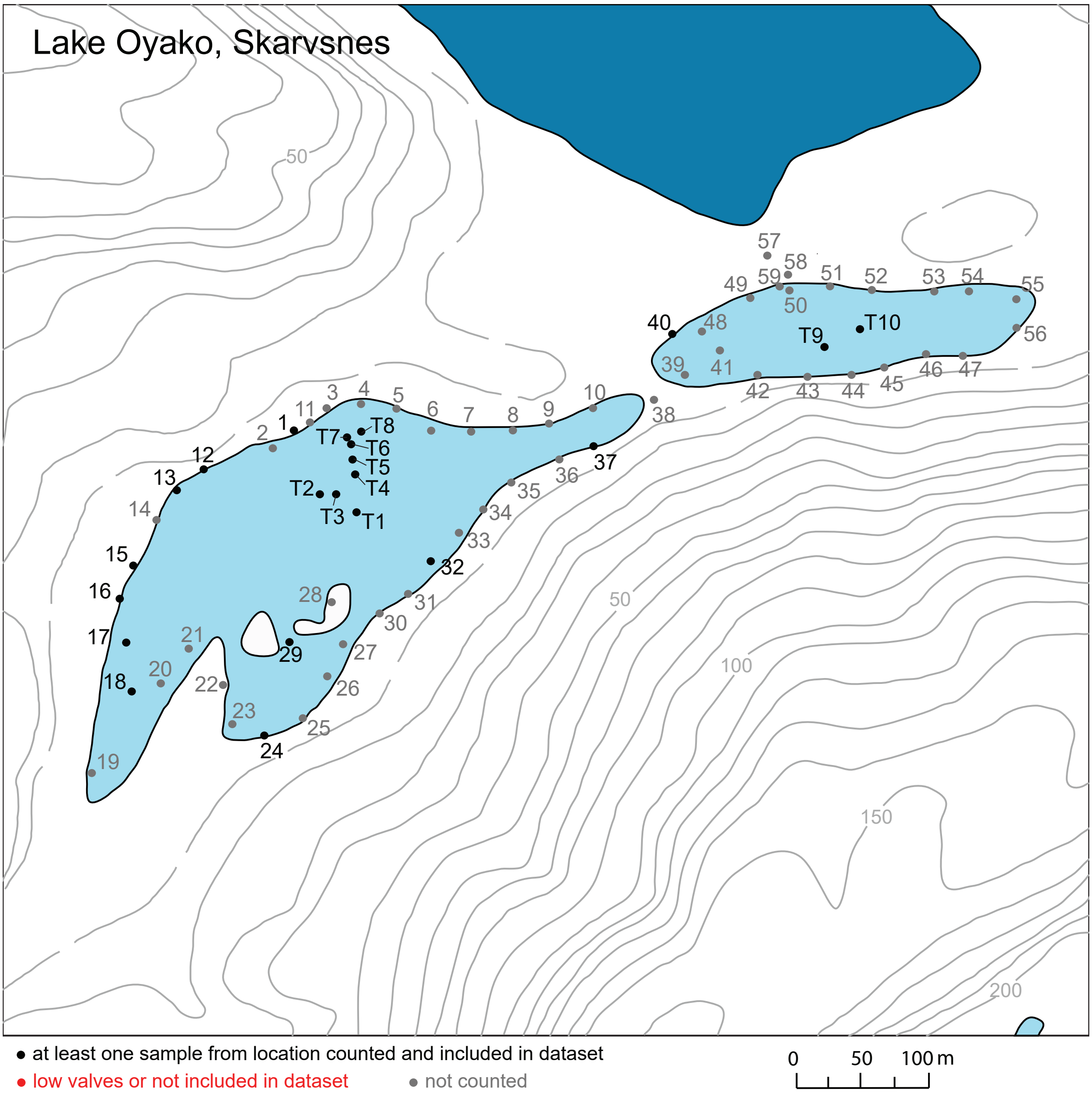
Supplementary Figure 3.1 cont. d) Lake Kuwai



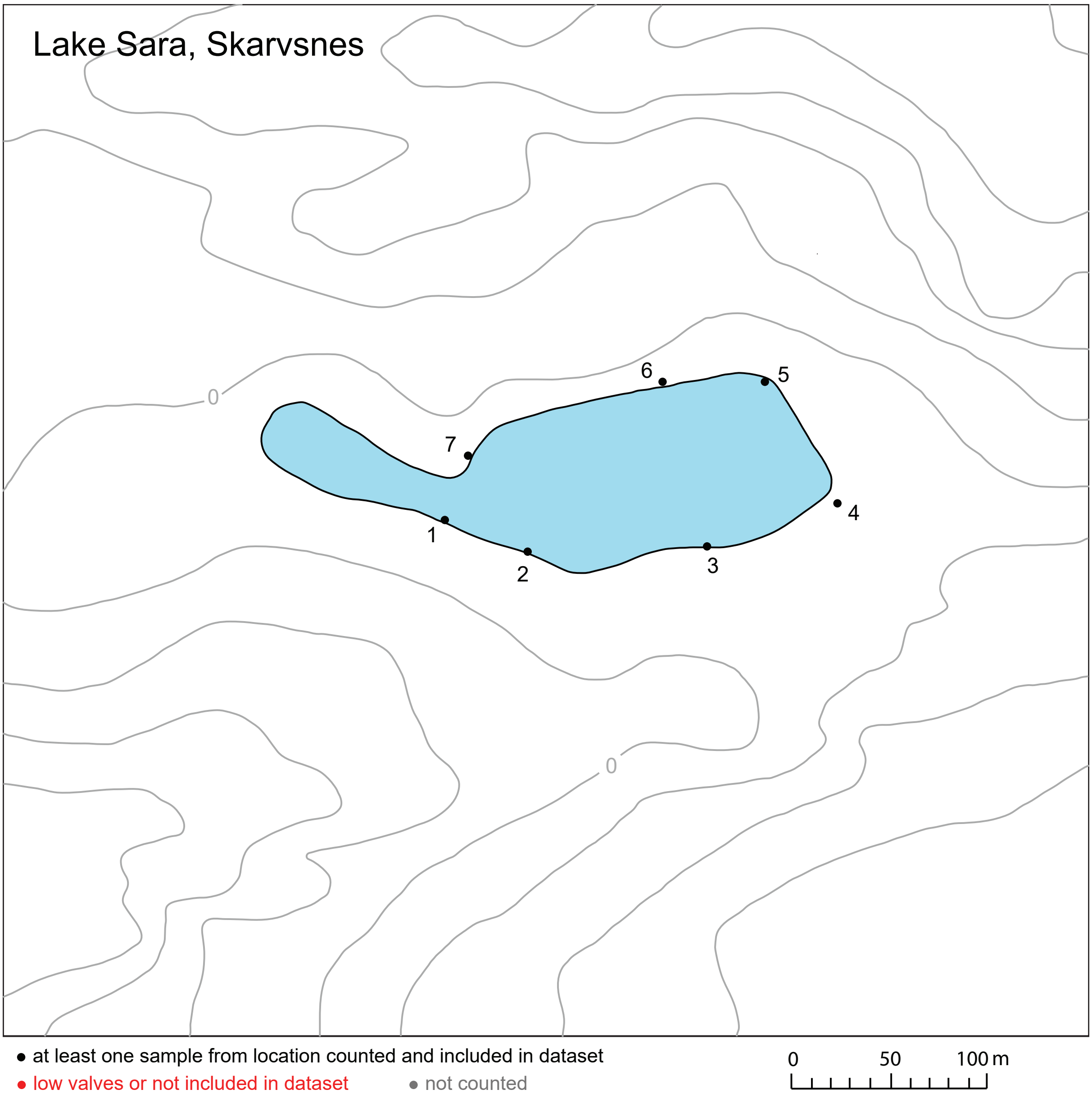
Supplementary Figure 3.1 cont. e) Lake Naga



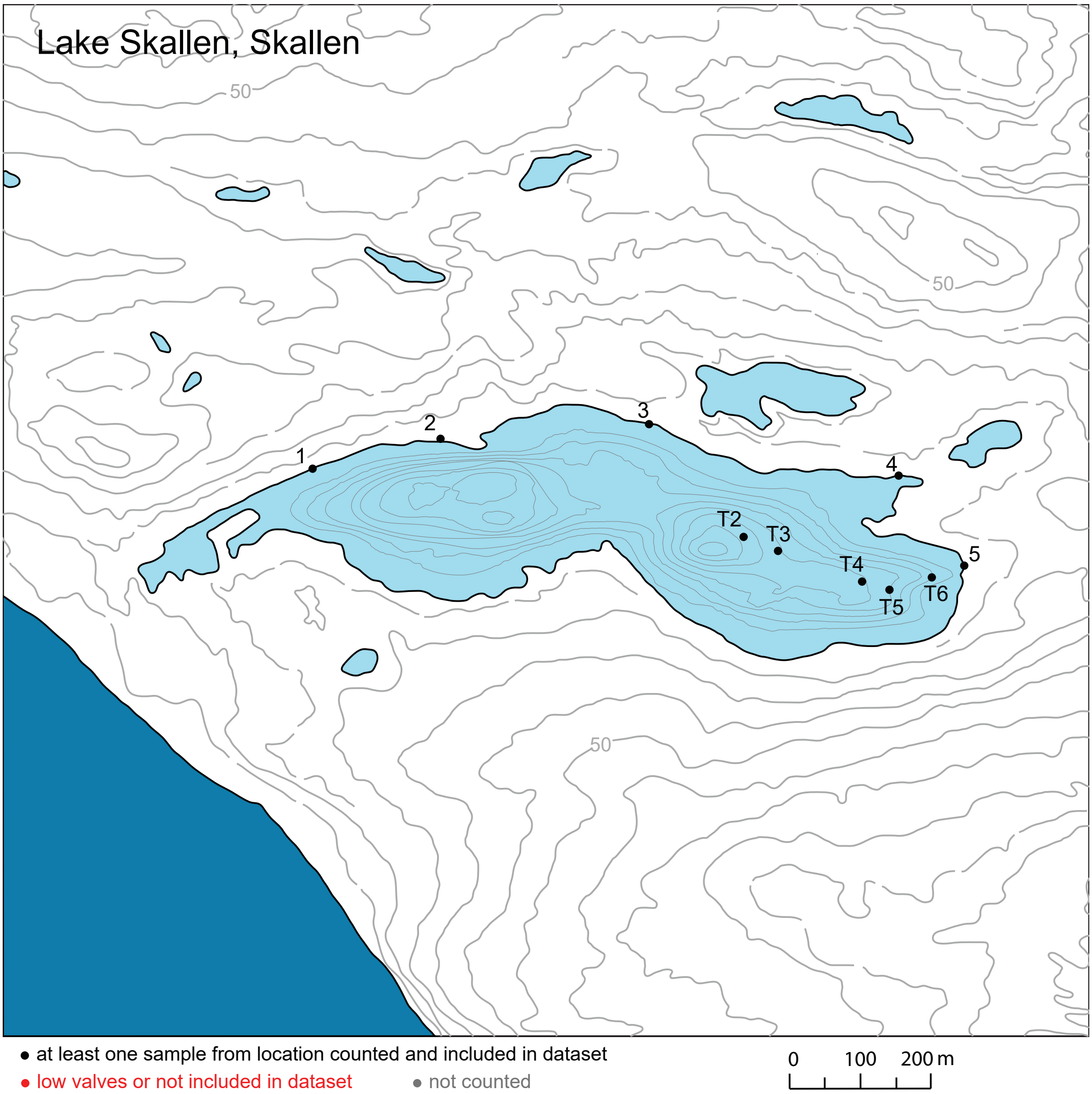
Supplementary Figure 3.1 cont. f) Lake Namazu



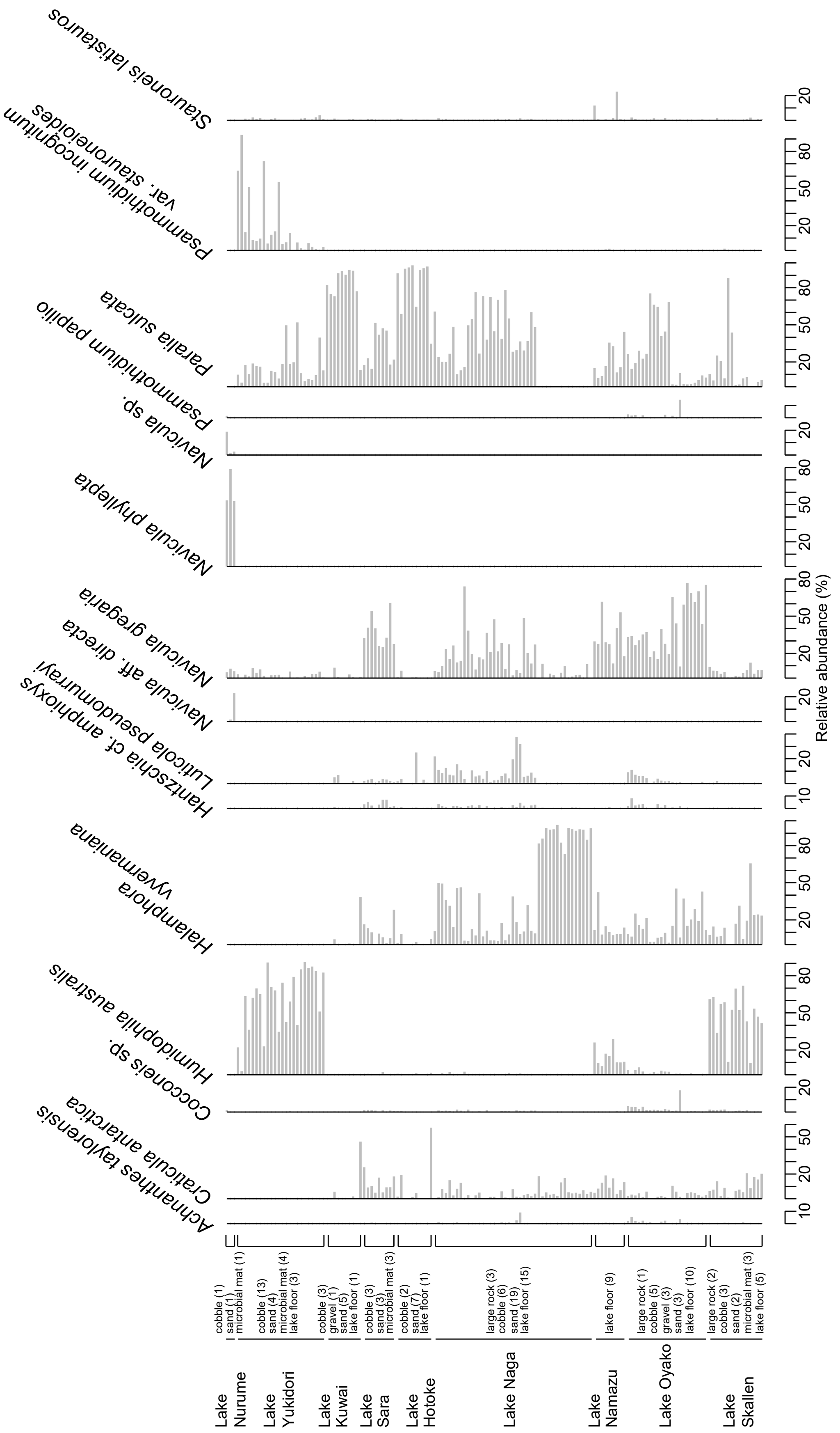
Supplementary Figure 3.1 cont. g) Lake Naga



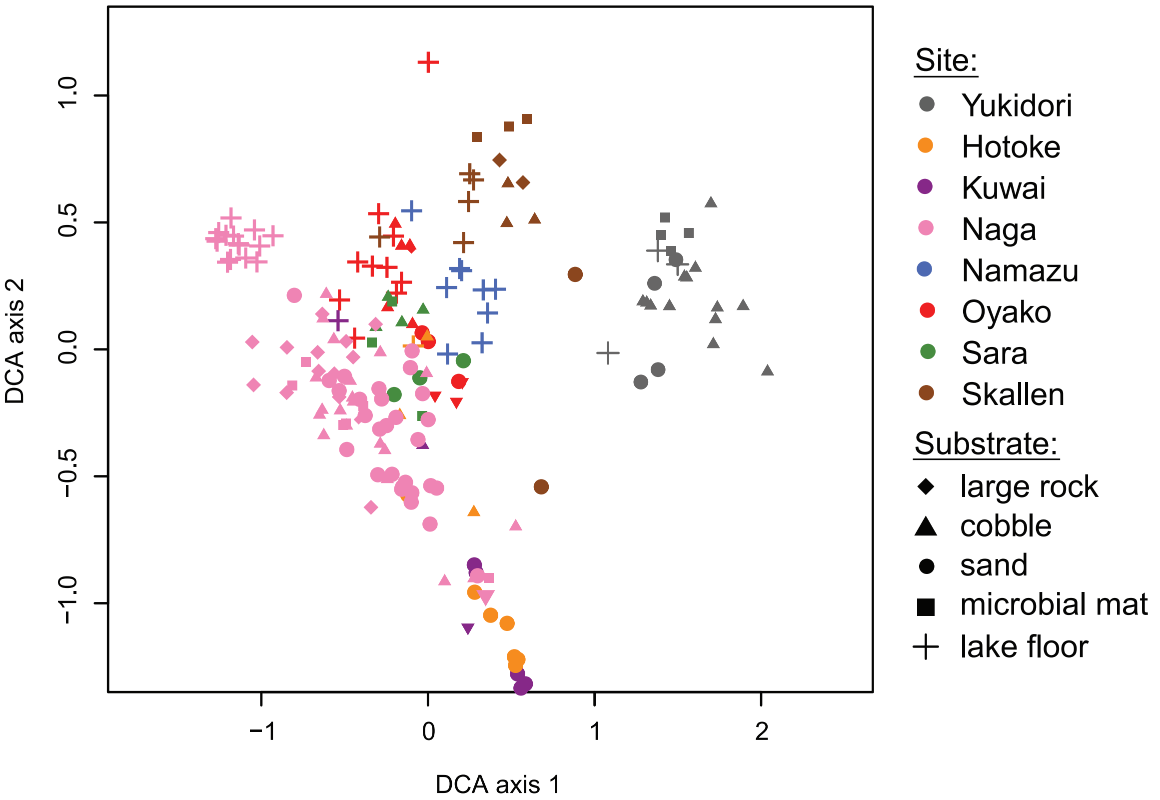
Supplementary Figure 3.1 cont. h) Lake Sara



Supplementary Figure 3.1 cont. i) Lake Skallen



Supplementary Figure 3.2 – diatom abundance of samples collected from nine lakes in Lützow-Holm Bay.



Supplementary Figure 3.3 – Detrended correspondence analysis of lake samples for comparison to the NMDS analysis presented in the text.

CHAPTER 4

Rudd, R.C., Tyler, J.J., Tibby, J., Yokoyama, Y., Fukui, M. & Takano, Y.
Coherent patterns of late Holocene environmental change inferred from two lake diatom records from Lützow-Holm Bay, East Antarctica

Supplementary information concerning this chapter follows the text. Data tables concerning this chapter are provided in Appendix 2.

Statement of Authorship

Title of Paper	Coherent patterns of late Holocene environmental change inferred from two lake diatom records in Lützow-Holm Bay, East Antarctica
Publication Status	☐ Published ☐ Accepted for Publication ☐ Submitted for Publication ☑ Unpublished and Unsubmitted w ork w ritten in manuscript style
Publication Details	

Principal Author

Name of Principal Author (Candidate)	Rachel Rudd		
Contribution to the Paper	Preparation and analysis of samples for diatom analysis, statistical analysis, figure production, manuscript preparation and editing.		
Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	21/11/2019

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Jonathan Tyler		
Contribution to the Paper	Provided guidance and assistance in data analysis, interpretation and manuscript editing		
Signature		Date	19/11/2019

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Contribution to the Paper	Provided guidance and assistance in data analysis, interpretation and manuscript editing		
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Name of Co-Author	Yusuke Yokoyama		
Contribution to the Paper	Assisted in the acquisition of radiocarbon data		
Signature		Date	15/11/2019

Name of Co-Author	Manabu Fukui		
Contribution to the Paper	Provided sample material, onsite chemical data acquisition for water profile during the field survey at Skarvsnes.		
Signature		Date	23-Oct-2019

Name of Co-Author	Yoshinori Takano		
Contribution to the Paper	Provided sample material and conducted preliminary bulk carbon ($^{14}C/^{12}C$, $^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) isotope analysis of 15 samples, elemental data analysis, and created core archives during the field survey at Skarvsnes.		
Signature		Date	23-Oct-2019

Coherent patterns of late Holocene environmental change inferred from two lake diatom records in Lützow-Holm Bay, East Antarctica

Abstract

Elucidating the climatic history of Antarctica is fundamental to fully understanding Southern Hemisphere climate processes. Instrumental records of climate in Antarctica are short and sparse, and paleoclimate research is dominated by ice core research, which is largely confined to the continental interior. Lake sediments from coastal ice-free regions offer a different perspective on past climate in Antarctica, giving insights from the climatically sensitive margins of the continent, to complement those for the interior. Lake sediment cores from two freshwater lakes, Lake Hamagiku and Lake Naga, from the Skarvsnes foreland in East Antarctica have been used to generate high resolution diatom reconstructions which span the past 3000 years, constrained using radiocarbon dating. Both sites show variability in the relative abundance of several key taxa, which may be attributed to conductivity, nutrient availability and lake water depth based on a regional diatom species training set as well as statistical techniques including detrended correspondence analysis and canonical correspondence analysis. Dominant taxa and ordination axes reveal a coherent shift in both records, identified using change point analysis to be approximately 1800 cal. yr BP. Sustained periodicity is observed in the records from both lakes with a wavelength of 256–512 years between 2500 and 1000 cal. yr BP, and closer to 128 years in wavelength between 500 and 100 cal. yr BP. By examining sediment records from two neighbouring lake sites, this study identifies shared forcing, the variability of which is attributed to changes in ice cover duration and extent, tentatively inferred as changes to regional temperature.

Introduction

High latitude regions are very sensitive to climatic changes (Douglas & Smol, 1999) yet instrumental records in these regions are often sparse, and spatially limited (Stenni *et al.*, 2017). Instrumental records from Antarctica typically extend back to the International Geophysical Year in 1957–58 (Nicolas & Bromwich, 2014), and exhibit large fluctuations in interannual to decadal temperatures, such that placing these trends in the context of longer-term climate is important to understand natural and anthropogenic forcing (Schneider, 2005; Goosse *et al.*, 2012; Nicolas & Bromwich, 2014). This is especially important as the Antarctic Ice Sheets have the potential to contribute enormously to global sea level rise (Jones *et al.*, 2016). For an extended perspective on past climate, and to interpret the highly variable nature of interannual to decadal temperature measurements in the context of past variability, natural archives must be utilised.

Ice core records provide an exceptional insight into climate and atmospheric gas composition over timescales from seasons through to hundreds of thousands of years (Petit *et al.*, 1999; EPICA community members, 2004; Stenni *et al.*, 2017). However, Antarctic ice cores are largely limited to the interior of the continent and regions of high snow accumulation and preservation, and are rare in the coastal region due to ice sheet dynamics (Stenni *et al.*, 2017). Palaeolimnological studies of lakes along the coastline in rocky, seasonally ice-covered regions can therefore provide a valuable perspective on past climate to complement ice core records. Records from these regions are particularly important as these areas represent the interface between the continent and ocean-atmosphere dynamics which are key to Southern Hemisphere climate, such as the Southern Westerly Winds and associated phenomena.

A significant proportion of interannual climate variability in the Southern Hemisphere is associated with the Southern Annular Mode (SAM) and El Niño-Southern Oscillation (ENSO) indices. The SAM is a measure of the atmospheric pressure gradient across the southern mid-high latitudes. A positive SAM phase correlates with a poleward contraction of the westerly winds circling Antarctica, and is associated with colder temperatures in Antarctica (Thompson & Wallace, 2000; Gillett, Kell & Jones, 2006). Recent trends indicate more positive phases of the SAM which are believed to lie outside natural variation (Thompson & Solomon, 2002; Abram *et al.*, 2014) and may be heightened by anthropogenic forcing (Marshall *et al.*, 2004) but by placing these trends in the context of past variability we can understand if these are within the range of natural variability observed. ENSO is the largest mode of ocean-atmospheric variability on decadal and sub-decadal timescales (Diaz, 1992), however, the relationships between ENSO and climate variability over the Antarctic continent have been found to be inconsistent both spatially and through time (Turner, 2004). Nevertheless, it has been shown that ENSO may have a strong effect on the height and mass of ice shelves in West Antarctica (Paolo *et al.*, 2018).

Many lakes at high latitudes are sensitive to the balance between hydrological input and evaporation (Verleyen *et al.*, 2012; Tavernier *et al.*, 2014). Furthermore, in perennially frozen Arctic lakes, ice cover duration and extent has been reported to be a key driver of ecological change (Douglas & Smol, 1999; Griffiths *et al.*, 2017). The timing and duration of the ice free season predominantly reflects the temperature of the region, but is also dependant on wind strength, cloud cover and lake size (Douglas & Smol, 1999; Noon *et al.*, 2001). Ice melt is preferentially focused in the littoral zones during summer months, and depending on the regional temperature and the size of the lake, the lake may be entirely exposed, or a persistent floating ice raft may form, surrounded by a liquid moat, such that littoral taxa dominate the overall lake assemblage (Smol, 1983, 1988; Douglas & Smol, 1999). Griffiths *et al.* (2017) found that in a series of lakes in the arctic across a gradient of ice cover duration, lakes with an extended ice-free season were found to have a greater diversity of diatom species, attributed to the establishment of new habitats. During warmer years, overall productivity is also expected to increase (Douglas & Smol, 1999). Through these mechanisms, diatoms in Antarctic lake sediments provide an indirect record of climate variability, particularly temperature, via the holistic lake ecological and chemical response.

Lakes in ice-free regions of Antarctica remain frozen for much of the year with ice thickness reaching up to two metres. In Lützow-Holm Bay, the study area of this chapter, there are several ice free regions, and the lakes in these regions are hosts for mats of diatoms, green algae and cyanobacteria, which grow amongst aquatic mosses on the lake floor (Imura *et al.*, 1999). Microbial sediments accumulate over time, forming organic rich layers up to two metres thick on the lake floor (Imura *et al.*, 1999). Fossil diatoms preserved in these sediments provide an opportunity to study lake ecology through time, and have been used to track isostatic uplift and infer climate variability in the region (Takano *et al.*, 2012; Tavernier *et al.*, 2014; Rudd *et al.*, 2016).

This study aims to add to the knowledge of Antarctic and Southern Hemisphere climate by developing two high resolution diatom records from lakes in coastal East Antarctica. By studying lake sediment cores from neighbouring lakes, the study aims to distinguish between regional effects and those existing in a single catchment (Jones, Hodgson & Chepstow-Lusty, 2000).

Site description

Lützow-Holm Bay in East Antarctica hosts several ice-free regions, which contain more than 100 lakes with a range of morphologies and water chemistry characteristics (Tanabe *et al.*, 2016). Lake Hamagiku (previously known as Lake Abi, as in Chapter 2 of this thesis) and Lake Naga are located in the Skarvsnes ice-free region (Figure 4.1), approximately 50km south of Syowa Station in Lützow-Holm Bay. They are located at 70 and 100m above sea level respectively, and are covered in ice which melts during the summer months. Lake Hamagiku is at most 4 metres deep with a surface area of 20,000 m^2, while Lake Naga is 10 metres deep with a surface area of 48,000 m^2 (Ohtsuka *et al.*, 2006). These lakes are fed by melt water from snow and inflow from small snowbanks within their catchment. The specific conductivity of Lake Hamagiku is 0.18 mS/cm (Ohtsuka *et al.*, 2006) and Lake Naga is 1.7 mS/cm (Chapter 3).

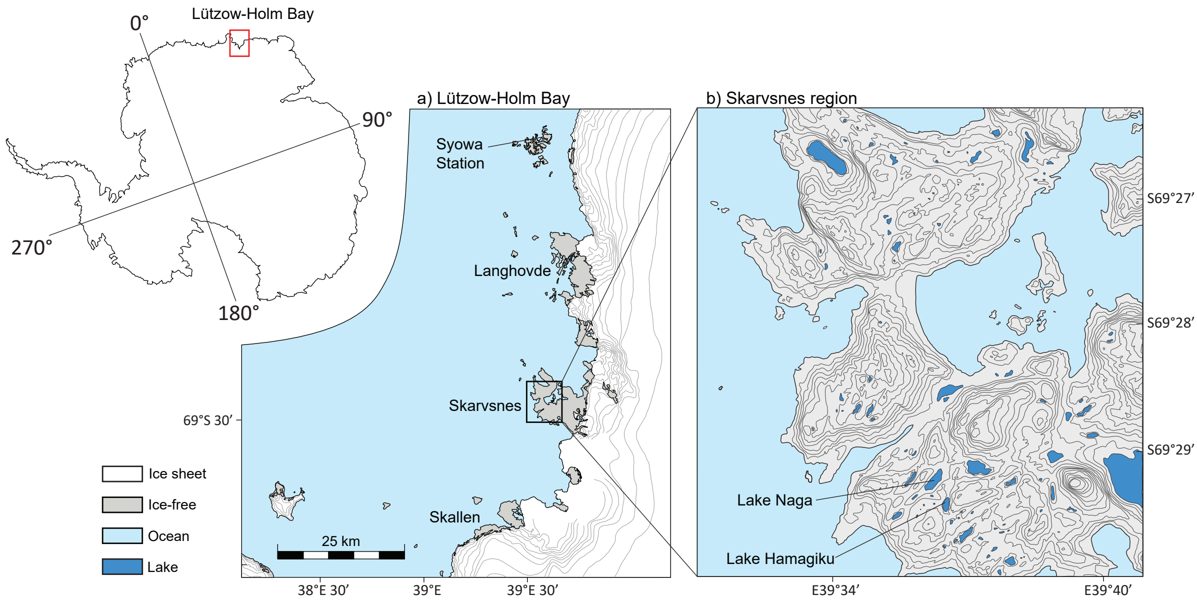

Figure 4.1 Location of Lützow-Holm Bay in East Antarctica a) Syowa Station and the Skarvsnes region, b) study sites in the Skarvsnes region, Lake Hamagiku and Lake Naga, maps adapted from a Geographical Survey Institute map (Geospatial Information Authority of Japan, 1987) and Takano et al. (2012). Contour intervals for the ice sheet in a) are 100m and for the ice-free region in b) is 10m

Methods

Climate correlation at Syowa station

Monthly temperature recorded at Syowa Station, located at 69°00'S 39°35'E (Japan Meteorological Agency) was correlated against NCEP/NCAR reanalysis data (Kalnay *et al.*, 1996) over the period from 1966 to 2018. For this time period, there were 17 missing values in the monthly Syowa Station dataset which were replaced with a calculated median of the available data for the corresponding month.

Sample collection and age modelling

The Lake Hamagiku (Ab5S) and Lake Naga (Ng5S) lake sediment cores used in this study were collected in January 2006 during the 47th Japanese Antarctic Research Expedition, using a piston-operated coring device.

The chronology for Lake Hamagiku used in this study has been revised from a previous study (Rudd et al., 2016, Chapter 2 of this thesis) and consists of 19 radiocarbon dates from bulk organic material. The chronology for Lake Naga consists of 15 radiocarbon dates from bulk organic material. Samples were prepared with an acid-alkali-acid treatment before being converted to graphite following Yokoyama *et al.* (2007), and then analysed by accelerator mass spectrometry at the University of Tokyo or at Beta Analytic, Inc. (Miami, FL, USA). Radiocarbon ages were calibrated to calendar years using BACON (Blaauw & Christen, 2011) using R (R Core Team, 2018), combined with the Southern Hemisphere atmospheric calibration curve (Hogg *et al.*, 2013). The uppermost sediments were constrained using a coring date of CE 2006, i.e. -56 years before present (CE 1950). Radiocarbon dates and calibrated ages are provided in Supplementary Table 4.1.

Fossil diatom analysis

Samples for diatom analysis for both lakes were subsampled from magnetic susceptibility cubes as outlined in Chapter 2 of this thesis. As discussed in Chapter 2, there is some uncertainty surrounding the order of samples from the uppermost 45 cm of the Lake Hamagiku core. These uncertainties are confined to the data presented in Chapter 2 and do not extend to the new part of the record presented here, or to the samples from Lake Naga. Any uncertainty is indicated in the plots of diatom relative abundance.

For both lakes, samples for diatom analysis were prepared using a method adapted from Battarbee et al. (2001) involving HCl and H_2O_2 digestion. Species were identified from various studies of surface sediment samples and paleolimnological studies from the East Antarctic coastline (Hirano, 1983; Hodgson, Vyverman & Sabbe, 2001; Sabbe *et al.*, 2003; Ohtsuka *et al.*, 2006; Spaulding *et al.*, 2019). Diatom valve concentration per milligram of sediment was estimated using sediment weight, aliquot volume and transect length of counts (adapted from Davis, 1965; Battarbee & Kneen, 1982).

For Lake Hamagiku, 232 contiguous samples along the core were analysed for diatom species composition, the uppermost 84 of which were reported by Rudd et al. (2016 — Chapter 2 of this thesis). Due to the dominance of the species *Humidophila australis* in many samples, slides were counted for 200 diatom valves counting all species, and then a second count of 200 valves was conducted, not including *H. australis* so as to discern prevalence and variability of less common species, a method adapted from a technique described by Battarbee et al. (2001). In samples where *H. australis* comprised less than 50% of the species observed, samples were counted for a total 500 valves counting all species. For Lake Naga, 236 contiguous samples along the length of the core were analysed. In these samples, there was frequently a dominance of *Halamphora vyvermaniana*, and so slides were counted in the same way as for Lake Hamagiku to account for this dominance by a single species.

Statistical analyses of diatom records

Detrended Correspondence Analysis (DCA) is used to assess variability in species assemblage over time by reducing the assemblage data to a series of principal vectors (Hill & Gauch, 1980). DCA was conducted using the decorana function in the VEGAN package (Oksanen *et al.*, 2018) for R (R Core Team, 2018), with prior square root transformation to reduce the influence of highly abundant taxa (Mills *et al.*, 2014). In order to place these records in the context of a modern dataset, the data are plotted passively on a Canonical Correspondence Analysis (CCA) of a surface dataset for the Lützow-Holm Bay region (Tavernier *et al.* 2014).

Due to taxonomic revisions, some taxa have changed names since the development of the Lützow-Holm Bay dataset by Tavernier *et al.* (2014). A revision of the *Halamphora* genus in Antarctica (Van de Vijver *et al.*, 2014), notes that most literature records of *Halamphora veneta* from the Antarctic continent are likely to be *Halamphora vyvermaniana*, which is assumed to include the *H. veneta* identified by Tavernier *et al.* (2014). The dataset also includes *Diadesmis australis* which has been reclassified as *Humidophila australis* (Lowe *et al.*, 2014) and *Psammothidium metakryophilum* which is a combination of the species *Navicula papilio* and *Psammothidium papilio* (Kopalová *et al.*, 2012).

Change point analysis was used to objectively compare the timing of a shift in the dominant diatom species in each lake. The analysis was performed using unpublished code by Jonathan Tyler, modified from the changepoint package (Killick & Eckley, 2014) in R, as per Tibby *et al.* (2018). The change point analysis was set to identify the most significant change point in each record. In order to assess the uncertainty around the timing of these change points, probability density functions were created following Tibby *et al.* (2018) by constructing an ensemble of 2000 chronologies for each record using Bacon (Blaauw & Christen, 2011). These analyses were performed on individual species data and DCA axes to assess change points in the overall diatom assemblage. Similar analyses were performed on diatom concentrations in the sediment.

To test for shared frequencies of variability between the two lakes, wavelet and cross-wavelet analysis was performed on individual diatom species timeseries, on DCA axes and on combinations of these. Data were linearly interpolated to a period of 20 years, as the records have an average of 1 sample every 12 years. Wavelet analyses were conducted using the WaveletComp package (Roesch & Schmidbauer, 2018) in R, with default settings and a significance level of 0.05 for the plotted contours. Solid lines indicate where a significant periodicity was identified, and arrows on cross wavelets indicate phasing and lead/lag relationships between timeseries.

Results

Southern Hemisphere climate reanalysis

Monthly temperature records from Syowa Station for the period 1966 to 2018 have a strong negative correlation with zonal winds (Figure 4.2a) along the coastline of East Antarctica. Monthly temperature also has a positive correlation with sea surface temperature in the region (Figure 4.2b). A correlation of Antarctic Oscillation (SAM) and air temperature at 850 mb (Figure 4.2c) is consistent with Figure 4.2a, showing a negative correlation along the east Antarctic coastline.

Sediment description and chronology

The sediments of Lake Hamagiku and Lake Naga consist of laminated algal biofilm, with filamentous mosses and occasional sand grains in the organic material. The sediments are green to grey in colour, and there is very little change observed in the cores throughout their length.

The radiocarbon dates for each core fall in stratigraphic order, with no age reversals in the measurement and calibration error (Figure 4.3) except for a small reversal in the oldest two radiocarbon dates of the Lake Naga core which has a minimal effect on the model (Figure 4.3b). Both lakes appear to have had a relatively constant sediment accumulation rate, of approximately 40cm per 1000 years, with the Lake Hamagiku core extending to 2800 cal. yr BP and Lake Naga to 3100 cal. yr BP.

Diatom assemblage analysis

LAKE HAMAGIKU

Of more than 20 taxa observed in the core samples of Lake Hamagiku, only 8 were found with a relative abundance of more than 1% (Figure 4.4). Prior to 1800 cal. yr BP, *Humidophila australis* was only represented by a few valves, yet this species dominates the assemblage in sediments younger than 1800 cal. yr BP. In this younger section, *H. australis* is present in the sediment with an abundance of between 50 to 90% in most samples, with a very slight decrease since 500 cal. yr BP. The second and third most abundant species in the record, *Navicula gregaria* and *Craticula antarctica*, are more common in the sediments older than 1800 cal. yr BP and have a lower relative abundance as *H. australis* abundance increases. Both species show large fluctuations in their relative abundance through the record, with *N. gregaria* relative abundances ranging from 0.3–97%, and *C. antarctica* relative abundances ranging from 0–67%.

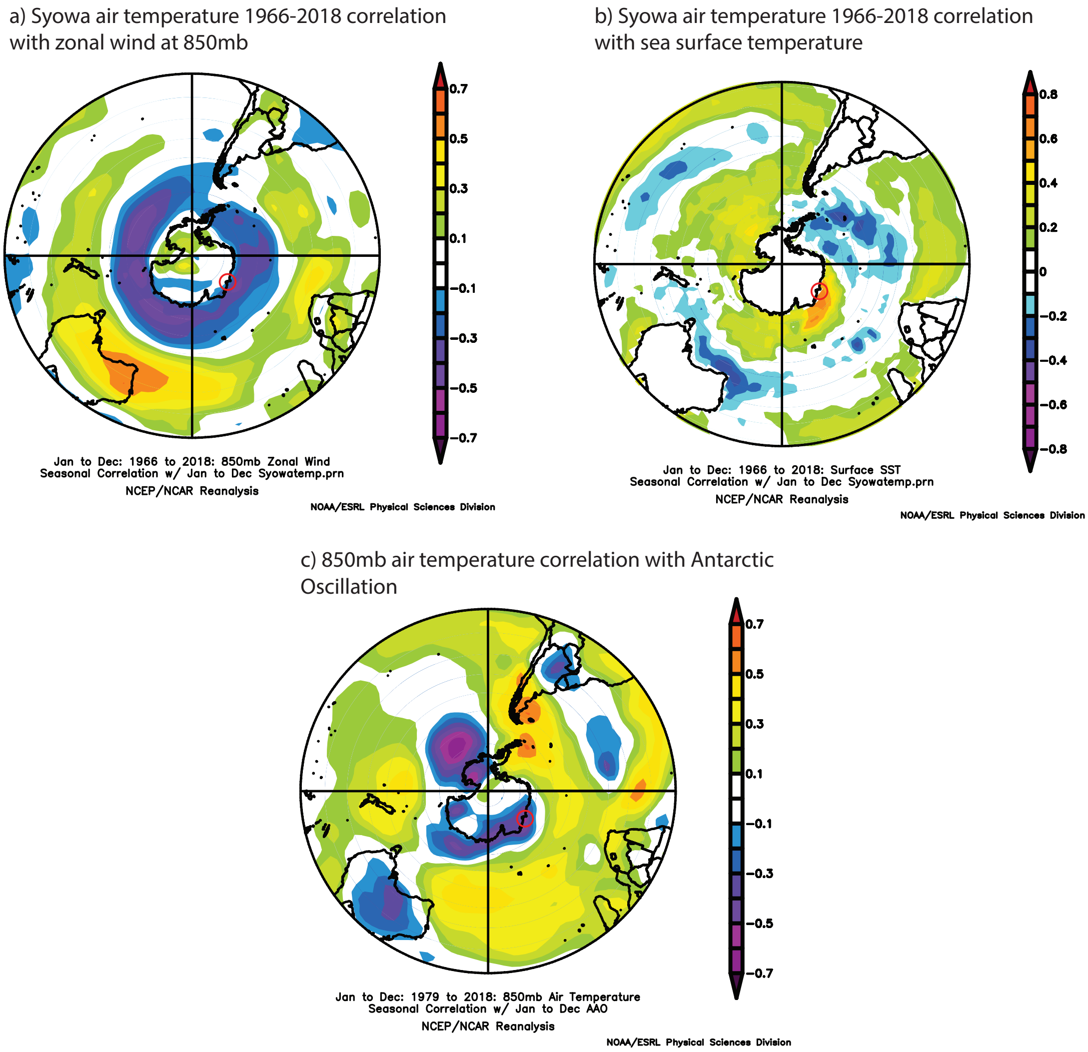

Figure 4.2 NCEP reanalysis of data across the southern hemisphere, with the location of Syowa Station indicated in each by a red circle. a) Monthly air temperature measurements at Syowa Station from 1966 to 2018 correlated with zonal winds at 850mb, b) Monthly air temperature measurements at Syowa Station from 1966 to 2019 correlation with sea surface temperatures, c) 850mb air temperature correlation with the Antarctic Oscillation.

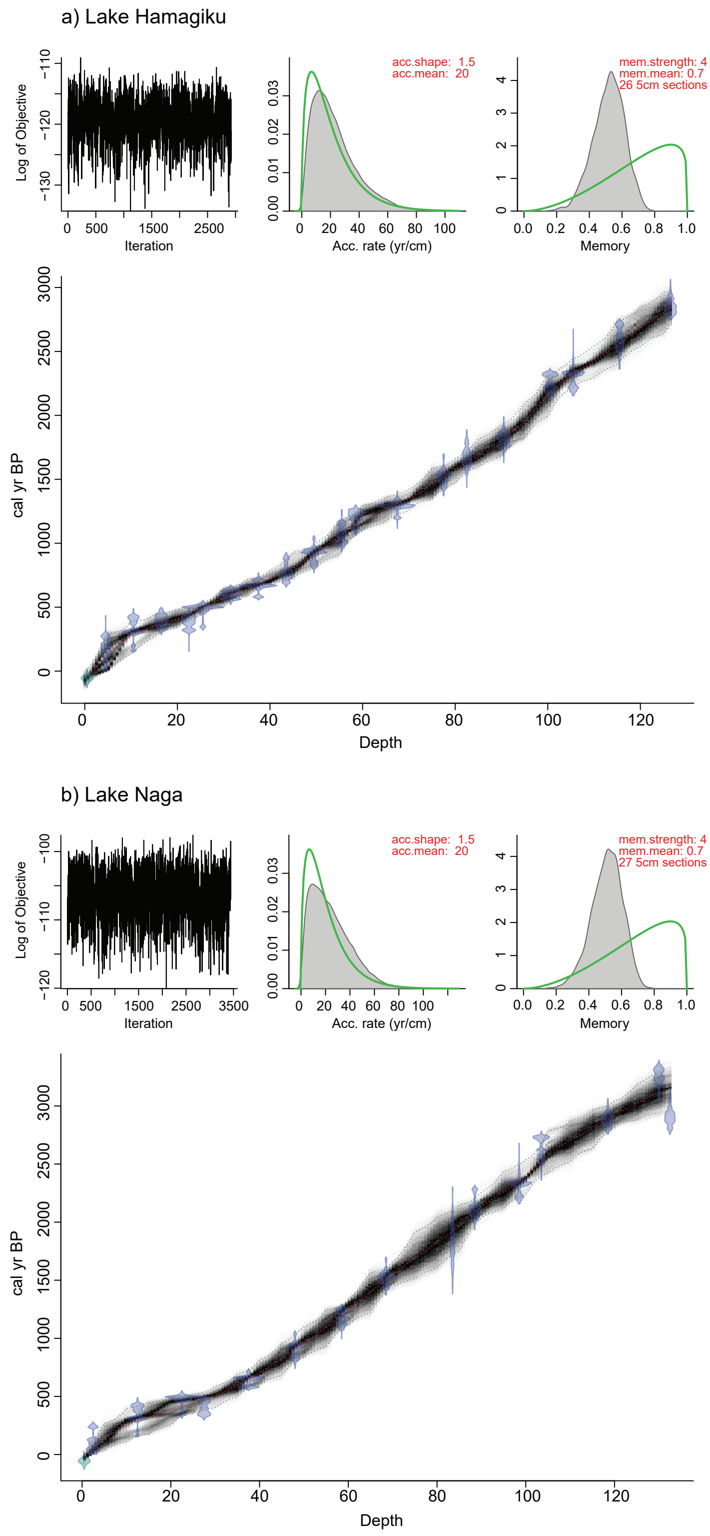

Figure 4.3 Age model for the a) Lake Hamagiku and b) Lake Naga sediment cores. Upper panels indicate the iterations performed, accumulation rate and memory used to construct the model. Lower panels show probability density functions for each calibrated age in blue, the grey curve indicates the age–depth model and the red curve is the best fit model.

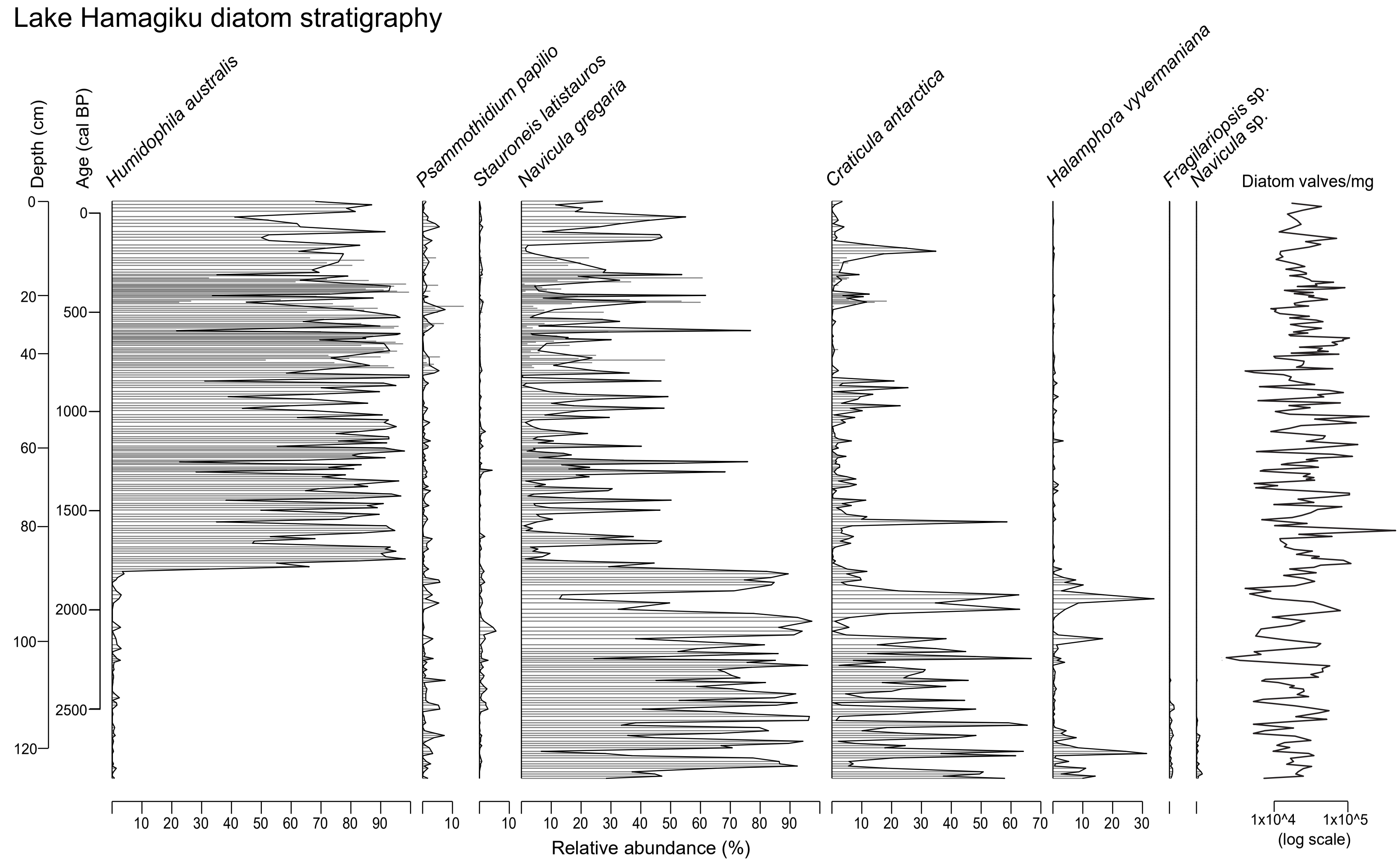

Figure 4.4 Stratigraphic diagram of all diatom species above 1% in at least one sample in the Lake Hamagiku record. The bars indicate individual samples, and the uncertainty in ordering of younger samples is indicated by the lines over the species data which are averaged for uncertain samples. The concentration of diatoms in the sediment is also shown, plotted with a log scale due to large fluctuations.

Psammothidium papilio and *Stauroneis latistauros* are also observed throughout the record, although at a lower relative abundance (maximum relative abundance 14% for *P. papilio* and 6% for *S. latistauros*). *Halamphora vyvermaniana* is also present throughout the core, yet is more abundant earlier in the record, with two local maxima of just over 30% at 2700 and 1900 cal. yr BP. The two final species observed at over 1% relative abundance are a species of *Fragilariopsis* (likely *F. curta* or *F. cylindrus* although accurate identification was hindered by the often fragmented nature of valves) and a species of *Navicula* (possibly *N. directa*). Both these taxa are marine in origin and were observed in very low abundances in the oldest part of the core, with no observations in the more recent 2000 years of sediment.

LAKE NAGA

The Lake Naga diatom record also consists of a limited number of taxa, with only six taxa observed to have a relative abundance of over 1% (Figure 4.5). *Halamphora vyvermaniana* is the most common species throughout the core, although this species varies greatly in abundance. From 3100–1900 cal. yr BP, these fluctuations are greater, ranging from 36–91%. After 1900 cal. yr BP, *H. vyvermaniana* is more consistently present at a higher abundance, with most samples above 80%, except for two local minima, of 45% at 1500 cal. yr BP and 35% at 500 cal. yr BP. The relative abundance of *H. vyvermaniana* decreases slightly in the recent sediments.

As at Lake Hamagiku, the two species with the next highest relative abundances are *N. gregaria* and *C. antarctica*. These two species have large fluctuations in abundance over the record, ranging from 0–31% for *N. gregaria*, and 0–59% for *C. antarctica*. The relative abundance of *N. gregaria* increases in the recent sediments, from around 250 cal. yr BP. *Hantzschia cf. amphioxys*, was also observed in the Lake Hamagiku sediments, although always with a relative abundance of less than 1%. *Fragilariopsis* sp. and *Navicula* sp. were observed in low abundance, as in the sediments of Lake Hamagiku. These taxa are often represented by single valves, and are more common in the oldest samples of the core.

The calculated concentrations of diatom valves per milligram of sediment were highly variable throughout both records, such that they are displayed in Figures 4.4 and 4.5 on a log scale. There was one very large peak in diatom concentration at Lake Hamagiku, at approximately 1500 cal. yr BP.

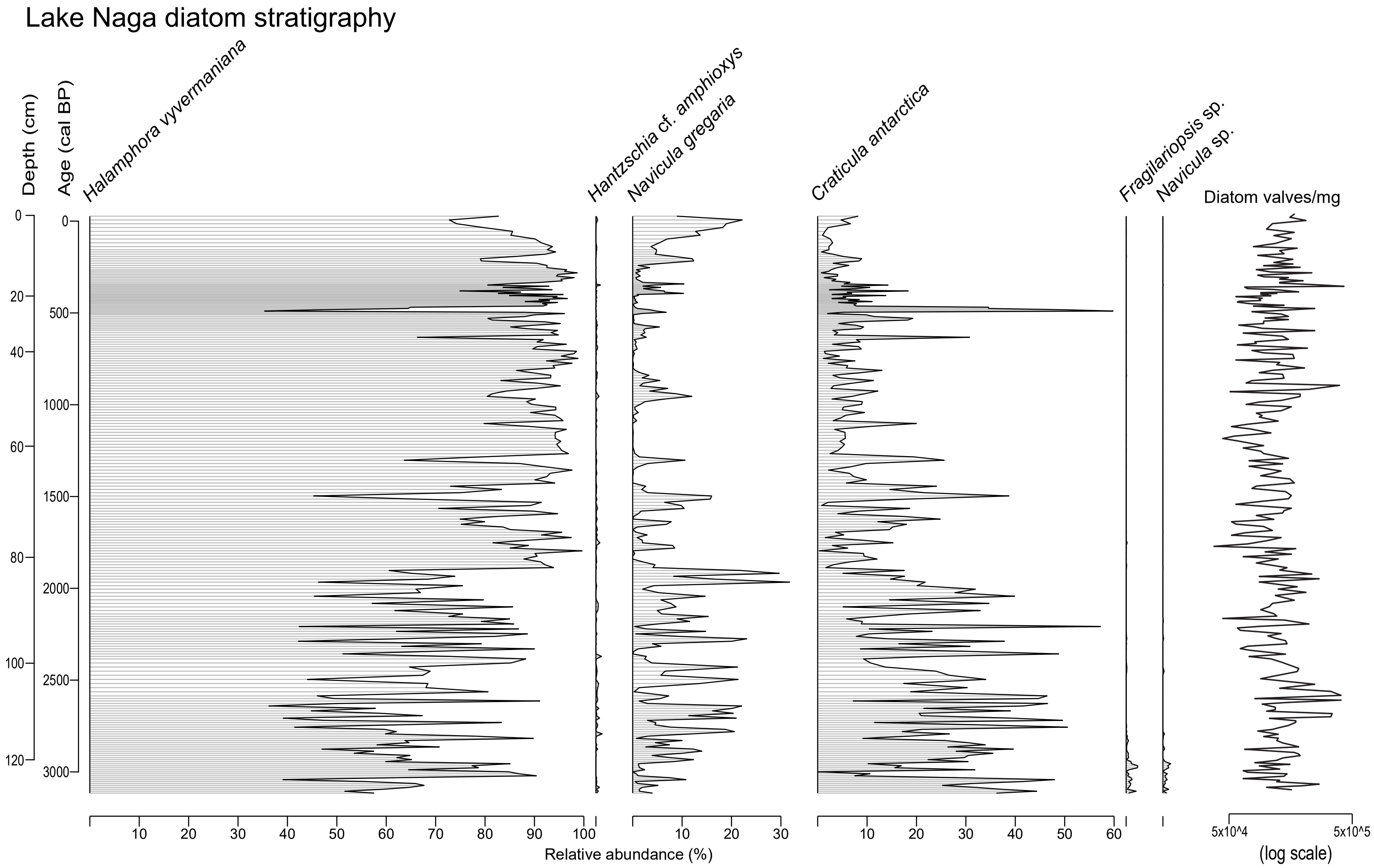

Figure 4.5 Stratigraphic diagram of all diatom species above 1% in at least one sample in the Lake Naga record. The bars indicate individual samples. The concentration of diatoms in the sediment is also shown, plotted with a log scale due to large fluctuations.

Statistical analyses of fossil diatom data

The DCA highlights two levels of variability in the data at each site. The samples from Lake Hamagiku plot in two groups (Figure 4.6a), one group is the older samples, with positive DCA axis 1 scores, characterised by a higher abundance of the positively weighted *C. antarctica* and *N. gregaria* with some *H. vyvermaniana.* The second group is the younger samples, with *H. australis* dominant, which plot with more negative DCA axis 1 scores. DCA axis 1 summarises the first level of variability in the diatom record, which essentially reflects the abundance of the dominant species *H. australis* (negative loading on DCA xis 1) relative to other species in the record, primarily *N. gregaria* and *C. antarctica* (positive loading on DCA axis 1). The second DCA axis is largely driven by the abundances of *N. gregaria* (positive loading) and *C. antarctica* (negative loading) relative to one another. This variability along DCA axis 2 is more substantial in the older samples, which vary between *N. gregaria* and *C. antarctica,* while the younger samples also vary along this axis, they are also influenced by the dominance of *H. australis*.

The samples from Lake Naga plot in one scattered group within the DCA plot (Figure 4.6b) with a small trend of younger samples plotting with positive scores on DCA axes 1 and 2, and older samples plotting with negative DCA scores on axes 1 and 2. The first DCA axis largely reflects the relative abundance of the dominant species *H. vyvermaniana* (positive loading) in relation to the other species in the record. As with Lake Hamagiku, the relative abundance of *N. gregaria* (positive loading) and *C. antarctica* (negative loading) drives variability along DCA axis 2.

Diatom assemblage data from the two lake sediment records are plotted passively on a CCA of the Tavernier *et al.* (2014) transfer function dataset (Figure 4.6c). The two lakes exhibit similar patterns, with the samples from the Lake Naga record plotting amongst the samples from the older section of the Lake Hamagiku record, with a similar assemblage characterised by *N. gregaria, C. antarctica* and *H. vyvermaniana*. The first level of variability identified in the DCA, between the dominant species at each site and the other species in the two records, can be associated with conductivity, aluminium and sulphate ions in the lake water, and to a lesser extent sample depth, from the Tavernier *et al.* (2014) dataset. The second level of variability identified in the two records, the ratio of *N. gregaria* to *C. antarctica* appears to be associated with pH, oxidation-reduction potential, dissolved oxygen content and total nitrogen in this dataset.

The most significant change point identified in the Lake Hamagiku DCA axis 1 timeseries, corresponds to the point where *H. australis* becomes dominant in the record at approximately 1800 cal. yr BP (Figure 4.6d). A similar, yet smaller scale change point is identified in DCA axis

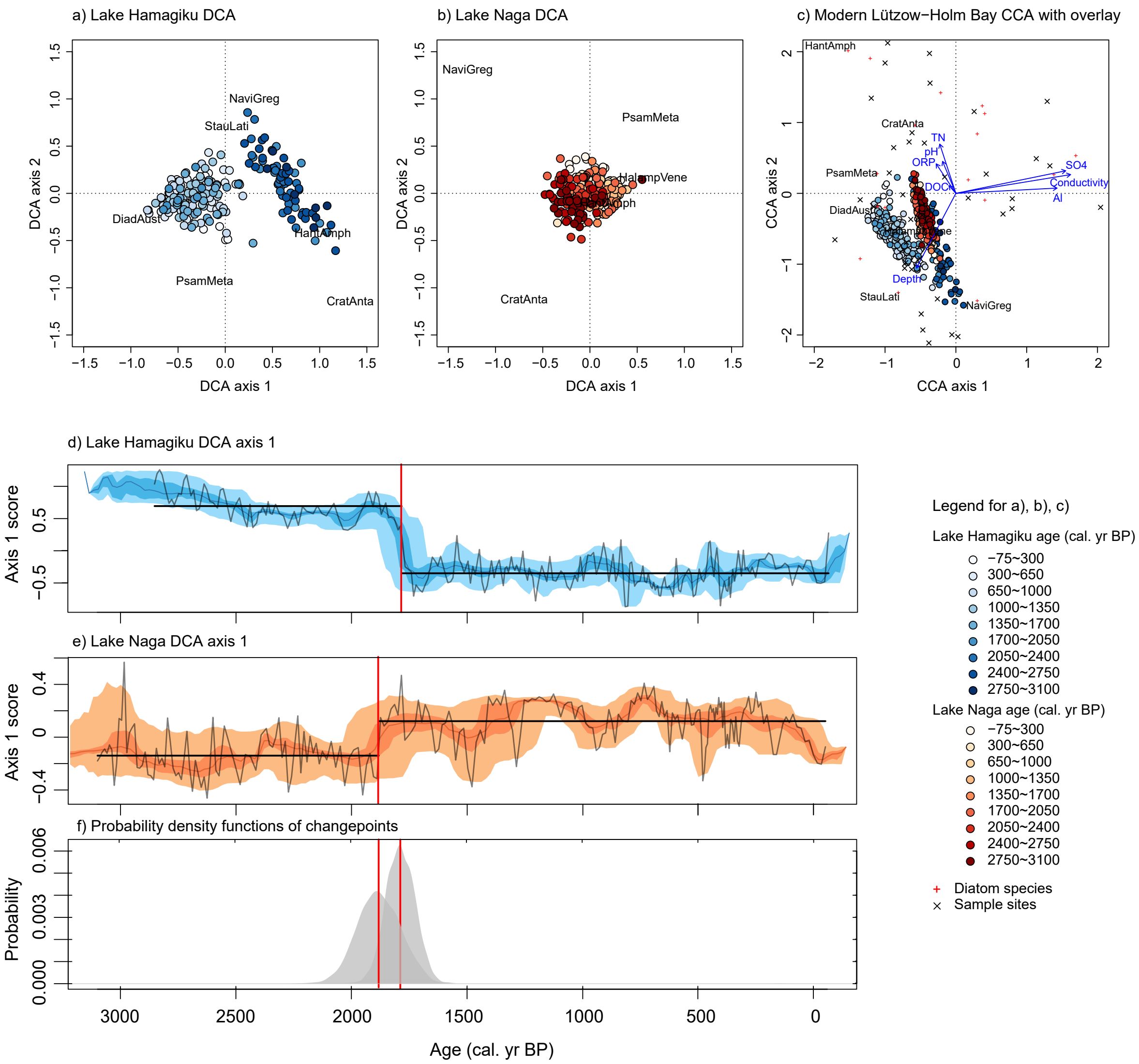

Figure 4.6 Detrended correspondence analyses (DCA) of a) Lake Hamagiku and b) Lake Naga diatom data, c) canonical correspondence analysis (CCA) of a modern surface diatom dataset produced by Tavernier *et al*. (2014) overlain with data from both cores passively to illustrate the fossil diatom assemblages within the context of the modern species-environment relationships. d) and e) DCA axis 1 vs time for Lakes Hamagiku and Naga respectively, with the largest changepoint identified in each record indicated by red vertical lines. f) indicates the timing of the changepoints shown in d) and e) and indicates their relative timing due to the errors in the age modelling with probability density functions.

Species abbreviations in a), b) and c) refer to species in the Tavernier et al. (2014) dataset: CratAnta: *Craticula antarctica*, DiadAust: *Humidophila australis*, HalamphVene: *Halamphora vyvermaniana*, HantAmph: *Hantzschia* cf. *amphioxys*, NaviGreg: *Navicula gregaria*, PsamMeta: *Psammothidium papilio*, StauLati: *Stauroneis latistauros*

1 of the Lake Naga data (Figure 4.6e) at approximately 1900 cal. yr BP with overlap between the probability density functions of these two events (Figure 4.6f) based on the errors of the age models. The change points observed in the first DCA axes at both sites were consistent with the change points observed in the most dominant species at each site (supplementary Figure 4.1). Due to the highly variable nature of the diatom valve concentration in the sediments, change point analyses did not identify coherent shifts in the overall diatom concentration.

Wavelet analysis highlights several periodicities at different wavelengths in the dataset. The wavelet analysis of *H. australis* abundance at Lake Hamagiku (Figure 4.7a) indicates several times of periodicity, with one at the younger end of the record, at around 300–500 cal. yr BP, with a periodicity of around 128 years. There is another period of significant periodicity, from approximately 1000–2000 cal. yr BP, with a sustained periodicity of just over 256 years, but also patches of periodicity over shorter, decadal scales during this time. The wavelet analysis of *H. vyvermaniana* abundance in Lake Naga (Figure 4.7b) shows more smaller periods of periodicity and less sustained zones. There are several significant regions of less than 100 years periodicity, and three zones at 400–600, 1200–1700 and 2000–2500 cal. yr BP with a periodicity of between 128 and 256 years. For the first DCA axis of each lake (Figure 4.7c and 4.7d) there are small, patchy intervals of periodicity on smaller timescales, and more sustained zones of significant periodicity over larger timescales. The most sustained periodicity in the Lake Hamagiku DCA 1 axis occurs with a period of between 256–512 years, between 1000 and 2500 years, similar to the wavelet of *H. australis* abundance. Two areas of significant periodicity from 200 to 500 and 1500 to 2200 years cal. yr BP also occur with a wavelength of approximately 128 years. The Lake Naga DCA 1 axis wavelet also indicates sustained periodicity throughout the record at a longer timescale, yet the periodicity is less distinct, and has a wavelength of between 256 and just over 512 years, from around 500 to 2000 years cal. yr BP. This record also exhibits smaller areas of significant periodicity, at 300–500, 1200–1700 cal. yr BP, with a periodicity of 128–256 years. The cross wavelet (Figure 4.7e) of DCA axis 1 at each site confirms the similarities between the two records, with a coherent periodicity observed between 800–2250 cal. yr BP of just over 256 years, and less sustained periodicities of around 128 years at 100–500 cal. yr BP and 1200–2500 cal. yr BP.

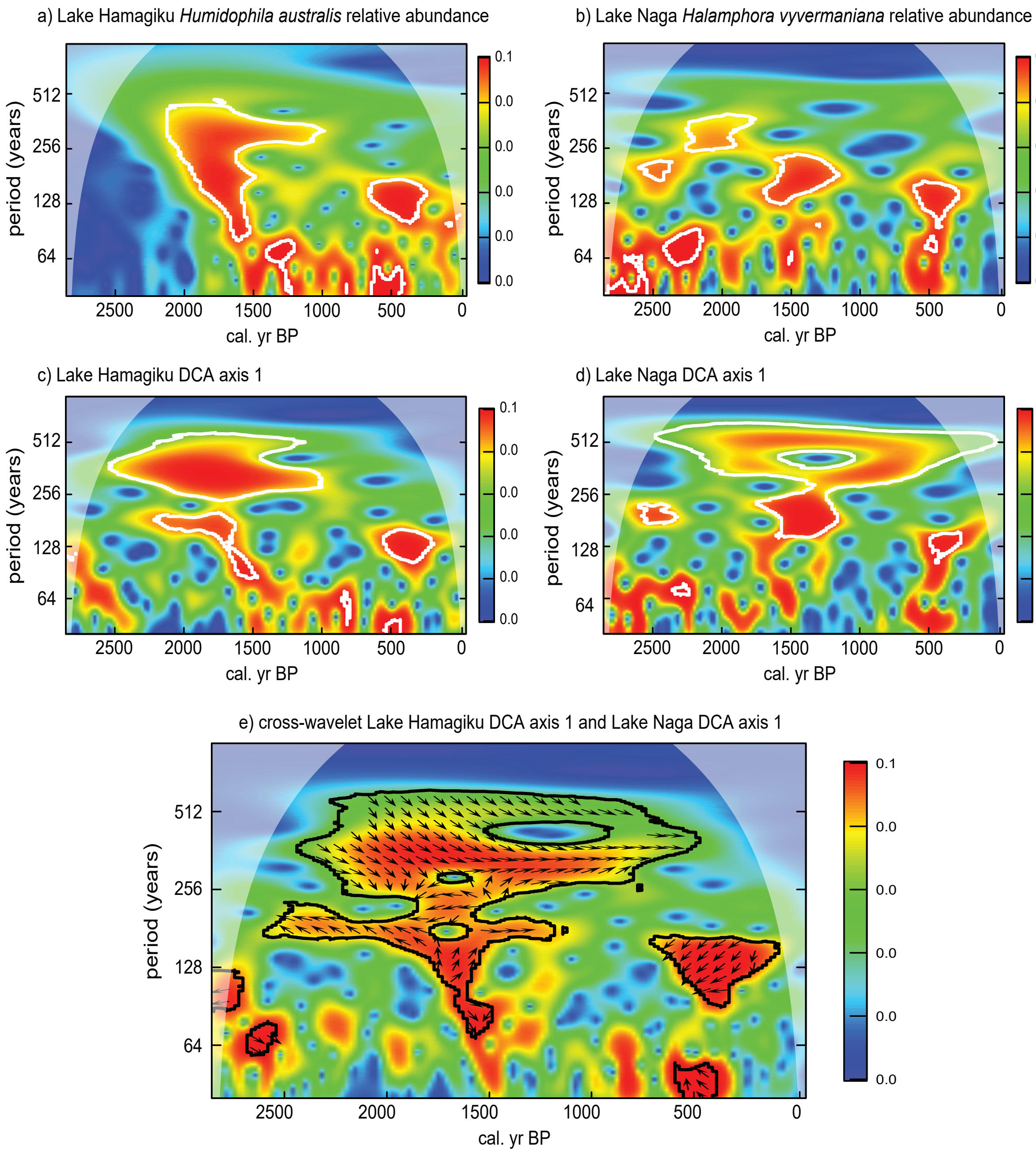

Figure 4.7 Wavelet analyses of dominant diatom taxa and DCA axes for Lakes Hamagiku and Naga. a) and b) are the relative abundances of the dominant species present within each lake sediment core, Humidophila australis at Lake Hamagiku and Halamphora vyvermaniana at Lake Naga, c) and d) are wavelets for the first DCA axis of Lakes Hamagiku and Naga respectively, and e) is a cross wavelet indicating coherent periodicity of the first DCA axis of each site. The x axis of each wavelet is the age along the sediment core.

Discussion

Diatoms preserved in the sediments of East Antarctic lakes have been used to track the timing of glacial retreat and isostatic uplift, yet few studies have used fossil diatoms as a proxy of climate variability over decadal to centennial timescales. This study presents two high resolution records from neighbouring lakes to determine shared forcing and variability in the region over the last 3000 years.

In many East Antarctic lakes of lower altitude, marine diatoms are common in lake sediment records due to the isolation of the basins from the ocean during isostatic uplift (Tavernier *et al.*, 2014; Verleyen *et al.*, 2017), yet Lake Hamagiku and Lake Naga sit well above the relative sea level high stand of around 30 metres for the Skarvsnes region (Verleyen *et al.*, 2017). The presence of marine species in these lakes, located 70 and 100 metres above sea level, is unexpected and the valves may have been transported by wind or birds (Atkinson, 1972; Kristiansen, 1996). These marine species are not observed above 1% relative abundance from 2400 cal. yr BP until present, which may be due to a decrease in wind strength and associated transport, or they may be observed as having a lower abundance due to an increase in the absolute concentration of freshwater diatoms as they became more established in the lakes. While there is no discernible change to the diatom valve concentration over time to support this idea, the marine taxa are present in such low abundances that this might not be captured in the valve concentration data which exhibit large fluctuations over time.

The most immediate difference between the diatom records from Lake Hamagiku and Lake Naga is that, although each lake has a single species dominate the record, the dominant species is different in each lake. Moreover, the dominant species in each lake is rarely observed in the other. *H. australis* is rarely observed in the Lake Naga record, while *H. vyvermaniana* is present at Lake Hamagiku but is uncommon, particularly since 1800 cal. yr BP. Morphological differences between the sites may contribute to these differences. Lake Naga has a considerably larger surface area and is also more than twice the depth of Lake Hamagiku, affecting the duration of ice cover and light attenuation. Another possible factor to explain the difference between the two lake records is that Lake Naga has a slightly higher specific conductivity than Lake Hamagiku. Specific conductivity is the dominant factor influencing diatom assemblage composition in these lakes and in other regions along the Antarctic coastline and on the Sub-Antarctic Islands (Verleyen *et al.*, 2003; Kopalová *et al.*, 2013; Tavernier *et al.*, 2014; Saunders *et al.*, 2015). In Chapter 3 of this thesis, *H. australis* was more abundant in the freshest sites sampled in the Lützow-Holm Bay region, and has been observed in freshwater lakes in other Antarctic regions (Sabbe *et al.*, 2003, as *Diadesmis* cf. *perpusilla*; Gibson, Roberts & Van de Vijver, 2006, as *Diadesmis* sp. a; Van de Vijver *et al.*, 2010). From the same study (Chapter 3), *H. vyvermaniana* was found to be dominant in samples from Lake Naga (which has a higher specific conductivity than most of the other lakes studied in Chapter 3), particularly in the samples from the lake floor transect, and to a lesser extent in the lake floor sample from Lake Kuwai and samples from most substrates in Lake Oyako and Lake Skallen, all in the Skarvsnes region. Specific conductivity or one of the morphological differences between the lakes may result in conditions unsuitable for *Humidophila australis* at Lake Naga, or to instead favour *Halamphora vyvermaniana*.

Changes in salinity in Antarctic lakes have been attributed, particularly for closed basins, to fluctuations in the balance between precipitation and evaporation. This relationship is complicated by inflow from multiyear snowbanks and glaciers, the size of which vary with location and catchment size, and the input from these sources is also a product of regional temperature. The ionic composition of the lake water at these sites was reported by Ohtsuka *et al.* (2006) with sodium (Na^+) the most common cation measured (14 mg/L at Lake Hamagiku and 164 mg/L at Lake Naga) followed by calcium, magnesium and potassium ions. Chloride ions (Cl^-) were the most common anion in both lakes (25 mg/L at Lake Hamagiku and 292 mg/L at Lake Naga) with sulfate ions also detected. The source of salinity in low altitude lakes is a relic from sea water trapped in the basin during isostatic uplift. In lakes above the marine highstand, the origin of salts is less clear, but they may be blown in either as sea spray or with snow from sea ice or may be incorporated from precipitation and glacier or snowbank meltwater.

Two levels of variation have been identified from the statistical analyses performed on these diatom records. The first is the relative abundance of the dominant species at each site, namely *H. australis* at Lake Hamagiku and *H. vyvermaniana* at Lake Naga, relative to the other species preserved in the records. At both sites, a coherent shift is observed in the first level of variability, at approximately 1800 cal. yr BP, and although the apparent magnitude of this shift and the exact timing varies between the two sites, the timing is within the error of the age models. In the Lake Naga record, the relative abundance of *H. vyvermaniana* decreases in the most recent sediments, accompanied by an increase in relative abundance of *N. gregaria*. A similar trend may be observed at Lake Hamagiku, with several more sustained increases in relative abundance of *N. gregaria* since around 500 cal. yr BP, and a slight decrease in the average relative abundance of *H. australis*. The second level of variability in these records is of the fluctuations between two species, *N. gregaria* and *C. antarctica*, throughout both records.

The overlap in the timing of the shift in the dominant species in the study lakes, in combination with the marked differences in the lakes, suggests it results from a shared forcing rather than a phenomenon affecting a single lake system (eg. lake ontogeny). Due to the proximity of the lakes however, the spatial scale of the forcing driving this shift cannot be fully resolved, and other records in the region do not aid this interpretation. A study of nearby Lake Mago, in the Skarvsnes region, by Tavernier *et al.* (2014) reports a very similar assemblage to that of Lake Naga, with a large abundance of *H. veneta* (assumed to be *H. vyvermaniana*) and *C. antarctica,* with *N. gregaria* also present. Due to the lower altitude of this site, the basin was still submerged in the ocean at 1800 cal. yr BP so the presence of a similar shift could not be assessed. The fossil diatom composition of sediments from three lakes on West Ongul Island in Lützow-Holm Bay were studied by Tavernier (2014), yet there are no consistent or sustained changes in species assemblage at 1800-1900 cal. yr BP between these lakes. At Ô-Ike, *Halamphora vyvermaniana* (as *H. veneta*) relative abundance decreases at around this time, but increases again in the recent sediments (Tavernier, 2014).

The shift in the Lake Hamagiku record with the rise to dominance of *H. australis* is much more pronounced than the change observed at Lake Naga, which may be due to the larger surface area and depth of Lake Naga, making it less susceptible to change or slower to respond compared to the shallow Lake Hamagiku. The increase of *H. australis* at 1800 cal. yr BP may be attributed to a freshening of Lake Hamagiku, but may also reflect a change in habitat availability. The abrupt nature of the shift in the Lake Hamagiku record may indicate a threshold response. The CCA of the Lützow-Holm Bay dataset (Tavernier *et al.* 2014) supports the interpretation of Lake Hamagiku freshening as this shift is associated with a decrease in conductivity and perhaps an increase in water depth (Figure 4.6c). A freshening event at Lake Hamagiku may be associated with warmer conditions and increased snow melt input, or alternatively, colder conditions and decreased evaporation. The amount of input into these lakes from snow melt is limited by the size of snowbanks in their catchments, and so there is only a finite amount of fresh water which could enter these lakes during warmer conditions. Furthermore, in warmer years, the length of time for which the lakes are ice-free is expected to be longer, and so it may follow that there would be an increase in the duration of seasonal evaporation to counter inflow. Brine formation in the bottom of the lakes below the ice cover, through the process of brine rejection, may also mean that cooler climates are associated with lake water that is more saline relative to during ice-free conditions. This process is expected to have a greater impact in shallower lakes, where the proportion of ice to liquid water is greater, although the water column is mixed following the melting of lake ice, and stratification is not observed (see Figure 2.2). Considering these various influences, it is likely that warmer conditions were responsible for this freshening event.

For Lake Naga, from Chapter 3 of this thesis, *H. vyvermaniana* is associated with lake floor samples in the Lützow-Holm Bay region and was not commonly found in the littoral zone. The increase in *H. vyvermanina* in Lake Naga is therefore likely to represent an increase in the ice-free duration and the length of time for which light is available to these habitats, but may also be associated with an increase in water depth or an increase in the mossy algal mat habitats on the lake floor in which it was abundant (Chapter 3). From Chapter 3, *Craticula antarctica* relative abundance was observed to increase slightly as depth increased for the lake floor samples from Lake Naga, although this relationship is not statistically significant ($p < 0.05$). It is possible that *C. antarctica* is adapted to the low light conditions in the deepest part of Lake Naga, and that increases in relative abundance represent extended ice free periods and warmer conditions, although as the species was also observed in the littoral region this cannot be confidently inferred. With these competing mechanisms in mind, the shift in these lakes at 1800 cal. yr BP is tentatively associated with warmer conditions, associated with longer ice-free conditions at Lake Naga, reflected as an increase in *Halamphora vyvermaniana* relative abundance.

If the increase in *H. australis* at Lake Hamagiku and *H. vyvermaniana* at Lake Naga at around 1800 cal. yr BP is attributed to changes in ice cover, then it may also follow that the other, small fluctuations in the major taxa relative to *C. antarctica* and *N. gregaria* also represent changes in ice cover and lake hydrology associated with temperature. From the NCEP climate reanalysis of the region (Figure 4.2), temperature is negatively correlated to westerly winds in this region, and so a decadal to centennial record of diatom assemblage variability at these sites may reflect trends on a similar timescale to the strength of winds surrounding the Antarctic continent, with stronger winds associated with lower temperatures in Lützow-Holm Bay.

From the CCA (Figure 4.6c), *N. gregaria* is associated with lower pH, total nitrogen and oxidation-reduction potential in these lakes compared to *C. antarctica.* Periods of time with more *N. gregaria* may reflect less ice cover coupled with variation in one or more of these other variables. As there was no depth transect sampled at Lake Hamagiku, the relationship of these species to depth and light at this site may be inferred from the study at Lake Naga, although there are fundamental differences between these lakes which may affect these relationships. Due to the shallower nature of Lake Hamagiku, the difference in light attenuation between the surface and the deepest area of the lake would not be expected to be very large, so the low light adaptation of *C. antarctica* suggested previously may not be as applicable. Lake Hamagiku is also expected to be ice free for longer than Lake Naga due to the smaller surface area, which was observed by aerial photographs to be the case during the 2017–2018 summer (see Chapter 1 – Figure 1.3). As discussed in Chapter 3 of this thesis, the ecological preferences of *C. antarctica* remain uncertain. As a key taxa in these low diversity records, a better understanding of the locations in which this species is found has the potential to vastly improve the interpretation of climate variability from the sediments in these lakes. More depth transects across lakes in the

Lützow-Holm Bay region may shed light on the proposed low light adaption of *C. antarctica* and to assess if *N. gregaria* shows any similar patterns in distribution.

In addition to a shared shift in dominant taxa in these records, the periodicities in the abundance of the dominant species and the less abundant taxa is similar between the two sites, as shown in the wavelet analyses presented in Figure 4.7. The wavelets of the major taxa at each site show periodicity of around 128 years in the youngest part of the record, and longer wavelength variability earlier in the record, of between 256 and 512 years. Wavelet analysis of DCA axis 1 for each lake (Figure 4.7c and d) shows further consistency in the periodicity of relative abundance of the major taxa relative to *N. gregaria* and *C. antarctica*. These wavelet analyses show a coherent periodicity of 256–512 years in wavelength through much of the record, and a periodicity of around 128 years in the younger sediments, around 500–200 cal. yr BP. The cross-wavelet of DCA axis 1 from Lake Hamagiku and Lake Naga (Figure 4.6e) confirms the coherence in these two records, indicating strong periodicity between 2250–750 cal. yr BP of 256–512 years, and more recently, from 500–200 cal. yr BP, a periodicity of around 128 years. If the shift in the diatom record at Lake Hamagiku between the secondary taxa *N. gregaria* and *C. antarctica* to the dominant *H. australis* at 1800 cal. yr BP represents a change in temperature, it is possible that the fluctuations of these secondary species also reflects subtle fluctuations in temperature, and associated changes to specific conductivity and ice cover.

It has been suggested that for lakes with seasonal ice cover, diversity and productivity will increase in years with a longer ice-free season (Douglas & Smol, 1999). Diatom diversity is expected to increase with an increase in the duration of the ice-free season, but large changes in diversity are not observed at these sites over the 3000 year records. It is possible that temperature change is not substantial enough to promote notable increases in species diversity, or that the introduction of new species is limited due to limited dispersal mechanisms. The diatom productivity, approximated for valve concentration, does not exhibit large fluctuations over the 3000 years studied, which may reflect other limitations, including nutrient availability at these sites.

Conclusions and future directions

The diatom assemblages archived at Lakes Hamagiku and Naga in the Lützow-Holm Bay are of low diversity yet display fluctuations in overall productivity and in the relative abundances of major species. Both sites record similar levels of variability relating to key species, and an abrupt shift in conditions approximately 1800 years cal. yr BP is identified in both lakes. Temperature is interpreted to be a key driver of variability at these sites, due to its effect on ice cover duration and extent. Due to the strong correlation between temperature in this region and zonal winds in the Southern Hemisphere, the periodicity observed here is tentatively associated with the strength or position of westerly winds.

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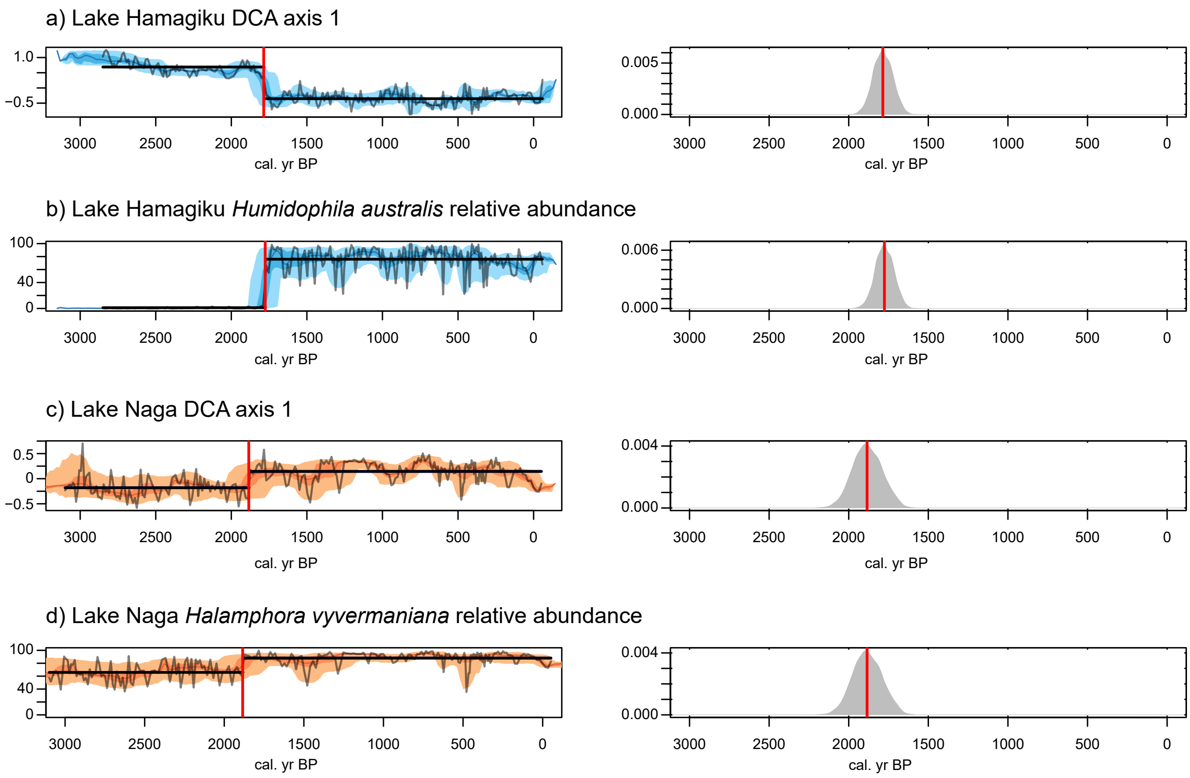
Supplementary table 4.1 Radiocarbon dates and calibrated ages for a) Lake Hamagiku

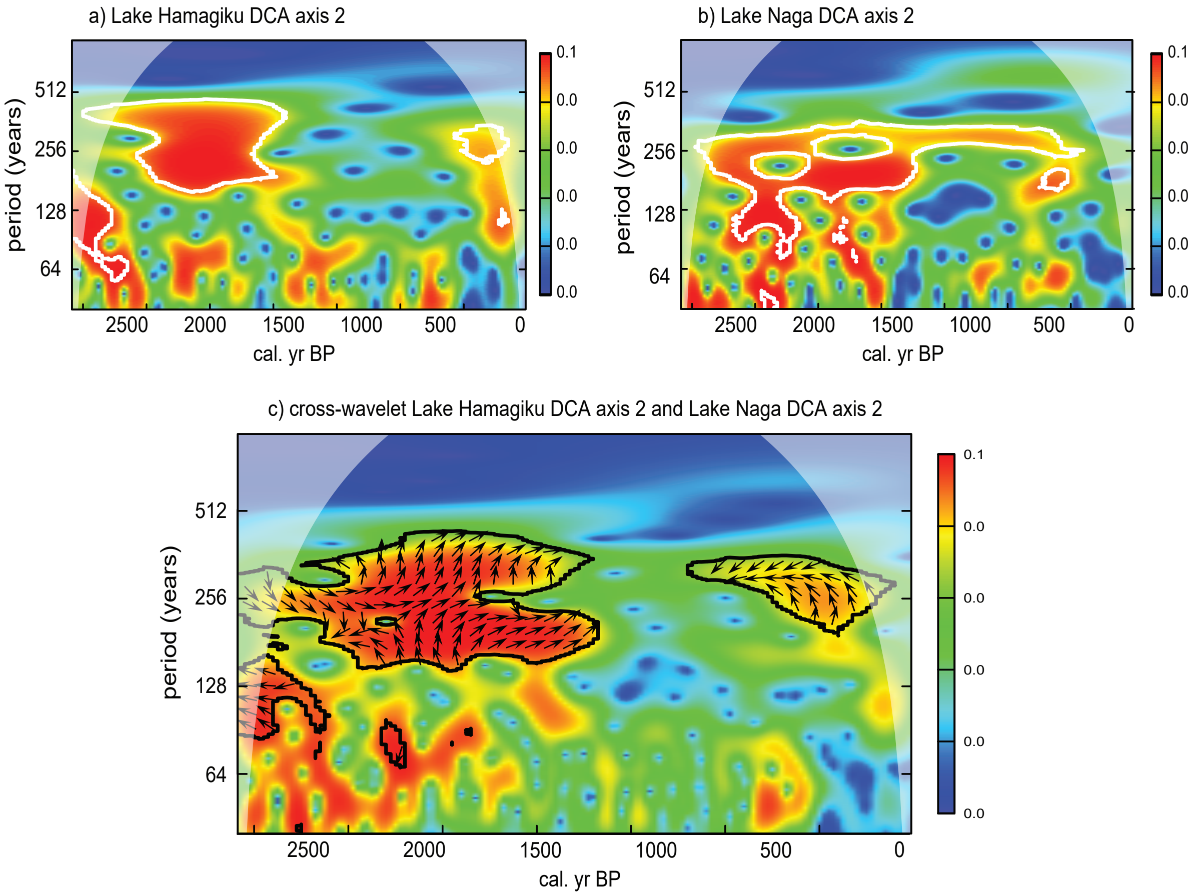
Depth (cm)	^{14}C age (yrs BP)	SD	$\delta^{13}C$ (‰ PDB)	Calibrated ages (cal. yr BP)		Lab code
				Age range	Weighted mean	
4.5	210	40	-17.9	-49–244	103	Beta-255053
10.5	300	30	-17.3	96–357	275	Beta-387423
16.5	360	30	-18.2	307–428	362	Beta-387424
22.5	340	30	-19.9	397–486	441	Beta-387425
25.5	480	30	-19.3	445–528	490	Beta-315377
31.5	660	30	-19.4	545–643	592	Beta-387426
37.5	770	30	-18.4	634–729	680	Beta-387427
43.6	895	45	-	712–885	784	UT-AMS#12-071114
49.5	1060	30	-19.8	822–1022	921	Beta-387428
55.5	1210	30	-18.0	985–1172	1071	Beta-387429
58.5	1320	30	-17.6	1072–1233	1149	Beta-318040
67.5	1420	30	-18.0	1220–1371	1303	Beta-387430
77.5	1670	30	-17.7	1436–1595	1524	Beta-387431
82.5	1800	50	-18.3	1559–1736	1647	Beta-223650
90.5	1920	30	-18.6	1740–1947	1831	Beta-387432
100.5	2300	30	-17.7	2119–2321	2220	Beta-390637
105.5	2330	30	-16.9	2209–2427	2318	Beta-318041
115.5	2560	30	-17.0	2443–2724	2582	Beta-390638
126.5	2790	40	-17.6	2754–2967	2838	Beta-219369

Supplementary table 4.1 Radiocarbon dates and calibrated ages for b) Lake Naga

Depth (cm)	^{14}C age (yrs BP)	SD	$\delta^{13}C$ (‰ PDB)	Calibrated age (cal. yr BP)		Lab code
				Age range	Weighted mean	
2.5	120	30	-24.0	-60–103	17	Beta-315376
12.5	310	30	-24.5	152–396	265	Beta-390639
22.5	460	30	-23.9	328–490	409	Beta-390640
27.5	400	35	-	379–529	466	UT-AMS#10
37.5	740	30	-23.0	568–714	642	Beta-390641
48.0	1050	40	-25.4	796–1026	898	Beta-223649
58.5	1300	30	-22.4	1077–1271	1189	Beta-390642
68.5	1670	30	-23.9	1405–1609	1507	Beta-318038
83.5	1910	125	-	1747–2076	1923	UT-AMS#11
88.5	2160	30	-22.9	1985–2203	2084	Beta-390643
98.5	2340	30	-22.2	2220–2477	2348	Beta-390644
108.5	2600	30	-20.7	2490–2808	2658	Beta-318039
118.5	2820	30	-22.3	2777–2990	2871	Beta-390645
130.5	3090	30	-21.6	2919–3293	3094	Beta-390646
132.5	2840	40	-22.2	2941–3321	3121	Beta-219368



Supplementary figure 4.1 Most significant change point in a) Lake Hamagiku DCA axis 1 b) Lake Hamagiku *Humidophila australis* relative abundance c) Lake Naga DCA axis 1 d) Lake Naga *Halamphora vyvermaniana* relative abundance.



Supplementary figure 4.2 Wavelet analysis of a) Lake Hamagiku DCA axis 2 b) Lake Naga DCA axis 2 c) cross wavelet Lake Hamagiku DCA axis 2 and Lake Naga DCA axis 2

CHAPTER 5

Rudd, R.C., Tyler, J.J., Tibby, J., Yokoyama, Y., Fukui, M. & Takano, Y.
Stable lake productivity throughout the late Holocene inferred from organic carbon and nitrogen isotopes in two East Antarctic lakes

Supplementary information concerning this chapter follows the text. Data tables concerning this chapter are provided in Appendix 2.

Statement of Authorship

Title of Paper	Stable lake productivity throughout the late Holocene inferred from organic carbon and nitrogen isotopes in two East Antarctic lakes
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Principal Author

Name of Principal Author (Candidate)	Rachel Rudd		
Contribution to the Paper	Preparation and analysis of samples for isotope analysis, statistical analysis, figure production, manuscript preparation and editing.		
Overall percentage (%)	90		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	21/11/2019

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Jonathan Tyler		
Contribution to the Paper	Provided guidance and assistance in data analysis, interpretation and manuscript editing		
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Contribution to the Paper	Provided guidance and assistance in data analysis, interpretation and manuscript editing		
Signature		Date	21/11/2019

Name of Co-Author	Yusuke Yokoyama		
Contribution to the Paper	Assisted in the acquisition of radiocarbon data		
Signature		Date	15/11/2019

Name of Co-Author	Manabu Fukui		
Contribution to the Paper	Provided sample material, onsite chemical data acquisition for water profile during the field survey at Skarvsnes.		
Signature		Date	23-Oct-2019

Name of Co-Author	Yoshinori Takano		
Contribution to the Paper	Provided sample material and conducted preliminary bulk carbon ($^{14}C/^{12}C$, $^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) isotope analysis of 15 samples, elemental data analysis, and created core archives during the field survey at Skarvsnes.		
Signature		Date	23-Oct-2019

Stable lake productivity throughout the late Holocene inferred from organic carbon and nitrogen isotopes in two East Antarctic lakes

Abstract

Lake primary productivity is a significant palaeoecological indicator as it is determined by multiple climate and environmental signals. Changes in primary production are a key part of ecosystem dynamics, especially in remote environments such as the ice-free areas in coastal Antarctica. This study uses carbon and nitrogen elemental concentrations and isotope ratios to investigate changes in aquatic productivity from two lakes in Lützow-Holm Bay, East Antarctica. In these records, the short-term variability exceeds any observable long-term trends over the past 3000 years. On average, Lake Hamagiku has higher $\delta^{13}C$ values and higher total organic carbon concentrations than Lake Naga, interpreted to reflect either greater productivity as the result of a longer ice-free duration due to the size of the lake, or changes in the ratio of mosses relative to cyanobacteria and algal material in these sediments. Both lakes have similar $\delta^{15}N$ and low nitrogen concentrations, resulting in high C:N values. These results are interpreted in conjunction with the diatom records presented in Chapter 4 of this thesis, to test hypotheses surrounding diatom assemblage changes through time. The limited nitrogen and phosphorus concentrations in these lakes is interpreted to be a key control on primary productivity, and to have limited any significant increases in productivity over the late Holocene. Changes in lake productivity did not coincide with changes in diatom species assemblage, although the factors controlling overall productivity and diatom productivity remain unclear.

Introduction

Changes in aquatic primary productivity reflect changes in nutrient availability, light availability and temperature. This is particularly relevant in high latitude lakes, where temperature, in conjunction with wind strength and lake size, determines the duration of ice-free conditions which in turn have consequences for nutrient cycling and light availability. Measurements of bulk organic carbon and nitrogen concentrations in lake sediments and their associated stable isotope ratios are one method by which insights into productivity can be gleaned (Meyers & Teranes, 2001). These methods have been shown globally to provide insight into past climate via changes in lake and catchment productivity and element cycling (Meyers & Teranes, 2001; Leng *et al.*, 2005).

Geochemical studies of water and sediment are common in the McMurdo Dry Valleys, the largest ice free region in Antarctica (eg. Noon *et al.*, 2002; Healy *et al.*, 2006; Hopkins *et al.*, 2006). Stable isotopes have been used in this area to track water movement (Noon *et al.*, 2002), understand the origin and cycling of soil organic matter (Burkins *et al.*, 2000; Hopkins *et al.*, 2006; Faucher *et al.*, 2017) and study the geochemistry and stratification of ponds (Healy *et al.*, 2006). However, geochemical studies of lake sediments to infer past environmental change in Antarctica are few.

Wharton *et. al* (1993) and Lawson *et al.* (2004) studied lakes in the Taylor Valley, one of the McMurdo Dry Valleys, to characterise organic matter transformations for use in future palaeoenvironmental studies. Both studied Lake Hoare and Lake Fryxell, while Lawson *et. al* (2004) also studied East Lake Bonney and West Lake Bonney. These lakes had permanent ice cover across much of the lake surface area, and it was found that the sediment of the seasonally exposed moat region had higher $\delta^{13}C$ and occasionally lower $\delta^{15}N$. Lake Hoare was found to be depleted in ^{15}N, attributed to low rates of organic decomposition (Wharton *et al.*, 1993). During a year in which larger moats formed due to ice melt, $\delta^{13}C$ values were lower in the benthic organic matter, attributed to turbidity induced light limitation or increased aquatic CO_2 concentrations (Lawson *et al.*, 2004).

In Lützow-Holm Bay, changes in productivity have been inferred to have a significant effect on $\delta^{13}C$ values, while TOC values reflect overall productivity as well as changes to sediment composition including increases in aquatic mosses relative to algae and cyanobacteria

(Matsumoto *et al.*, 2010; Takano *et al.*, 2012). Interpretations of bulk organic matter geochemistry are challenged by the unknown mixing of terrestrial and aquatic organic matter in most systems, although in Antarctic lake systems this uncertainty is negligible as the catchments are mostly organic matter free. Matsumoto *et al.* (2006) examined organic components from lake sediments covering 2330 years at Ô-ike on West Ongul Island, and 1550 years at Lake Namazu in the Skarvsnes region. High organic content was reported at Lake Namazu, and an increase in the total organic carbon (TOC) to total nitrogen (TN) ratio occurred at approximately 1100 years BP, interpreted as an increase in aquatic moss at this time. Matsumoto *et al.* (2010) report a 7000 year long record of lake sediment change from Lake Skallen Oike in the Skallen region, where the principal environmental change was the transition from marine to lacustrine conditions at around 3590 cal. yr BP. Biological productivity increased by more than eight times following this transition. Takano *et al.* (2012) used a fossil diatom record in conjunction with stable isotope records to track the environmental change associated with the marine to lacustrine transition in Lake Skallen in the Skallen region and Lake Oyako in the Skarvsnes region.

Lake Hamagiku and Lake Naga are two freshwater lakes in the Skarvsnes region of Lützow-Holm Bay in East Antarctica. A study of the fossil diatom records of these two lakes (Chapter 4 of this thesis) found both records to have low species diversity and variations in relative abundances over decadal-centennial timescales. Both lakes exhibit coherent periodicities in their fossil diatom assemblages at varying wavelengths. The study identified a statistically significant change point in the fossil diatom assemblages of both lakes at around 1800 cal. yr BP, after which a single species became dominant in the diatom assemblage at each site. Several hypotheses are proposed to explain changes in both the short and long term variability in diatoms species, including changes in wind strength and temperature in the region. One hypothesis relates to changes in nutrient cycling and productivity in the lakes, as a result of temperature, ice cover and ice-related disturbance of littoral sediments. This study aims to develop a record of lake palaeoproductivity using organic carbon and nitrogen elemental and isotope ratios at Lake Hamagiku and Lake Naga. The geochemical record is used to compliment the diatom records presented in chapter 4, and to constrain the interpretation of lake environmental change through the last 3,000 years. In particular, we test the occurrence of a shared change point at approximately 1800 cal. yr BP and a shared ~250 year periodicity, as recorded in the diatom species. Detailed records of carbon and nitrogen concentrations and stable isotope ratios have not previously been developed in this region, so this study also provides an opportunity to understand the dynamics of lake chemistry and productivity over decadal-centennial timescales.

Methods

Sample collection and age modelling

The sample collection and age modelling used in this study is presented in Chapter 4 of this thesis. The Lake Hamagiku (Ab5S) and Lake Naga (Ng5S) sediment cores were collected in January 2006 during the 47th Japanese Antarctic Research Expedition, using a piston-operated coring device (Figure 5.1).

The chronologies for Lake Hamagiku and Lake Naga consist of 19 and 15 radiocarbon dates respectively, all from bulk organic material. Samples were prepared with an acid-alkali-acid treatment before being converted to graphite following Yokoyama *et al.* (2007), and then analysed by accelerator mass spectrometry at the University of Tokyo or at Beta Analytic, Inc. (Miami, FL, USA). Radiocarbon ages were calibrated to calendar years using BACON (Blaauw & Christen, 2011) using R (R Core Team, 2018), combined with the Southern Hemisphere atmospheric calibration curve (Hogg *et al.*, 2013). The uppermost sediments were constrained using a coring date of -56 years before present (AD 2006). Radiocarbon dates and calibrated ages are provided in Supplementary Table 4.1 (following Chapter 4). The uncertainty regarding the orientation of some samples in the uppermost section of the Lake Hamagiku core is consistent with previous chapters. This section is interpreted with some caution and in figures, all data is plotted in the order that is most likely to be correct.

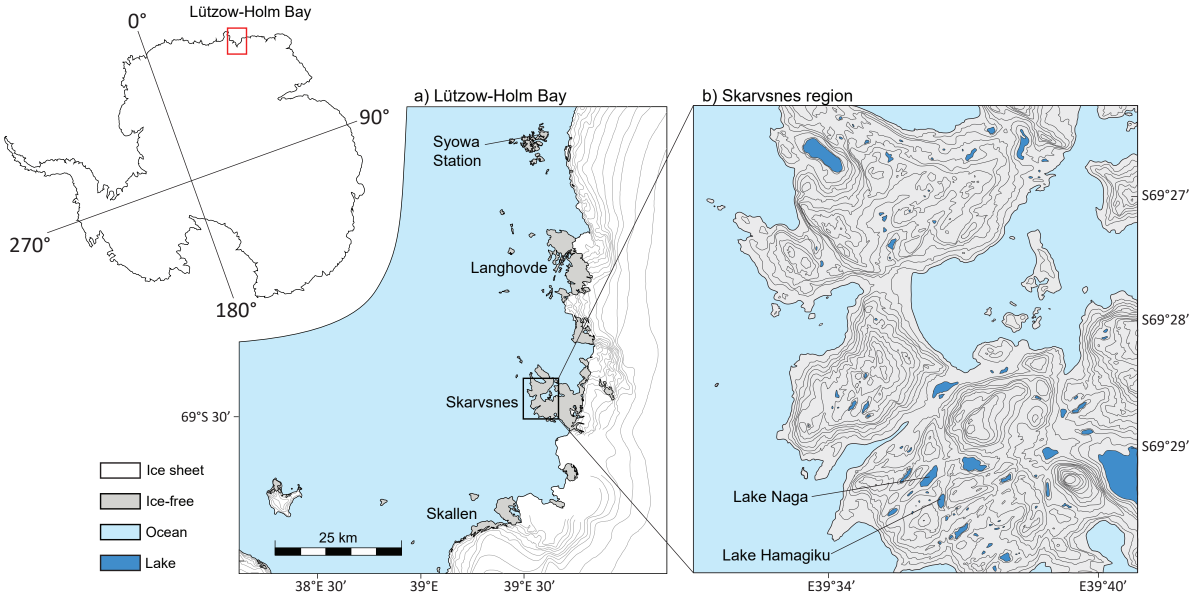

Figure 5.1 Location of Lützow-Holm Bay in East Antarctica a) Syowa Station and the Skarvsnes region, b) study sites in the Skarvsnes region, Lake Hamagiku and Lake Naga, maps adapted from a Geographical Survey Institute map (Geospatial Information Authority of Japan, 1987) and Takano et al. (2012). Contour intervals for the ice sheet in a) are 100m and for the ice free region in b) is 10m

Geochemical analyses

Total organic carbon (TOC) and total nitrogen (TN) percentages as well as carbon and nitrogen isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) were determined for 232 contiguous samples for Lake Hamagiku, and 236 contiguous samples for Lake Naga, corresponding to the samples used for fossil diatom analysis in Chapter 4. The Lake Naga sediments were suspected to contain small amounts of carbonates, due to a fizzing reaction during the acidification step of the diatom preparation for Chapter 4, so samples for stable isotope analysis were prepared twice each, once with an acid pre-treatment and once without. All samples were freeze dried and ground to a homogenous powder prior to analysis. Samples for acid pre-treatment were weighed into silver capsules, then acidified using the acid-fumigation method, where approximately 50 μL of deionised water was added to each capsule, and the samples were left in a vacuum desiccator with concentrated hydrochloric acid vapour for up to four hours, before being left to dry overnight in a 40°C oven (Harris, Horwáth & Van Kessel, 2001). All samples were combusted in a EuroVector EuroEA elemental analyser, in-line with a Nu Instruments Nu Horizon CF-IRMS at the University of Adelaide. Samples were corrected using two-point drift, size, and isotope corrections with internal standards Glycine (C: -31.2, N: +1.32, C:N=2) and Glutamic Acid (C: -16.7, N: -6.18, C:N=5), and a QC standard TPA (triphenylamine - C: -29.2, N: -0.54, C:N=18). All internal standards were calibrated to international standards; USGS 40 and 41, IAEA CH-6, NBS 22 and 24 for carcbon isotopes; IAEA N1, N2, and NO3, and USGS 25, 32, 40 and 41 for nitrogen isotopes. All carbon and nitrogen isotope ratios are expressed on the delta scale ($\delta^{13}C$ and $\delta^{15}N$) to per mille (‰) relative to VPDB and AIR, respectively. Most samples from the lakes contained very low TN, and some $\delta^{15}N$ values are not presented here due to large errors in measurement as a result of the small samples size. 11 samples were lost during analysis, and as such no data is reported at Lake Naga between 615 and 750 cal. yr BP for TOC, $\delta^{13}C$ and C:N. There were only small differences observed between the samples which had an acid pre-treatment and those which did not, particularly for the Lake Hamagiku sedimetns, so the data presented here is a combination from both treatment groups for both lakes. $\delta^{13}C$ and TOC are reported from the acid-treated samples, and $\delta^{15}N$ and TN from the samples without acid-treatment due to potential for changes to these values during acidification (Harris *et al.*, 2001). Molecular C:N ratios for each lake were calculated using the TOC from the acid-treated samples and the TN from the samples without acid-treatment.

Statistical analysis

To test for shared frequencies of variability in the records from these lakes, wavelet power spectrums were computed for carbon and nitrogen concentrations and $\delta^{13}C$ values for each lake. Wavelets were not calculated for the $\delta^{15}N$ records, due to the sparse nature of the data as a result of the limited nitrogen content of the samples. Data was linearly interpolated to a period of 20 years, as the records have an average of 1 sample every 12 years. Wavelet analyses were conducted using the WaveletComp package (Roesch & Schmidbauer, 2018) in R, with a

Morlet wavelet and a significance level of 0.05.

As change points were identified in the fossil diatom assemblages at these sites, probabilistic change point analyses were also conducted on the records presented here. This change point analysis was not conducted on the nitrogen isotope records, due to the irregularity of the dataset. Probabilistic change point analysis was performed using unpublished code by Jonathan Tyler, adapted from the changepoint package (Killick & Eckley, 2014) in R, as per Tibby *et al.* (2018). The change point analysis was set to identify five change points in each record, and the minimum segment length was set to five samples in order to avoid single high or low samples from determining the results, and to identify sustained changes to the records. In order to visualise the time uncertainty of these change points, probability density functions were created by constructing an ensemble of 2000 chronologies for each lake using Bacon (Blaauw & Christen, 2011).

Results

Sediment description and chronology

The sediments of Lake Hamagiku and Lake Naga consist of laminated algal biofilm, with some mosses and occasional sand grains in the organic material. The sediments are green to grey in colour, and there is very little visible change in sedimentology observed in the cores throughout their length.

The radiocarbon dates for each core fall in stratigraphic order, with no indications of age reversals in the measurement and calibration error (Figure 5.2). Both lakes appear to have a relatively constant sediment accumulation rate, of approximately 40cm per 1000 years, with the Lake Hamagiku core extending to 2800 cal. yr BP and Lake Naga to 3100 cal. yr BP. There is a small reversal in the oldest two radiocarbon dates of the Lake Naga core (Figure 5.2b), which has a minimal effect on the model. Refer to Chapter 4 of this thesis for more detail on the chronology of these cores.

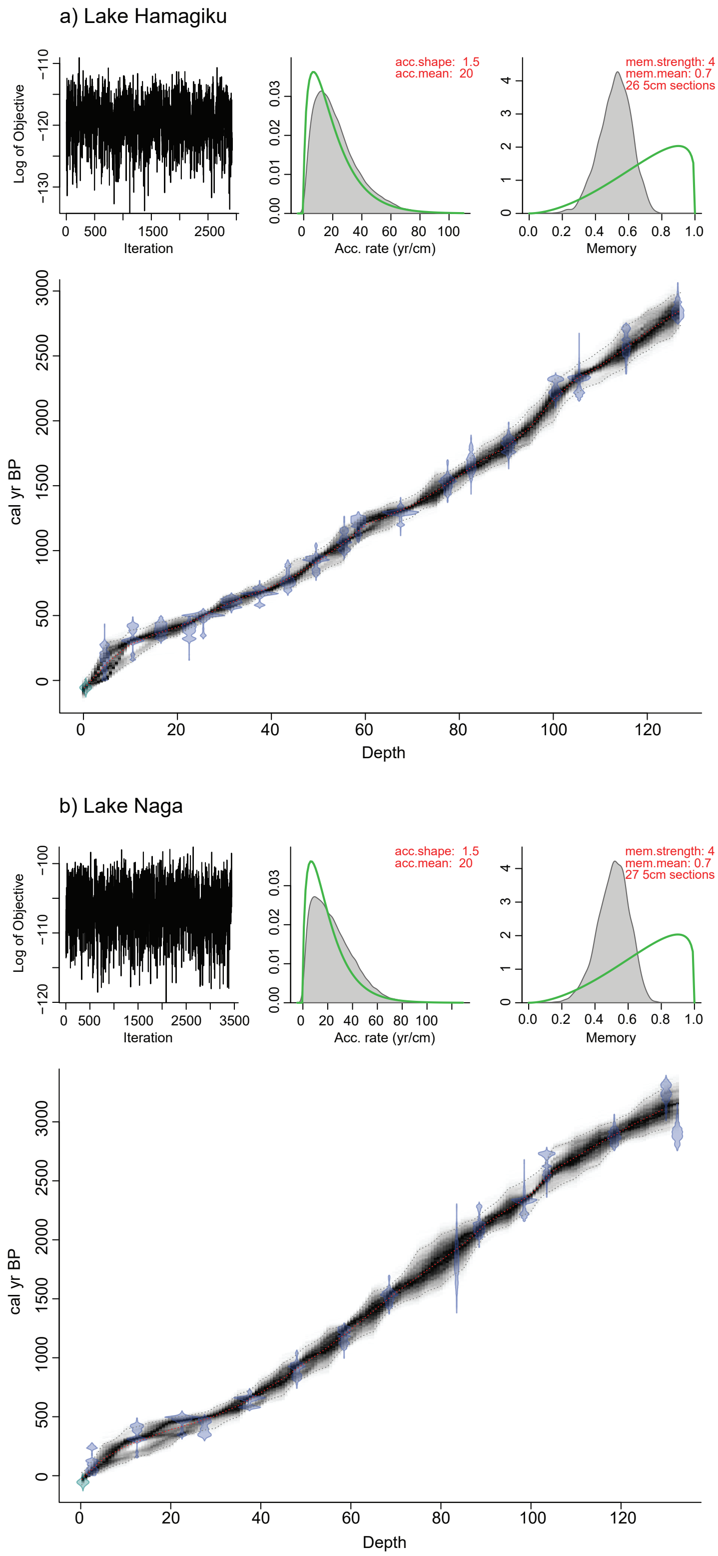

Figure 5.2 Age model for the a) Lake Hamagiku and b) Lake Naga sediment cores. Upper panels indicate the iterations performed, accumulation rate and memory used to construct the model. Lower panels show probability density functions for each calibrated age are shown in blue, the grey curve indicates the age–depth model and the red curve is the best fit model.

Geochemistry of lake sediments

LAKE HAMAGIKU

TOC in the sediment core from Lake Hamagiku ranges from 2 to 17%, with fluctuations between these values (Figure 5.3). TN concentrations are low throughout the record, ranging from 0 to just over 1.5%, fluctuating between these values and no long-term trend is discernible over this timescale. There are several local maxima, where TN reached over 1.5% at 300, 1300 and 1750 cal. yr BP. The sediment C:N ratios range from 5 to 33, and a small, long term decreasing trend is observed from the oldest to the most recent sediments. Fluctuations in C:N are small during much of the record, but with periods of higher variability and some increased values, at around 200, 1500 and 2200 cal. yr BP. $\delta^{13}C$ values range between -22‰ to -15‰, and $\delta^{15}N$ values range from around 0‰ to just over 2‰ at various points in the record. There is no discernible long-term trends in these data.

LAKE NAGA

The TOC in the Lake Naga sediments ranged from 0 to 10%, slightly lower than the range observed at Lake Hamagiku where some samples exceed 15% TOC (Figures 5.4 and 5.5). The range of TN is small, with most values falling between 0 and 1%, but with one peak of just over 1% at around 2600 cal. yr BP. For most of the record, these values are smaller than those observed for Lake Hamagiku (Figure 5.5). The C:N ratio for much of the Lake Naga record ranges from 5 to 20 (Figure 5.4), although values of over 30 were measured from sediments aged between 1000 and 1500 cal. yr BP, and again at around 4300 cal. yr BP with C:N ratios of 25. There are also several lower values, between 0 and 5, at around 350 and 1500 cal. yr BP. Variations in $\delta^{13}C$ at Lake Naga (Figure 5.4) do not appear to fluctuate as much as the Lake Hamagiku record over decadal to centennial timescales. Instead, there appears to be a longer

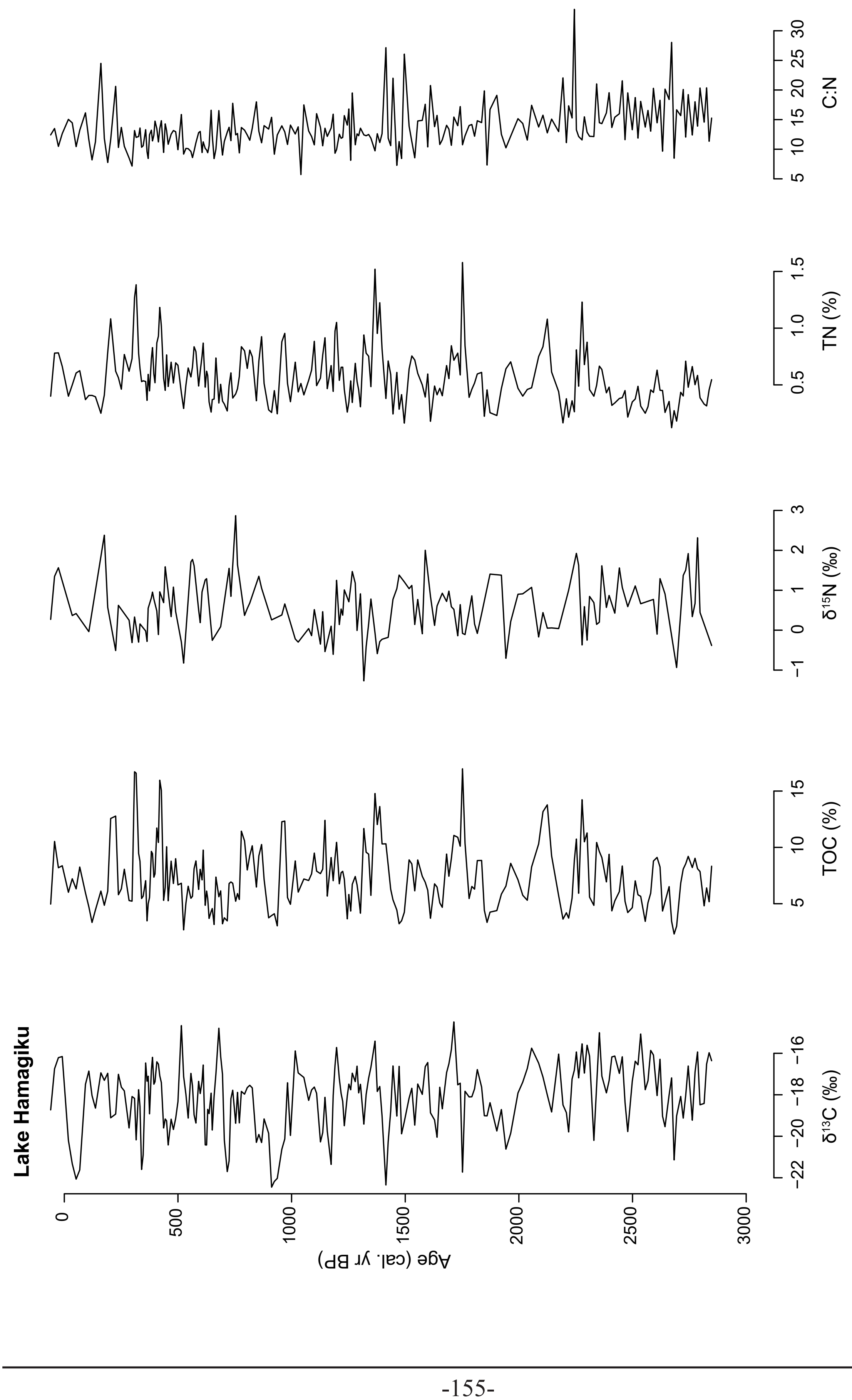

Figure 5.3 $\delta^{13}C$, total organic carbon (TOC), $\delta^{15}N$, total nitrogen (TN) and C:N ratio in the Lake Hamagiku core.

time-scale trend to these data, with values of around -25‰ in the oldest part of the record at ~3100 cal. yr BP, increasing to around -18‰ at ~2500 cal. yr BP, and then decreasing again to -25‰ at around 1700 cal. yr BP. There is another small increase in $\delta^{13}C$ at around 1000 cal. yr BP, whilst $\delta^{13}C$ in the most recent sediments decrease again to around -25‰, with the exception of a local maximum in $\delta^{13}C$ of -19‰ at around 400 cal. yr BP. $\delta^{13}C$ ranges from -26‰ to -15‰, with the mean and range of the data lower than that of Lake Hamagiku (Figure 5.5). $\delta^{15}N$ values range from -2‰ to almost 3‰ in this record. Values are mostly higher during the earlier part of the record, and fluctuations become more pronounced in the more recent half of the core, with large decreases in $\delta^{15}N$. The $\delta^{15}N$ range for Lake Naga is quite similar to the range of Lake Hamagiku values (Figure 5.5).

Statistical analysis and comparison to diatom data

Wavelet analysis of the Lake Hamagiku and Lake Naga organic geochemical data exhibits periodicities ranging from just below 64 years to over 256 years in wavelength (Figure 5.6). For the $\delta^{13}C$ record at Lake Hamagiku (Figure 5.6a), there is very little sustained periodicity through the record. There are smaller timeframes in which periodicity is identified, the strongest and most sustained of which is ~1400–700 cal. yr BP with a wavelength of between 128 and 256 years. There is another shorter timeframe periodicity of around 256 years from 2300 to 1900 cal. yr BP, and two periods of 128 year wavelength at 1700 and 500 cal. yr BP.

The Lake Naga $\delta^{13}C$ record (Figure 5.6b) exhibits periodicity over multiple timescales from 2800 to 1500 cal. yr BP, the most sustained of which has a wavelength of just over 256 years. There is no significant periodicity between 1500 and 800 cal. yr BP. There is a periodicity identified between 800 and 500 cal. yr BP, although the wavelength is not well defined, and is between 64 and 200 years.

The wavelet analysis of Lake Hamagiku TOC (Figure 5.6c) exhibits sustained periodicity from 2500 to 1000 cal. yr BP of around 256 years in wavelength, and from 1000 to 0 cal. yr BP

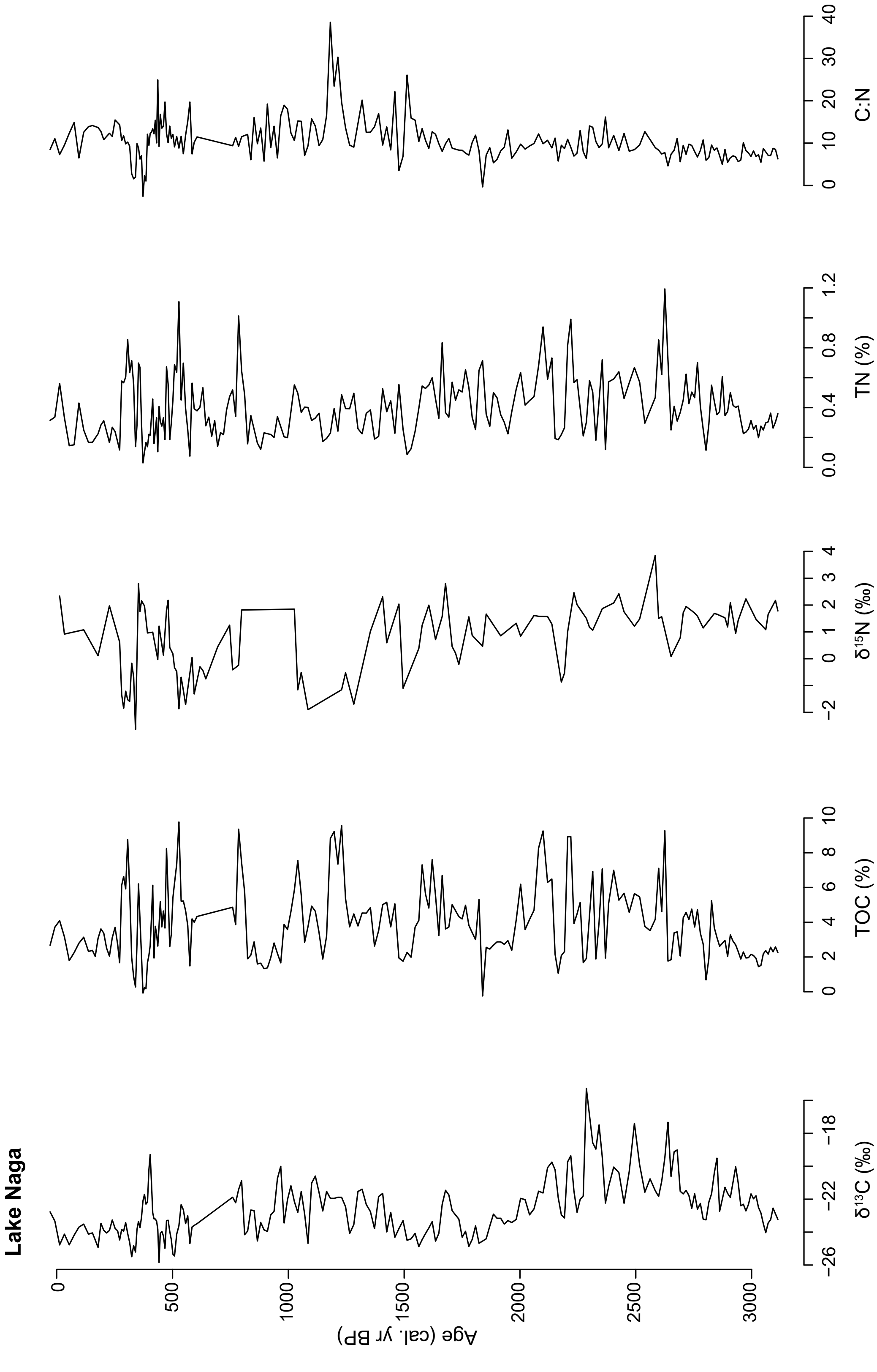

Figure 5.4 $\delta^{13}C$, total organic carbon (TOC), $\delta^{15}N$, total nitrogen (TN) and C:N ratio in the Lake Naga core.

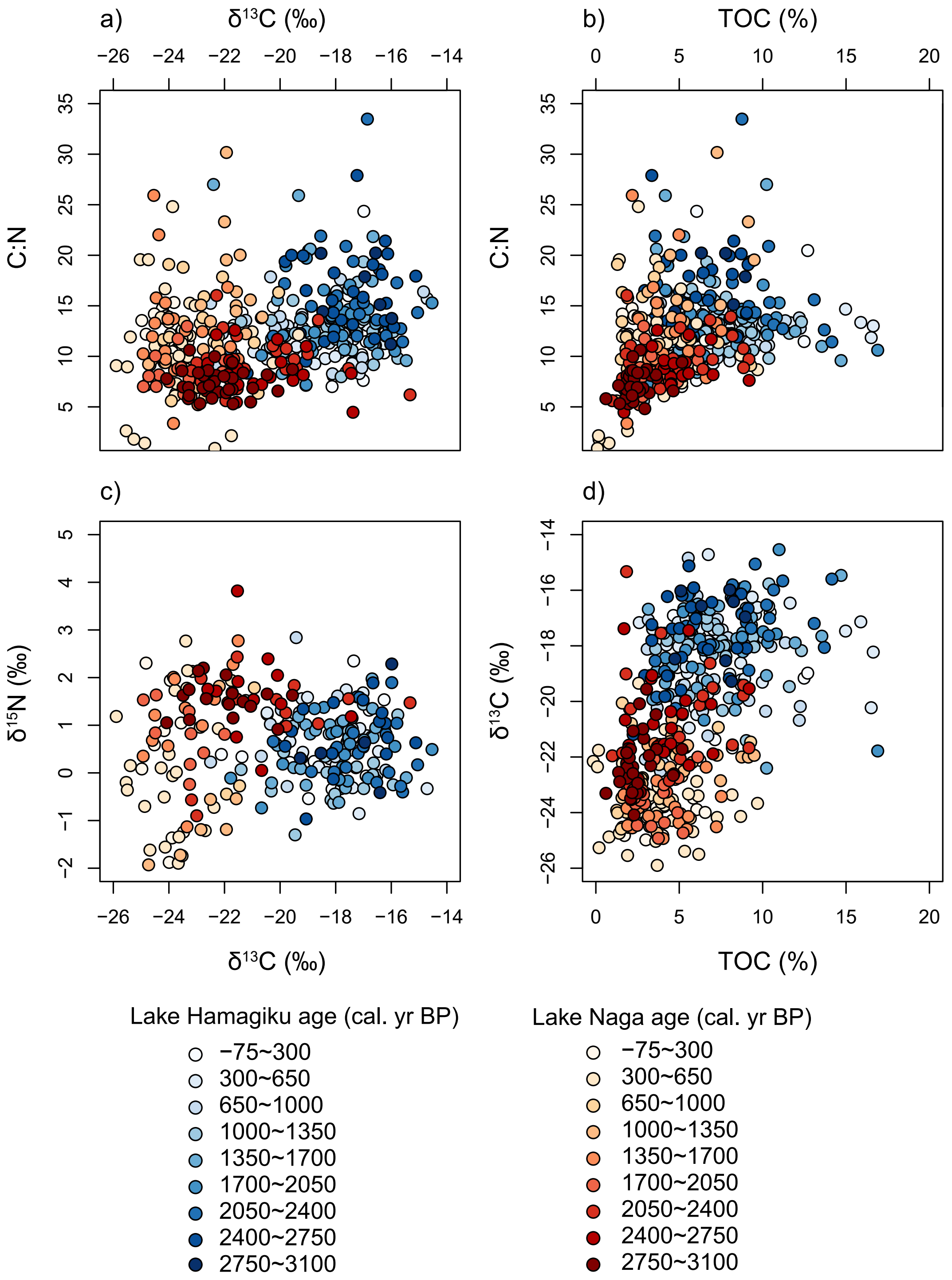

Figure 5.5 a) C:N ratio vs. $\delta^{13}C$ in core samples from both lakes b) C:N ratio vs. TOC% in core samples from both lakes c) $\delta^{15}N$ vs. $\delta^{13}C$ in core samples from both lakes d) $\delta^{13}C$ vs. TOC% in core samples from both lakes. Colours of points indicate the lake and age of the sample analysed as shown in the legend.

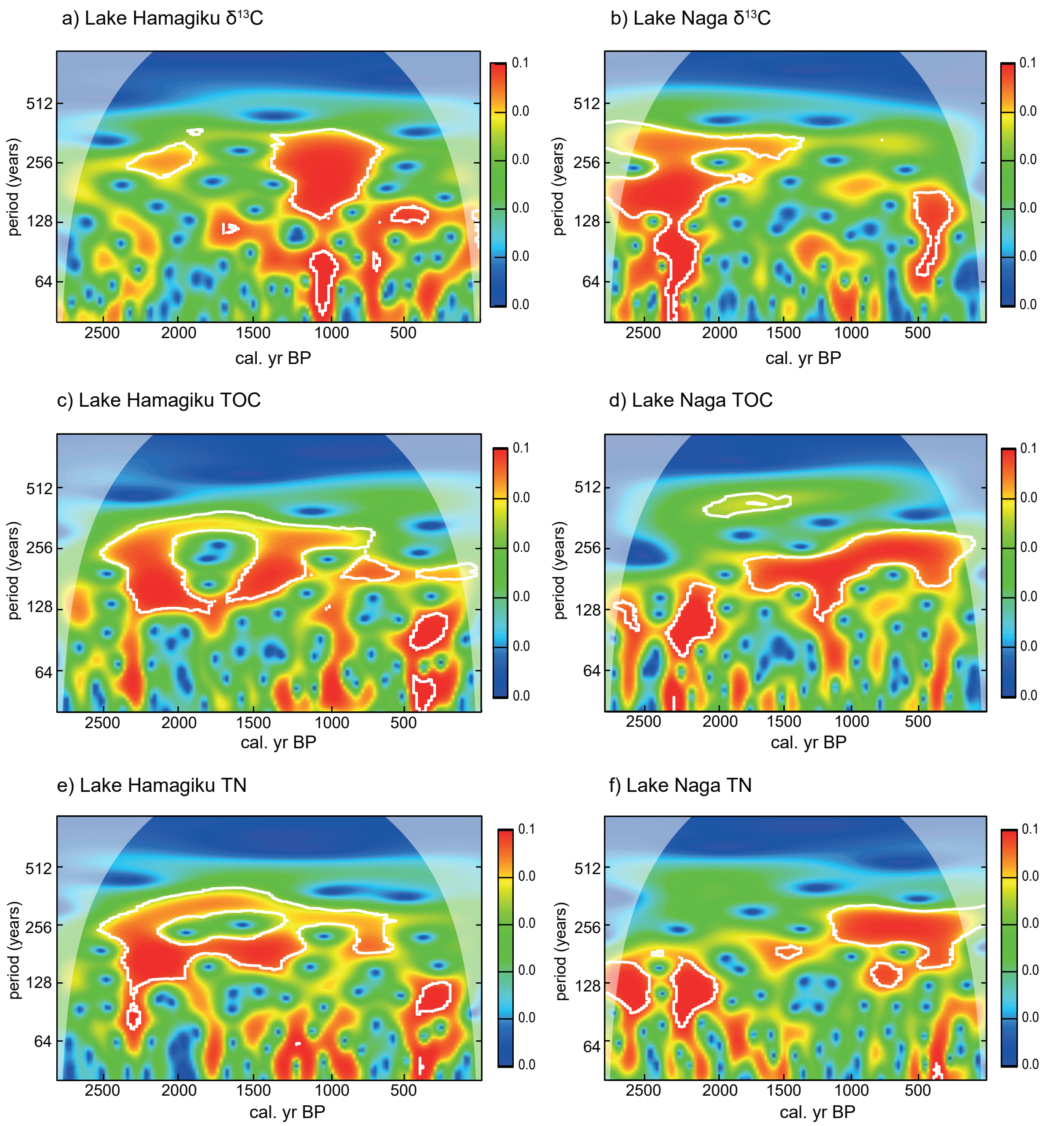

Figure 5.6 Wavelets of lake sediment core data a) Lake Hamagiku $\delta^{13}C$ b) Lake Naga $\delta^{13}C$ c) Lake Hamagiku total organic carbon (TOC) d) Lake Naga total organic carbon (TOC) e) Lake Hamagiku total nitrogen (TN) f) Lake Naga total nitrogen (TN).

of closer to 200 years in wavelength. There are also periods of smaller wavelength periodicity identified, from 2300 to 1200 of closer to 128 years wavelength, and from 500 to 200 cal. yr BP of variable wavelengths up to 128 years.

The Lake Naga TOC wavelet diagram (Figure 5.6d) shows a strong periodicity sustained from 1900 to 400 cal. yr BP of just less than 256 years earlier in the record, moving to around 256 years in the more recent sediments. There are also two shorter periods of periodicity from 2800 to 2600 and 2400 to 2100 cal. yr BP with a wavelength of close to 128 years.

The Lake Hamagiku TN record (Figure 5.6e) exhibits similar periodicities to that of TOC at the same site (Figure 5.6c). There is sustained periodicity observed between 2500 and 500 cal. yr BP of ~256 years, with some shorter wavelength periodicity also observed during this time. In the more recent sediments, 500–200 cal. yr BP, the observed periodicity is of a shorter wavelength of less than 128 years.

The Lake Naga TN record (Figure 5.6f) also exhibits similarities to the wavelet of TOC at Lake Naga (Figure 5.6d). The wavelength of the periodicity identified is shorter in the older sediments, around 128 years between 2800 to 2500 cal. yr BP and 2400 to 2000 cal. yr BP. In the younger sediments, there is sustained periodicity from 1300 to 0 cal. yr BP of ~256 years.

The change points identified in the records (Supplementary figures 5.2 and 5.3) are largely inconsistent between the individual records of each site, with the exception of some in the TOC and TN. The change points identified are also not consistent between the two lakes. With the exception two small changes in $\delta^{13}C$ and TOC % at Lake Hamagiku, most records do not exhibit any change points near the timing of those identified in the fossil diatom records. The major diatom taxa from the fossil diatom records in Chapter 4 are plotted against the organic geochemical data in Supplementary figures 5.4 and 5.5. There are very low correlations observed between these variables.

Discussion

The concentrations and stable isotope ratios of carbon and nitrogen in the sediments of other lakes in Lützow-Holm Bay have previously been used to track the isolation of lake basins from the ocean, and increases in productivity have been interpreted from these proxies across these transitions (Matsumoto *et al.*, 2010; Takano *et al.*, 2012). Few studies have analysed these components over decadal-centennial timescales for the purposes of assessing environmental change in this region. The geochemical results presented in this study are highly variable over short timescales, and long-term trends are difficult to distinguish.

Interpretation of TOC, C:N, $\delta^{13}C$ and $\delta^{15}N$ at Lake Hamagiku and Lake Naga

The concentration of TOC in a sediment core records a balance between initial production, and the degree of degradation (Meyers & Teranes, 2001; Leng *et al.*, 2005). The range of TOC values observed along the Lake Hamagiku core is slightly higher than those observed in the Lake Naga core, suggesting either greater productivity at Lake Hamagiku, or alternatively, better preservation. These differences in productivity may be a result of the morphological differences between the two lakes. Lake Hamagiku has a smaller lake surface area than Lake Naga, and a longer ice-free season as a result, increasing the duration of light penetration to the lake floor. Lake Hamagiku is also shallower than Lake Naga (Lake Hamagiku is at maximum 4 m deep, while Lake Naga is 10 m deep), which is likely to allow for a greater light intensity to the lake floor, promoting productivity in these sediments.

C:N ratios can be used to distinguish sources of organic matter, whether terrestrial or aquatic, corresponding to algae and vascular plants (Meyers & Lallier-Vergès, 1999; Meyers & Teranes, 2001). In these lakes, terrestrial contributions to the lake sediments are expected to be minimal, such that the lake sediments archive processes and productivity within the lakes, and are primarily aquatic in origin. Algal source material is expected to have C:N values less than 10

(Meyers & Lallier-Vergès, 1999; Meyers & Teranes, 2001), yet the values for these sediments range from 5-33 at Lake Hamagiku and 5-20 at Lake Naga. Matsumoto *et al.* (2010) report a C:N range of 5-15 at Lake Skallen, and Matsumoto *et al.* (2006) report 10-20 for Lake Namazu, and 8-13 for Ô-ike. Takano *et al.* (2012) report a narrow range of 8-12 at Lake Skallen, and similar values for Lake Oyako (8-11). These ranges are comparable to those observed at Lake Naga, yet the values for Lake Hamagiku are slightly larger at some stages in the core. Higher C:N values than expected were observed by Olsen *et al.* (2013) in late-Holocene lake sediments from Southwest Greenland, and attributed to nitrogen deficiency. Olsen *et al.* (2013) also observed very low $\delta^{15}N$ values of around 0-1‰, similar to the -2 to 3‰ $\delta^{15}N$ values observed at Lake Hamagiku and Lake Naga. It is possible that the low C:N values in Lake Hamagiku and Lake Naga are also due to limited nitrogen in the lake systems. The low $\delta^{15}N$ values are close to that of atmospheric nitrogen, suggesting that nitrogen fixation is the primary source of nitrogen into the lakes. Predominantly benthic algal production may also increase C:N values as nitrogen is preferentially removed from the surface sediments in these nutrient limited lakes (Talbot, 2001; Gibson *et al.*, 2006; Olsen *et al.*, 2013).

The $\delta^{13}C$ values for Lake Hamagiku (-22‰ to -15‰) are also slightly higher than for Lake Naga (-26‰ to -15‰, Figure 5.5). From previous studies in this region and further abroad, changes in productivity have been inferred to have a significant effect on $\delta^{13}C$ values. Due to the preferential removal of ^{12}C by aquatic plants during photosynthesis, the carbon pool of a lake becomes enriched in ^{13}C, and so this may also represent a higher rate of productivity at Lake Hamagiku relative to Lake Naga. $\delta^{13}C$ values were measured for the surface benthic mats of 17 lakes in the Lützow-Holm Bay region by Tanabe *et al.* (2019), which ranged from -28.90‰ at Lake Ougi, to -9.14‰ at Lake Yukidori. Lake Ougi is 2.2 m deep, while Lake Yukidori is 4.5 m deep, with a notable difference in the intensity of photosynthetically available radiation (PAR), and ultraviolet radiation (UV) at the maximum water depth of the two lakes– 121.7 mW/m^2 PAR and 18.1 mW/m^2 UV for Lake Ougi, and 42.0 mW/m^2 PAR and 0.9 mW/m^2 UV at Lake Yukidori (Tanabe *et al.*, 2019). This may indicate that the differences in $\delta^{13}C$ are related to light intensity, with productivity inhibited at Lake Ougi due to the light intensity in the shallow lake. For three of the lakes studied (Nyorai, Maruyama and Tanago), the moss found in the surface sediment, *Leptobryum* sp., was isolated, and $\delta^{13}C$ measurements were found to be between 4 and 7‰ lower than for the bulk surface sediments at the same sites (Tanabe *et al.*, 2019). This suggests that changes in $\delta^{13}C$ values through time may also reflect the amount of aquatic moss relative to cyanobacteria and diatoms within the sediments. Both Lake Naga and Lake Hamagiku (as A-4) were observed to have the two aquatic moss species found in the region, *Bryum pseudotriquetrum* and *Leptobryum* sp. (Imura *et al.*, 2003). The distribution of these mosses in the Lützow-Holm Bay region was compared to the electrical conductivity of the lakes studied, and although both were found across a wide range of conductivities, *Bryum pseudotriquetrum* was observed to be more vigorous in the lower salinity lakes, while *Leptobryum* sp. was not observed in the lakes with lowest electrical conductivity (Imura *et al.*, 2003). These aquatic mosses may have a strong influence on the variability observed in the $\delta^{13}C$ records of these lakes, but to date, significant uncertainties remain concerning the environmental determinants over the abundance of moss in the lakes, the productivity of the moss versus the cyanobacteria and diatoms within the benthic mats, and consequently the impact of that balance on $\delta^{13}C$ in the sediments.

Comparison between organic geochemistry data and diatom relative abundances

Change point analysis of diatom species data from Lake Naga and Hamagiku both demonstrated a shift at 1800 cal. yr BP within age uncertainty. However, this change point was not observed in the geochemistry data described here. The abrupt transition observed in the sediments of Lake Hamagiku with the increase in abundance of *Humidophila australis*, a species associated with lakes of very low salinity in this region and around East Antarctica (Verleyen *et al.*, 2003; Kopalová *et al.*, 2013; Saunders *et al.*, 2015 and Chapter 3 of this thesis), occurs at around 1800 cal. yr BP. The records presented in this chapter for Lake Hamagiku do not appear to change at this time, although soon after, at around 1750 cal. yr BP, there is a local minima of $\delta^{13}C$ to -22‰ and a local maxima in TOC and TN, while the $\delta^{15}N$ values are close to the average value of the record. At Lake Naga, the change point observed in the diatom data was subtle compared to in the Lake Hamagiku records, and was characterised by an increase in relative abundance of *Halamphora vyvermaniana* and an overall decrease of *Navicula gregaria* and *Craticula antarctica*. The $\delta^{13}C$ of the Lake Naga sediment is also low at this time, at around -25‰, although this is not dissimilar to the values throughout the record, and there does not appear to be an associated increase in TOC or TN during this time. This shift is interpreted to be less dramatic at Lake Naga due to the larger size of the lake, insulating it from abrupt changes. The records presented in this chapter exhibit periodicities, which although are not as sustained as in the fossil diatom records presented in Chapter 4, are observed to have comparable wavelengths. It was hypothesised that changes in the diatom assemblage presented in Chapter 4 may be associated with changes to lake productivity, but the records presented in this study do not appear to support this hypothesis.

This study set out to test the hypothesis that the shift in diatom species assemblage at these sites reflected a change in lake productivity, despite the absence of a pronounced increase in diatom concentration. While the $\delta^{13}C$ record suggests changes in lake productivity, there is little to be discerned in terms of overall trends. If overall lake productivity does not show any marked changes through this record, this may be a result of the limited nutrients in the lake systems being recycled within the surface sediments (Gibson *et al.*, 2006; Tanabe *et al.*, 2016), limiting larger increases in overall lake productivity. This might also explain the fairly regular sediment accumulation rate observed in the age models for these sites, as large increases in productivity at these sites would be expected to result in a greater accumulation rate, as most of these sediments are composed of organic material.

Conclusions and future work

The carbon and nitrogen concentrations and stable isotopes reported here exhibit high variability over short timescales. Lake Hamagiku, with a higher range of TOC and $\delta^{13}C$, is interpreted to have greater overall lake productivity than Lake Naga. Both lakes have low nitrogen concentrations, and C:N values are high as a result. These values are comparable to other high latitude lakes. The influence of varying aquatic moss productivity in these lakes is believed to complicate these interpretations, but the drivers of aquatic moss productivity compared to diatom productivity are unclear.

The records presented do not archive a shift to coincide with the change point identified in the diatom records. This is consistent with the diatom valve concentration, which, while also highly variable, does not appear to change at this time. These discrepancies suggest that the changes in diatom species composition were not accompanied by changes to lake productivity, which may not change in a pronounced manner due to the limitations imposed by the low nutrient conditions. The dramatic, synchronous change in diatom species composition may therefore represent a smaller change in lake ecology, and a threshold response, which did not alter the whole lake system.

Bulk measurements of stable isotopes in sediment organic matter such as those presented here have the disadvantage of representing an integrated signal of catchment and in-lake processes, making interpretations complex, although in this case the catchment processes may have less of an impact than in other regions. A useful complement to the bulk sediment results presented here would be to analyse the stable isotope composition of the diatom silica preserved in the sediment. Targeting one specific component in a complex lake system in combination with the bulk organic measurements undertaken here may allow for more confident interpretations of past change (van Hardenbroek *et al.*, 2018).

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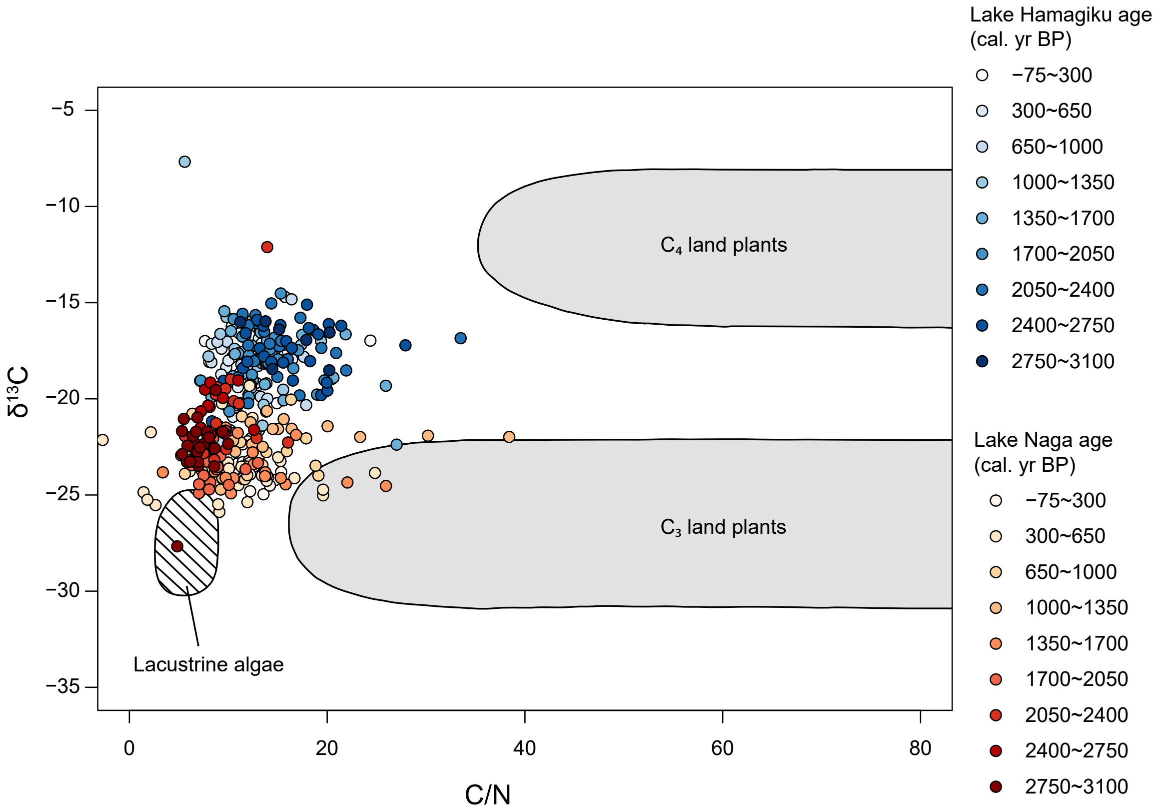
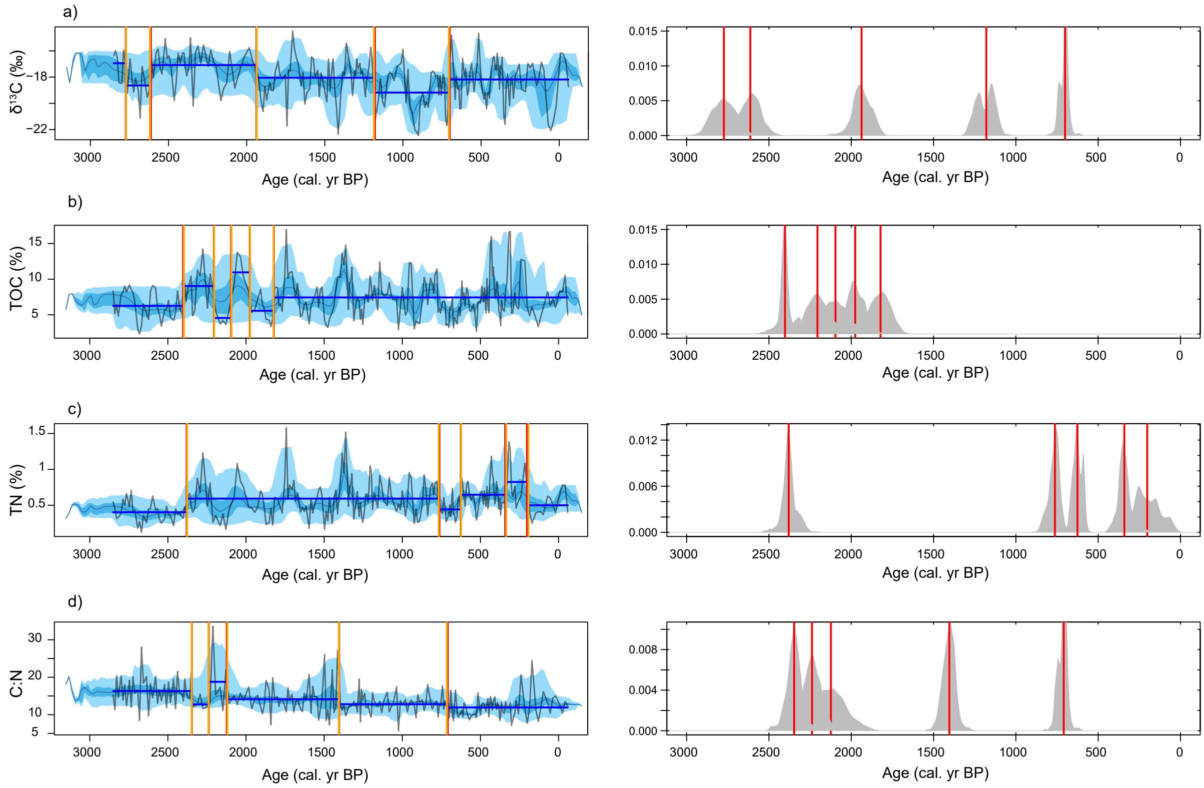
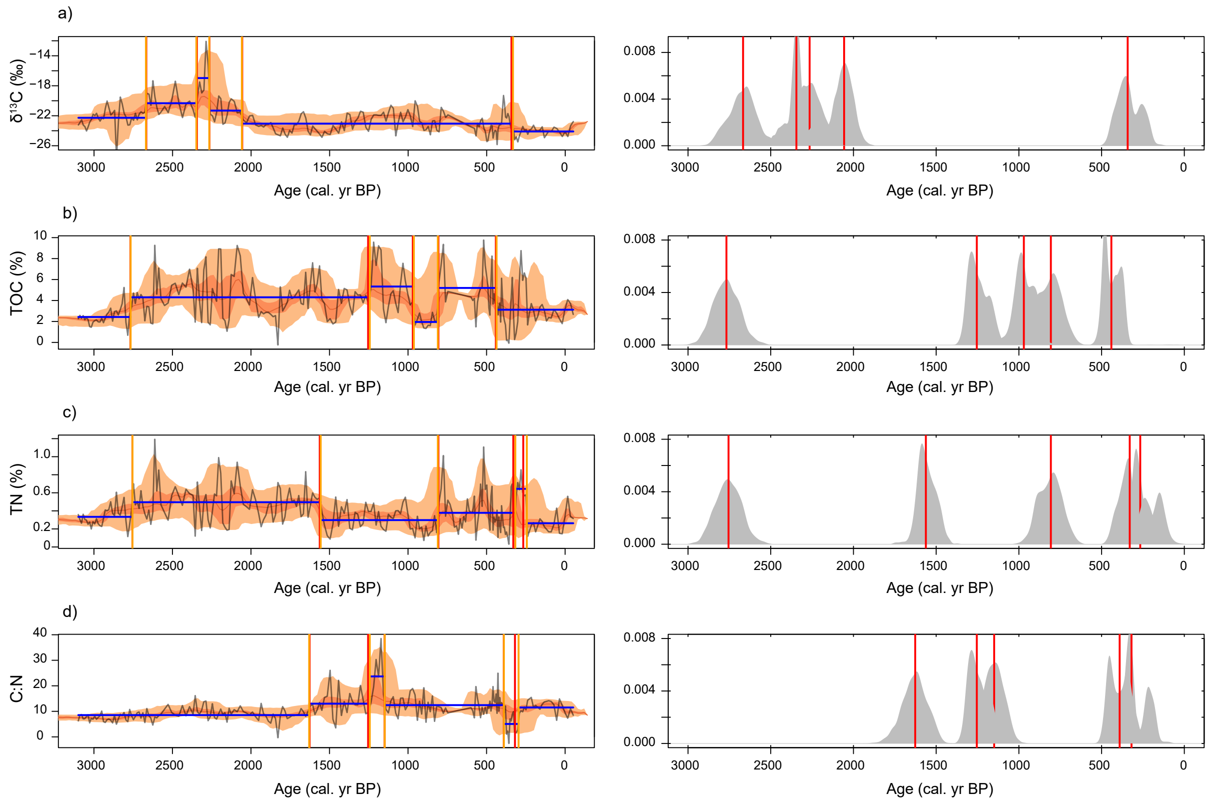


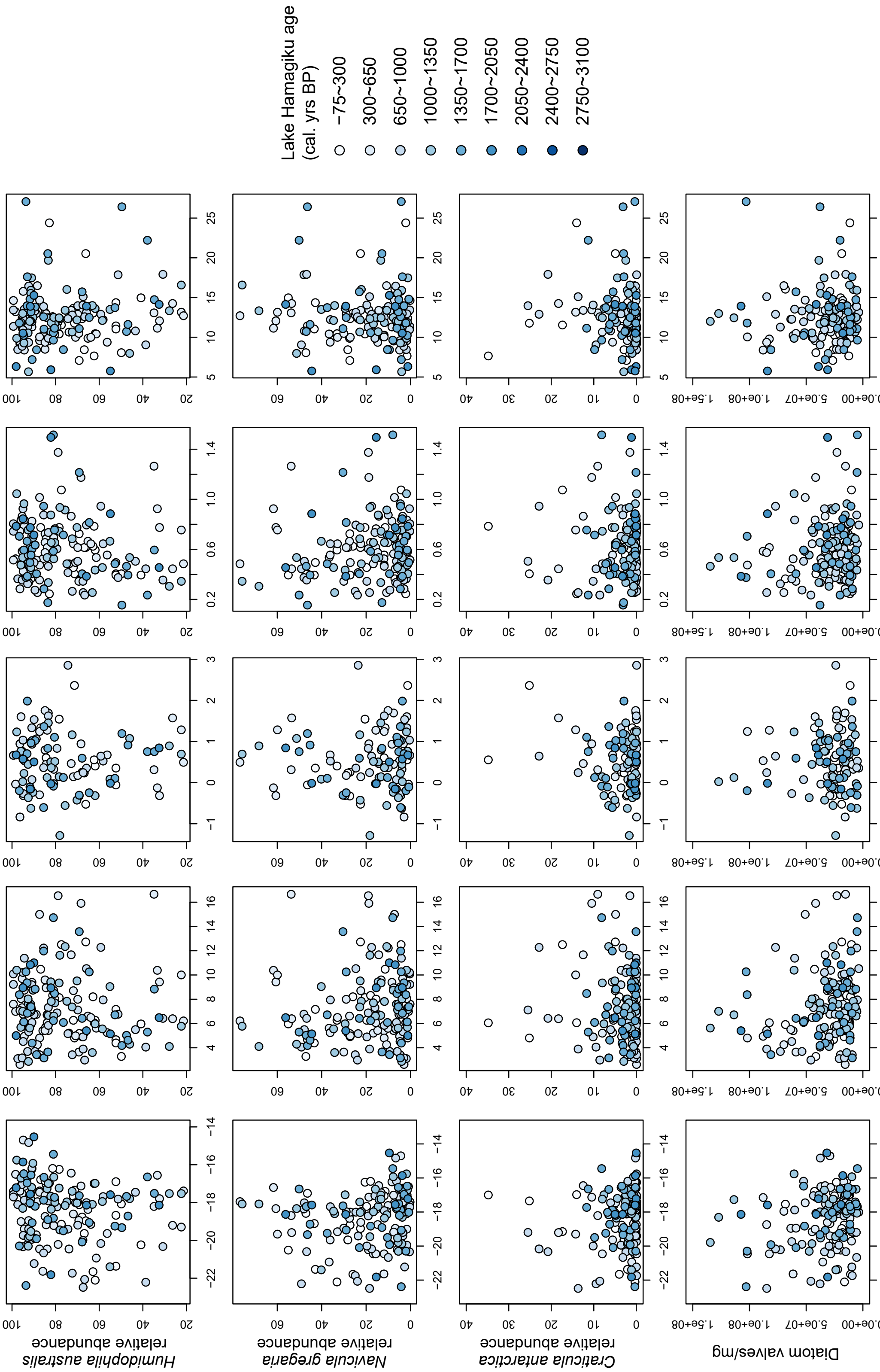
Supplementary figure 5.1 $\delta^{13}C$ vs. C/N of Lake Hamagiku and Laku Naga sediment core data (adapted from Meyers and Lallier -Vergés, 1999).



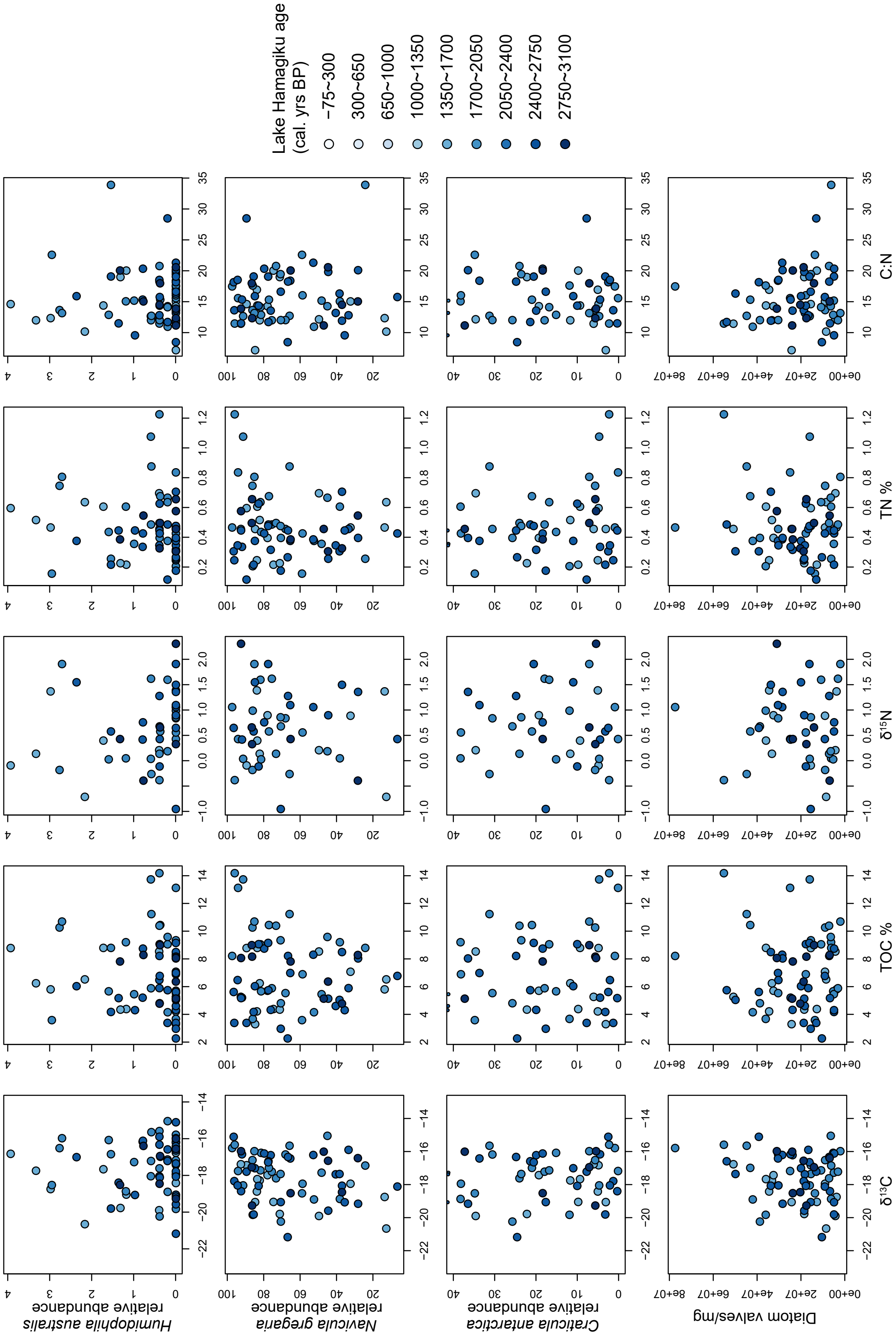
Supplementary figure 5.2 Lake Hamagiku changepoint analysis a) $\delta^{13}C$ b) TOC c) TN d) C:N



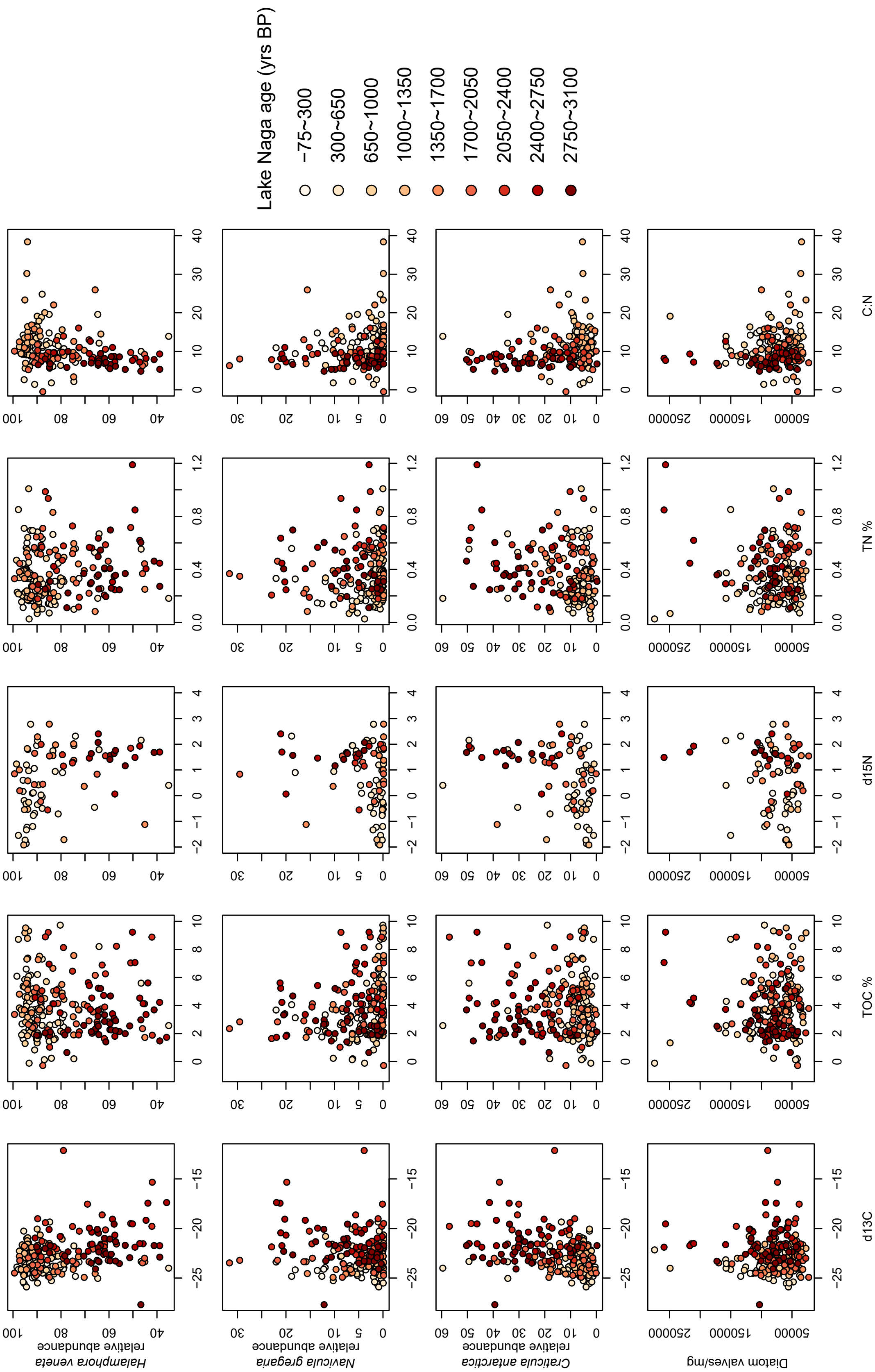
Supplementary figure 5.3 Lake Naga changepoint analysis a) $\delta^{13}C$ b) TOC c) TN d) C:N



Supplementary figure 5.4 a) Lake Hamagiku scatter plots of stable isotope and concentration data with diatom relative abundances, after the 1800 cal. yr BP shift in the fossil diatom assemblage



Supplementary figure 5.4 b) Lake Hamagiku scatter plots of stable isotope and concentration data with diatom relative abundances, before the 1800 cal. yr BP shift in the fossil diatom assemblage



Supplementary figure 5.5 Lake Naga scatter plots of stable isotope and concentration data with diatom relative abundances

CHAPTER 6

Discussion - synthesis of Southern Hemisphere climate over the last 3000 years

Discussion – synthesis of Southern Hemisphere climate over the last 3000 years

In this chapter, the key findings of this thesis are summarised and interpreted collectively in the context of palaeoclimate records from both the Antarctic region and the Southern Hemisphere. The regional warming interpreted from the ~1800 cal. yr BP shift in the fossil diatom assemblages in Lake Hamagiku and Lake Naga (Chapter 4) is broadly consistent with ice core temperature reconstructions and a sea surface temperature reconstruction from west of the Antarctic Peninsula (Shevenell *et al.*, 2011; Stenni *et al.*, 2017). Shared periodicities observed in the fossil diatom assemblages of Lake Hamagiku and Lake Naga (Chapter 4) bear strong similarities to the ~250 year periodicity observed in numerous palaeoclimate records from the Southern Hemisphere, and also to a reconstruction of total solar irradiance, highlighting the importance of the records presented in this thesis, and the coastal Antarctic region, in elucidating a thorough understanding of climate variability in the Southern Hemisphere during the late Holocene.

Summary of major findings

<u>Chapter 2: 900-year record from Lake Hamagiku</u>

In Chapter 2, a 900-year record of fossil diatom assemblages from the sediments of Lake Hamagiku (known under the name Lake Abi at the time of publication) was presented. The record had low species diversity, and fluctuations in species relative abundances were interpreted as reflecting subtle variations in salinity (specific conductivity), water depth and nutrient availability, guided by a regional diatom training set compiled by Tavernier *et al.* (2014). The interpretation of this record was limited by uncertainties surrounding the taxa observed. The genus *Humidophila* is associated with moist, humid and aerophilic habitats, yet the species *Humidophila australis* (known as *Diadesmis australis* at time of publication) dominated the diatom assemblage in the sediments of Lake Hamagiku throughout the 900-year record studied. Although the fluctuations observed were attributed to changes in specific conductivity, it was uncertain if this was the sole driver of change considering the low specific conductivity observed in the modern lake system.

<u>Chapter 3: study of modern diatom-environment associations</u>

With the purpose of developing a greater understanding of diatom ecology in the region, nine lakes in the Lützow-Holm Bay region were sampled during the 59th Japanese Antarctic Research Expedition (JARE), and the results of this study were presented in Chapter 3. The sampling strategy involved collecting samples from the various substrates present in the littoral zone of each lake, and along depth transects at some sites to determine the impact of light attenuation and habitat on diatom assemblages. In these lakes, the substrates in the littoral region consisted of some, or all of, large rock surfaces, cobbles, gravels, sands and some microbial mat-like material. Deeper than approximately two metres water depth, the lake floors are covered with a matrix of mosses, diatoms, green algae and cyanobacteria (Imura *et al.*, 1999).

Specific conductivity was the primary factor explaining variation in diatom assemblages, regardless of the substrate from which the sample was collected. This finding is consistent with previous studies of diatom ecology in Antarctic and Sub-Antarctic lakes (Verleyen *et al.*, 2003; Kopalová *et al.*, 2013; Tavernier *et al.*, 2014; Saunders *et al.*, 2015). This study also identified a difference between the diatom assemblages from the mossy substrate on the lake floor and the diatom assemblages from the littoral region, regardless of littoral substrate type. Some key species-environment relationships were identified. *Humidophila australis* was found in only the freshest lakes studied. *Halamphora vyvermaniana* was primarily found in lake floor samples, particularly at Lake Naga, whereas *Psammothidium papilio* showed a strong affinity to the littoral substrates in several lakes. *Craticula antarctica* was found in the deepest lake floor samples at Lake Naga, and it was proposed that a higher relative abundance of this species may be a result of warmer periods, where this deeper part of the lake is exposed for longer due to an extended ice-free season, although the species was also found on some littoral substrates. The depth transect at Lake Naga also suggested that sediment focusing may not be marked at these sites from the littoral region to the lake floor, due to the low observations of *P. papilio* in these samples despite the species being a major component of the diatom assemblages in the littoral zone.

Chapter 4: 3000-year fossil diatom records from Lake Hamagiku and Lake Naga

In the light of these new insights into diatom ecology in East Antarctica, Chapter 4 presents two high resolution fossil diatom records. This chapter extends the record from Lake Hamagiku (Chapter 2) and presents a new record for neighbouring Lake Naga. Both lakes have been dominated by a single species for approximately the last 1800 years – *Humidophila australis* at Lake Hamagiku and *Halamphora vyvermaniana* at Lake Naga. During this time, there were fluctuations in the second and third most abundant species in both lakes, *Navicula gregaria* and *Craticula antarctica*, relative to the dominant species. Prior to 1800 cal. yr BP, both sites were more variable, with greater relative abundances of the less abundant taxa at both lakes, including *N. gregaria* and *C. antarctica*. The shift in fossil diatom assemblage at 1800 cal. yr BP was most marked at Lake Hamagiku where *H. australis* emerged from being a rare taxon in the older sediments to become dominant thereafter. The difference in magnitude of this change between the two sites is likely due to the differences in surface area and depth of these lakes, with Lake Naga having around twice the surface area and depth of Lake Hamagiku, and so expected to be less susceptible to sudden change due to a buffering effect by the size of the water body. At Lake Naga, *H. vyvermaniana* was observed throughout the record, but at a lower relative abundance prior to 1900 cal. yr BP. Change point analysis was used to objectively compare the timing of these events, which were found to overlap within the error of the age models. As well as this finding of a marked change in fossil diatom composition at a comparable time, this study also identified pervasive shared periodicities in variability. Variability of diatom relative abundances in these sites – particularly between the dominant taxon at each site versus the lesser taxa – is interpreted as reflecting changes in the duration and extent of ice cover. This interpretation stems from the role of ice in isolating the lakes from the surrounding environment for much of the year, limiting nutrient input and light availability.

<u>Chapter 5: elemental and stable isotope records of lake sediments</u>

It was anticipated that changes in the duration of ice cover might be reflected by increases and decreases in diatom productivity, as inferred by diatom valve concentration in the sediments. However, there is little coherence between changes in the diatom species and diatom concentration, suggesting the restrictions imposed by nutrient limitation and other factors may have played an important role in regulating diatom productivity at these sites. In order to further investigate these relationships, bulk organic carbon and nitrogen concentrations and stable isotope ratios were investigated (Chapter 5). Carbon and nitrogen isotope ratios, and the relative concentration of C:N in lake sediments are commonly applied proxies of lake productivity (Meyers & Lallier-Vergès, 1999). At Lake Naga and Lake Hamagiku, the carbon and nitrogen elemental and isotope data were highly variable over decadal-centennial timescales, yet failed to exhibit any long-term trends. Both lakes had low nitrogen concentrations throughout the 3000-year records, which resulted in high C:N values. These high C:N values were interpreted to reflect nutrient limitation, and changes in C:N were interpreted to reflect changes in aquatic productivity. $\delta^{13}C$ values were interpreted as archiving changes in lake productivity, although the amount of moss relative to the diatoms and cyanobacteria in the sediment at these sites may also have affected these values, as isolated *Leptobryum* sp. from several lakes in the Lützow-Holm Bay region was found to have more negative $\delta^{13}C$ values than the bulk surface sediment (Tanabe *et al.*, 2019). No notable or sustained changes were identified in these records to coincide with the shift in fossil diatom assemblages at 1800 cal. yr BP. The results of this study suggest that the processes of lake productivity and nutrient cycling inferred from these records do not explain the changes observed in the diatom species, and highlight the importance of a multi-proxy approach to palaeolimnology in these lakes.

Patterns of change in fossil diatom records in Lützow-Holm Bay in the context of regional records

Significant changes in the fossil diatom assemblages occurred at approximately 1800 cal. yr BP, synchronous within error, at both Lake Hamagiku and Lake Naga. At Lake Hamagiku, *Humidophila australis* became abundant, and dominated the assemblage since 1800 BP. At Lake Naga, a similarly pronounced shift occurred, whereby *Halamphora vyvermaniana*, which was present throughout the record, became consistently dominant relative to *Navicula gregaria* and *Craticula antarctica*. This change is interpreted to reflect a freshening event at Lake Hamagiku, based on the increase in abundance of *H. australis*, a species prevalent in the least saline lakes in the modern diatom study in Chapter 3. Salinity in these lakes, which do not have a history of connection to the ocean, is thought to initially derive from salts entering the lake via precipitation, meltwater input or to have been blown in with sea ice or sea spray. As outflow is low, the salt is retained and concentrated by evaporation. A freshening event at Lake Hamagiku may therefore be associated with one of two processes – colder conditions coupled with a decrease in evaporation, or warmer conditions and increased snow melt, freshwater input and salt dilution.

These two scenarios are both complicated by competing factors, which ultimately make interpreting the changes identified in the fossil diatom records difficult. Under cooler conditions, brine formation in the bottom of the lakes below the ice cover, through the process of brine rejection, may mean that cooler climates are associated with lake water that is more saline relative to during ice-free conditions. This process is expected to have a greater impact in shallower lakes, where the proportion of ice to liquid water is greater, although the water column is mixed following the melting of lake ice, and stratification is not observed (see Figure 2.2). Under warmer conditions, input of snow melt from snowbanks within lake catchments is expected to be greater, although this may be limited by the size of the snowbanks and the amount by which they are replenished by precipitation. Furthermore, in warmer years, the length of time for which the lakes are ice-free is expected to be longer, and so it may follow that there would be an increase in the duration of seasonal evaporation to counter inflow. Considering the balance of various influences, it was concluded that fresher lake conditions are more likely to have occurred during warmer conditions, although some uncertainty remains.

For Lake Naga, in the study of modern diatoms in the lakes (Chapter 3), *Halamphora vyvermaniana* was found primarily on the mossy substrates across the lake floor. An increase in the relative abundance of *Halamphora vyvermaniana* was interpreted as an increase in the duration of ice-free conditions, and as such, the 1800 cal. yr BP shift in fossil diatom assemblage is interpreted to reflect a reduction in the duration of ice cover driven by a shift towards warmer conditions. Based on the combination of information from both Lake Naga and Lake Hamagiku, the coherent change in fossil diatom assemblages was interpreted to be indicative of warming in the region at 1800 cal. yr BP.

The spatial extent of the forcing which caused this shift is difficult to determine, but the occurrence of a simultaneous change in two lakes indicates it may have been a regional event. Several other lake sediment records exist for Lützow-Holm Bay, and these vary according to their temporal resolution and sensitivity to hydroclimatic change. For example, Lake Mago, another lake in the Skarvsnes region, has a history of isostatic uplift isolating the basin from the ocean (Tavernier *et al.*, 2014). The Lake Mago sediments record freshwater conditions from 1120 cal. yr BP (Tavernier *et al.*, 2014), and so the basin was under the ocean at the time of the change point identified in Lakes Hamagiku and Naga. Fossil diatom records have also been analysed for three lakes on West Ongul Island, Nishi Ike, Yumi Ike and Ô-Ike, which were all lacustrine systems at 1800 cal. yr BP (Tavernier, 2014). The records from West Ongul Island do not exhibit a marked shift at ~1800 cal. yr BP, however their low resolution makes it difficult to detect if there was a change at this point that was not sustained. The records for Nishi Ike and Yumi Ike are both of a lower resolution, with only five samples analysed in the last 1800 years. For Ô-Ike a higher resolution record was generated for approximately the last 1000 years, in which time *Halamphora vyvermaniana* (as *H. veneta*) increased in relative abundance. The morphology of the lakes studied in the Skarvsnes region are not dissimilar to those from West Ongul Island, indicating that differences in ice cover duration as a result of differences in lake surface area and depth cannot explain the absence of a similar shift in diatom assemblage at these sites. Ô-Ike is the deepest at 11.2 m and has a surface area of 51,500 m^2 (Imura *et al.*, 2003), slightly larger than Lake Naga, and Yumi Ike and Nishi Ike are 5 m and 6 m deep respectively (Tavernier, 2014), between the depths of Lake Hamagiku and Lake Naga. Ô-Ike, Yumi Ike and Nishi Ike sit between 10 and 23 m altitude, and the relatively small topographic relief of the Ongul Islands compared to the Skarvsnes region may have altered the relative influence of wind strength and temperature in moderating ice cover duration at these sites.

Isotope and major element concentrations have been measured from Lake Oyako and Lake Skallen (Matsumoto *et al.*, 2010; Takano *et al.*, 2012). Lake Oyako was situated below sea level at 1800 cal. yr BP, but Lake Skallen was exposed at 1940 ± 100 cal. yr BP. Stable isotope data from Lake Skallen indicate that the principal environmental change was the transition from marine to lacustrine conditions at around 3590 cal. yr BP (Matsumoto *et al.*, 2010). Organic matter composition was also determined for lake sediments covering 2330 years at Ô-ike on West Ongul Island, and 1550 years at Lake Namazu in the Skarvsnes region (Matsumoto *et al.*, 2006). These studies do not report any shifts or changes at ~1800 cal. yr BP, but as no changes were observed in the organic carbon and nitrogen concentrations and isotope records and at Lake Hamagiku and Lake Naga at this time, this is perhaps not surprising. The absence of pronounced change in the isotope records from Lake Hamagiku and Lake Naga in concert with the absence of change at 1800 cal. yr BP in other studies of the Lützow-Holm Bay region suggests that the forcing behind the shift was either extremely localised, or small enough to trigger a threshold response from the diatom assemblages without disrupting lake productivity.

It is possible that the change in fossil diatom assemblage observed at ~1800 cal. yr BP is the expression of the end of the mid-Holocene hypsithermal (MHH) in this region, which has been described from lake sediments in other Antarctic regions, which would suggest a cooler change as opposed to the warmer conditions interpreted in this thesis. In the Lützow-Holm Bay region, the isolation of Lake Skallen from the ocean at ~3590 cal. yr BP was thought to be associated with the MHH, through ongoing glacial retreat in the region (Matsumoto *et al.*, 2010). The timing of this shift observed at Lake Hamagiku and Lake Naga is slightly later than the end of the hypsithermal reported in other studies, which range from 3000 corr. ^{14}C yr BP in coastal Victoria Land (Baroni & Orombelli, 1994) to ~2000 uncorrected ^{14}C yr BP in the Bunger Hills, which corresponds to 1700–2100 cal. yr BP (Roberts, McMinn & Zwartz, 2000). One of the common proxies used to indicate the MHH is an increase in biogenic productivity, although neither the diatom concentrations or the $\delta^{13}C$ values at Lake Hamagiku and Lake Naga suggest significant changes in lake productivity through this time period. For Jaw Lake in the Bunger Hills, a period of increased salinity was associated with the MHH, and the end of this period was abrupt lake water dilution at ~1900 uncorrected ^{14}C yr BP (Roberts *et al.*, 2000), which corresponds to a calibrated age of between 1600 and 1990 cal. yr BP. This may be similar to the freshening event at Lake Hamagiku, although as the Jaw Lake record is only constrained using a single radiocarbon date for each of two cores collected, further work is required to constrain the timing of this event across the East Antarctic region. To conclude, several studies of lake sediments in the Lützow-Holm Bay region have been conducted, however few of those indicate a major shift at ~1800 cal. B.P. Significantly, few of those records offer the temporal resolution and chronological precision of the data presented in this thesis from Lakes Naga and Hamagiku, which can in part explain the lack of a clear and coherent signal. In addition, many of the lake sediments in the region track major marine-freshwater transitions due to isostatic uplift and lake isolation, which possibly obscures any subtle change in climatic conditions.

Comparison with regional ocean and ice records

Temperature is interpreted to have been a major driver of variability in the palaeolimnological records for Lake Hamagiku and Lake Naga. Oxygen isotopes in ice cores have been used to reconstruct temperature in Antarctica and provide an insight into temperature change above the ice sheet. Locations discussed in the following text are illustrated in Figure 6.1a. Dome Fuji is the closest ice core record to the lakes in Lützow-Holm Bay. Oxygen and deuterium isotope inferred temperature from Dome Fuji Ice Core – estimated for both the ice core location and the moisture source (Uemura *et al.*, 2018) – exhibit variable patterns over the last 3000 years, with a marked cooling period coinciding with the major shift in diatom species at Lützow-Holm Bay, immediately prior to a sustained period of warmer temperatures between 1700–400 cal. yr BP (Figure 6.2a). At first glance, this period of warming was relatively minor, however it is notable in the context of the last 8000 years (Uemura *et al.*, 2018). The moisture source for the Dome Fuji site has been determined using backward trajectory modelling, and identified as 40–70°S (Reijmer, Van den Broeke & Scheele, 2002; Uemura *et al.*, 2018).

Composite reconstructions of Antarctic temperature have been produced for different regions, and for the whole continent, integrating the stable isotope temperature reconstructions from multiple ice core locations (Stenni *et al.*, 2017). These reconstructions exhibit a long-term cooling trend from 1950 to 50 cal. yr BP and warming trends from 50 cal. yr BP (East Antarctic and whole Antarctic reconstructions shown in Figure 6.2b)(Stenni *et al.*, 2017). The warmest temperature anomalies are observed from 1650 to 950 cal. yr BP, which is consistent with the interpretation of warmer conditions in the Lützow-Holm Bay region from 1800 cal. yr BP (change points shown in Figure 6.2d). Without the context of the period before these records begin at 1950 cal. yr BP (0 CE), it is unclear if the warm conditions from 1650 to 50 cal. yr BP were preceded by cooler conditions.

Sea surface temperatures (SSTs) inferred using the TEX_{86} organic paleothermometer from ODP site 1098, west of the Antarctic Peninsula (location shown in Figure 6.1a) display variability through the last 3000 years similar to those inferred from this study (Shevenell *et al.*, 2011; Figure 6.2). This record exhibits low SSTs from 2700–1700 cal. yr BP followed by an abrupt increase in SST at ~1700 cal. yr BP of around six degrees, after which warmer conditions persisted until ~500 cal. yr BP. The age model for this record was constructed using radiocarbon dating of organic matter and foraminiferal calcite (Domack *et al.*, 2001), and is also subject to a degree of error, within which the ~1700 cal. yr BP temperature increase may be coincident with the diatom assemblage change observed in Lützow-Holm Bay (Figure 6.2).

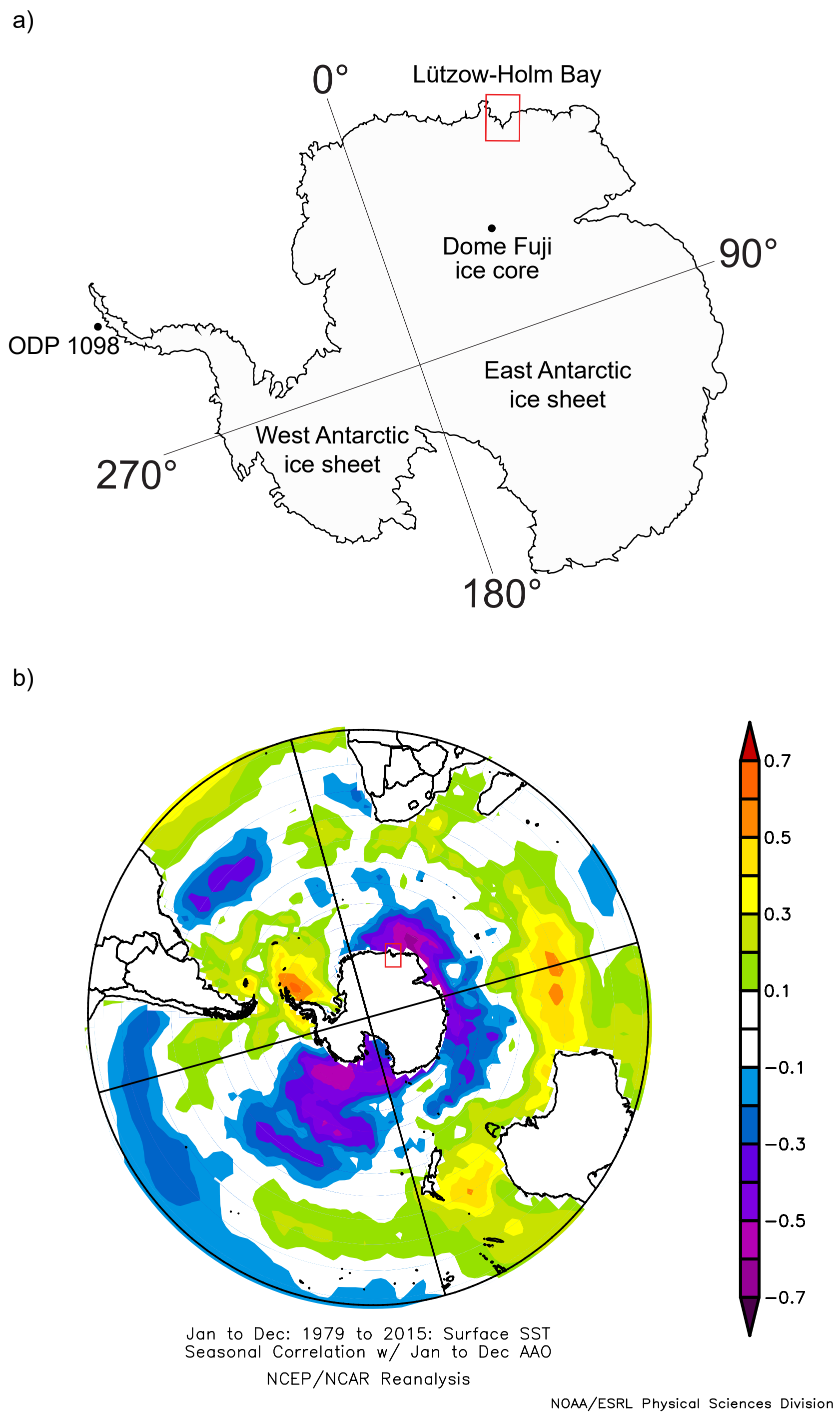
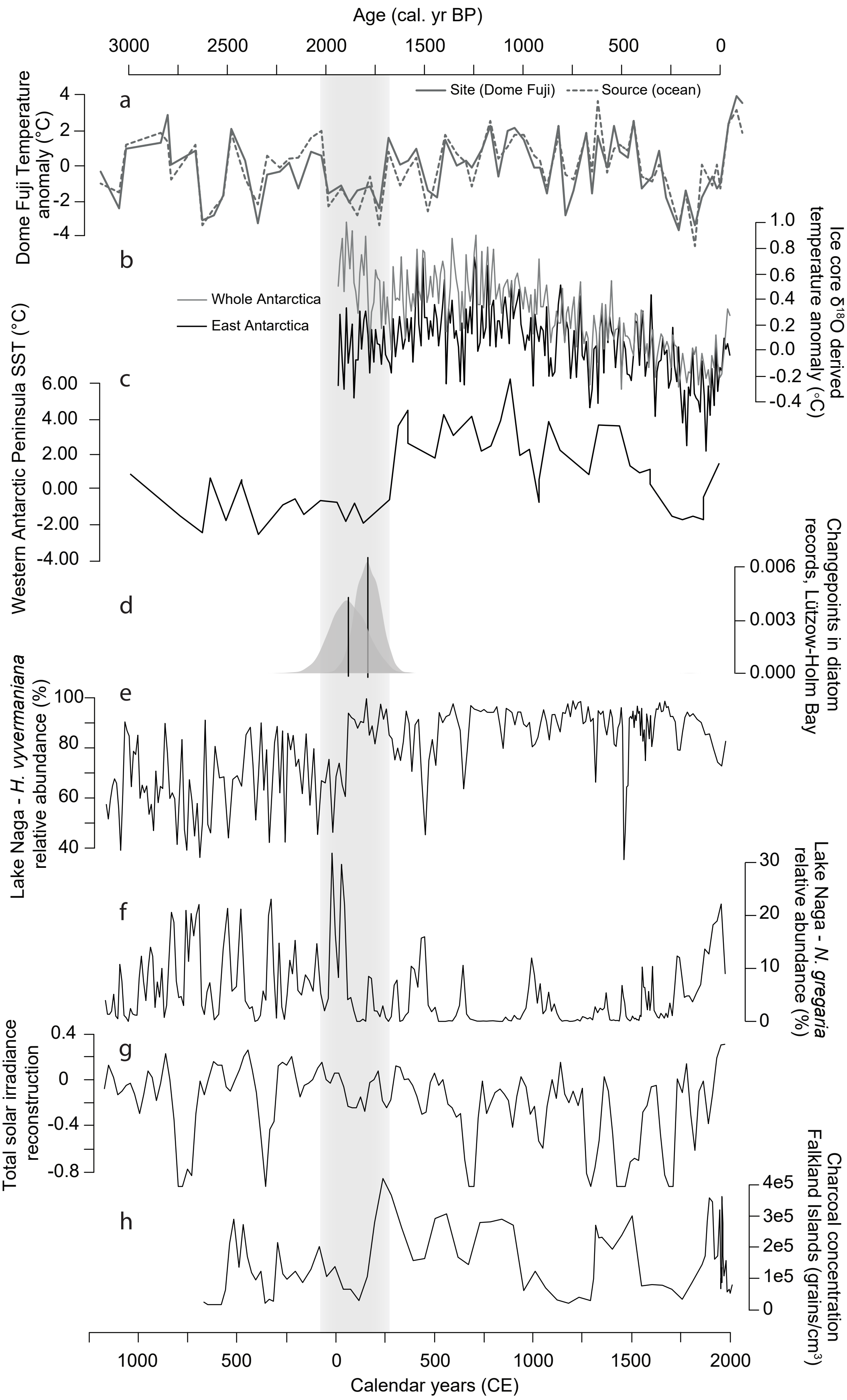


Figure 6.1 a) locations of sites referenced in the text b) reanalysis of sea surface temperature and Antarctic Oscillation from 1979 to 2015.

In Chapter 4, it was suggested that inferred changes in temperature in the Lützow-Holm Bay region may be associated with variability in the Southern Annular Mode (SAM). In the modern day, a strong negative correlation can be observed between SAM and temperature in Lützow-Holm Bay, which contrasts with a positive correlation west of the Antarctic Peninsula (Figure 6.1b). An increase in temperature at ODP 1098 would therefore be expected to coincide with cooler conditions at Lützow-Holm Bay. If the interpretation of the fossil diatom assemblages, and the temperature warming inferred for the 1800 cal. yr BP shift is correct, then it appears that this expected relationship, which is based on contemporary observations over an inter-annual timescale does not hold in the past. This in turn implies that the mechanisms which drive inter-annual variability in the Antarctic margins over the last century – namely the SAM do not explain multi-decadal to centennial variability over the last 3000 years. Further deciphering these patterns should therefore be a focus of future research.

In both Lake Hamagiku and Lake Naga, there is also evidence of a recent trend, with a slight decrease in both *Humidophila australis* and *Halamphora vyvermaniana* (Figure 6.2e for *H. vyvermaniana* relative abundance) over the past ~300 years, alongside increases in the littoral taxon *Navicula gregaria* at both sites (Figure 6.2f). Not all littoral taxa are observed to increase however, most notably *Psammothidium papilio* - a significant component of the littoral assemblage at Lake Naga (Chapter 3) - which is uncommon in lake floor sediments and is not observed to increase in the recent sediments from the sediment cores (Chapter 4). Compared to the significant shift at ~1800 cal. yr B.P., the recent changes in both lakes are relatively minor, however nevertheless the changes post ~300 cal. yr B.P. may indicate a trend towards a lake ecosystem more similar to that prior to 1800 cal. yr BP, tentatively interpreted as a cooling trend. A decrease in temperature is observed in the Dome Fuji temperature anomaly (Figure 6.2a), East Antarctic and Antarctic continent composite temperature anomalies (Figure 6.2b) and the Western Antarctic Peninsula SST reconstruction (Figure 6.c) from ~500 cal. yr BP. These records show a temperature increase over the past ~50 years which is not evident in the lake Naga or Hamagiku cores, however this may reflect an incomplete retention of the uppermost sediments during coring, or instead a lagged response of the lake ecosystem to contemporary warming.

Figure 6.2 (following page) Comparison of Lützow-Holm Bay diatom assemblages to regional records a) Dome Fuji ice core temperature anomaly reconstruction (Uemura *et al*., 2018) b) East Antarctic and whole Antarctic ice core composite temperature anomaly reconstructions (Stenni *et al*., 2017) c) Western Antarctic Peninsula sea surface temperature reconstruction (Shevenell *et al*., 2011) d) change points identified in the fossil diatom assemblages from Lützow-Holm Bay, Chapter 4, e) *Halamphora vyvermaniana* relative abundance, Lake Naga, f) *Navicula gregaria* relative abundance, Lake Naga, g) Total solar irradiance reconstruction (Steinhilber *et al*., 2012), h) Charcoal concentration from Falkland Islands peat sequence (Turney *et al*., 2016).


Age (cal. yr BP)
3000
2500
2000
1500
1000
500
0
a
Site (Dome Fuji)
Source (ocean)
Dome Fuji Temperature anomaly (°C)
4
2
0
-2
-4
b
Whole Antarctica
East Antarctica
Ice core δ18O derived temperature anomaly (°C)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
c
Western Antarctic Peninsula SST (°C)
6.00
4.00
2.00
0.00
-2.00
-4.00
d
Changepoints in diatom records, Lützow-Holm Bay
0.006
0.003
0.000
e
Lake Naga - H. vyvermaniana relative abundance (%)
100
80
60
40
f
Lake Naga - N. gregaria relative abundance (%)
30
20
10
0
g
Total solar irradiance reconstruction
0.4
0
-0.4
-0.8
h
Charcoal concentration Falkland Islands (grains/cm3)
4e5
3e5
2e5
1e5
0
1000
500
0
500
1000
1500
2000
Calendar years (CE)

Periodicities archived in lake sediments

Another key finding of this thesis is the detection of shared periodicities in the records from both lakes. These are strongest, and most sustained, in the diatom records (Chapter 4), but less sustained periodicity of similar wavelengths was also detected in the stable isotope records (Chapter 5). The first DCA axis of the diatom assemblage data at each site primarily reflects the relative abundance of the major taxon at each site relative to the abundance of *N. gregaria* and *C. antarctica*. This variability has been interpreted to reflect changes to ice cover, as a result of changes in regional temperature, and was used for wavelet analysis in Chapter 4.

Cross wavelet analysis between diatom DCA 1 axes from Lake Naga and Lake Hamagiku highlights a significant shared periodicity at these sites, with a periodicity of ~128 years in wavelength in the most recent 500 years, and a sustained periodicity of between 128 to 512 years in wavelength from 2500 to 500 cal. yr BP, although the 256 year band has the strongest power levels, and is sustained from 2300 to 750 cal. yr BP (Figure 4.7). Significant periodic variability with a similar wavelength has previously been noted in analysis of aeolian dust particles in the EPICA Dome C and Vostok ice cores (Delmonte *et al.*, 2005), albeit earlier in the Holocene. Fluctuations in dust concentration at these sites are dependent on the meridional pressure gradient, the SAM, and differences in dust size are attributed to differing transport pathways or source locations. The composite record of the dust sizes at each site display periodicities of 150 to 500 years, and a common 200-year periodicity at both sites, although these are out of phase. These oscillations are suggested to align with solar activity (Turney *et al.*, 2005; Adolphi *et al.*, 2014), namely the Suess - de Vries cycle of solar variability, as identified in reconstructed total solar irradiance (TSI) based on $\Delta^{14}C$ and beryllium-10 records through the Holocene (Steinhilber *et al.*, 2012).

Wavelet analysis of inferred TSI exhibits a poorly defined periodicity from 2800 to 2000 cal. yr BP of ~256 years in wavelength, and from 1500 to 0 cal. yr BP of 256 years wavelength moving to 128 years in the recent part of the record (Figure 6.3a). However, cross wavelet analysis between Lake Hamagiku DCA axis 1 and TSI (Figure 6.3b) exhibits significant coherent periodicity throughout the whole record, with a wavelength of between 256 and 512 years in the oldest parts of the record, moving to 256 years through the middle and 128 years in the most recent 800 years. Similarly, cross wavelet analysis between TSI and Lake Naga DCA axis 1 (Figure 6.3b) exhibits sustained coherent periodicity of ~256 years between 2300 to 1000 cal. yr BP, and of ~128 years between 800 to 0 cal. yr BP (Figure 6.3c). Visual comparison also supports the inference that changes in the diatom records from Lake Naga and Lake Hamagiku coincide with changes in reconstructed TSI (Figure 6.2). This is most clearly observed in the relative abundances of *Navicula gregaria* at Lake Naga (Figure 6.2f), particularly from 3000 to

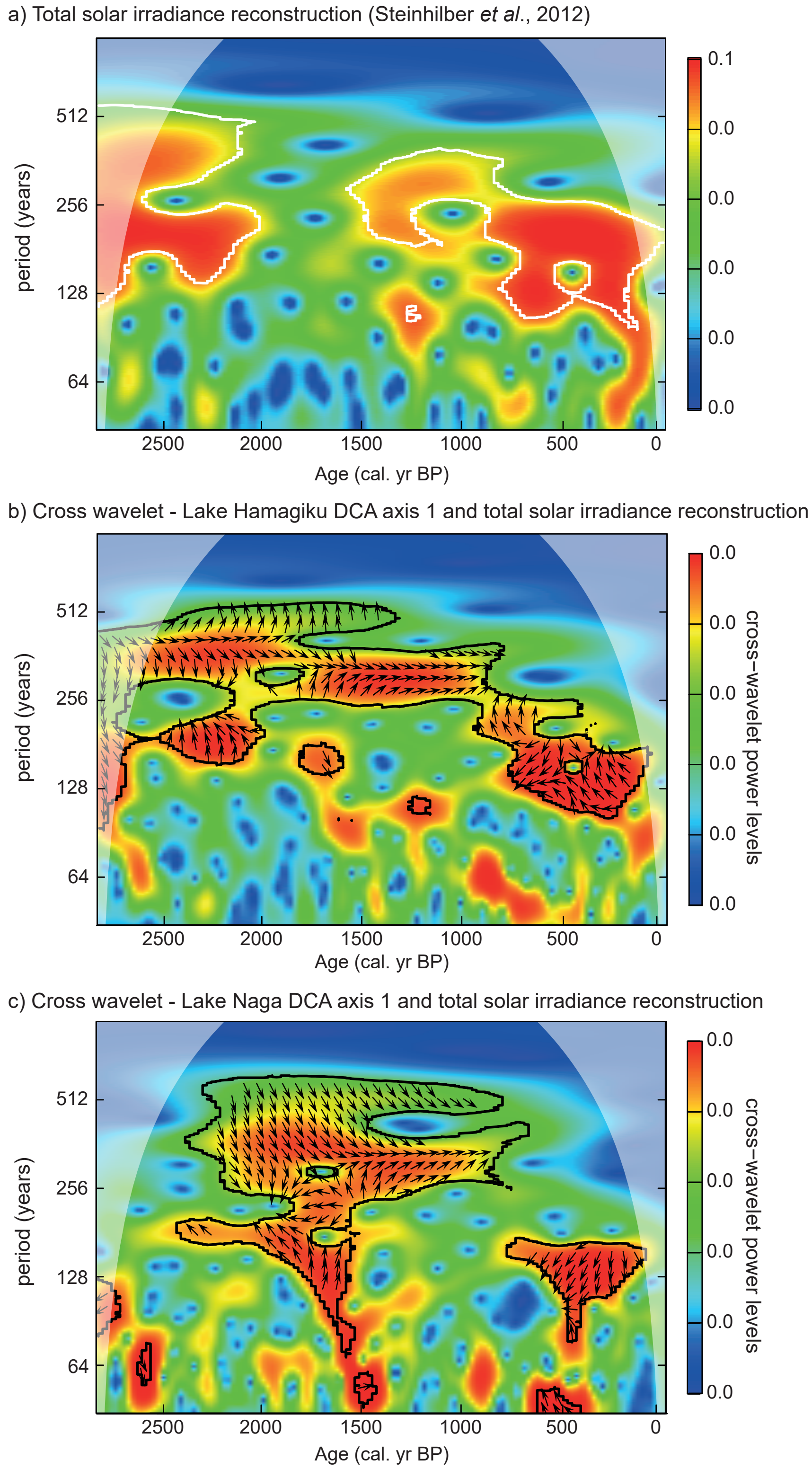


Figure 6.3 a) wavelet of total solar irradiance reconstruction (Steinhilber *et al*., 2012) b) cross wavelet comparison of total solar irradiance reconstruction and Lake Hamagiku fossil diatom DCA axis 1 c) cross wavelet comparison of total solar irradiance reconstruction and Lake Naga fossil diatom DCA axis 1. Arrows for cross wavelet plots indicate phase differences, where arrows pointing to the right indicate that the two series are in phase at the respective period.

1000 cal. yr BP. Increases in *N. gregaria* relative abundance are interpreted to reflect a greater littoral input in the lake sediment record as a result of a decrease in the ice-free duration and associated decrease in *Halamphora vyvermaniana* relative abundance (Figure 6.2e). Periods of decreased TSI (Figure 6.2g) from 3000 to 1000 cal. yr BP generally correspond to increases in *N. gregaria* relative abundance (Figure 6.2f), although the relative magnitude of these changes do not scale proportionately.

These observations support and extend inferences made from exotic pollen and charcoal deposition in a peat sequence in the Falkland Islands (Turney *et al.*, 2016). The Falklands lie in the path of the Southern Hemisphere westerly airflow (52° S) and increases in charcoal in the sediments are therefore interpreted to reflect increased westerly wind strength or positioning of the westerlies near this site during these times (Figure 6.2h). Turney *et al.* (2016) identified a 250-year periodicity in the charcoal record from this peat sequence between 2500 to 1000 cal. yr BP (Figure 6.4a) which is remarkably similar to the wavelet analysis from Lake Naga and Lake Hamagiku diatoms. This similarity is highlighted by the cross wavelet analysis in Figure 6.4b and c. All sites show a pervasive and sustained periodicity between 256 and 500 years through most of the record, moving to a shorter wavelength periodicity in the recent 500 years. Importantly, in all cases the 250-year periodicity does not extend into the most recent 1000 years, as was previously reported for the Falkland Islands charcoal record (Turney et al. 2016).

Several additional studies highlight the prevalence of a ~250 year periodicity, possibly linked to solar irradiance, in or around the Southern Ocean region. Southern Ocean productivity has shown evidence of this periodicity in the Palmer Deep record on the western side of the Antarctic Peninsula presented by Leventer *et al.* (1996) and dated by Domack *et al.* (2001). From Lake Hambre in southern Patagonia, aquatic productivity archived in lake sediments was found to exhibit a periodicity of 200–240 years, coherent with TSI variability (Pérez-Rodríguez *et al.*, 2016). Also in southern Chile, in Torres del Paine, sediments from Lago Cipreses revealed repeated dry/warm conditions associated with the Southern Annular Mode, with a ~200 year cyclicity (Moreno *et al.*, 2014). Further afield, periodicity on this time scale is also reported in reconstructions of the intertropical convergence zone (Poore, Quinn & Verardo, 2004) and from marine diatom records in the north-east Pacific (Galloway *et al.*, 2013), both of which attribute the periodicity observed as reflecting solar variability.

The presence of these similar periodicities across the Southern Hemisphere suggests that there is an atmospheric connection between them, influencing either sea ice extent, sea surface temperatures or the westerly winds themselves (Shindell & Schmidt, 2004; Turney *et al.*, 2016). Multiple studies have found a response to solar irradiance in the SAM, including CMIP5 simulations which indicate a positive SAM response to solar irradiance variations across

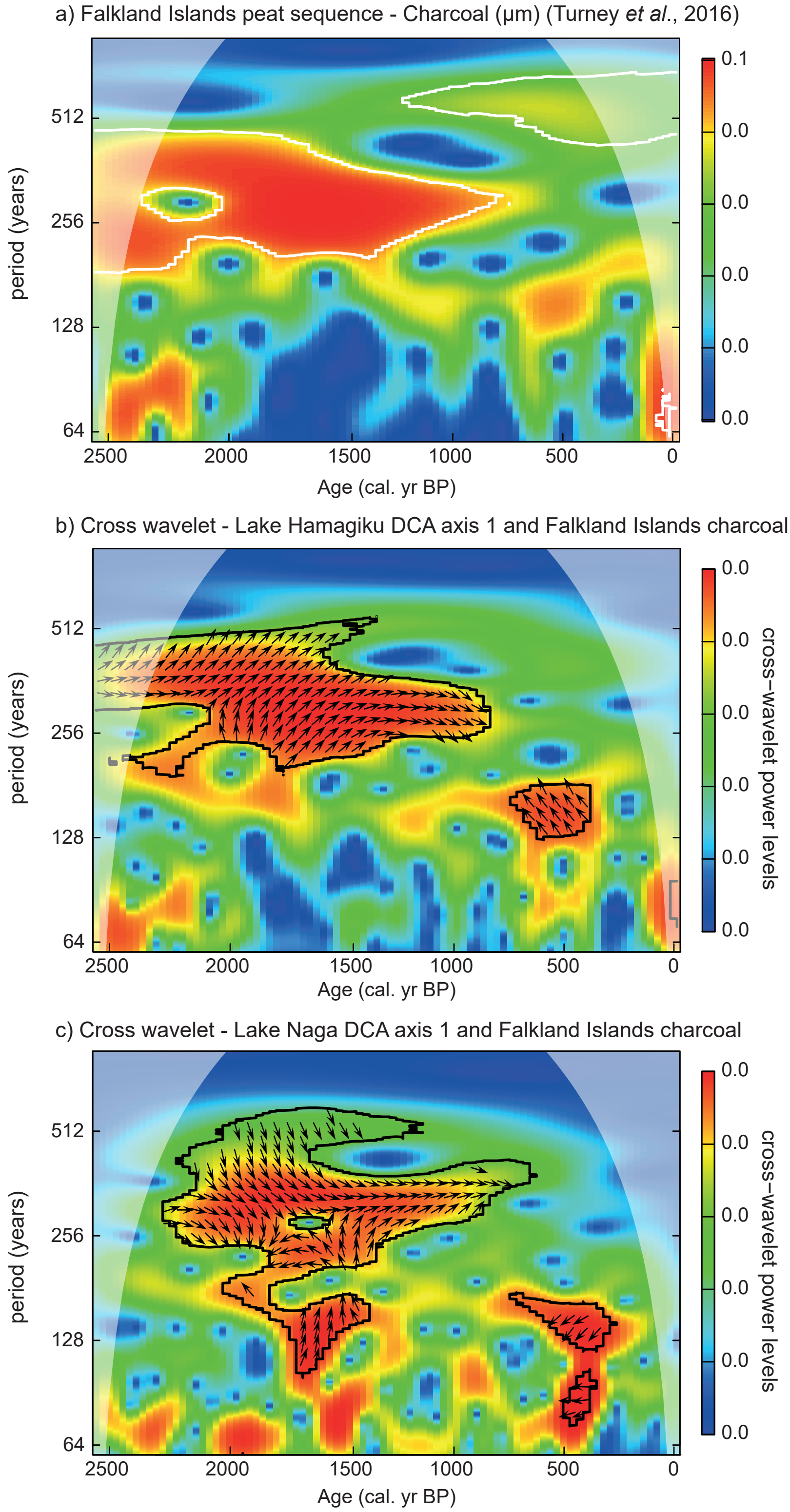


Figure 6.4 a) wavelet of charcoal concentration from Canopus Hill peat sequence, Falkland Islands (Turney *et al*., 2016) b) cross wavelet comparison of Canopus Hill charcoal concentration and Lake Hamagiku fossil diatom DCA axis 1 c) cross wavelet comparison of Canopus Hill charcoal concentration and Lake Naga fossil diatom DCA axis 1. Arrows for cross wavelet plots indicate phase differences, where arrows pointing to the right indicate that the two series are in phase at the respective period.

all seasons (Gillett & Fyfe, 2013), yet the mechanisms by which solar periodicity influences the Southern Hemisphere westerly airflow are complex. One possible mechanism is via changes in stratospheric ozone, the concentrations of which are modulated by changing solar ultraviolet radiation (Haigh, 1996; Lean & Rind, 1998). Changes in stratospheric ozone have been shown to drive annular mode changes, particularly in the Southern Hemisphere (Thompson & Solomon, 2002; Gillett & Thompson, 2003). Ozone depletion in the stratosphere leads to a reduction in absorption of incoming radiation, increasing the meridional temperature gradient (Thompson & Solomon, 2002; Perlwitz *et al.*, 2008; Dennison, McDonald & Morgenstern, 2015). These connections may explain the observation of similar periodicities in the records described here. Irrespective of the mechanisms behind an apparent link between TSI and southern westerly winds, the distinct variability within southern westerly wind records has implications both for carbon cycling between the Southern Ocean and the atmosphere, as well as for hydroclimate variability in the southern continents, including Australia. Deciphering these patterns further and identifying their underlying causes should therefore represent a key focus of future research.

Conclusions

The records presented in this thesis of climate variability in the Lützow-Holm Bay region include a synchronous change in fossil diatom assemblages and shared periodicities, which are attributed to changes in lake ice cover duration and extent, as a result of regional temperature variability. The variability archived at these sites bears strong similarities to records from both the Antarctic and the Southern Ocean region, as described in this chapter. The similarities described highlight the importance of the coastal Antarctic region, and the records presented in this thesis, in linking the ice core records developed for the Antarctic continent, and records from lower latitudes, in further developing an understanding of Southern Hemisphere climate processes over the late Holocene.

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Appendix 1

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A diatom-inferred record of lake variability during the last 900 years in Lützow–Holm Bay, East Antarctica

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ABSTRACT: Decadal–centennial-scale climate variability in coastal Antarctica remains poorly understood due to the limited number of highly resolved, well-dated records. We present a 900-year, decadal-scale reconstruction based on sedimentary diatoms from Lake Abi in Lützow–Holm Bay, East Antarctica. Hydrological change is inferred from diatom ecological preferences in conjunction with an existing regional training set and implies that lake water specific conductivity, depth and nitrogen availability are the key drivers of diatom assemblage change. Lake Abi underwent a series of subtle environmental changes related to these environmental variables, possibly driven by changes in catchment snow melt and the duration of seasonal ice cover. Ordination is used to trace the major patterns of change in the diatom community, with notable shifts identified between 470 and 400 and at ~350 cal a BP (where present = CE 1950). The frequency of environmental variability at Lake Abi is broadly consistent with a record of the Interdecadal Pacific Oscillation during the last millennium, but contrasts with the apparent climate stability elsewhere in eastern Antarctica. Further research is required to constrain the limnological and ecological responses of lakes in coastal Antarctica to obtain more rigorous palaeoclimate reconstructions from these sites of immense potential. Copyright © 2016 John Wiley & Sons, Ltd.

KEYWORDS: climate; East Antarctica; late Holocene; palaeolimnology; Skarvsnes.

Introduction

Antarctic ice-shelf collapse and glacial retreat are highly publicized climatic trends of recent decades. An understanding of natural climate variability on decadal to centennial timescales is paramount, to discern the extent to which trends are within the bounds of natural variability, or are anthropogenically forced (Abram *et al.*, 2014; IPCC, 2014; PAGES 2k Consortium, 2013; Schmidt *et al.*, 2014). Southern Hemisphere climate and oceanography plays an important feedback role in the global climate system (Rintoul *et al.*, 2001; Russell *et al.*, 2006; Toggweiler *et al.*, 2006). Furthermore, hemisphere-wide climate oscillators result in marked variability in regional hydroclimates, which have a substantial impact upon the economic and environmental prosperity of South America, Africa and Australia. Most notably, the Southern Annular Mode (SAM) – which tracks the inter-annual position of the westerly jet (Kidson, 1988; Gillett *et al.*, 2006; Abram *et al.*, 2014) – and the El-Niño Southern Oscillation (ENSO) play a major role in short-term climate variability in the Southern Hemisphere (Karoly, 1989; Garreaud and Battisti, 1999; Vance *et al.*, 2013). However, uncertainties remain concerning many aspects of low-frequency and long-term climate variability, such as the drivers of ENSO variability (Emile-Geay *et al.*, 2013), linkages between ENSO and SAM, and the stationarity of teleconnections between these phenomena and climates in the Southern Hemisphere (Gallant *et al.*, 2013).

Highly resolved, multi-centennial palaeoclimate records are sparse in the Southern Hemisphere, relative to the Northern Hemisphere, reflecting the dominance of ocean and sparsely populated continents (Neukom and Gergis, 2012). Information from Antarctica is heavily weighted towards ice core records, which provide an unparalleled record of climate and atmospheric gas and particulate composition (Leuenberger and Siegenthaler, 1992; Petit *et al.*, 1999; Augustin *et al.*, 2004; Spahni *et al.*, 2005; Vance *et al.*, 2013; Mulvaney *et al.*, 2013). Antarctic ice core records for the past 2000 years indicate that most of the continent warmed slightly during the Medieval Climate Anomaly (800–1300 AD) and was cooler during the Little Ice Age (1300–1850 AD) with some spatial variation in extent (Bertler *et al.*, 2011; PAGES 2k Consortium, 2013; Mulvaney *et al.*, 2012; Neukom *et al.*, 2014). Since 1850, Antarctic ice core records exhibit less temporal variability, with the exception of the Antarctic Peninsula, which over the past 50 years has been warming rapidly compared to moderate warming in West Antarctica and moderate cooling in East Antarctica (Mulvaney *et al.*, 2012; Bromwich *et al.*, 2013). However, despite the benefits of ice core records, the extent to which they afford a complete picture of regional and/or continental climate variability is uncertain. Ice core records are inherently constrained geographically and do not provide information on surface hydrological processes, such as melting and evaporation. Therefore, lake sediment records from coastal ice-free regions of Antarctica which reflect local hydrological balance can provide complementary information (Roberts *et al.*, 2001; Tavernier *et al.*, 2014).

Lake sediments archive chemical, biological and physical characteristics of lakes, which in turn reflect changes in past climate (Battarbee, 2000; Jones *et al.*, 2000; Hodgson *et al.*, 2001). Fossil diatoms preserved in lake sediment are

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particularly useful, due to their sensitivity to chemical and physical lake conditions, as well as their prevalence and high preservation potential in sediments (Birks *et al*., 1990; Battarbee *et al*., 2001; Round *et al*., 2007). Diatoms are particularly sensitive to salinity (Battarbee *et al*., 2001; Fritz, 2007; Spaulding *et al*., 2010; Stager *et al*., 2012), which in closed basins or lakes with long residence times is primarily a function of the hydrological balance between precipitation and evaporation (Verleyen *et al*., 2003; Roberts *et al*., 2006; Spaulding *et al*., 2010). The nexus between climate, salinity and diatom response is modulated by several factors such as basin shape and size (Fritz, 2008), landscape position (Webster *et al*., 1996) and water chemistry variables other than salinity (Saros and Fritz, 2000). As a result, replication of fossil diatom studies is important but rare in Antarctica due to the challenges of research in this remote region.

The aquatic ecosystems within the Skarvsnes Foreland, East Antarctica, have been the subject of several studies. Diatoms and blue-green algae sampled from lakes and streams in the region are documented by Hirano (1983) and Ohtsuka *et al*. (2006). Takano *et al*. (2012) analysed sediments from two lakes in Lützow–Holm Bay, including Lake Skallen in Skarvsnes, and used diatoms and sediment geochemistry to document the transition from marine to lacustrine conditions during glacial-isostatic uplift. Most recently, Tavernier *et al*. (2014) studied a sediment core from Lake Mago (Mago Ike) in Skarvsnes. Tavernier *et al*. (2014) developed and applied a regional diatom-based transfer function for lake water salinity, from which they concluded that there is no evidence for distinct climatic change between the Medieval Climate Anomaly and the Little Ice Age in East Antarctica. Here we present a new record of environmental change in East Antarctica for the past 900 years based on a study of diatoms within the uppermost 45 cm of sediment from Lake Abi, in the Skarvsnes Foreland, approximately 2 km from Lake Mago. Palaeoclimate inferences are based on previous observations of diatom autecological preferences (Hirano, 1983; Sabbe *et al*., 2003; Verleyen *et al*., 2003), a regional surface sediment training set and associated salinity transfer function (Tavernier *et al*., 2014). The data provide a new perspective on climate change and variability in coastal Antarctica, while highlighting some of the challenges facing palaeoclimate and palaeolimnological research in the region.

Site description

The Skarvsnes Foreland is one of several ice-free regions along the coast of Lützow–Holm Bay in East Antarctica (Fig. 1). Lakes in Antarctica are restricted to these ice-free regions and range from hypersaline to freshwater (Tavernier *et al*., 2014). The climate across most of Antarctica, including Showa Station in Lützow–Holm Bay (location shown in Fig. 1b), is classified as an ice cap climate, with no months where the average daily temperature is above 0 °C (Kottek *et al*., 2006). Monthly climate data for the Showa Station is provided in Supplementary Information Table S1.

Lake Abi is seasonally ice-free, and located within the Skarvsnes Foreland (69°29′26.2″S, 39°36′04.9″), 100 m above sea level. The lake is fed by snowfield melt and most volume loss is by evaporation. The lake is at maximum 4 m deep, with a surface area of 2000 m^2 (Ohtsuka *et al*., 2006). As with many lakes in the region, the lake floor of Lake Abi is dominated by microbial mats composed of cyanobacteria, green algae and diatoms, with occasional aquatic moss and little allochthonous sediment input (Hirano, 1983; Ohtsuka *et al*., 2006).

Methods

Sample collection and subsampling

The Ab5S core from Lake Abi was collected in January 2006 during the 47th Japanese Antarctic Research Expedition, using a piston-operated coring device. An Ekman grab sample of the sediment–water interface was also collected and a visual comparison of this and the top of the core taken with the piston corer led to the firm conclusion that the uppermost core samples are representative of an undisturbed sediment–water interface. During the same expedition, the water column profile of the lake was determined using a multiple water quality sensor (YSI 6600EDS/YSI Nanotech, Inc.) for water temperature, pH, conductivity, dissolved oxygen, oxidation–reduction potential, turbidity and concentration of chlorophyll. Sediment was sampled from the core using contiguous $22 \times 22 \times 22$-mm cubes. These samples were further subsampled for diatom analysis.

Due to dehydration during storage and transport, most of the sediment samples had shrunk within the storage cubes. Therefore, subsamples were taken at intervals proportional to the size of the sediment cube at the time of sampling, by cutting the sample in half, then in half again. The sediments were subsampled parallel to the orientation of the pervasive sediment laminations. Due to the shrinking, some samples may have rotated within their boxes. In these instances, the same sampling strategy was followed, cutting the sediment perpendicular to laminations, but there are uncertainties with regards to precise sample orientation in these instances. This uncertainty is indicated in the figures where relevant.

Diatom analysis

Samples were prepared using a method adapted from Battarbee *et al*. (2001) involving HCl and H_2O_2 digestion. Diatom frustules were mounted onto slides using Naphrax. Slides were analysed at a magnification of 1000× using a Nikon Eclipse E600 microscope, and taxonomic assignments were aided by scanning electron microscopy. Due to the high prevalence of one species, *Diadesmis australis*, slides were counted for 200 valves counting all valves, and then another 200, not counting the *D. australis* valves to better characterize the variation of other species (following a method suggested by Battarbee *et al*., 2001). Diatom data are reported and subsequently analysed as percentage relative abundance for all taxa, as is common practice. Species were identified with floras derived from studies of lake surface sediments in the Skarvsnes region (Hirano, 1983; Ohtsuka *et al*., 2006) as well as other lake sediment diatom studies from East Antarctica, namely the Amery Oasis (Cremer *et al*., 2004), and the Larsemann Hills and Rauer Islands (Sabbe *et al*., 2003).

Age modelling and nitrogen isotope analysis

A chronology for the Lake Abi core was established using 19 radiocarbon dates from bulk organic material. Following acid–alkali–acid pretreatment, samples were converted to graphite following Yokoyama *et al*. (2007), which was analysed by accelerator mass spectrometry (AMS) at the University of Tokyo or at Beta Analytic, Inc. (Miami, FL, USA). Radiocarbon ages were calibrated to calendar years using BACON (Blaauw and Christen, 2011) combined with the Southern Hemisphere atmospheric calibration curve (Hogg *et al*., 2013). A coring date of −56 years (AD 2006) before present (cal a BP, where present is 1950) was used to constrain the age of the uppermost sediments.

To assess whether the sediments were deposited in freshwater, we determined sediment nitrogen isotopic composition

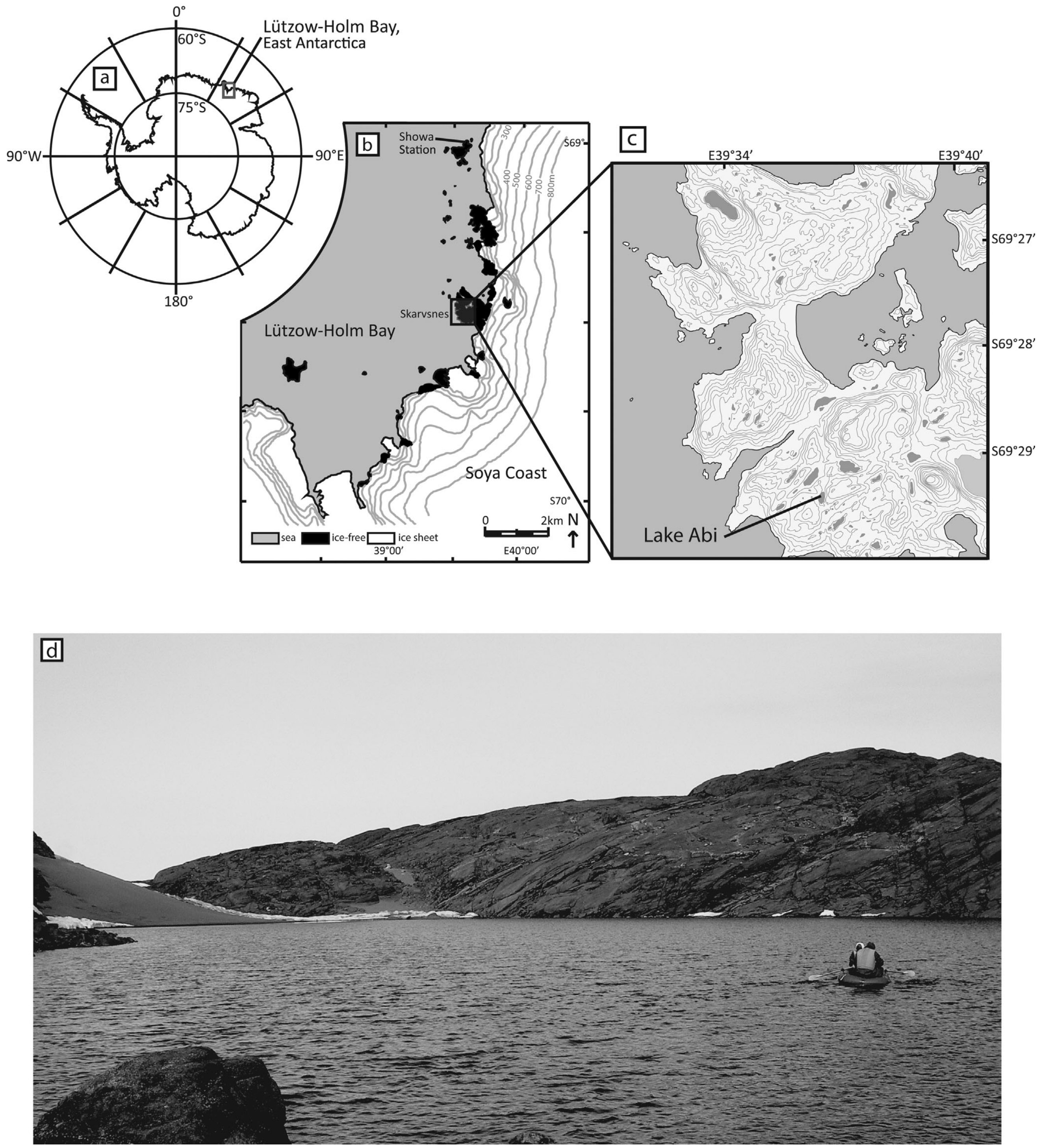

Figure 1. (a) Location map of Lützow–Holm Bay in East Antarctica; (b) ice-free areas and ice sheet extent within Lützow–Holm Bay, as well as the location of Showa Station (contour interval is 100 m) (adapted from Takano *et al.* (2012); (c) detailed map of the Skarvsnes ice-free region highlighting the location of Lake Abi (contour interval is 10 m) (adapted from Geographical Survey Institute, 1987) – the white areas on this figure are ocean; (d) landscape of Lake Abi at Skarvsnes. Photo taken in January 2006.

using an elemental analyser (Costech 4010 or Flash 2000) – isotope ratio mass spectrometer (ThermoFinnigan, Delta Plus or ThermoFinnigan Delta V Advantage) as described by Takano *et al.* (2015). Nitrogen isotopic compositions are expressed as per mil (‰) deviations as:

$$\delta^{15}N = [(^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{standard} - 1] \times 1000 \quad (‰\ vs.\ \text{Air})$$

The standard deviations for nitrogen isotopic compositions using authentic working standard reagents (cf. Tayasu *et al.*, 2011) were: BG-A ($n=12$, $\delta^{15}N < \pm 0.25‰$), BG-P ($n=6$, $\delta^{15}N < \pm 0.24‰$) and BG-T ($n=9$, $\delta^{15}N < \pm 0.26‰$) in the first validation, and BG-A ($n=10$, $\delta^{15}N < \pm 0.26‰$), BG-P ($n=6$, $\delta^{15}N < \pm 0.18‰$) and BG-T ($n=7$, $\delta^{15}N < \pm 0.38‰$) in the second validation.

Numerical analysis and diatom conductivity reconstruction

To identify major patterns of ecological change in diatom assemblages, detrended correspondence analysis (DCA) was used, reducing the species data to a limited number of principal vectors (Hill and Gauch, 1980). DCA was conducted with square-root transformation of diatom percentage data to reduce the influence of the highly abundant taxa (*sensu* Mills *et al.*, 2014). The relationship between diatom species assemblages in the Lake Abi core and the diatoms and environmental variables in the modern Lützow–Holm Bay training set of Tavernier *et al.* (2014) was explored by performing canonical correspondence analysis (CCA) upon the modern data and plotting the Lake Abi diatoms passively within the ordination space. CCA was also conducted using square-root-transformed diatom data, with the exclusion of two training set samples from site SK4 which were marked outliers in the ordination. Both DCA (DECORANA) and CCA were carried out using VEGAN for R (Oksanen *et al.*, 2013).

Lake water conductance was inferred using the transfer function of Tavernier *et al.* (2014), namely a two-component weighted averaging partial least squares model, with a jack-knifed r^2 between diatom-inferred and measured specific conductance of 0.85 and a root mean squared error of prediction of 0.10 mS cm^{-1}. The Lake Abi fossil flora is well represented in the calibration set, with >99% of the diatoms found in each sample represented in Tavernier *et al.* (2014). Furthermore, each of the species found in the Lake Abi core are well represented in Tavernier *et al.* (2014). Each species has an N_2 value (Hill, 1973) exceeding four, with the exception of *Hantzschia c.f. amphioxys*, which is not abundant in the Lake Abi record.

Results

Limnology, lithology and geochronology

Water temperature at Lake Abi varied between 3.7 and 4.1 °C in the vertical profile (Fig. 2). Other parameters such as pH, electrical conductivity, dissolved oxygen, oxidation–reduction potential and chlorophyll concentration did not fluctuate markedly with depth, suggesting that there was no significant chemocline in the water column at the time of sampling. The benthic microbial mat (maximum water depth: 4 m) could be observed during sampling, indicating low turbidity.

The Ab5S core consists of green–grey laminated algal biofilm, including some mosses and medium- to coarse-grained sands within the organic layers (Fig. 3). There are few to no discernible changes in lithology throughout the 1.2 m of sediment. The nitrogen isotopic composition of the entire Ab5S sequence exhibits typical freshwater limnological characteristics (depth 0–130 cm, $n = 20$; $\delta^{15}N$ from −1.6 to +1.5‰ *vs.* Air), similar to the freshwater sedimentological stages in Lake Oyako at Skarvsnes and Lake Skallen in the Skallen area (Takano *et al.*, 2012).

Nineteen radiocarbon dates, reported in Supplementary Information Table S2, are all in stratigraphic order, with no evidence for age reversals within the radiocarbon measurement and calibration error. The radiocarbon dates suggest a relatively constant sediment accumulation rate of approximately 40 cm per 1000 years (Fig. 3). The extrapolated age of the radiocarbon dates to the present day does not entirely overlap with the estimated age of the sediment surface, based on coring date. This implies that the uppermost 5 cm of sediment represents an approximate period between 300 and 150 years, the upper end of which is around half the sediment accumulation rate of the rest of the core.

Diatom species abundances

Eighty-four contiguous samples over the uppermost 45-cm section from Lake Abi core Ab5S were analysed for diatoms at 5-mm intervals. Seven species dominated, with several others observed, represented by only occasional valves. There were no distinct arrivals or disappearances in the section analysed, covering 900 years (Fig. 4). Nevertheless, changes in relative abundance did occur, and these are documented below.

Diadesmis australis was the most abundant diatom species observed. It is considerably more abundant than any other throughout the core, and is the second most abundant in only seven of the 84 samples. *D. australis* has an almost oscillatory pattern of abundance, varying around 80–90%, with a maximum abundance of 99.5% in three samples, at 820, 810 and 400 cal a BP. Aside from at these times, there are local maxima at 780, 720, 665, 605, 580, 525, 490, 430, 360, 265, 195, 120 and −40 cal a BP (Fig. 4). *Navicula gregaria* is the second most abundant species in the core section and has a highest relative abundance at 595 cal a BP of 76.9%. *N. gregaria* also has many local maxima, at 790, 740, 645, 540, 500, 455, 410, 360, 320, 305, 160 and 30 cal a BP, with small variations around these peaks (Fig. 4).

The third most abundant species is *Craticula antarctica*. This species has very low abundance in samples older than ~470 cal a BP, where there is a notable increase peaking at 450 cal a BP to 18.4%, and followed by another larger increase in abundance peaking at 220 cal a BP to 34.9% (Fig. 4).

Psammothidium papilio has a notable increase in abundance from 485 to 470 cal a BP, peaking at 475 cal a BP to 13.8%. Other small peaks of 5–7% occur at 790, 720, 560, 360 and 95 cal a BP. *P. papilio* otherwise shows low variation, with a particularly low abundance from 690 to 605 cal a BP.

Stauroneis latistauros has a maximum abundance at 460 cal a BP of 1.5%. There are three other smaller peaks in abundance at 790, 330 and 90 cal a BP, each around 0.8–1%. This species also shows a distinctly lower relative abundance around 665–595 cal a BP, similar to *P. papilio*.

Halamphora veneta is observed at very low abundance in some samples. Eight samples have an abundance of over 0.5%, and the maximum is 0.9% at 560 cal a BP. *Hantzschia cf. amphioxys* is the least common of the seven species in Fig. 4, and only observed in 16 samples. The largest peak in abundance (0.25%) occurs near the base of the studied section of core, at 790 cal a BP.

Ordination of diatom data

Changes in the diatom species assemblages at Lake Abi are summarized using DCA (Fig. 5a), as well as CCA (Fig. 5b) to relate patterns in species assemblages within contemporary ecosystems to environmental parameters. The first DCA axis, which explains 36.3% of the variance in the dataset, is characterized by positive weighting of *C. antarctica*, *S. latistauros* and *N. gregaria*. The other four major taxa exhibit a negative association with DCA axis 1, in particular *Halamphora veneta* and *Hantzschia cf. amphioxys* (Fig. 5a). The second DCA axis explains 26.0% of the total variance. It is characterized by positive weighting by *C. antarctica* and also, to a lesser extent, by *D. australis*. The other five major taxa exhibit a negative weighting, in particular *N. gregaria* (Fig. 5a). Plotted against time in Fig. 6(e), the first DCA axis shows a shift from negative to positive values at around 450 cal BP, a decline between 400 and 350 cal a BP, followed by a subsequent return to positive DCA scores after 350 cal a BP (Fig. 6e).

As seen in Fig. 5(b), CCA axis 1 is strongly associated with lake water salinity, whilst CCA axis 2 corresponds to changes

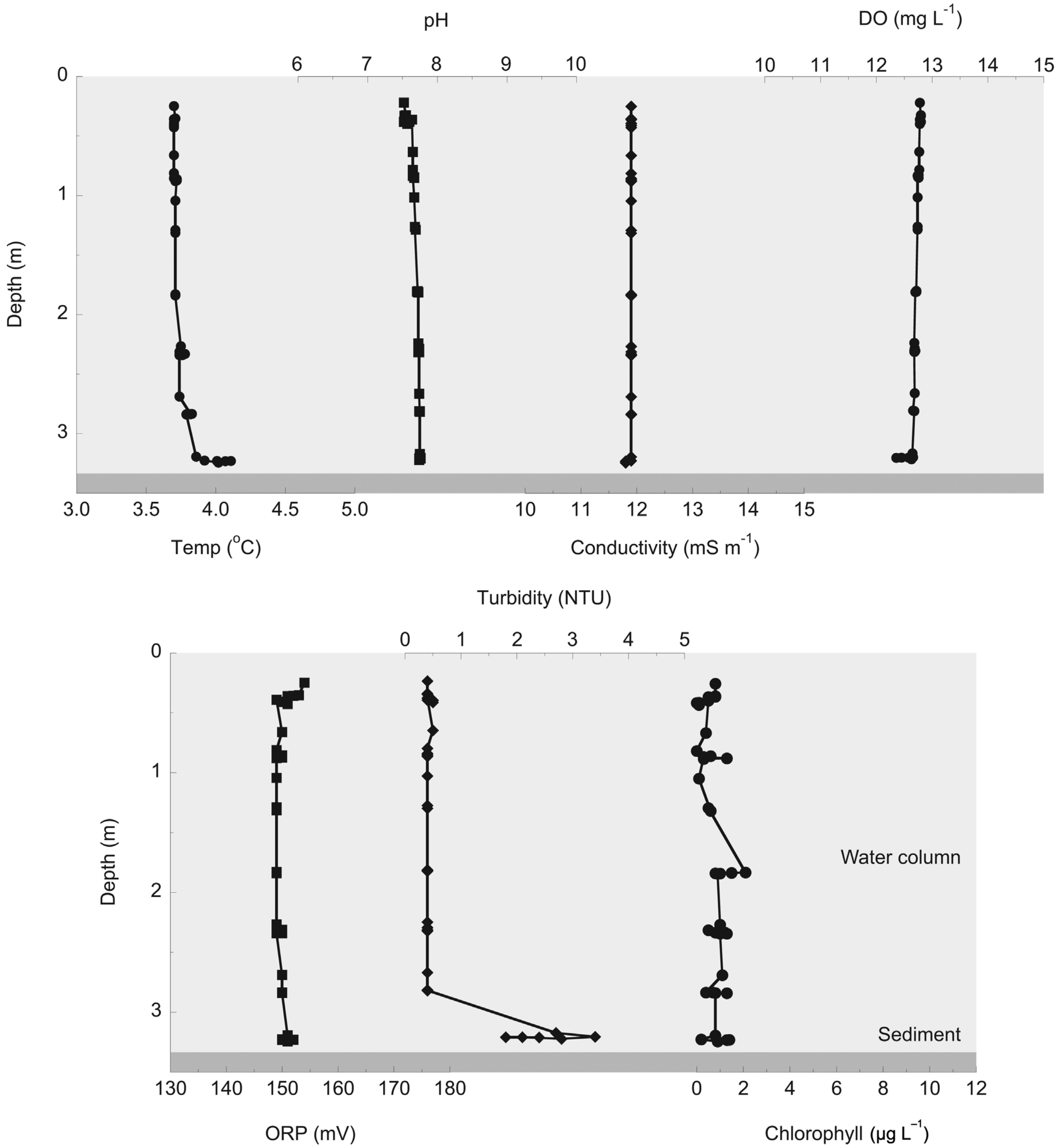

Figure 2. Vertical physical and chemical water profiles of Lake Abi at the time of sampling.

along a nutrient gradient, with sites positively loaded against CCA axis 2 associated with lakes with high total nitrogen, high oxidation–reduction potential, and low pH and lake depth (Tavernier *et al.*, 2014). When plotted passively within this CCA biplot, the diatom species from Lake Abi closely associate with other lakes in Lützow–Holm Bay, namely samples collected in Skarvsnes, West Ongul Islands and East Ongul Islands (Fig. 5b). The passive Lake Abi timetrack varies along a fairly linear gradient that most strongly associates with CCA axis 2, and hence is interpreted to relate to changes in lake depth, total nitrogen concentration and, to a lesser extent, with the salinity gradient of CCA axis 1. The Lake Abi passive scores for CCA axis 2 particularly correlate negatively with the relative abundance of *Navicula gregaria* ($r^2 = 0.60$, $p < 0.001$).

Diatom-inferred lake water conductivity

Using the diatom transfer function based on the Lützow–Holm Bay calibration dataset (Tavernier *et al.*, 2014), a record of conductivity change over time for Lake Abi is presented in Fig. 6(f). Diatom-inferred conductivity exhibits a low amplitude of variability which falls well within the ± 0.1 mS cm^{-1} reconstruction uncertainty, thus implying that there was no significant change in conductivity. However, diatom-inferred conductivity positively correlates with DCA axis 1

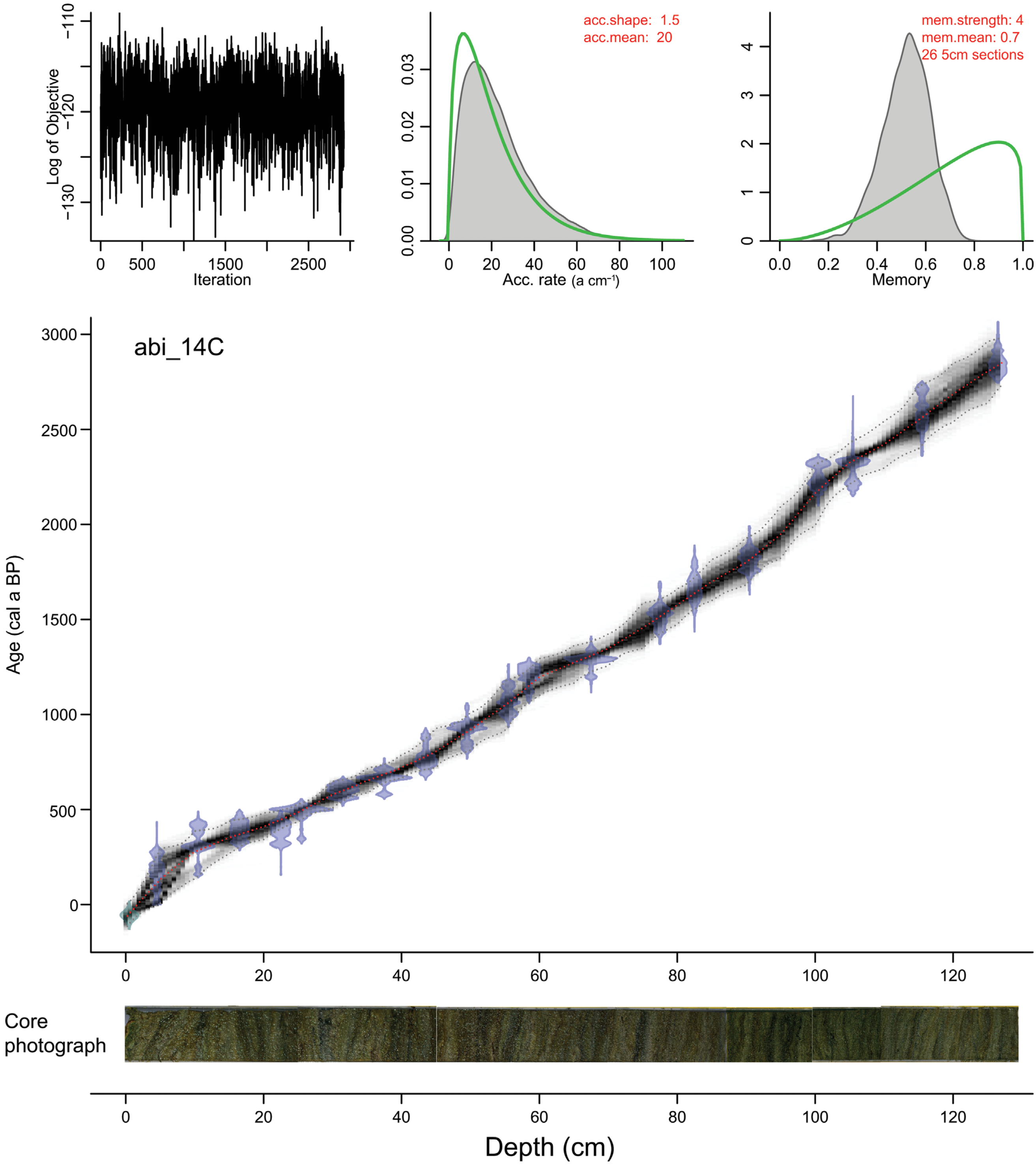

Figure 3. Bacon age model for the Lake Abi sediment core, where probability density functions for each calibrated age are shown in blue, the grey curve indicates the age–depth model and the red curve is the best fit model. Upper panels indicate the iterations performed, accumulation rate and memory used to construct the model. Beneath the age model is a photograph of the core.

($r^2 = 0.66$, $p < 0.001$) suggesting that although subtle, the pattern of change in the diatom-inferred conductivity does represent environmental changes at Lake Abi. As expected, diatom-inferred conductivity also correlates positively with the passive CCA axis 1 scores ($r^2 = 0.61$, $p < 0.001$).

Discussion

Chronology

The 19 radiocarbon dates from the Ab5S core indicate a near constant rate of sediment accumulation throughout the last 3000 years, providing confidence in the age model despite some limitations. Radiocarbon dating is best conducted using terrestrial organic matter, where the source of the fixed carbon can be unequivocally assigned to atmospheric CO_2 (Lowe *et al.*, 1997). In the case of Lake Abi, this was not possible due to an absence of terrestrial plant macrofossils in the sediments, reflecting an absence of vegetation in the lake catchment. Although this situation is not optimal, we have confidence in the Lake Abi age model, firstly because there is not likely to be any source of aged, detrital organic carbon from the lake catchment, which is also bereft of soil.

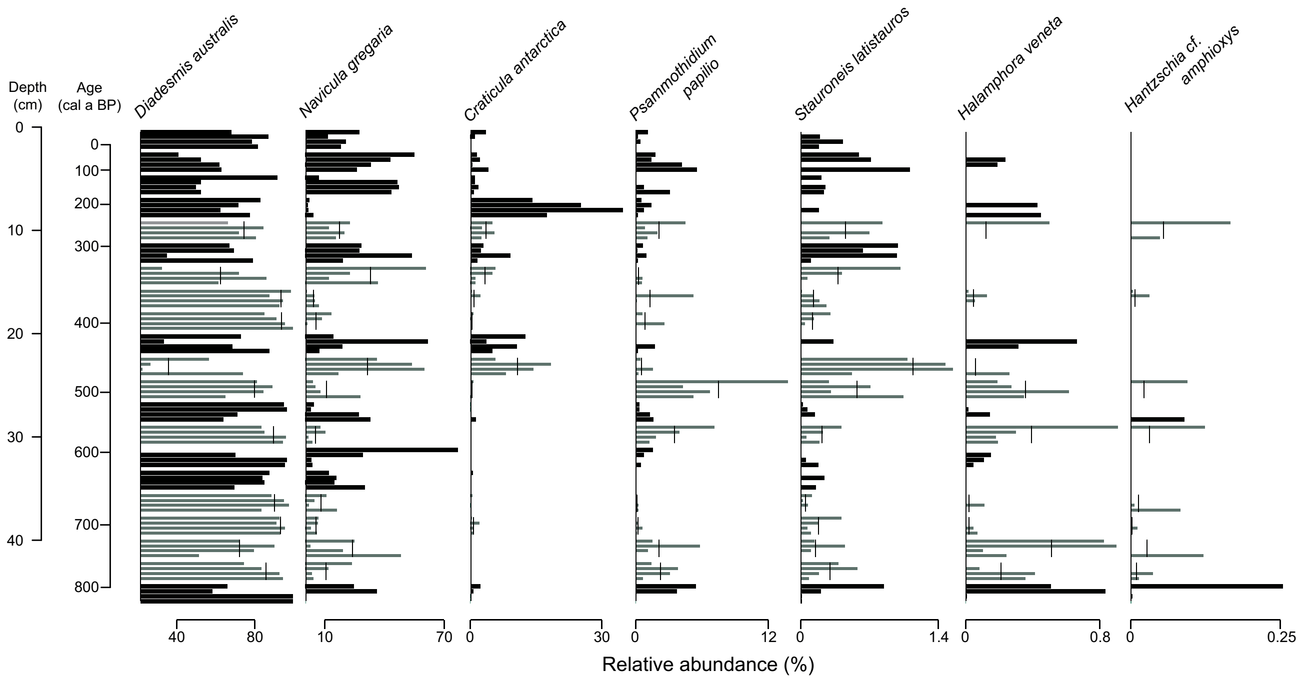

Figure 4. Stratigraphic diagram of all diatom species above 0.25% in at least one sample in the Lake Abi record. Lighter bars indicate where sediment realignment may have occurred within the sediment cubes, and average bars are calculated and included for these samples. Note that scales vary for relative abundance between species.

Secondly, the shallow lake depth of Lake Abi (<4 m) is likely to allow a constant mixing of lake water and the maintenance of isotopic equilibrium with atmospheric CO_2 (*sensu* Björck and Wohlfarth, 2001). These factors, plus the overall consistency of radiocarbon dates, support the assumption that bulk organic matter is a suitable medium for radiocarbon dating at this site.

One source of uncertainty in the Lake Abi radiocarbon chronology relates to the change in sediment accumulation rate near to the top of the core, whereby the coring date does not intersect an extrapolation of the radiocarbon-only age model (Fig. 3). This disagreement may relate to a number of factors, including a reservoir effect, the loss of some material from the top of the core or compaction during coring.

Changes in groundwater-derived inorganic carbon (a freshwater reservoir effect) can lead to alterations in the apparent ^{14}C age of aquatic carbon (Björck and Wohlfarth, 2001). A reservoir effect from old carbon is a possibility in a lake with high organic content from the microbial mats, and limited lake water mixing due to low inflow and outflow, as well as

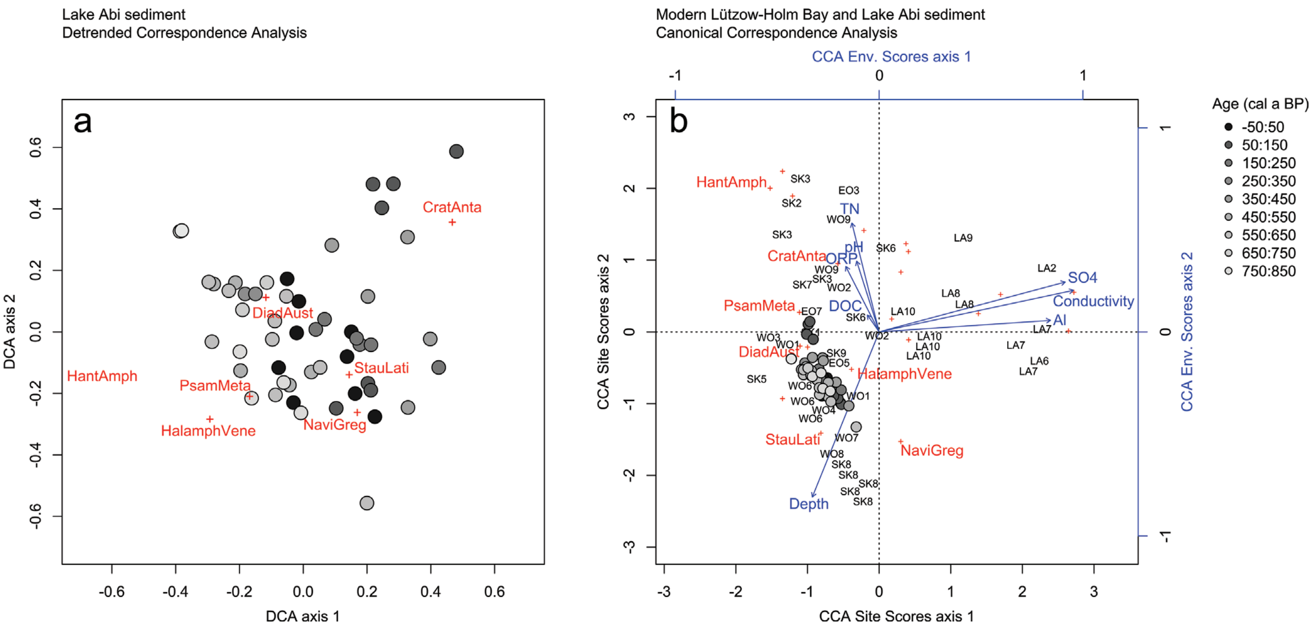

Figure 5. (a) DCA ordination biplot for the first two axes of the Lake Abi samples, with major diatom species labelled. (b) CCA plot of modern diatom samples and environmental variables in Lützow–Holm Bay within the training set of Tavernier *et al.* (2014), excluding two outlier sites as described in the text. Lake Abi diatom data plotted passively within the CCA ordination space (grey points). In both plots, the age of the Lake Abi samples is indicated by the grey shading, as depicted in the key.

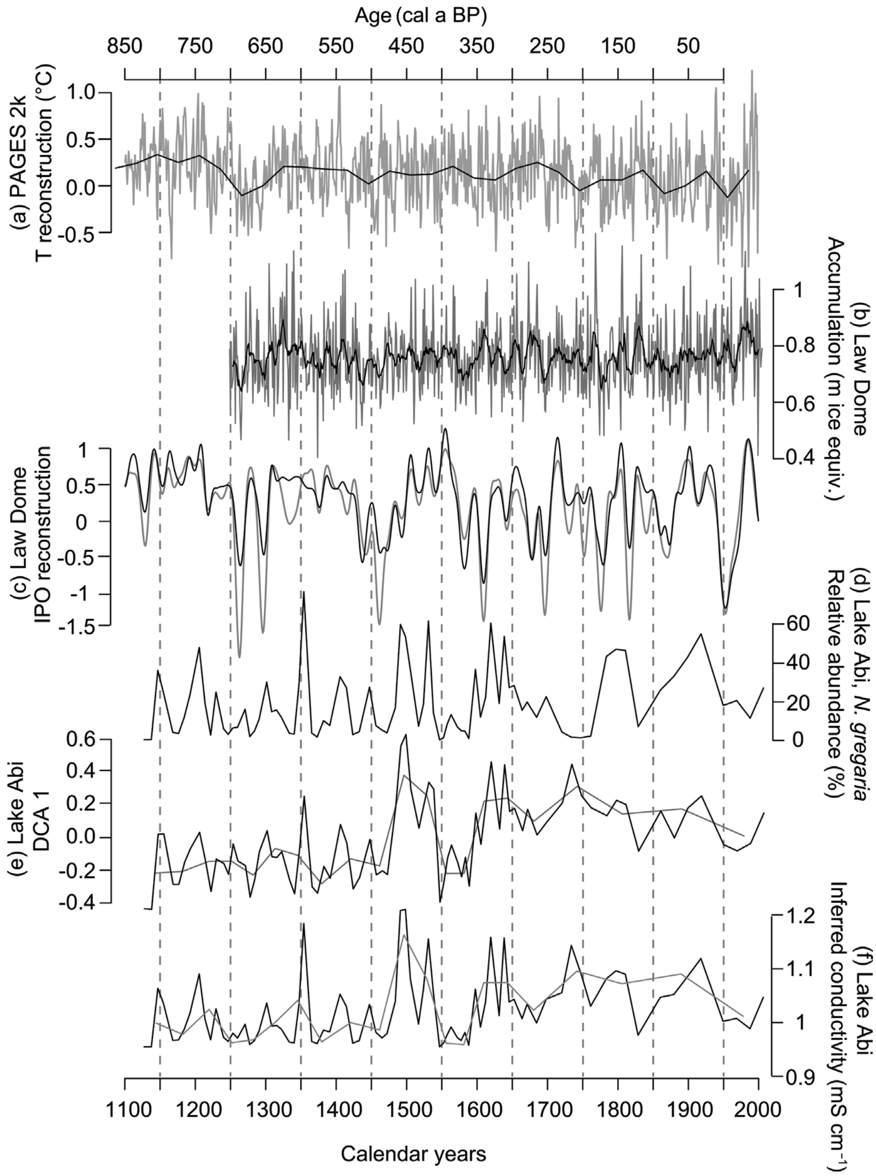

Figure 6. Compilation of climate and hydroclimate reconstructions for the past 900 years. (a) Antarctic regional temperature reconstruction – the black line indicates a 30-year average (PAGES 2k Consortium, 2013); (b) ice accumulation rate at Law Dome in East Antarctica – black line indicates a nine-sample moving average (Vance *et al.*, 2012); (c) Interdecadal Pacific Oscillation index reconstruction from the Law Dome ice core record, where the grey line indicates a piecewise linear fit model and black is a decision tree model reconstruction (Vance *et al.*, 2015); (d) relative abundance in the Lake record of *N. gregaria*; (e) DCA axis 1 scores for Lake Abi species data; (f) inferred conductivity reconstructed for Lake Abi species data (root mean square error of prediction = 0.1 mS cm^{-1}). In (e) and (f), grey lines indicate four-sample averages.

ice cover for part of the year. However, the laminated nature of the sediments suggests macro-scale bioturbation is limited, and this coupled with low temperatures, resulting in slow breakdown and respiration, could result in limited transfer of carbon from the sediment to the water column. Although a reservoir effect cannot be ruled out, at such low temperatures, with perennially frozen soil and groundwater, a significant groundwater influence is unlikely. Furthermore, reservoir effects are rarely observed in freshwater lakes in coastal Antarctica (Hodgson *et al.*, 2001).

Loss of surficial sediment during coring is another possible explanation for the apparent reduction in accumulation rate in the uppermost section of the core. However, as described above, the mucilaginous nature of the surficial sediments at Lake Abi, and the strong similarity between the sediment–water interface observed in both the Ekman grab and in the uppermost sediments collected by the piston corer, suggests limited sediment loss or disturbance during coring. As with reservoir effects, although we cannot comprehensively rule out sediment loss as being the explanation for the lower accumulation rate in the uppermost sediments, we deem this explanation unlikely.

Compaction is a common problem when using piston corers to sample soft, surficial sediments (Glew *et al.*, 2001). At Lake Abi, the spongy nature of the sediments lends them to compaction, particularly in the well-hydrated uppermost sediments. We therefore conclude that compaction is the most likely explanation for the change in sediment accumulation rate depicted in Fig. 3, whereby the uppermost sediments expelled water and air during coring. A range of low-impact gravity corers have been developed to counter this (e.g. Renberg and Hansson, 2008); however, such methods were not employed when coring Lake Abi. Furthermore, limited sample availability precluded the application of additional dating techniques (e.g. ^{210}Pb) to constrain the sediment accumulation rate in the uppermost sediments. Due to the uncertainties with respect to the age and accumulation rate of the top 5 cm of sediment, we have deliberately avoided interpreting the timing and significance of changes in the uppermost sediment record.

Ecological preferences of diatom taxa found in the sediments of Lake Abi

The diatom species within the analysed section of the Lake Abi core have a very low diversity, characteristic of lakes at higher latitudes, with diversity in lakes found to decrease southward on the Antarctic continent (Jones, 1996). The value of diatoms as palaeoenvironmental tracers is limited by what is known about their physical and chemical preferences, a problem that is particularly marked in Antarctica due to inherent practical challenges of field collection and observation. Nevertheless, despite these uncertainties, it is still possible to make informed interpretations on the basis of diatom species assemblages. Ohtsuka *et al.* (2006) found that diatom composition in lakes within the Skarvsnes Foreland was not affected by the presence or absence of mosses within the lakes, and that the main environmental gradient was electrical conductivity (a measure of salinity). Ohtsuka *et al.* (2006) suggest *D. australis*, *P. papilio* and *H. veneta* may have very low phosphate optima, but also conclude that most lakes in the region are likely to be oligotrophic (low in nutrients), so it is likely that many of the species observed are tolerant of low phosphate conditions.

Diadesmis australis, the most common species in the sediments of Lake Abi (Fig. 4), is characteristic of small ponds (Hodgson *et al.*, 2005), and has been observed throughout Antarctica and East Antarctic lakes (Sabbe *et al.*, 2003; Cremer *et al.*, 2004; Van de Vijver *et al.*, 2010). This small species was reclassified by Van de Vijver *et al.* (2010) from *Diadesmis cf. perpusilla*. *D. australis* was observed as *Navicula arcuata* in Skarvsnes lakes (Hirano, 1983), and as *D. cf. perpusilla* in saline lakes in East Antarctica. It has been suggested that *Diadesmis australis* may be halophobic (salt intolerant) and have a low phosphate optimum, but from its abundance in a range of locations may have a much larger tolerance than previously documented (Ohtsuka *et al.*, 2006). The species has been found on moist rocks, mosses and soils as an aerophilic species, meaning it tolerates being exposed to air (Krammer and Lange-Bertalot, 1986), but its distribution suggests it is not limited to these habitats.

Craticula antarctica, *Navicula gregaria* and *Stauroneis latistauros* are all Naviculoids, a morphological type which is often associated with motile diatoms that inhabit biofilms and sediment surfaces (Round *et al.*, 2007). *Navicula gregaria* is believed to be a cosmopolitan and common species (Lange-Bertalot, 2001), but is rare in continental Antarctica (Kellogg and Kellogg, 2002). *N. gregaria* is, however, reported from several Skarvsnes lakes at the sediment surface, including in Lake Abi (Ohtsuka *et al.*, 2006). *Craticula antarctica* was described as a new species by Van de Vijver *et al.* (2010). *C. antarctica* has been previously reported from Antarctica under several other names, including from the East Antarctic Vestfold Hills, Larsemann Hills and Rauer Islands as *C. molesta* (Roberts and McMinn, 1999; Sabbe *et al.*, 2003), and from Skarvsnes as *Craticula* sp. (Ohtsuka *et al.*, 2006). *Stauroneis latistauros* was also described as a new species in 2004 (Van de Vijver *et al.*, 2004). This species and several other new species were separated from *S. anceps*, which was believed to have a very widespread distribution across Antarctica (Kellogg and Kellogg, 2002). The distribution of *S. latistauros* is now unclear due to taxonomic reorganization, but the species has been reported from East Antarctica as *S. anceps* (Sabbe *et al.*, 2003) and from Skarvsnes lakes (Ohtsuka *et al.*, 2006). *S. latistauros* has a low specific conductance optimum (Van de Vijver *et al.*, 2004), as do *N. gregaria* and *C. antarctica*, in the context of the Lützow–Holm Bay training set (Fig. 4b; Tavernier *et al.*, 2014). However, while *S. latistauros* and *N. gregaria* associate most closely with the deeper, nutrient-poor lakes within the training set, *C. antarctica* exhibits positive loading on CCA axis 2, demonstrating a greater affiliation with shallower, relatively nutrient-rich and moderately more saline lakes (Fig. 4b; Tavernier *et al.*, 2014).

Psammothidium papilio is believed to be prevalent across Antarctica, but has previously been reported under other names (Sabbe *et al.*, 2003; Kopalová *et al.*, 2012). *P. papilio* has been documented from freshwater lakes in the Larsemann Hills and Rauer Islands (Sabbe *et al.*, 2003) and the Amery Oasis (Cremer *et al.*, 2004) in East Antarctica as well as from Skarvsnes lakes (Ohtsuka *et al.*, 2006). Although commonly affiliated with sand substrates (epipsammic), the genus *Psammothidium* has also been observed growing attached to rocks (epilithic) in other locations (Flower *et al.*, 2007) and may also be epilithic in Antarctica. As with *C. antarctica*, *P. papilio* was also commonly collected from shallow depths in the Lützow–Holm Bay training set (Tavernier *et al.*, 2014). *H. veneta* is found around Antarctica, including lakes in the Vestfold Hills, the Larsemann Hills and Rauer Islands of East Antarctica (Roberts and McMinn, 1999; Sabbe *et al.*, 2003).

Diatom species change at Lake Abi in the context of regional environmental conditions

DCA of the Lake Abi diatom assemblages results in species groupings that agree well with the ecological preferences of those taxa (as described above). *H. veneta*, *P. papilio* and to a lesser extent *D. australis*, all non-motile, periphytic taxa, exhibit negative loading on DCA axis 1. By contrast, the naviculoids *N. gregaria*, *S. latistauros* and *C. antarctica* all exhibit positive loading on DCA axis 1 (Fig. 5a). Changes in the DCA axis 1 scores therefore reflect shifts between these groups, a pattern which is clear from the raw diatom data, where periods of high *N. gregaria* relative abundance, for example, correspond with lower concentrations of *H. veneta* (Fig. 4). DCA axis 2 predominantly reflects the offset between *C. antarctica*, which is positively loaded on DCA axis 2, and the other naviculoids: *N. gregaria* and *S. latistauros*. The most common taxon, *D. australis*, is situated centrally in the DCA biplot. It follows that the major patterns of change in the diatom assemblages result from changes in the relative abundance of the additional taxa (Fig. 5a).

CCA axis 1 is positively associated with lake water conductivity (salinity) in Lützow–Holm Bay (Fig. 5b). CCA axis 2 is positively linked to lake water total nitrogen concentrations, oxidation–reduction potential and pH, and negatively associated with water depth at the sampling site (Fig. 5b). The distribution of species found at Lake Abi within the regional CCA plot (Fig. 5b) mimics that in the Lake Abi-specific DCA biplot (Fig. 5a), with *C. antarctica* in particular lying separate from the other species found in Lake Abi. All taxa found at Lake Abi are negatively loaded upon CCA axis 1, suggesting that the lake sits among the least saline lakes in the region. When plotted passively within the CCA plot, the diatom assemblages from Lake Abi cluster closely to other lakes in Skarvsnes (note that Lake Abi was not part of the training set) as well as water bodies in West Ongul Island, and are situated along CCA axis 2. Hence, an important component of change in the diatom species assemblage at Lake Abi reflects a pattern of fluctuating nitrogen availability and/or lake water depth. This pattern of change is illustrated in Fig. 6 through the concentration of *Navicula gregaria*.

Diatom-inferred conductivity exhibits only very moderate change through the record, well within the reconstruction uncertainty, and hence should be treated with caution (cf. Tavernier *et al.*, 2014). These small changes are probably related to the lake water being freshwater with only a minor sensitivity to changes in evaporative salt concentration or dilution. However, the correlation between diatom-inferred salinity and both DCA axis 1 and the passive CCA axis 1 scores suggests that these patterns of change represent real changes in the diatom assemblage alongside an additional effect of changing lake water nutrient status over shorter timescales (Fig. 6e,f).

Lake water depth, nitrogen availability and salinity can all be related to climate-driven changes in catchment snow melt and seasonal lake ice cover. The water balance of Antarctic lakes is, however, complicated, particularly in systems where wind-blown snow is a major contributor to water input. However, due to the low temperatures it is logical to infer that changes in catchment snow melt have an important influence upon lake water depth. Water depth in turn affects lake ice cover, with lakes <2.5 m deep commonly freezing entirely during the winter (Verleyen *et al.*, 2012). Because of this freezing, shallow lakes in Lützow–Holm Bay are commonly characterized by an absence of cyanobacterial mats, a higher percentage of epipsammic and aerophilous diatoms and an increase in the mobilization of nutrients from the sediments (Fig. 5b; Tavernier *et al.*, 2014). By contrast, increases in snow melt and lake water depth promote the development of microbial mats, which in turn draw down available nutrients into the sediment. Such changes in snow melt and lake level will also result in changes in lake water conductivity, depending on the initial solute concentration in the lake water (Verleyen *et al.*, 2012). The current water depth at Lake Abi is ~4 m, which is close to the threshold of complete freezing on a seasonal basis under conditions of lower temperature and reduced snow melt. Consequently, the palaeolimnological records from Lake Abi and similar lakes in the region potentially provide sensitive archives of climate-driven environmental changes. Of course, this hypothetical interpretation requires significant further research, both in the form of contemporary limnological monitoring as well as through the analysis of complementary sediment properties, both sedimentological and geochemical (e.g. Hodgson *et al.*, 2005; Noon *et al.*, 2001; Noon *et al.*, 2003). These questions represent major goals for ongoing research.

Regional significance of the Lake Abi record

Irrespective of the mechanisms behind the diatom species change at Lake Abi, the record exhibits low amplitude variability, which may provide valuable insights into the nature of climate and environmental change in coastal Antarctica and the Southern Hemisphere (Fig. 6). These shifts include an overall change to higher DCA axis 1 scores and subtly increased conductivity after ~470 cal a BP (Fig. 6e,f) and marked decadal–centennial-scale variability in nutrient availability and/or lake depth, as indicated by changes in CCA axis 2 and the relative abundance of *N. gregaria* (Fig. 6d). The changes in *N. gregaria* in particular are comparable to the Interdecadal Pacific Oscillation reconstruction using the Law Dome ice core record (Vance *et al.*, 2015). However, both modes of variability contrast with the apparently stable continent-wide temperature reconstruction (PAGES 2k Consortium, 2013) and the record of ice accumulation at Law Dome (Van Ommen *et al.*, 2004). These patterns of change at Lake Abi, although poorly constrained to date, suggest that significant information can be extracted from lake sediment records in coastal Antarctica that may provide complementary climate records to ice core data, particularly with respect to surface hydrological change, as well as the intrinsic ecological value of such information. In particular, brackish closed lakes should be targeted in future research projects, as the moisture balance in these systems is expected to react more sensitively than freshwater lakes (Verleyen *et al.*, 2012).

Conclusion

The 900-year diatom-based reconstruction from Lake Abi, Lützow–Holm Bay, Antarctica, was characterized by relatively moderate changes in species composition. Changes in the diatom assemblage are tentatively inferred to reflect changes in lake salinity, nutrient status and water depth. The lake became moderately more oligotrophic and saline after 450 cal a BP, with notable peaks in oligotrophy and salinity centred on 470 and 200 cal a BP (Fig. 6f). In addition, the record exhibits decadal–centennial-scale variability, which is reminiscent of the Law Dome Interdecadal Pacific Oscillation reconstruction (Vance *et al.*, 2015). It is possible that these changes reflect changes in catchment precipitation and ice melt, although uncertainties associated with our understanding of the limnology and diatom autoecology of Lake Abi prevent a more confident interpretation. Thus, further research into modern day lake ecology, in addition to the further generation of new records, is required to fully resolve the centennial-scale spatiotemporal patterns of climate in this globally important region.

Supporting Information

Additional supporting information may be found in the online version of this article.

Table S1. Climate data from the Showa Station in East Antarctica (see Fig. Abram et al., 2014 for location) sourced from the Japan Meteorological Agency (2010). Climate data were collected over 30 years from 1981 to 2010, except for wind direction, which was collected over 21 years from 1990 to 2010.

Table S2. Radiocarbon dates and calibrated age ranges for core Ab5S. Up to three possible calibrated age ranges are given per ^{14}C age where they exist, along with the probability of each age range.

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Abbreviations. AMS, accelerator mass spectrometry; CCA, canonical correspondence analysis; DCA, detrended correspondence analysis; ENSO, El-Niño Southern Oscillation; SAM, Southern Annular Mode.

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Appendix 2

This appendix comprises data tables which accompany Chapter 3, 4 and 5.

Table 1 - Sampling locations for Chapter 3

Table 2 - Diatom counts presented in Chapter 3

Table 3 - Diatom counts for fossil diatom records presented in Chapter 4
- a) Lake Hamagiku
- b) Lake Naga

Table 4 - Stable isotope data presented in Chapter 5
- a) Lake Hamagiku, no pre-treatment,
- b) Lake Hamagiku, acid pre-treatment
- c) Lake Naga, no pre-treatment
- d) Lake Naga, acid pre-treatment

Table 1 - Sampling locations, Lützow-Holm Bay

Sample location	Date	Latitude	Longitude	No. of substrates sampled (for littoral only)
Nurume 1	21/01/2018	S69° 13.472'	E039° 39.422'	2
Nurume 2	21/01/2018	S69° 13.437'	E039° 39.414'	2
Nurume 3	21/01/2018	S69° 13.394'	E039° 39.422'	2
Nurume 4	21/01/2018	S69° 13.352'	E039° 39.454'	2
Nurume 5	21/01/2018	S69° 13.331'	E039° 39.567'	2
Nurume 6	21/01/2018	S69° 13.341'	E039° 39.664'	1
Nurume 7	21/01/2018	S69° 13.365'	E039° 39.689'	3
Nurume 8	21/01/2018	S69° 13.408'	E039° 39.638'	3
Nurume 9	21/01/2018	S69° 13.431'	E039° 39.536'	1
Nurume 10	21/01/2018	S69° 13.499'	E039° 39.622'	1
Yukidori 1	22/01/2018	S69° 14.413'	E039° 45.416'	3
Yukidori 2	22/01/2018	S69° 14.431'	E039° 45.387'	4
Yukidori 3	22/01/2018	S69° 14.432'	E039° 45.365'	2
Yukidori 4	22/01/2018	S69° 14.429'	E039° 45.412'	2
Yukidori 5	22/01/2018	S69° 14.444'	E039° 45.465'	2
Yukidori 6	22/01/2018	S69° 14.440'	E039° 45.627'	2
Yukidori 7	22/01/2018	S69° 14.417'	E039° 45.669'	3
Yukidori 8	22/01/2018	S69° 14.420'	E039° 45.729'	2
Yukidori 9	22/01/2018	S69° 14.418'	E039° 45.777'	3
Yukidori T1	22/01/2018	S69° 14.375'	E039° 45.574'	-
Yukidori T2	22/01/2018	S69° 14.414'	E039° 45.526'	-
Yukidori T3	22/01/2018	S69° 14.432'	E039° 45.478'	-
Hotoke 1	11/01/2018	S69° 28.599'	E039° 33.713'	1
Hotoke 2	11/01/2018	S69° 28.568'	E039° 33.682'	2
Hotoke 3	11/01/2018	S69° 28.551'	E039° 33.669'	2
Hotoke 4	11/01/2018	S69° 28.569'	E039° 33.640'	2
Hotoke 5	11/01/2018	S69° 28.597'	E039° 33.623'	2
Hotoke 6	11/01/2018	S69° 28.619'	E039°33.629'	1
Hotoke 7	11/01/2018	S69° 28.618'	E039° 33.713'	1
Hotoke surface	11/01/2018	lake centre		-
Kuwai 1	11/01/2018	S69° 28.456'	E039° 34.356'	2
Kuwai 2	11/01/2018	S69° 28.463'	E039° 34.311'	2
Kuwai 3	11/01/2018	S69° 28.462'	E039° 34.277'	2
Kuwai 4	11/01/2018	S69° 28.444'	E039° 34.276'	2
Kuwai 5	11/01/2018	S69° 28.428'	E039° 34.284'	2
Kuwai 6	11/01/2018	S69° 28.420'	E039° 34.276'	2
Kuwai surface	11/01/2018	lake centre		-
Naga 1	5/01/2018	S69° 29.167'	E039° 35.861'	3
Naga 2	5/01/2018	S69° 29.163'	E039° 35.891'	2
Naga 3	5/01/2018	S69° 29.160'	E039° 35.908'	2
Naga 4	5/01/2018	S69° 29.156'	E039° 35.939'	2
Naga 5	5/01/2018	S69° 29.152'	E039° 35.965'	1
Naga 6	5/01/2018	S69° 29.161'	E039° 35.981'	1
Naga 7	5/01/2018	S69° 29.173'	E039° 35.988'	1
Naga 8	5/01/2018	S69° 29.186'	E039° 36.000'	1
Naga 9	5/01/2018	S69° 29.196'	E039° 35.997'	1
Naga 10	6/01/2018	S69° 29.234'	E039° 36.062'	1
Naga 11	6/01/2018	S69° 29.229'	E039° 36.002'	2

Table 1 - cont.

Sample location	Date	Latitude	Longitude	No. of substrates sampled (for littoral only)
Naga 12	6/01/2018	S69° 29.247'	E039° 36.103'	2
Naga 13	6/01/2018	S69° 29.261'	E039° 35.962'	1
Naga 14	6/01/2018	S69° 29.292'	E039° 35.889'	2
Naga 15	6/01/2018	S69° 29.314'	E039° 35.814'	2
Naga 16	6/01/2018	S69° 29.332'	E039° 35.780'	1
Naga 17	6/01/2018	S69° 29.331'	E039° 35.736'	1
Naga 18	6/01/2018	S69° 29.352'	E039° 35.727'	2
Naga 19	6/01/2018	S69° 29.369'	E039° 35.749'	2
Naga 20	6/01/2018	S69° 29.338'	E039° 35.669'	1
Naga 21	6/01/2018	S69° 29.334'	E039° 35.606'	1
Naga 22	6/01/2018	S69° 29.333'	E039° 35.568'	2
Naga 23	6/01/2018	S69° 29.314'	E039° 35.564	2
Naga 24	6/01/2018	S69° 29.292'	E039° 35.584'	2
Naga 25	6/01/2018	S69° 29.354'	E039° 35.471'	
Naga 26	6/01/2018	S69° 29.364'	E039° 35.456'	2
Naga 27	6/01/2018	S69° 29.382'	E039° 35.421'	2
Naga 28	6/01/2018	S69° 29.129'	E039° 36.001'	2
Naga 29	17/01/2018	S69° 29.168'	E039° 35.878'	1
Naga 30	17/01/2018	S69° 29.192'	E039° 35.823'	1
Naga 31	17/01/2018	S69° 29.202'	E039° 35.789'	2
Naga 32	17/01/2018	S69° 29.219'	E039° 35.753'	1
Naga 33	17/01/2018	S69° 29.231'	E039° 35.708'	3
Naga 34	17/01/2018	S69° 29.250'	E039° 35.684'	2
Naga 35	17/01/2018	S69° 29.268'	E039° 35.649'	1
Naga 36	17/01/2018	S69° 29.357'	E039° 35.420'	2
Naga 37	17/01/2018	S69° 29.374'	E039° 35.362'	2
Naga 38	17/01/2018	S69° 29.392'	E039° 35.332'	2
Naga 39	17/01/2018	S69° 29.403'	E039° 35.294'	1
Naga 40	17/01/2018	S69° 29.417'	E039° 35.260'	2
Naga 41	17/01/2018	S69° 29.420'	E039° 35.310'	2
Naga 42	17/01/2018	S69° 29.405'	E039° 35.368'	2
Naga 43	17/01/2018	S69° 29.393'	E039° 35.389'	2
Naga 44	17/01/2018	S69° 29.160'	E039° 35.975'	1
Naga 45	17/01/2018	S69° 29.173'	E039° 35.983'	1
Naga E1	17/01/2018	S69° 29.204'	E039° 35.884'	-
Naga E2	17/01/2018	S69° 29.221'	E039° 35.863'	-
Naga E3	17/01/2018	S69° 29.190'	E039° 35.913'	-
Naga E4	17/01/2018	S69° 29.206'	E039° 35.834'	-
Naga E5	17/01/2018	S69° 29.243'	E039° 35.949'	-
Naga E6	17/01/2018	S69° 29.261'	E039° 35.746'	-
Naga S01	24/01/2018	S69° 29' 12.4"	E039° 35' 42.5"	-
Naga S02	24/01/2018	S69° 29' 10.8"	E039° 35' 48.1"	-
Naga S03	24/01/2018	S69° 29' 10.6"	E039° 35' 48.3"	-
Naga S04	24/01/2018	S69° 29' 09.2"	E039° 35' 51.3"	-
Naga S05	24/01/2018	S69° 29' 08.9"	E039° 35' 50.5"	-
Naga S06	24/01/2018	S69° 29' 08.9"	E039° 35' 51.6"	-
Naga S07	24/01/2018	S69° 29' 08.3"	E039° 35' 52.1"	-
Naga S08	24/01/2018	S69° 29' 08.0"	E039° 35' 52.6"	-

Table 1 - cont.

Sample location	Date	Latitude	Longitude	No. of substrates sampled (for littoral only)
Naga S09	24/01/2018	S69° 29' 07.7"	E039° 35' 53.1"	-
Namazu 01	18/01/2018	S69° 30.017'	E039° 42.079'	-
Namazu 02	18/01/2018	S69° 29.998'	E039° 42.192'	-
Namazu 03	18/01/2018	S69° 30.014'	E039° 42.141'	-
Namazu 04	18/01/2018	S69° 30.023'	E039° 42.037'	-
Namazu 05	18/01/2018	S69° 30.025'	E039° 41.986'	-
Namazu 06	18/01/2018	S69° 30.025'	E039° 41.929'	-
Namazu 07	18/01/2018	S69° 30.026'	E039° 41.889'	-
Namazu 08	18/01/2018	S69° 30.012'	E039° 41.986'	-
Namazu 09	18/01/2018	S69° 30.003'	E039° 41.945'	-
Oyako 1	8/01/2018	S69° 28.494'	E039° 36.078'	3
Oyako 2	8/01/2018	S69° 28.505'	E039° 36.064'	1
Oyako 3	8/01/2018	S69° 28.489'	E039° 36.113'	2
Oyako 4	8/01/2018	S69° 28.488'	E039° 36.152'	2
Oyako 5	8/01/2018	S69° 28.490'	E039° 36.191'	1
Oyako 6	8/01/2018	S69° 28.498'	E039° 36.231'	1
Oyako 7	8/01/2018	S69° 28.499'	E039° 36.276'	1
Oyako 8	8/01/2018	S69° 28.498'	E039° 36.322'	2
Oyako 9	8/01/2018	S69° 28.496'	E039° 36.364'	2
Oyako 10	8/01/2018	S69° 28.493'	E039° 36.413'	1
Oyako 11	10/01/2018	S69° 28.495'	E039° 36.093'	3
Oyako 12	10/01/2018	S69° 28.512'	E039° 35.972'	2
Oyako 13	10/01/2018	S69° 28.520'	E039° 35.938'	3
Oyako 14	10/01/2018	S69° 28.533'	E039° 35.911'	2
Oyako 15	10/01/2018	S69° 28.549'	E039° 35.884'	1
Oyako 16	10/01/2018	S69° 28.564'	E039° 35.874'	1
Oyako 17	10/01/2018	S69° 28.582'	E039° 35.887'	1
Oyako 18	10/01/2018	S69° 28.601'	E039° 35.893'	2
Oyako 19	10/01/2018	S69° 28.634'	E039° 35.848'	3
Oyako 20	10/01/2018	S69° 28.599'	E039° 35.925'	2
Oyako 21	10/01/2018	S69° 28.585'	E039° 35.957'	2
Oyako 22	10/01/2018	S69° 28.601'	E039° 35.983'	2
Oyako 23	10/01/2018	S69° 28.615'	E039° 36.007'	3
Oyako 24	10/01/2018	S69° 28.624'	E039° 36.044'	2
Oyako 25	12/01/2018	S69° 28.613'	E039° 36.085'	2
Oyako 26	12/01/2018	S69° 28.596'	E039° 36.113'	2
Oyako 27	12/01/2018	S69° 28.583'	E039° 36.131'	2
Oyako 28	12/01/2018	S69° 28.567'	E039° 36.119'	2
Oyako 29	12/01/2018	S69° 28.582'	E039° 36.071'	2
Oyako 30	12/01/2018	S69° 28.572'	E039° 36.178'	2
Oyako 31	12/01/2018	S69° 28.563'	E039° 36.205'	2
Oyako 32	12/01/2018	S69° 28.550'	E039° 36.229'	2
Oyako 33	12/01/2018	S69° 28.539'	E039° 36.262'	2
Oyako 34	12/01/2018	S69° 28.530'	E039° 36.292'	1
Oyako 35	12/01/2018	S69° 28.519'	E039° 36.321'	2
Oyako 36	12/01/2018	S69° 28.510'	E039° 36.375'	2
Oyako 37	12/01/2018	S69° 28.505'	E039° 36.413'	2
Oyako 38	12/01/2018	S69° 28.491'	E039° 36.482'	2

Table 1 - cont.

Sample location	Date	Latitude	Longitude	No. of substrates sampled (for littoral only)
Oyako 39	12/01/2018	S69° 28.476'	E039° 36.517'	2
Oyako 40	12/01/2018	S69° 28.459'	E039° 36.497'	2
Oyako 41	14/01/2018	S69° 28.466'	E039° 36.556'	2
Oyako 42	14/01/2018	S69° 28.476'	E039° 36.611'	4
Oyako 43	14/01/2018	S69° 28.480'	E039° 36.656'	2
Oyako 44	14/01/2018	S69° 28.480'	E039° 36.703'	2
Oyako 45	14/01/2018	S69° 28.477'	E039° 36.740'	2
Oyako 46	14/01/2018	S69° 28.473'	E039° 36.789'	3
Oyako 47	14/01/2018	S69° 28.469'	E039° 36.831'	2
Oyako 48	16/01/2018	S69° 28.459'	E039° 36.536'	1
Oyako 49	16/01/2018	S69° 28.445'	E039° 36.590'	2
Oyako 50	16/01/2018	S69° 28.442'	E039° 36.634'	3
Oyako 51	16/01/2018	S69° 28.441'	E039° 36.680'	1
Oyako 52	16/01/2018	S69° 28.436'	E039° 36.730'	2
Oyako 53	16/01/2018	S69° 28.443'	E039° 36.797'	1
Oyako 54	16/01/2018	S69° 28.443'	E039° 36.837'	2
Oyako 55	16/01/2018	S69° 28.446'	E039° 36.890'	2
Oyako 56	16/01/2018	S69° 28.459'	E039° 36.899'	1
Oyako 57	16/01/2018	S69° 28.428'	E039° 36.609'	1
Oyako 58	16/01/2018	S69° 28.437'	E039° 36.630'	2
Oyako 59	16/01/2018	S69° 28.441'	E039° 36.623'	2
Oyako T1	9/01/2018	S69° 28.528'	E039° 36.147'	-
Oyako T2	9/01/2018	S69° 28.521'	E039° 36.106'	-
Oyako T3	9/01/2018	S69° 28.521'	E039° 36.124'	-
Oyako T4	9/01/2018	S69° 28.513'	E039° 36.145'	-
Oyako T5	9/01/2018	S69° 28.508'	E039° 36.141'	-
Oyako T6	9/01/2018	S69° 28.501'	E039° 36.141'	-
Oyako T7	9/01/2018	S69° 28.499'	E039° 36.137'	-
Oyako T8	9/01/2018	S69° 28.497'	E039° 36.151'	-
Oyako T9	12/01/2018	S69° 28.468'	E039° 36.674'	-
Oyako T10	16/01/2018	S69° 28.461'	E039° 36.715'	-
Sara 1	19/01/2018	S69° 28.871'	E039° 39.242'	2
Sara 2	19/01/2018	S69° 28.887'	E039° 39.226'	1
Sara 3	19/01/2018	S69° 28.895'	E039° 39.286'	3
Sara 4	19/01/2018	S69° 28.893'	E039° 39.415'	2
Sara 5	19/01/2018	S69° 28.885'	E039° 39.510'	2
Sara 6	19/01/2018	S69° 28.852'	E039° 39.457'	3
Sara 7	19/01/2018	S69° 28.852'	E039° 39.383'	3
Skallen T1	28/01/2018	S69° 40.330'	E039° 25.290'	-
Skallen T2	28/01/2018	S69° 40.326'	E039° 25.323'	-
Skallen T3	28/01/2018	S69° 40.336'	E039° 25.399'	-
Skallen T4	28/01/2018	S69° 40.361'	E039° 25.586'	-
Skallen T5	28/01/2018	S69° 40.366'	E039° 25.647'	-
Skallen T6	28/01/2018	S69° 40.357'	E039° 25.742'	-
Skallen 1	29/01/2018	S69° 40.262'	E039° 24.324'	2
Skallen 2	29/01/2018	S69° 40.244'	E039° 24.625'	3
Skallen 3	29/01/2018	S69° 40.236'	E039° 25.092'	3
Skallen 4	29/01/2018	S69° 40.275'	E039° 25.650'	3
Skallen 5	29/01/2018	S69° 40.347'	E039° 25.811'	2

Table 2 - Diatom counts presented in Chapter 3

Location	site	substrate	sample depth (m)	Psammothidium papilio	Navicula gregaria	Luticola pseudomurrayi	Halamphora vyvermaniana	Craticula antarctica	Cocconeis fragments
18OY 24a	oyako	cobble	0.25	14.45	33.86	11.06	6.55	3.39	4.29
18OY 29a	oyako	cobble	0.15	19.13	26.47	7.12	25.14	2.67	4.00
18OY 32a	oyako	cobble	0.25	29.07	30.45	6.00	15.69	4.38	2.31
18OY 37a	oyako	cobble	0.05	22.71	35.27	6.04	12.80	1.21	4.35
18OY 40a	oyako	cobble	0.2	26.64	37.15	4.21	21.50	5.84	1.64
18OY 16a	oyako	gravel	0.25	75.38	16.96	0.24	2.36	0.47	1.65
18OY 17a	oyako	gravel	0.2	66.28	21.63	1.63	2.33	0.47	1.86
18OY 18a	oyako	gravel	0.15	64.57	15.38	3.96	5.59	1.63	1.63
18OY 1c	oyako	large rocks	0.2	26.48	33.20	9.09	8.70	2.37	4.74
18OY 12b	oyako	sand	0.25	40.89	39.48	2.35	6.35	2.35	1.18
18OY 13b	oyako	sand	0.25	44.59	27.76	1.75	9.62	1.31	2.62
18OY 15a	oyako	sand	0.25	68.65	19.22	2.06	1.60	0.69	1.83
18OYT1 surface	oyako	depth	8.8	1.91	65.63	0.95	15.27	10.50	0.72
18OYT2 surface	oyako	depth	8	1.63	44.19	0.00	45.35	5.81	1.16
18OYT3 surface	oyako	depth	7	11.02	9.40	1.30	5.83	1.62	17.50
18OYT4 surface	oyako	depth	6	2.38	59.38	0.24	37.29	0.00	0.24
18OYT5 surface	oyako	depth	5	1.88	76.71	0.47	15.29	4.47	0.00
18OYT6 surface	oyako	depth	4	2.29	68.80	0.00	20.34	5.26	0.91
18OYT7 surface	oyako	depth	3	3.23	61.29	0.43	28.60	4.52	0.65
18OYT8 surface	oyako	depth	2	5.39	70.11	0.22	19.10	2.92	0.45
18OYT9 surface	oyako	depth	3.4	9.16	43.70	1.34	42.94	1.72	0.00
18OYT10 surface	oyako	depth	6.4	7.45	75.28	0.00	12.06	3.13	0.45
18Hm 3a	sara	cobble	0.15	17.66	32.34	2.10	16.47	25.45	1.50
18Hm 5a	sara	cobble	0.15	22.90	40.79	3.05	13.30	9.16	1.74
18Hm 7a	sara	cobble	0.1	14.48	54.30	3.85	9.95	10.41	1.36
18Hm 2a	sara	microbial mat	0.05	45.32	32.60	3.24	1.39	9.25	0.00
18Hm 3c	sara	microbial mat	0	17.92	60.69	2.15	5.26	9.32	1.19
18Hm 4b	sara	microbial mat	0.1	21.97	27.51	1.16	28.21	18.03	0.69
18Hm 1a	sara	sand	0.15	51.52	40.23	0.00	0.29	4.92	1.16
18Hm 3b	sara	sand	0.15	42.02	26.06	1.88	8.92	17.14	0.23
18Hm 6a	sara	sand	0.1	47.15	25.13	3.89	5.96	5.18	1.30

Table 2 - cont.

Location	site	substrate	sample depth (m)	Hantzschia cf. amphioxys	Stauroneis latistauros	Gomphonema sp.	Humidophila arcuata	Achnanthes taylorensis	Humidophila australis	Amphora gourdonii
18OY 24a	oyako	cobble	0.25	8.13	2.26	0.68	0.00	5.42	0.90	1.58
18OY 29a	oyako	cobble	0.15	2.34	1.11	0.89	0.00	2.00	3.78	1.11
18OY 32a	oyako	cobble	0.25	3.11	0.46	0.00	0.00	1.15	6.00	0.00
18OY 37a	oyako	cobble	0.05	3.62	0.48	1.93	0.00	2.42	2.66	0.48
18OY 40a	oyako	cobble	0.2	0.00	0.00	0.23	0.00	0.00	0.47	0.23
18OY 16a	oyako	gravel	0.25	0.12	0.00	0.00	0.00	1.18	0.94	0.24
18OY 17a	oyako	gravel	0.2	0.23	1.63	0.00	0.00	0.70	2.09	0.00
18OY 18a	oyako	gravel	0.15	3.73	0.47	0.00	0.00	0.47	0.93	0.00
18OY 1c	oyako	large rocks	0.2	1.98	0.40	0.40	0.00	1.98	3.95	0.00
18OY 12b	oyako	sand	0.25	0.59	0.47	0.00	0.00	1.65	3.29	0.00
18OY 13b	oyako	sand	0.25	2.73	1.75	0.00	0.00	2.40	2.62	0.00
18OY 15a	oyako	sand	0.25	0.00	0.46	0.69	0.00	0.23	2.52	0.00
18OYT1 surface	oyako	depth	8.8	0.72	0.00	0.72	0.00	0.00	0.48	0.48
18OYT2 surface	oyako	depth	8	0.47	0.00	0.00	0.00	0.00	0.93	0.00
18OYT3 surface	oyako	depth	7	2.11	0.65	0.00	0.00	3.57	0.97	9.08
18OYT4 surface	oyako	depth	6	0.24	0.00	0.00	0.00	0.00	0.00	0.00
18OYT5 surface	oyako	depth	5	0.00	0.00	0.00	0.00	0.00	0.71	0.00
18OYT6 surface	oyako	depth	4	0.11	0.00	0.46	0.00	0.00	1.14	0.00
18OYT7 surface	oyako	depth	3	0.00	0.00	0.43	0.00	0.00	0.43	0.00
18OYT8 surface	oyako	depth	2	0.22	0.45	0.00	0.00	0.00	0.67	0.22
18OYT9 surface	oyako	depth	3.4	0.19	0.76	0.00	0.00	0.00	0.00	0.19
18OYT10 surface	oyako	depth	6.4	0.45	0.30	0.00	0.00	0.00	0.00	0.30
18Hm 3a	sara	cobble	0.15	3.29	0.30	0.00	0.00	0.00	0.00	0.00
18Hm 5a	sara	cobble	0.15	5.34	1.09	0.00	0.00	0.44	0.87	0.22
18Hm 7a	sara	cobble	0.1	2.26	0.90	0.45	0.00	0.90	0.00	0.23
18Hm 2a	sara	microbial mat	0.05	7.05	0.46	0.00	0.00	0.00	0.46	0.00
18Hm 3c	sara	microbial mat	0	1.08	0.00	0.72	0.00	0.00	0.00	0.00
18Hm 4b	sara	microbial mat	0.1	1.73	0.46	0.00	0.00	0.00	0.00	0.23
18Hm 1a	sara	sand	0.15	0.14	0.00	0.00	0.00	0.00	0.58	0.29
18Hm 3b	sara	sand	0.15	3.05	0.47	0.00	0.00	0.23	0.00	0.00
18Hm 6a	sara	sand	0.1	6.99	0.52	0.00	0.00	0.26	2.33	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Fragilariopsis sp. fragments	Pseudofallacia sp.	Psammothidium stauroneioides	Navicula phyllepta	Tryblionella sp.	Navicula sp 2 (Namazu a)
18OY 24a	oyako	cobble	0.25	0.23	0.00	0.00	0.00	0.23	0.00
18OY 29a	oyako	cobble	0.15	0.22	0.00	0.00	0.00	0.00	0.00
18OY 32a	oyako	cobble	0.25	1.15	0.00	0.00	0.00	0.00	0.00
18OY 37a	oyako	cobble	0.05	1.21	0.00	0.00	0.00	0.00	0.00
18OY 40a	oyako	cobble	0.2	1.40	0.23	0.00	0.00	0.00	0.00
18OY 16a	oyako	gravel	0.25	0.24	0.24	0.00	0.00	0.00	0.00
18OY 17a	oyako	gravel	0.2	0.47	0.00	0.00	0.00	0.00	0.00
18OY 18a	oyako	gravel	0.15	0.00	0.00	0.47	0.00	0.00	0.00
18OY 1c	oyako	large rocks	0.2	0.40	0.00	0.00	0.00	0.00	0.00
18OY 12b	oyako	sand	0.25	0.71	0.00	0.00	0.00	0.00	0.00
18OY 13b	oyako	sand	0.25	0.44	0.00	0.00	0.00	0.00	0.00
18OY 15a	oyako	sand	0.25	1.14	0.46	0.00	0.46	0.00	0.00
18OYT1 surface	oyako	depth	8.8	0.48	0.00	0.00	0.00	0.00	0.00
18OYT2 surface	oyako	depth	8	0.23	0.00	0.00	0.23	0.00	0.00
18OYT3 surface	oyako	depth	7	3.24	1.30	0.00	0.00	0.00	0.00
18OYT4 surface	oyako	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
18OYT5 surface	oyako	depth	5	0.00	0.00	0.00	0.00	0.00	0.00
18OYT6 surface	oyako	depth	4	0.23	0.00	0.00	0.00	0.00	0.00
18OYT7 surface	oyako	depth	3	0.22	0.00	0.00	0.00	0.00	0.00
18OYT8 surface	oyako	depth	2	0.22	0.00	0.00	0.00	0.00	0.00
18OYT9 surface	oyako	depth	3.4	0.00	0.00	0.00	0.00	0.00	0.00
18OYT10 surface	oyako	depth	6.4	0.30	0.00	0.00	0.00	0.00	0.00
18Hm 3a	sara	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 5a	sara	cobble	0.15	0.65	0.00	0.00	0.00	0.00	0.00
18Hm 7a	sara	cobble	0.1	0.23	0.00	0.00	0.00	0.00	0.00
18Hm 2a	sara	microbial mat	0.05	0.23	0.00	0.00	0.00	0.00	0.00
18Hm 3c	sara	microbial mat	0	0.24	0.72	0.00	0.00	0.00	0.00
18Hm 4b	sara	microbial mat	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 1a	sara	sand	0.15	0.29	0.29	0.00	0.00	0.00	0.00
18Hm 3b	sara	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 6a	sara	sand	0.1	1.30	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Navicula aff. Directa	Unknown (oyako a)	Unknown (oyako b)	Navicula sp. (Nurume b)	Pinnularia borealis	Pinnularia quadraterea	Pseudostaurosira sp.
18OY 24a	oyako	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	2.93
18OY 29a	oyako	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00	1.11
18OY 32a	oyako	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OY 37a	oyako	cobble	0.05	0.00	0.00	0.00	0.00	0.00	0.00	2.17
18OY 40a	oyako	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OY 16a	oyako	gravel	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OY 17a	oyako	gravel	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.47
18OY 18a	oyako	gravel	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.93
18OY 1c	oyako	large rocks	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.79
18OY 12b	oyako	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OY 13b	oyako	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OY 15a	oyako	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT1 surface	oyako	depth	8.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT2 surface	oyako	depth	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT3 surface	oyako	depth	7	0.00	0.00	0.00	0.00	0.00	0.32	4.54
18OYT4 surface	oyako	depth	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT5 surface	oyako	depth	5	0.00	0.00	0.24	0.00	0.00	0.00	0.00
18OYT6 surface	oyako	depth	4	0.00	0.00	0.23	0.00	0.00	0.00	0.00
18OYT7 surface	oyako	depth	3	0.00	0.22	0.00	0.00	0.00	0.00	0.00
18OYT8 surface	oyako	depth	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT9 surface	oyako	depth	3.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18OYT10 surface	oyako	depth	6.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 3a	sara	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.90
18Hm 5a	sara	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.44
18Hm 7a	sara	cobble	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.23
18Hm 2a	sara	microbial mat	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 3c	sara	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 4b	sara	microbial mat	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 1a	sara	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.29
18Hm 3b	sara	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 6a	sara	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Paralia sulcata	Small cocconeis sp.	OY24a unknown	centric sp. a	Unknown (coarse striae)	Pinnularia microstauron
18OY 24a	oyako	cobble	0.25	1.81	0.00	1.13	1.13	0.00	0.00
18OY 29a	oyako	cobble	0.15	2.22	0.67	0.00	0.00	0.00	0.00
18OY 32a	oyako	cobble	0.25	0.00	0.00	0.00	0.00	0.23	0.00
18OY 37a	oyako	cobble	0.05	1.93	0.72	0.00	0.00	0.00	0.00
18OY 40a	oyako	cobble	0.2	0.47	0.00	0.00	0.00	0.00	0.00
18OY 16a	oyako	gravel	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18OY 17a	oyako	gravel	0.2	0.00	0.00	0.00	0.00	0.23	0.00
18OY 18a	oyako	gravel	0.15	0.23	0.00	0.00	0.00	0.00	0.00
18OY 1c	oyako	large rocks	0.2	2.77	0.00	0.00	1.58	1.19	0.00
18OY 12b	oyako	sand	0.25	0.71	0.00	0.00	0.00	0.00	0.00
18OY 13b	oyako	sand	0.25	2.40	0.00	0.00	0.00	0.00	0.00
18OY 15a	oyako	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18OYT1 surface	oyako	depth	8.8	1.67	0.00	0.00	0.48	0.00	0.00
18OYT2 surface	oyako	depth	8	0.00	0.00	0.00	0.00	0.00	0.00
18OYT3 surface	oyako	depth	7	14.59	0.97	0.00	7.13	4.86	0.00
18OYT4 surface	oyako	depth	6	0.24	0.00	0.00	0.00	0.00	0.00
18OYT5 surface	oyako	depth	5	0.00	0.00	0.00	0.00	0.24	0.00
18OYT6 surface	oyako	depth	4	0.00	0.00	0.00	0.00	0.23	0.00
18OYT7 surface	oyako	depth	3	0.00	0.00	0.00	0.00	0.00	0.00
18OYT8 surface	oyako	depth	2	0.00	0.00	0.00	0.00	0.00	0.00
18OYT9 surface	oyako	depth	3.4	0.00	0.00	0.00	0.00	0.00	0.00
18OYT10 surface	oyako	depth	6.4	0.00	0.00	0.00	0.15	0.15	0.00
18Hm 3a	sara	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 5a	sara	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 7a	sara	cobble	0.1	0.00	0.00	0.00	0.45	0.00	0.00
18Hm 2a	sara	microbial mat	0.05	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 3c	sara	microbial mat	0	0.00	0.00	0.00	0.72	0.00	0.00
18Hm 4b	sara	microbial mat	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 1a	sara	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 3b	sara	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Hm 6a	sara	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Craspedostauros laevissiumus	Luticola sp. (narrow)	Navicula sp. (Nr a)
18OY 24a	oyako	cobble	0.25	0.00	0.00	0.00
18OY 29a	oyako	cobble	0.15	0.00	0.00	0.00
18OY 32a	oyako	cobble	0.25	0.00	0.00	0.00
18OY 37a	oyako	cobble	0.05	0.00	0.00	0.00
18OY 40a	oyako	cobble	0.2	0.00	0.00	0.00
18OY 16a	oyako	gravel	0.25	0.00	0.00	0.00
18OY 17a	oyako	gravel	0.2	0.00	0.00	0.00
18OY 18a	oyako	gravel	0.15	0.00	0.00	0.00
18OY 1c	oyako	large rocks	0.2	0.00	0.00	0.00
18OY 12b	oyako	sand	0.25	0.00	0.00	0.00
18OY 13b	oyako	sand	0.25	0.00	0.00	0.00
18OY 15a	oyako	sand	0.25	0.00	0.00	0.00
18OYT1 surface	oyako	depth	8.8	0.00	0.00	0.00
18OYT2 surface	oyako	depth	8	0.00	0.00	0.00
18OYT3 surface	oyako	depth	7	0.00	0.00	0.00
18OYT4 surface	oyako	depth	6	0.00	0.00	0.00
18OYT5 surface	oyako	depth	5	0.00	0.00	0.00
18OYT6 surface	oyako	depth	4	0.00	0.00	0.00
18OYT7 surface	oyako	depth	3	0.00	0.00	0.00
18OYT8 surface	oyako	depth	2	0.00	0.00	0.00
18OYT9 surface	oyako	depth	3.4	0.00	0.00	0.00
18OYT10 surface	oyako	depth	6.4	0.00	0.00	0.00
18Hm 3a	sara	cobble	0.15	0.00	0.00	0.00
18Hm 5a	sara	cobble	0.15	0.00	0.00	0.00
18Hm 7a	sara	cobble	0.1	0.00	0.00	0.00
18Hm 2a	sara	microbial mat	0.05	0.00	0.00	0.00
18Hm 3c	sara	microbial mat	0	0.00	0.00	0.00
18Hm 4b	sara	microbial mat	0.1	0.00	0.00	0.00
18Hm 1a	sara	sand	0.15	0.00	0.00	0.00
18Hm 3b	sara	sand	0.15	0.00	0.00	0.00
18Hm 6a	sara	sand	0.1	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Psammothidium papilio	Navicula gregaria	Luticola pseudomurrayi	Halamphora vyvermaniana	Craticula antarctica	Cocconeis fragments
18KW 1a	kuwai	cobble	0.2	82.27	0.03	0.00	0.01	0.00	0.00
18KW 2a	kuwai	cobble	0.2	74.91	0.02	0.01	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	72.99	8.40	5.04	4.32	5.76	0.48
18KW 3a	kuwai	gravel	0.25	91.69	0.98	6.85	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	93.52	0.08	0.03	0.02	0.01	0.00
18KW 2b	kuwai	sand	0.3	90.46	0.08	0.01	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	94.43	2.91	0.48	0.97	0.48	0.00
18KW 5b	kuwai	sand	0.2	93.67	0.97	1.95	0.00	1.95	0.24
18KW 6b	kuwai	sand	0.2	77.10	0.00	0.03	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	13.57	0.95	0.24	38.57	46.19	0.00
18HT 2a	hotoke	cobble	0.3	91.59	0.60	1.80	1.50	1.80	0.60
18HT 4a	hotoke	cobble	0.3	58.80	6.01	3.86	8.58	19.31	0.86
18HT 1a	hotoke	sand	0.25	95.31	0.02	0.06	0.01	0.01	0.00
18HT 2b	hotoke	sand	0.25	96.34	0.03	0.07	0.01	0.03	0.01
18HT 3b	hotoke	sand	0.25	98.04	0.49	0.00	0.00	1.47	0.00
18HT 4b	hotoke	sand	0.25	64.64	0.97	25.03	2.19	4.62	0.00
18HT 5b	hotoke	sand	0.3	94.50	0.00	0.10	0.03	0.02	0.00
18HT 6a	hotoke	sand	0.3	95.74	0.00	3.07	0.00	0.47	0.00
18HT 7a	hotoke	sand	0.3	97.09	0.00	0.73	0.49	0.49	0.24
Hotoke surface	hotoke	depth	3	34.78	0.00	0.69	4.58	57.44	0.00
18Yk 1a	yukidori	cobble	0.2	9.79	3.09	0.00	0.00	0.00	0.00
18Yk 1b	yukidori	cobble	0.2	3.35	0.24	0.00	0.00	0.00	0.00
18Yk 2a	yukidori	cobble	0.2	17.64	2.75	0.00	0.00	0.00	0.00
18Yk 2b	yukidori	cobble	0.2	10.26	1.40	0.00	0.00	0.00	0.00
18Yk 3a	yukidori	cobble	0.1	18.79	8.12	0.00	0.00	0.00	0.00
18Yk 4a	yukidori	cobble	0.2	16.83	4.33	0.24	0.00	0.00	0.00
18Yk 5a	yukidori	cobble	0.2	16.17	7.06	0.23	0.00	0.00	0.00
18Yk 5b	yukidori	cobble	0.25	3.21	1.83	0.00	0.00	0.00	0.00
18Yk 6a	yukidori	cobble	0.2	3.26	0.23	0.00	0.00	0.00	0.00
18Yk 7a	yukidori	cobble	0.15	12.94	2.24	0.00	0.00	0.00	0.00
18Yk 8a	yukidori	cobble	0.2	12.02	2.40	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Hantzschia cf. amphioxys	Stauroneis latistauros	Gomphonema sp.	Humidophila arcuata	Achnanthes taylorensis	Humidophila australis	Amphora gourdonii
18KW 1a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	1.08	1.44	0.00	0.00	0.00	0.00	0.24
18KW 3a	kuwai	gravel	0.25	0.00	0.49	0.00	0.00	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	0.00	0.02	0.00	0.00	0.00	0.00	0.00
18KW 2b	kuwai	sand	0.3	0.00	0.01	0.00	0.00	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	0.00	0.73	0.00	0.00	0.00	0.00	0.00
18KW 5b	kuwai	sand	0.2	0.24	0.97	0.00	0.00	0.00	0.00	0.00
18KW 6b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	0.00	0.48	0.00	0.00	0.00	0.00	0.00
18HT 2a	hotoke	cobble	0.3	0.00	1.20	0.00	0.00	0.00	0.90	0.00
18HT 4a	hotoke	cobble	0.3	0.86	1.29	0.00	0.00	0.43	0.00	0.00
18HT 1a	hotoke	sand	0.25	0.02	0.07	0.00	0.00	0.00	0.01	0.00
18HT 2b	hotoke	sand	0.25	0.04	0.09	0.00	0.00	0.00	0.00	0.00
18HT 3b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4b	hotoke	sand	0.25	0.61	0.73	0.00	0.00	0.00	1.22	0.00
18HT 5b	hotoke	sand	0.3	0.00	0.01	0.00	0.00	0.00	0.01	0.00
18HT 6a	hotoke	sand	0.3	0.00	0.47	0.00	0.00	0.00	0.24	0.00
18HT 7a	hotoke	sand	0.3	0.49	0.49	0.00	0.00	0.00	0.00	0.00
Hotoke surface	hotoke	depth	3	0.00	0.23	0.00	0.00	0.46	1.60	0.00
18Yk 1a	yukidori	cobble	0.2	0.00	0.17	0.00	0.00	0.00	22.16	0.00
18Yk 1b	yukidori	cobble	0.2	0.00	0.24	0.00	0.00	0.00	2.87	0.00
18Yk 2a	yukidori	cobble	0.2	0.11	1.37	0.00	0.00	0.00	63.46	0.00
18Yk 2b	yukidori	cobble	0.2	0.00	0.70	0.00	0.00	0.00	36.36	0.00
18Yk 3a	yukidori	cobble	0.1	0.00	2.32	0.00	0.00	0.00	62.18	0.00
18Yk 4a	yukidori	cobble	0.2	0.24	0.96	0.00	0.00	0.00	69.71	0.00
18Yk 5a	yukidori	cobble	0.2	0.00	1.82	0.00	0.00	0.00	65.15	0.00
18Yk 5b	yukidori	cobble	0.25	0.00	0.00	0.00	0.00	0.00	22.94	0.00
18Yk 6a	yukidori	cobble	0.2	0.00	0.23	0.00	0.00	0.00	90.70	0.00
18Yk 7a	yukidori	cobble	0.15	0.00	1.00	0.00	0.00	0.00	70.90	0.00
18Yk 8a	yukidori	cobble	0.2	0.00	1.60	0.00	0.00	0.00	68.14	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Fragilariopsis sp. fragments	Pseudofallacia sp.	Psammothidium stauroneioides	Navicula phyllepta	Tryblionella sp.	Navicula sp 2 (Namazu a)
18KW 1a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	0.24	0.00	0.00	0.00	0.00	0.00
18KW 3a	kuwai	gravel	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 6b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 1a	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 3b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 5b	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 6a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 7a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
Hotoke surface	hotoke	depth	3	0.23	0.00	0.00	0.00	0.00	0.00
18Yk 1a	yukidori	cobble	0.2	0.00	0.00	64.43	0.17	0.00	0.00
18Yk 1b	yukidori	cobble	0.2	0.00	0.00	93.30	0.00	0.00	0.00
18Yk 2a	yukidori	cobble	0.2	0.00	0.00	14.66	0.00	0.00	0.00
18Yk 2b	yukidori	cobble	0.2	0.00	0.00	51.28	0.00	0.00	0.00
18Yk 3a	yukidori	cobble	0.1	0.00	0.00	8.58	0.00	0.00	0.00
18Yk 4a	yukidori	cobble	0.2	0.00	0.00	7.69	0.00	0.00	0.00
18Yk 5a	yukidori	cobble	0.2	0.00	0.00	9.57	0.00	0.00	0.00
18Yk 5b	yukidori	cobble	0.25	0.00	0.00	72.02	0.00	0.00	0.00
18Yk 6a	yukidori	cobble	0.2	0.00	0.00	5.58	0.00	0.00	0.00
18Yk 7a	yukidori	cobble	0.15	0.00	0.00	12.69	0.00	0.00	0.00
18Yk 8a	yukidori	cobble	0.2	0.00	0.00	15.43	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Navicula aff. Directa	Unknown (oyako a)	Unknown (oyako b)	Navicula sp. (Nurume b)	Pinnularia borealis	Pinnularia quadraterea	Pseudostaurosira sp.
18KW 1a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 3a	kuwai	gravel	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18KW 6b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 1a	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 3b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 5b	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 6a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18HT 7a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hotoke surface	hotoke	depth	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 1a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 1b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 3a	yukidori	cobble	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 4a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 5a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 5b	yukidori	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 6a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 7a	yukidori	cobble	0.15	0.00	0.00	0.00	0.00	0.25	0.00	0.00
18Yk 8a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.40	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Paralia sulcata	Small cocconeis sp.	OY24a unknown	centric sp. a	Unknown (coarse striae)	Pinnularia microstauron
18KW 1a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2a	kuwai	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18KW 3a	kuwai	gravel	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18KW 2b	kuwai	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18KW 5b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18KW 6b	kuwai	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4a	hotoke	cobble	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 1a	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 2b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 3b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 4b	hotoke	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18HT 5b	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 6a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18HT 7a	hotoke	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
Hotoke surface	hotoke	depth	3	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 1a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.17
18Yk 1b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 3a	yukidori	cobble	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 4a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 5a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 5b	yukidori	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 6a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 7a	yukidori	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 8a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Craspedostauros laevissiumus	Luticola sp. (narrow)	Navicula sp. (Nr a)
18KW 1a	kuwai	cobble	0.2	0.00	0.00	0.00
18KW 2a	kuwai	cobble	0.2	0.00	0.00	0.00
18KW 5a	kuwai	cobble	0.25	0.00	0.00	0.00
18KW 3a	kuwai	gravel	0.25	0.00	0.00	0.00
18KW 1b	kuwai	sand	0.3	0.00	0.00	0.00
18KW 2b	kuwai	sand	0.3	0.00	0.00	0.00
18KW 3b	kuwai	sand	0.25	0.00	0.00	0.00
18KW 5b	kuwai	sand	0.2	0.00	0.00	0.00
18KW 6b	kuwai	sand	0.2	0.00	0.00	0.00
Kuwai surface	kuwai	depth	3.6	0.00	0.00	0.00
18HT 2a	hotoke	cobble	0.3	0.00	0.00	0.00
18HT 4a	hotoke	cobble	0.3	0.00	0.00	0.00
18HT 1a	hotoke	sand	0.25	0.00	0.00	0.00
18HT 2b	hotoke	sand	0.25	0.00	0.00	0.00
18HT 3b	hotoke	sand	0.25	0.00	0.00	0.00
18HT 4b	hotoke	sand	0.25	0.00	0.00	0.00
18HT 5b	hotoke	sand	0.3	0.00	0.00	0.00
18HT 6a	hotoke	sand	0.3	0.00	0.00	0.00
18HT 7a	hotoke	sand	0.3	0.00	0.00	0.00
Hotoke surface	hotoke	depth	3	0.00	0.00	0.00
18Yk 1a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 1b	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 2a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 2b	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 3a	yukidori	cobble	0.1	0.00	0.00	0.00
18Yk 4a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 5a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 5b	yukidori	cobble	0.25	0.00	0.00	0.00
18Yk 6a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 7a	yukidori	cobble	0.15	0.00	0.00	0.00
18Yk 8a	yukidori	cobble	0.2	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Psammothidium papilio	Navicula gregaria	Luticola pseudomurrayi	Halamphora vyvermaniana	Craticula antarctica	Cocconeis fragments
18Yk 8b	yukidori	cobble	0.2	6.65	2.71	0.00	0.00	0.00	0.00
18Yk 9a	yukidori	cobble	0.2	18.25	0.00	0.00	0.00	0.00	0.00
18Yk 1c	yukidori	microbial mat	0	10.95	0.24	0.00	0.00	0.00	0.00
18Yk 2d	yukidori	microbial mat	0	4.50	1.66	0.00	0.00	0.00	0.00
18Yk 7b	yukidori	microbial mat	0.2	6.38	0.47	0.00	0.00	0.00	0.00
18Yk 9c	yukidori	microbial mat	0	5.36	3.26	0.23	0.00	0.00	0.00
18Yk 2c	yukidori	sand	0.1	49.66	0.23	0.00	0.00	0.00	0.00
18Yk 3b	yukidori	sand	0.1	18.41	5.31	0.00	0.00	0.00	0.95
18Yk 6b	yukidori	sand	0.25	19.77	0.00	0.00	0.00	0.00	0.00
18Yk 9b	yukidori	sand	0.3	51.96	0.46	0.23	0.00	0.00	0.00
Yukidori T1	yukidori	depth	8	9.33	3.35	0.00	0.00	0.00	0.00
Yukidori T2	yukidori	depth	5	39.72	5.20	0.00	0.00	0.00	0.00
Yukidori T3	yukidori	depth	3.5	13.21	0.47	0.00	0.00	0.00	0.00
18Sk 1b	skallen	cobble	0.2	25.19	5.73	1.91	6.49	14.12	1.53
18Sk 2a	skallen	cobble	0.1	20.86	3.48	0.70	6.95	2.09	1.85
18Sk 3b	skallen	cobble	0.1	6.78	4.93	0.00	13.77	8.84	2.06
18Sk 1a	skallen	large rocks	0.2	10.24	9.06	0.00	7.87	6.30	1.97
18Sk 3a	skallen	large rocks	0.2	5.12	6.05	0.00	14.65	7.44	1.40
18Sk 2c	skallen	microbial mat	0	1.39	1.86	0.00	16.94	6.50	0.70
18Sk 3c	skallen	microbial mat	0	1.86	1.17	0.00	31.47	7.46	1.17
18Sk 4c	skallen	microbial mat	0	6.73	3.94	0.00	4.64	5.34	0.70
18Sk 2b	skallen	sand	0.2	87.59	0.49	0.00	0.49	0.97	0.00
18Sk 5b	skallen	sand	0.15	43.75	0.46	0.00	0.69	0.00	0.00
Skallen T2	skallen	depth	7	7.73	6.32	0.23	19.44	20.61	1.41
Skallen T3	skallen	depth	6	0.66	12.47	0.22	65.65	8.53	0.00
Skallen T4	skallen	depth	6	0.71	3.56	0.00	23.99	17.58	0.00
Skallen T5	skallen	depth	5	3.72	6.51	0.00	24.42	15.58	0.47
Skallen T6	skallen	depth	4	5.58	6.51	0.00	23.49	20.23	0.23
18Ng 1b	naga	cobble	0.35	20.06	23.50	12.61	36.10	4.58	1.15
18Ng 14a	naga	cobble	0.2	26.67	15.48	7.14	31.43	15.00	0.71
18Ng 16a	naga	cobble	0.15	48.47	26.34	6.49	14.12	2.67	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Hantzschia cf. amphioxys	Stauroneis latistauros	Gomphonema sp.	Humidophila arcuata	Achnanthes taylorensis	Humidophila australis	Amphora gourdonii
18Yk 8b	yukidori	cobble	0.2	0.00	0.49	0.00	0.00	0.00	34.73	0.00
18Yk 9a	yukidori	cobble	0.2	0.00	0.24	0.00	0.00	0.00	74.41	0.00
18Yk 1c	yukidori	microbial mat	0	0.24	1.46	0.00	0.00	0.00	85.16	0.00
18Yk 2d	yukidori	microbial mat	0	0.12	1.89	0.00	0.00	0.00	91.12	0.00
18Yk 7b	yukidori	microbial mat	0.2	0.24	0.47	0.00	0.00	0.00	86.29	0.00
18Yk 9c	yukidori	microbial mat	0	0.00	0.70	0.00	0.00	0.00	87.41	0.00
18Yk 2c	yukidori	sand	0.1	0.00	0.23	0.00	0.00	0.00	42.63	0.00
18Yk 3b	yukidori	sand	0.1	0.19	0.19	0.00	0.00	0.00	59.20	0.00
18Yk 6b	yukidori	sand	0.25	0.00	0.00	0.00	0.00	0.00	79.07	0.00
18Yk 9b	yukidori	sand	0.3	0.00	0.23	0.00	0.00	0.00	40.18	0.00
Yukidori T1	yukidori	depth	8	0.00	2.39	0.00	0.00	0.00	83.73	0.00
Yukidori T2	yukidori	depth	5	0.00	4.02	0.00	0.00	0.00	51.06	0.00
Yukidori T3	yukidori	depth	3.5	0.00	0.94	0.00	0.00	0.00	82.55	0.00
18Sk 1b	skallen	cobble	0.2	0.00	1.91	0.00	0.00	0.00	33.97	4.20
18Sk 2a	skallen	cobble	0.1	0.35	0.00	0.00	0.00	0.46	57.24	0.70
18Sk 3b	skallen	cobble	0.1	0.10	0.00	0.41	0.00	0.82	58.58	1.64
18Sk 1a	skallen	large rocks	0.2	0.00	0.00	0.39	0.00	0.00	61.02	1.57
18Sk 3a	skallen	large rocks	0.2	0.00	0.23	0.00	0.00	0.23	62.79	1.40
18Sk 2c	skallen	microbial mat	0	0.00	0.00	0.46	0.00	0.00	69.61	2.32
18Sk 3c	skallen	microbial mat	0	0.00	0.23	0.00	0.00	0.23	52.21	3.50
18Sk 4c	skallen	microbial mat	0	0.23	0.00	0.00	0.00	1.16	71.93	3.25
18Sk 2b	skallen	sand	0.2	0.00	0.00	0.00	0.00	0.00	10.46	0.00
18Sk 5b	skallen	sand	0.15	0.69	0.00	0.00	0.00	0.23	52.55	0.69
Skallen T2	skallen	depth	7	0.23	0.94	0.00	0.00	0.00	43.09	0.00
Skallen T3	skallen	depth	6	0.22	2.19	0.00	0.00	0.00	9.63	0.44
Skallen T4	skallen	depth	6	0.00	0.24	0.00	0.00	0.24	53.44	0.00
Skallen T5	skallen	depth	5	0.00	0.93	0.00	0.00	0.00	46.98	0.70
Skallen T6	skallen	depth	4	0.00	0.93	0.00	0.00	0.23	41.63	0.70
18Ng 1b	naga	cobble	0.35	0.86	1.15	0.00	0.00	0.00	0.00	0.00
18Ng 14a	naga	cobble	0.2	0.24	0.48	0.00	0.00	0.24	2.14	0.00
18Ng 16a	naga	cobble	0.15	1.91	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Fragilariopsis sp. fragments	Pseudofallacia sp.	Psammothidium stauroneioides	Navicula phyllepta	Tryblionella sp.	Navicula sp 2 (Namazu a)
18Yk 8b	yukidori	cobble	0.2	0.00	0.00	55.42	0.00	0.00	0.00
18Yk 9a	yukidori	cobble	0.2	0.00	0.00	5.21	0.00	0.00	0.00
18Yk 1c	yukidori	microbial mat	0	0.00	0.00	1.70	0.00	0.00	0.00
18Yk 2d	yukidori	microbial mat	0	0.00	0.00	0.71	0.00	0.00	0.00
18Yk 7b	yukidori	microbial mat	0.2	0.00	0.00	5.91	0.00	0.00	0.00
18Yk 9c	yukidori	microbial mat	0	0.00	0.00	3.03	0.00	0.00	0.00
18Yk 2c	yukidori	sand	0.1	0.00	0.00	6.58	0.00	0.00	0.00
18Yk 3b	yukidori	sand	0.1	0.00	0.00	14.23	0.00	0.00	0.00
18Yk 6b	yukidori	sand	0.25	0.00	0.00	0.23	0.00	0.00	0.00
18Yk 9b	yukidori	sand	0.3	0.00	0.00	6.47	0.00	0.00	0.00
Yukidori T1	yukidori	depth	8	0.00	0.00	1.20	0.00	0.00	0.00
Yukidori T2	yukidori	depth	5	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T3	yukidori	depth	3.5	0.00	0.00	2.83	0.00	0.00	0.00
18Sk 1b	skallen	cobble	0.2	0.38	0.00	0.00	0.00	0.00	0.00
18Sk 2a	skallen	cobble	0.1	0.70	0.00	0.46	0.00	0.00	0.00
18Sk 3b	skallen	cobble	0.1	0.00	0.00	1.44	0.21	0.00	0.00
18Sk 1a	skallen	large rocks	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 3a	skallen	large rocks	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 2c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 3c	skallen	microbial mat	0	0.23	0.00	0.00	0.00	0.00	0.00
18Sk 4c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 2b	skallen	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 5b	skallen	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T2	skallen	depth	7	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T3	skallen	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T4	skallen	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T5	skallen	depth	5	0.23	0.00	0.00	0.00	0.00	0.00
Skallen T6	skallen	depth	4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1b	naga	cobble	0.35	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14a	naga	cobble	0.2	0.00	0.00	0.00	0.48	0.00	0.00
18Ng 16a	naga	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Navicula aff. Directa	Unknown (oyako a)	Unknown (oyako b)	Navicula sp. (Nurume b)	Pinnularia borealis	Pinnularia quadraterea	Pseudostaurosira sp.
18Yk 8b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 9a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	1.90	0.00	0.00
18Yk 1c	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.24	0.00	0.00
18Yk 2d	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 7b	yukidori	microbial mat	0.2	0.00	0.00	0.00	0.00	0.24	0.00	0.00
18Yk 9c	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2c	yukidori	sand	0.1	0.00	0.00	0.00	0.00	0.68	0.00	0.00
18Yk 3b	yukidori	sand	0.1	0.00	0.00	0.00	0.00	1.52	0.00	0.00
18Yk 6b	yukidori	sand	0.25	0.00	0.00	0.00	0.00	0.93	0.00	0.00
18Yk 9b	yukidori	sand	0.3	0.00	0.00	0.00	0.00	0.46	0.00	0.00
Yukidori T1	yukidori	depth	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T2	yukidori	depth	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T3	yukidori	depth	3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 1b	skallen	cobble	0.2	0.00	0.00	0.00	0.00	3.44	0.00	0.76
18Sk 2a	skallen	cobble	0.1	0.00	0.00	0.00	0.00	3.48	0.00	0.00
18Sk 3b	skallen	cobble	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 1a	skallen	large rocks	0.2	0.00	0.00	0.00	0.00	0.79	0.00	0.79
18Sk 3a	skallen	large rocks	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.23
18Sk 2c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.23	0.00
18Sk 3c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.47	0.00
18Sk 4c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.23	0.93
18Sk 2b	skallen	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 5b	skallen	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.23	0.46
Skallen T2	skallen	depth	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T3	skallen	depth	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T4	skallen	depth	6	0.00	0.24	0.00	0.00	0.00	0.00	0.00
Skallen T5	skallen	depth	5	0.00	0.00	0.23	0.00	0.00	0.00	0.00
Skallen T6	skallen	depth	4	0.00	0.47	0.00	0.00	0.00	0.00	0.00
18Ng 1b	naga	cobble	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14a	naga	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 16a	naga	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Paralia sulcata	Small cocconeis sp.	OY24a unknown	centric sp. a	Unknown (coarse striae)	Pinnularia microstauron
18Yk 8b	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 9a	yukidori	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 1c	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2d	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 7b	yukidori	microbial mat	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 9c	yukidori	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 2c	yukidori	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 3b	yukidori	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 6b	yukidori	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Yk 9b	yukidori	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T1	yukidori	depth	8	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T2	yukidori	depth	5	0.00	0.00	0.00	0.00	0.00	0.00
Yukidori T3	yukidori	depth	3.5	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 1b	skallen	cobble	0.2	0.00	0.00	0.00	0.00	0.38	0.00
18Sk 2a	skallen	cobble	0.1	0.00	0.00	0.00	0.00	0.70	0.00
18Sk 3b	skallen	cobble	0.1	0.00	0.00	0.00	0.00	0.41	0.00
18Sk 1a	skallen	large rocks	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 3a	skallen	large rocks	0.2	0.00	0.23	0.00	0.23	0.00	0.00
18Sk 2c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 3c	skallen	microbial mat	0	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 4c	skallen	microbial mat	0	0.00	0.23	0.00	0.23	0.46	0.00
18Sk 2b	skallen	sand	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Sk 5b	skallen	sand	0.15	0.00	0.00	0.00	0.00	0.23	0.00
Skallen T2	skallen	depth	7	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T3	skallen	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T4	skallen	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
Skallen T5	skallen	depth	5	0.00	0.23	0.00	0.00	0.00	0.00
Skallen T6	skallen	depth	4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1b	naga	cobble	0.35	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14a	naga	cobble	0.2	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 16a	naga	cobble	0.15	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Craspedostauros laevissiumus	Luticola sp. (narrow)	Navicula sp. (Nr a)
18Yk 8b	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 9a	yukidori	cobble	0.2	0.00	0.00	0.00
18Yk 1c	yukidori	microbial mat	0	0.00	0.00	0.00
18Yk 2d	yukidori	microbial mat	0	0.00	0.00	0.00
18Yk 7b	yukidori	microbial mat	0.2	0.00	0.00	0.00
18Yk 9c	yukidori	microbial mat	0	0.00	0.00	0.00
18Yk 2c	yukidori	sand	0.1	0.00	0.00	0.00
18Yk 3b	yukidori	sand	0.1	0.00	0.00	0.00
18Yk 6b	yukidori	sand	0.25	0.00	0.00	0.00
18Yk 9b	yukidori	sand	0.3	0.00	0.00	0.00
Yukidori T1	yukidori	depth	8	0.00	0.00	0.00
Yukidori T2	yukidori	depth	5	0.00	0.00	0.00
Yukidori T3	yukidori	depth	3.5	0.00	0.00	0.00
18Sk 1b	skallen	cobble	0.2	0.00	0.00	0.00
18Sk 2a	skallen	cobble	0.1	0.00	0.00	0.00
18Sk 3b	skallen	cobble	0.1	0.00	0.00	0.00
18Sk 1a	skallen	large rocks	0.2	0.00	0.00	0.00
18Sk 3a	skallen	large rocks	0.2	0.00	0.00	0.00
18Sk 2c	skallen	microbial mat	0	0.00	0.00	0.00
18Sk 3c	skallen	microbial mat	0	0.00	0.00	0.00
18Sk 4c	skallen	microbial mat	0	0.00	0.00	0.00
18Sk 2b	skallen	sand	0.2	0.00	0.00	0.00
18Sk 5b	skallen	sand	0.15	0.00	0.00	0.00
Skallen T2	skallen	depth	7	0.00	0.00	0.00
Skallen T3	skallen	depth	6	0.00	0.00	0.00
Skallen T4	skallen	depth	6	0.00	0.00	0.00
Skallen T5	skallen	depth	5	0.00	0.00	0.00
Skallen T6	skallen	depth	4	0.00	0.00	0.00
18Ng 1b	naga	cobble	0.35	0.00	0.00	0.00
18Ng 14a	naga	cobble	0.2	0.00	0.00	0.00
18Ng 16a	naga	cobble	0.15	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Psammothidium papilio	Navicula gregaria	Luticola pseudomurrayi	Halamphora vyvermaniana	Craticula antarctica	Cocconeis fragments
18Ng 23a	naga	cobble	0.1	10.13	12.66	15.47	45.85	8.16	1.97
18Ng 31a	naga	cobble	0.25	13.24	13.97	10.66	46.32	12.87	1.10
18Ng 33b	naga	cobble	0.25	15.97	74.05	3.63	3.27	0.00	0.00
18Ng 1a	naga	large rocks	0.3	60.74	5.63	21.93	10.96	0.00	0.30
18Ng 17a	naga	large rocks	0.25	24.08	4.90	11.02	49.80	1.22	1.22
18Ng 20a	naga	large rocks	0.3	20.13	9.74	8.44	49.35	7.79	0.65
18Ng 1c	naga	sand	0.5	49.63	38.33	0.49	2.95	2.95	1.97
18Ng 2b	naga	sand	0.5	54.75	19.32	10.63	12.56	0.32	0.00
18Ng 3b	naga	sand	0.5	76.27	6.96	5.71	7.45	2.73	0.25
18Ng 4b	naga	sand	0.5	26.76	16.76	6.47	41.47	5.00	0.59
18Ng 5a	naga	sand	0.4	73.22	15.10	3.93	6.64	0.81	0.10
18Ng 6a	naga	sand	0.25	38.02	36.54	9.88	11.36	0.49	1.48
18Ng 7a	naga	sand	0.3	72.52	20.94	1.26	3.45	1.57	0.10
18Ng 8a	naga	sand	0.4	44.75	47.49	2.51	3.42	1.60	0.23
18Ng 9a	naga	sand	0.4	70.29	21.59	2.98	2.78	0.82	0.10
18Ng 11b	naga	sand	0.45	38.80	28.22	6.00	17.64	6.00	0.71
18Ng 14b	naga	sand	0.15	78.28	7.58	8.08	3.54	1.01	1.01
18Ng 15b	naga	sand	0.25	55.15	27.32	4.12	8.25	0.00	1.03
18Ng 22b	naga	sand	0.15	28.31	2.21	19.49	38.97	7.72	0.37
18Ng 23b	naga	sand	0.1	29.50	6.51	37.74	18.22	1.74	1.30
18Ng 24b	naga	sand	0.25	36.60	4.24	31.83	8.49	1.06	1.06
18Ng 31b	naga	sand	0.3	29.30	48.35	5.49	10.62	2.93	1.10
18Ng 34b	naga	sand	0.35	36.88	20.27	6.31	31.89	3.99	0.00
18Ng 44a	naga	sand	0.25	60.29	11.76	8.82	11.18	2.06	1.18
18Ng 45a	naga	sand	0.25	48.19	27.13	4.68	9.12	4.21	1.17
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00	81.74	18.26	0.00
18Ng E2 surf	naga	depth	9.8	0.00	11.62	0.18	85.71	1.95	0.00
18Ng E3 surf	naga	depth	6.9	0.00	0.23	0.00	94.19	5.15	0.08
18Ng E4 surf	naga	depth	5.9	0.00	3.65	0.00	92.88	3.30	0.00
18Ng E5 surf	naga	depth	3.8	0.44	2.28	0.00	93.17	4.11	0.00
18Ng E6 surf	naga	depth	8.1	0.35	0.23	0.00	96.73	2.46	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Hantzschia cf. amphioxys	Stauroneis latistauros	Gomphonema sp.	Humidophila arcuata	Achnanthes taylorensis	Humidophila australis	Amphora gourdonii
18Ng 23a	naga	cobble	0.1	1.83	0.00	0.56	0.28	1.13	0.00	0.28
18Ng 31a	naga	cobble	0.25	1.10	0.00	0.00	0.00	0.37	0.37	0.00
18Ng 33b	naga	cobble	0.25	0.18	0.00	0.00	0.00	0.36	2.54	0.00
18Ng 1a	naga	large rocks	0.3	0.44	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 17a	naga	large rocks	0.25	3.67	1.63	0.00	0.00	1.22	0.82	0.00
18Ng 20a	naga	large rocks	0.3	1.95	0.00	0.00	0.00	0.00	1.30	0.00
18Ng 1c	naga	sand	0.5	1.72	0.00	1.97	0.00	0.00	0.00	0.00
18Ng 2b	naga	sand	0.5	2.42	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 3b	naga	sand	0.5	0.62	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 4b	naga	sand	0.5	2.65	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 5a	naga	sand	0.4	0.20	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 6a	naga	sand	0.25	1.73	0.49	0.00	0.00	0.00	0.00	0.00
18Ng 7a	naga	sand	0.3	0.16	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 8a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 9a	naga	sand	0.4	0.21	1.23	0.00	0.00	0.00	0.00	0.00
18Ng 11b	naga	sand	0.45	0.88	0.00	0.00	0.71	1.06	0.00	0.00
18Ng 14b	naga	sand	0.15	0.51	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 15b	naga	sand	0.25	0.52	1.03	0.00	0.00	1.03	1.55	0.00
18Ng 22b	naga	sand	0.15	2.57	0.37	0.00	0.00	0.00	0.00	0.00
18Ng 23b	naga	sand	0.1	1.08	0.00	0.43	0.00	2.60	0.00	0.00
18Ng 24b	naga	sand	0.25	4.51	1.59	0.00	0.00	9.02	1.06	0.53
18Ng 31b	naga	sand	0.3	2.20	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 34b	naga	sand	0.35	0.00	0.66	0.00	0.00	0.00	0.00	0.00
18Ng 44a	naga	sand	0.25	2.35	1.18	0.29	0.00	0.29	0.00	0.00
18Ng 45a	naga	sand	0.25	2.92	0.47	0.23	0.00	0.47	0.47	0.47
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E2 surf	naga	depth	9.8	0.53	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E3 surf	naga	depth	6.9	0.35	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E4 surf	naga	depth	5.9	0.17	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E5 surf	naga	depth	3.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E6 surf	naga	depth	8.1	0.23	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Fragilariopsis sp. fragments	Pseudofallacia sp.	Psammothidium stauroneioides	Navicula phyllepta	Tryblionella sp.	Navicula sp 2 (Namazu a)
18Ng 23a	naga	cobble	0.1	0.84	0.00	0.00	0.00	0.00	0.00
18Ng 31a	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 33b	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1a	naga	large rocks	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 17a	naga	large rocks	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 20a	naga	large rocks	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1c	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 2b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 3b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 4b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 5a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 6a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 7a	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 8a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 9a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 11b	naga	sand	0.45	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 15b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 22b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 23b	naga	sand	0.1	0.87	0.00	0.00	0.00	0.00	0.00
18Ng 24b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 31b	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 34b	naga	sand	0.35	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 44a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 45a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E2 surf	naga	depth	9.8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E3 surf	naga	depth	6.9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E4 surf	naga	depth	5.9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E5 surf	naga	depth	3.8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E6 surf	naga	depth	8.1	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Navicula aff. Directa	Unknown (oyako a)	Unknown (oyako b)	Navicula sp. (Nurume b)	Pinnularia borealis	Pinnularia quadraterea	Pseudostaurosira sp.
18Ng 23a	naga	cobble	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.28
18Ng 31a	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 33b	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1a	naga	large rocks	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 17a	naga	large rocks	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 20a	naga	large rocks	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1c	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 2b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 3b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 4b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.29
18Ng 5a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 6a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 7a	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 8a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 9a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 11b	naga	sand	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 15b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 22b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 23b	naga	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 24b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 31b	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 34b	naga	sand	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 44a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.59
18Ng 45a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.47
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E2 surf	naga	depth	9.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E3 surf	naga	depth	6.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E4 surf	naga	depth	5.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E5 surf	naga	depth	3.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E6 surf	naga	depth	8.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Paralia sulcata	Small cocconeis sp.	OY24a unknown	centric sp. a	Unknown (coarse striae)	Pinnularia microstauron
18Ng 23a	naga	cobble	0.1	0.56	0.00	0.00	0.00	0.00	0.00
18Ng 31a	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 33b	naga	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 1a	naga	large rocks	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 17a	naga	large rocks	0.25	0.00	0.00	0.00	0.41	0.00	0.00
18Ng 20a	naga	large rocks	0.3	0.65	0.00	0.00	0.00	0.00	0.00
18Ng 1c	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 2b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 3b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 4b	naga	sand	0.5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 5a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 6a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 7a	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 8a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 9a	naga	sand	0.4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 11b	naga	sand	0.45	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 14b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 15b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 22b	naga	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 23b	naga	sand	0.1	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 24b	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 31b	naga	sand	0.3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 34b	naga	sand	0.35	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 44a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng 45a	naga	sand	0.25	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E2 surf	naga	depth	9.8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E3 surf	naga	depth	6.9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E4 surf	naga	depth	5.9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E5 surf	naga	depth	3.8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng E6 surf	naga	depth	8.1	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Craspedostauros laevissiumus	Luticola sp. (narrow)	Navicula sp. (Nr a)
18Ng 23a	naga	cobble	0.1	0.00	0.00	0.00
18Ng 31a	naga	cobble	0.25	0.00	0.00	0.00
18Ng 33b	naga	cobble	0.25	0.00	0.00	0.00
18Ng 1a	naga	large rocks	0.3	0.00	0.00	0.00
18Ng 17a	naga	large rocks	0.25	0.00	0.00	0.00
18Ng 20a	naga	large rocks	0.3	0.00	0.00	0.00
18Ng 1c	naga	sand	0.5	0.00	0.00	0.00
18Ng 2b	naga	sand	0.5	0.00	0.00	0.00
18Ng 3b	naga	sand	0.5	0.00	0.00	0.00
18Ng 4b	naga	sand	0.5	0.00	0.00	0.00
18Ng 5a	naga	sand	0.4	0.00	0.00	0.00
18Ng 6a	naga	sand	0.25	0.00	0.00	0.00
18Ng 7a	naga	sand	0.3	0.00	0.00	0.00
18Ng 8a	naga	sand	0.4	0.00	0.00	0.00
18Ng 9a	naga	sand	0.4	0.00	0.00	0.00
18Ng 11b	naga	sand	0.45	0.00	0.00	0.00
18Ng 14b	naga	sand	0.15	0.00	0.00	0.00
18Ng 15b	naga	sand	0.25	0.00	0.00	0.00
18Ng 22b	naga	sand	0.15	0.00	0.00	0.00
18Ng 23b	naga	sand	0.1	0.00	0.00	0.00
18Ng 24b	naga	sand	0.25	0.00	0.00	0.00
18Ng 31b	naga	sand	0.3	0.00	0.00	0.00
18Ng 34b	naga	sand	0.35	0.00	0.00	0.00
18Ng 44a	naga	sand	0.25	0.00	0.00	0.00
18Ng 45a	naga	sand	0.25	0.00	0.00	0.00
18Ng E1 surf	naga	depth	9	0.00	0.00	0.00
18Ng E2 surf	naga	depth	9.8	0.00	0.00	0.00
18Ng E3 surf	naga	depth	6.9	0.00	0.00	0.00
18Ng E4 surf	naga	depth	5.9	0.00	0.00	0.00
18Ng E5 surf	naga	depth	3.8	0.00	0.00	0.00
18Ng E6 surf	naga	depth	8.1	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Psammothidium papilio	Navicula gregaria	Luticola pseudomurrayi	Halamphora vyvermaniana	Craticula antarctica	Cocconeis fragments
18Ng S01	naga	depth	10	0.00	4.35	0.00	82.42	13.23	0.00
18Ng S02	naga	depth	9	0.00	9.90	0.00	73.26	16.71	0.00
18Ng S03	naga	depth	8	0.00	0.00	0.06	94.22	5.27	0.03
18Ng S04	naga	depth	7	0.00	1.21	0.48	93.22	4.36	0.00
18Ng S05	naga	depth	6	0.00	2.43	0.00	92.02	4.90	0.00
18Ng S06	naga	depth	5	0.00	2.70	0.00	93.14	4.17	0.00
18Ng S07	naga	depth	4	0.00	0.00	0.07	92.88	6.87	0.00
18Ng S08	naga	depth	3	0.00	11.32	0.00	84.75	3.84	0.00
18Ng S09	naga	depth	2	0.00	0.17	0.00	94.04	5.74	0.00
18Nr 1a	nurume	cobble	0.25	0.00	4.71	0.00	0.00	0.00	1.41
18Nr 1b	nurume	sand	0.15	0.46	7.66	0.00	0.00	0.00	0.00
18Nr 9a	nurume	microbial mat	0.2	0.00	5.54	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Hantzschia cf. amphioxys	Stauroneis latistauros	Gomphonema sp.	Humidophila arcuata	Achnanthes taylorensis	Humidophila australis	Amphora gourdonii
18Ng S01	naga	depth	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S02	naga	depth	9	0.14	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S03	naga	depth	8	0.42	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S04	naga	depth	7	0.73	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S05	naga	depth	6	0.64	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S06	naga	depth	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S07	naga	depth	4	0.18	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S08	naga	depth	3	0.10	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S09	naga	depth	2	0.06	0.00	0.00	0.00	0.00	0.00	0.00
18Nr 1a	nurume	cobble	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.71
18Nr 1b	nurume	sand	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Nr 9a	nurume	microbial mat	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Fragilariopsis sp. fragments	Pseudofallacia sp.	Psammothidium stauroneioides	Navicula phyllepta	Tryblionella sp.	Navicula sp 2 (Namazu a)
18Ng S01	naga	depth	10	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S02	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S03	naga	depth	8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S04	naga	depth	7	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S05	naga	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S06	naga	depth	5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S07	naga	depth	4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S08	naga	depth	3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S09	naga	depth	2	0.00	0.00	0.00	0.00	0.00	0.00
18Nr 1a	nurume	cobble	0.25	0.00	0.00	0.00	53.41	3.76	0.00
18Nr 1b	nurume	sand	0.15	0.00	0.00	0.00	78.65	0.23	0.00
18Nr 9a	nurume	microbial mat	0.2	0.00	0.00	0.00	52.89	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Navicula aff. Directa	Unknown (oyako a)	Unknown (oyako b)	Navicula sp. (Nurume b)	Pinnularia borealis	Pinnularia quadraterea	Pseudostaurosira sp.
18Ng S01	naga	depth	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S02	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S03	naga	depth	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S04	naga	depth	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S05	naga	depth	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S06	naga	depth	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S07	naga	depth	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S08	naga	depth	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S09	naga	depth	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18Nr 1a	nurume	cobble	0.25	0.00	0.00	0.00	18.82	0.00	0.00	0.00
18Nr 1b	nurume	sand	0.15	1.62	0.00	0.00	1.39	0.00	0.00	0.00
18Nr 9a	nurume	microbial mat	0.2	22.86	0.00	0.00	2.77	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Paralia sulcata	Small cocconeis sp.	OY24a unknown	centric sp. a	Unknown (coarse striae)	Pinnularia microstauron
18Ng S01	naga	depth	10	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S02	naga	depth	9	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S03	naga	depth	8	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S04	naga	depth	7	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S05	naga	depth	6	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S06	naga	depth	5	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S07	naga	depth	4	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S08	naga	depth	3	0.00	0.00	0.00	0.00	0.00	0.00
18Ng S09	naga	depth	2	0.00	0.00	0.00	0.00	0.00	0.00
18Nr 1a	nurume	cobble	0.25	1.65	4.94	0.00	0.00	0.00	0.00
18Nr 1b	nurume	sand	0.15	0.00	1.86	0.00	0.00	0.00	0.00
18Nr 9a	nurume	microbial mat	0.2	0.00	9.93	0.00	0.00	0.00	0.00

Table 2 - cont.

Location	site	substrate	sample depth (m)	Craspedostauros laevissiumus	Luticola sp. (narrow)	Navicula sp. (Nr a)
18Ng S01	naga	depth	10	0.00	0.00	0.00
18Ng S02	naga	depth	9	0.00	0.00	0.00
18Ng S03	naga	depth	8	0.00	0.00	0.00
18Ng S04	naga	depth	7	0.00	0.00	0.00
18Ng S05	naga	depth	6	0.00	0.00	0.00
18Ng S06	naga	depth	5	0.00	0.00	0.00
18Ng S07	naga	depth	4	0.00	0.00	0.00
18Ng S08	naga	depth	3	0.00	0.00	0.00
18Ng S09	naga	depth	2	0.00	0.00	0.00
18Nr 1a	nurume	cobble	0.25	0.00	0.71	9.88
18Nr 1b	nurume	sand	0.15	1.62	5.57	0.93
18Nr 9a	nurume	microbial mat	0.2	1.15	3.70	1.15

Table 3 - Diatom counts from fossil diatom records a) Lake Hamagiku

Sample	Depth	Age	Humidophila australis	Navicula gregaria	Craticula antarctica	Stauroneis latistauros	Halamphora vyvermaniana
Ab5S 1a	0.24	-60	68.00	27.36	3.52	0.00	0.00
Ab5S 1b	0.71	-43	87.00	11.57	1.04	0.20	0.00
Ab5S 1c	1.19	-26	78.50	20.64	0.00	0.43	0.00
Ab5S 1d	1.66	-9	81.50	18.13	0.19	0.19	0.00
Ab5S 2a	2.44	18	41.00	55.17	1.48	0.59	0.00
Ab5S 2b	2.91	35	52.50	42.99	2.14	0.71	0.24
Ab5S 2c	3.39	52	62.00	33.25	0.38	0.00	0.19
Ab5S 2d	3.86	68	63.00	26.09	4.07	1.11	0.00
Ab5S 3a	4.64	93	91.50	7.18	1.02	0.21	0.00
Ab5S 3b	5.11	108	52.50	46.55	0.95	0.00	0.00
Ab5S 3c	5.59	122	50.00	47.25	1.75	0.25	0.00
Ab5S 3d	6.06	137	52.50	43.46	0.71	0.24	0.00
Ab5S 4a	6.84	161	83.00	2.30	14.11	0.00	0.00
Ab5S 4b	7.31	176	71.50	1.43	25.22	0.00	0.43
Ab5S 4c	7.79	191	62.50	1.69	34.88	0.19	0.00
Ab5S 4d	8.26	204	77.50	4.39	17.44	0.00	0.45
Ab5S 5a	9.04	226	66.33	22.67	5.00	0.83	0.50
Ab5S 5b	9.51	238	84.50	12.01	2.64	0.00	0.00
Ab5S 5c	9.99	251	72.00	19.88	5.46	0.70	0.00
Ab5S 5d	10.46	264	80.50	15.66	2.43	0.29	0.00
Ab5S 6a	11.24	285	67.00	28.38	2.97	0.99	0.00
Ab5S 6b	11.71	298	69.35	27.48	2.38	0.64	0.00
Ab5S 6c	12.19	309	35.03	53.87	9.14	0.98	0.00
Ab5S 6d	12.66	316	79.00	19.11	1.58	0.11	0.00
Ab5S 7a	13.44	327	32.50	60.75	5.74	1.01	0.00
Ab5S 7b	13.91	333	72.00	22.54	5.04	0.42	0.00
Ab5S 7c	14.39	340	86.00	12.12	1.11	0.07	0.00
Ab5S 7d	14.86	347	61.50	36.77	1.16	0.00	0.00
Ab5S 8a	15.64	358	98.50	1.06	0.32	0.02	0.02
Ab5S 8b	16.11	364	87.50	4.82	2.19	0.13	0.13
Ab5S 8c	16.59	369	94.50	5.06	0.08	0.19	0.06
Ab5S 8d	17.06	375	92.50	7.01	0.23	0.26	0.00
Ab5S 9a	17.84	383	85.00	13.35	0.68	0.30	0.00
Ab5S 9b	18.31	388	91.00	8.51	0.36	0.14	0.00
Ab5S 9c	18.79	394	95.50	1.40	0.45	0.05	0.00
Ab5S 9d	19.26	399	99.50	0.35	0.11	0.01	0.00
Ab5S 10a	20.04	407	73.00	14.45	12.56	0.00	0.00
Ab5S 10b	20.51	414	33.50	61.85	3.66	0.33	0.67
Ab5S 10c	20.99	420	68.50	18.90	10.55	0.00	0.32
Ab5S 10d	21.46	427	87.50	7.38	4.94	0.00	0.00
Ab5S 11a	22.24	437	56.50	36.32	5.66	1.09	0.00
Ab5S 11b	22.71	444	26.50	53.66	18.38	1.47	0.00
Ab5S 11c	23.19	450	22.50	60.06	14.34	1.55	0.00
Ab5S 11d	23.66	457	74.00	16.90	8.06	0.52	0.26
Ab5S 12a	24.44	470	81.00	3.99	0.67	0.29	0.19
Ab5S 12b	24.91	480	89.00	5.36	0.33	0.71	0.27
Ab5S 12c	25.39	490	84.50	7.71	0.15	0.31	0.62
Ab5S 12d	25.86	500	65.33	27.60	0.35	1.04	0.35

Table 3 a) - cont.

Sample	Depth	Age	Psammothidium papilio	Hantzschia cf. amphioxys	Centric unknown	Navicula sp.	Navicula sp. 4c
Ab5S 1a	0.24	-60	1.12	0.00	0.00	0.00	0.00
Ab5S 1b	0.71	-43	0.20	0.00	0.00	0.00	0.00
Ab5S 1c	1.19	-26	0.43	0.00	0.00	0.00	0.00
Ab5S 1d	1.66	-9	0.00	0.00	0.00	0.00	0.00
Ab5S 2a	2.44	18	1.77	0.00	0.00	0.00	0.00
Ab5S 2b	2.91	35	1.43	0.00	0.00	0.00	0.00
Ab5S 2c	3.39	52	4.18	0.00	0.00	0.00	0.00
Ab5S 2d	3.86	68	5.55	0.00	0.00	0.00	0.00
Ab5S 3a	4.64	93	0.09	0.00	0.00	0.00	0.00
Ab5S 3b	5.11	108	0.00	0.00	0.00	0.00	0.00
Ab5S 3c	5.59	122	0.75	0.00	0.00	0.00	0.00
Ab5S 3d	6.06	137	3.09	0.00	0.00	0.00	0.00
Ab5S 4a	6.84	161	0.51	0.00	0.00	0.00	0.09
Ab5S 4b	7.31	176	1.43	0.00	0.00	0.00	0.00
Ab5S 4c	7.79	191	0.75	0.00	0.00	0.00	0.00
Ab5S 4d	8.26	204	0.23	0.00	0.00	0.00	0.00
Ab5S 5a	9.04	226	4.50	0.17	0.00	0.00	0.00
Ab5S 5b	9.51	238	0.85	0.00	0.00	0.00	0.00
Ab5S 5c	9.99	251	1.96	0.00	0.00	0.00	0.00
Ab5S 5d	10.46	264	1.07	0.05	0.00	0.00	0.00
Ab5S 6a	11.24	285	0.66	0.00	0.00	0.00	0.00
Ab5S 6b	11.71	298	0.16	0.00	0.00	0.00	0.00
Ab5S 6c	12.19	309	0.98	0.00	0.00	0.00	0.00
Ab5S 6d	12.66	316	0.21	0.00	0.00	0.00	0.00
Ab5S 7a	13.44	327	0.00	0.00	0.00	0.00	0.00
Ab5S 7b	13.91	333	0.00	0.00	0.00	0.00	0.00
Ab5S 7c	14.39	340	0.63	0.00	0.07	0.00	0.00
Ab5S 7d	14.86	347	0.58	0.00	0.00	0.00	0.00
Ab5S 8a	15.64	358	0.09	0.00	0.00	0.00	0.00
Ab5S 8b	16.11	364	5.20	0.03	0.00	0.00	0.00
Ab5S 8c	16.59	369	0.11	0.00	0.00	0.00	0.00
Ab5S 8d	17.06	375	0.00	0.00	0.00	0.00	0.00
Ab5S 9a	17.84	383	0.60	0.00	0.00	0.08	0.00
Ab5S 9b	18.31	388	0.00	0.00	0.00	0.00	0.00
Ab5S 9c	18.79	394	2.61	0.00	0.00	0.00	0.00
Ab5S 9d	19.26	399	0.03	0.00	0.01	0.00	0.00
Ab5S 10a	20.04	407	0.00	0.00	0.00	0.00	0.00
Ab5S 10b	20.51	414	0.00	0.00	0.00	0.00	0.00
Ab5S 10c	20.99	420	1.73	0.00	0.00	0.00	0.00
Ab5S 10d	21.46	427	0.19	0.00	0.00	0.00	0.00
Ab5S 11a	22.24	437	0.44	0.00	0.00	0.00	0.00
Ab5S 11b	22.71	444	0.00	0.00	0.00	0.00	0.00
Ab5S 11c	23.19	450	1.55	0.00	0.00	0.00	0.00
Ab5S 11d	23.66	457	0.26	0.00	0.00	0.00	0.00
Ab5S 12a	24.44	470	13.78	0.10	0.00	0.00	0.00
Ab5S 12b	24.91	480	4.27	0.00	0.00	0.00	0.00
Ab5S 12c	25.39	490	6.71	0.00	0.00	0.00	0.00
Ab5S 12d	25.86	500	5.18	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	small hantzschia	melosira sp.	small cocconeis sp.	Amphora sp. a	Luticola pseudomurrayi
Ab5S 1a	0.24	-60	0.00	0.00	0.00	0.00	0.00
Ab5S 1b	0.71	-43	0.00	0.00	0.00	0.00	0.00
Ab5S 1c	1.19	-26	0.00	0.00	0.00	0.00	0.00
Ab5S 1d	1.66	-9	0.00	0.00	0.00	0.00	0.00
Ab5S 2a	2.44	18	0.00	0.00	0.00	0.00	0.00
Ab5S 2b	2.91	35	0.00	0.00	0.00	0.00	0.00
Ab5S 2c	3.39	52	0.00	0.00	0.00	0.00	0.00
Ab5S 2d	3.86	68	0.19	0.00	0.00	0.00	0.00
Ab5S 3a	4.64	93	0.00	0.00	0.00	0.00	0.00
Ab5S 3b	5.11	108	0.00	0.00	0.00	0.00	0.00
Ab5S 3c	5.59	122	0.00	0.00	0.00	0.00	0.00
Ab5S 3d	6.06	137	0.00	0.00	0.00	0.00	0.00
Ab5S 4a	6.84	161	0.00	0.00	0.00	0.00	0.00
Ab5S 4b	7.31	176	0.00	0.00	0.00	0.00	0.00
Ab5S 4c	7.79	191	0.00	0.00	0.00	0.00	0.00
Ab5S 4d	8.26	204	0.00	0.00	0.00	0.00	0.00
Ab5S 5a	9.04	226	0.00	0.00	0.00	0.00	0.00
Ab5S 5b	9.51	238	0.00	0.00	0.00	0.00	0.00
Ab5S 5c	9.99	251	0.00	0.00	0.00	0.00	0.00
Ab5S 5d	10.46	264	0.00	0.00	0.00	0.00	0.00
Ab5S 6a	11.24	285	0.00	0.00	0.00	0.00	0.00
Ab5S 6b	11.71	298	0.00	0.00	0.00	0.00	0.00
Ab5S 6c	12.19	309	0.00	0.00	0.00	0.00	0.00
Ab5S 6d	12.66	316	0.00	0.00	0.00	0.00	0.00
Ab5S 7a	13.44	327	0.00	0.00	0.00	0.00	0.00
Ab5S 7b	13.91	333	0.00	0.00	0.00	0.00	0.00
Ab5S 7c	14.39	340	0.00	0.00	0.00	0.00	0.00
Ab5S 7d	14.86	347	0.00	0.00	0.00	0.00	0.00
Ab5S 8a	15.64	358	0.00	0.00	0.00	0.00	0.00
Ab5S 8b	16.11	364	0.00	0.00	0.00	0.00	0.00
Ab5S 8c	16.59	369	0.00	0.00	0.00	0.00	0.00
Ab5S 8d	17.06	375	0.00	0.00	0.00	0.00	0.00
Ab5S 9a	17.84	383	0.00	0.00	0.00	0.00	0.00
Ab5S 9b	18.31	388	0.00	0.00	0.00	0.00	0.00
Ab5S 9c	18.79	394	0.00	0.00	0.00	0.00	0.00
Ab5S 9d	19.26	399	0.00	0.00	0.00	0.00	0.00
Ab5S 10a	20.04	407	0.00	0.00	0.00	0.00	0.00
Ab5S 10b	20.51	414	0.00	0.00	0.00	0.00	0.00
Ab5S 10c	20.99	420	0.00	0.00	0.00	0.00	0.00
Ab5S 10d	21.46	427	0.00	0.00	0.00	0.00	0.00
Ab5S 11a	22.24	437	0.00	0.00	0.00	0.00	0.00
Ab5S 11b	22.71	444	0.00	0.00	0.00	0.00	0.00
Ab5S 11c	23.19	450	0.00	0.00	0.00	0.00	0.00
Ab5S 11d	23.66	457	0.00	0.00	0.00	0.00	0.00
Ab5S 12a	24.44	470	0.00	0.00	0.00	0.00	0.00
Ab5S 12b	24.91	480	0.00	0.05	0.00	0.00	0.00
Ab5S 12c	25.39	490	0.00	0.00	0.00	0.00	0.00
Ab5S 12d	25.86	500	0.00	0.17	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Unknown 31a	Unknown 33b	Unknown 43b	Unknown 36c b	Unknown 37a	Unknown 40b
Ab5S 1a	0.24	-60	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 1b	0.71	-43	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 1c	1.19	-26	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 1d	1.66	-9	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 2a	2.44	18	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 2b	2.91	35	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 2c	3.39	52	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 2d	3.86	68	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 3a	4.64	93	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 3b	5.11	108	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 3c	5.59	122	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 3d	6.06	137	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 4a	6.84	161	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 4b	7.31	176	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 4c	7.79	191	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 4d	8.26	204	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 5a	9.04	226	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 5b	9.51	238	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 5c	9.99	251	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 5d	10.46	264	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 6a	11.24	285	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 6b	11.71	298	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 6c	12.19	309	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 6d	12.66	316	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 7a	13.44	327	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 7b	13.91	333	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 7c	14.39	340	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 7d	14.86	347	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 8a	15.64	358	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 8b	16.11	364	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 8c	16.59	369	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 8d	17.06	375	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 9a	17.84	383	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 9b	18.31	388	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 9c	18.79	394	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 9d	19.26	399	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 10a	20.04	407	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 10b	20.51	414	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 10c	20.99	420	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 10d	21.46	427	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 11a	22.24	437	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 11b	22.71	444	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 11c	23.19	450	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 11d	23.66	457	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 12a	24.44	470	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 12b	24.91	480	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 12c	25.39	490	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 12d	25.86	500	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Amphora sp. b	Fragilariopsis curta	Navicula directa	Diatom valves/g
Ab5S 1a	0.24	-60	0.00	0.00	0.00	16884703
Ab5S 1b	0.71	-43	0.00	0.00	0.00	42922642
Ab5S 1c	1.19	-26	0.00	0.00	0.00	23611599
Ab5S 1d	1.66	-9	0.00	0.00	0.00	14681348
Ab5S 2a	2.44	18	0.00	0.00	0.00	19917695
Ab5S 2b	2.91	35	0.00	0.00	0.00	22474832
Ab5S 2c	3.39	52	0.00	0.00	0.00	16465441
Ab5S 2d	3.86	68	0.00	0.00	0.00	11188902
Ab5S 3a	4.64	93	0.00	0.00	0.00	68594104
Ab5S 3b	5.11	108	0.00	0.00	0.00	26173056
Ab5S 3c	5.59	122	0.00	0.00	0.00	41728635
Ab5S 3d	6.06	137	0.00	0.00	0.00	29322671
Ab5S 4a	6.84	161	0.00	0.00	0.00	11732395
Ab5S 4b	7.31	176	0.00	0.00	0.00	11510162
Ab5S 4c	7.79	191	0.00	0.00	0.00	12693917
Ab5S 4d	8.26	204	0.00	0.00	0.00	10298705
Ab5S 5a	9.04	226	0.00	0.00	0.00	18911744
Ab5S 5b	9.51	238	0.00	0.00	0.00	25347746
Ab5S 5c	9.99	251	0.00	0.00	0.00	13909725
Ab5S 5d	10.46	264	0.00	0.00	0.00	20766828
Ab5S 6a	11.24	285	0.00	0.00	0.00	26346158
Ab5S 6b	11.71	298	0.00	0.00	0.00	26793295
Ab5S 6c	12.19	309	0.00	0.00	0.00	15575616
Ab5S 6d	12.66	316	0.00	0.00	0.00	23115314
Ab5S 7a	13.44	327	0.00	0.00	0.00	29409263
Ab5S 7b	13.91	333	0.00	0.00	0.00	31596814
Ab5S 7c	14.39	340	0.00	0.00	0.00	61806433
Ab5S 7d	14.86	347	0.00	0.00	0.00	35621499
Ab5S 8a	15.64	358	0.00	0.00	0.00	37330125
Ab5S 8b	16.11	364	0.00	0.00	0.00	20036430
Ab5S 8c	16.59	369	0.00	0.00	0.00	88203670
Ab5S 8d	17.06	375	0.00	0.00	0.00	63838768
Ab5S 9a	17.84	383	0.00	0.00	0.00	13201536
Ab5S 9b	18.31	388	0.00	0.00	0.00	17009672
Ab5S 9c	18.79	394	0.00	0.00	0.00	33214612
Ab5S 9d	19.26	399	0.00	0.00	0.00	18010274
Ab5S 10a	20.04	407	0.00	0.00	0.00	33569150
Ab5S 10b	20.51	414	0.00	0.00	0.00	28692959
Ab5S 10c	20.99	420	0.00	0.00	0.00	41923818
Ab5S 10d	21.46	427	0.00	0.00	0.00	51136574
Ab5S 11a	22.24	437	0.00	0.00	0.00	24017265
Ab5S 11b	22.71	444	0.00	0.00	0.00	18137225
Ab5S 11c	23.19	450	0.00	0.00	0.00	18763497
Ab5S 11d	23.66	457	0.00	0.00	0.00	28644816
Ab5S 12a	24.44	470	0.00	0.00	0.00	8710179
Ab5S 12b	24.91	480	0.00	0.00	0.00	10260976
Ab5S 12c	25.39	490	0.00	0.00	0.00	9702775
Ab5S 12d	25.86	500	0.00	0.00	0.00	11649690

Table 3 a) - cont.

Sample	Depth	Age	Humidophila australis	Navicula gregaria	Craticula antarctica	Stauroneis latistauros	Halamphora vyvermaniana
Ab5S 13a	26.64	515	95.00	4.53	0.13	0.03	0.00
Ab5S 13b	27.11	525	96.50	3.06	0.02	0.07	0.02
Ab5S 13c	27.59	535	71.00	27.26	0.15	0.15	0.15
Ab5S 13d	28.06	545	64.00	33.04	1.26	0.00	0.00
Ab5S 14a	28.84	557	83.50	7.77	0.17	0.41	0.91
Ab5S 14b	29.31	564	85.00	10.28	0.23	0.23	0.30
Ab5S 14c	29.79	571	96.00	1.82	0.10	0.06	0.18
Ab5S 14d	30.26	579	94.50	3.82	0.03	0.19	0.19
Ab5S 15a	31.04	591	21.50	76.93	0.00	0.00	0.00
Ab5S 15b	31.51	598	70.00	29.09	0.00	0.00	0.15
Ab5S 15c	31.99	606	96.50	3.34	0.00	0.05	0.11
Ab5S 15d	32.46	611	95.50	3.69	0.11	0.18	0.05
Ab5S 16a	33.24	620	87.50	12.00	0.50	0.00	0.00
Ab5S 16b	33.71	626	84.00	15.76	0.00	0.24	0.00
Ab5S 16c	34.19	631	85.00	14.93	0.08	0.00	0.00
Ab5S 16d	34.66	637	69.50	30.20	0.15	0.15	0.00
Ab5S 17a	35.44	646	88.50	10.93	0.46	0.12	0.00
Ab5S 17b	35.91	651	95.00	4.88	0.05	0.03	0.00
Ab5S 17c	36.39	659	97.50	2.03	0.01	0.07	0.11
Ab5S 17d	36.86	667	83.50	16.17	0.00	0.00	0.00
Ab5S 18a	37.64	680	92.50	6.83	0.26	0.41	0.00
Ab5S 18b	38.11	688	91.00	6.48	2.07	0.18	0.00
Ab5S 18c	38.59	696	95.50	3.16	0.58	0.07	0.04
Ab5S 18d	39.06	704	93.00	6.13	0.60	0.11	0.07
Ab5S 19a	39.84	717	72.50	25.03	0.00	0.14	0.83
Ab5S 19b	40.31	725	90.00	2.80	0.05	0.45	0.90
Ab5S 19c	40.79	733	79.50	19.17	0.00	0.10	0.10
Ab5S 19d	41.26	741	51.50	48.14	0.00	0.00	0.24
Ab5S 20a	42.04	754	74.50	23.72	0.00	0.38	0.00
Ab5S 20b	42.51	762	83.50	11.96	0.08	0.58	0.08
Ab5S 20c	42.99	770	92.50	3.56	0.23	0.19	0.41
Ab5S 20d	43.46	779	94.50	4.25	0.14	0.08	0.36
Ab5S 21a	44.24	793	66.00	24.76	2.20	0.85	0.51
Ab5S 21b	44.71	805	58.35	36.23	0.62	0.21	0.83
Ab5S 21c	45.19	816	99.50	0.46	0.01	0.01	0.01
Ab5S 21d	45.66	827	99.50	0.46	0.01	0.01	0.00
Ab5S 22a	46.44	845	30.94	46.91	20.85	0.33	0.33
Ab5S 22b	46.91	856	91.09	1.80	3.68	0.09	1.41
Ab5S 22c	47.39	868	95.12	0.59	2.53	0.00	0.31
Ab5S 22d	47.86	879	70.00	3.59	25.55	0.00	0.29
Ab5S 23a	48.64	899	89.62	9.43	0.65	0.10	0.15
Ab5S 23b	49.11	912	67.52	18.58	13.75	0.00	0.15
Ab5S 23c	49.59	924	38.81	49.25	9.55	0.60	1.79
Ab5S 23d	50.06	937	66.83	24.04	8.65	0.16	0.32
Ab5S 24a	50.84	957	85.65	10.16	3.23	0.00	0.07
Ab5S 24b	51.31	970	59.41	17.66	22.94	0.00	0.00
Ab5S 24c	51.79	982	43.54	47.94	6.13	0.53	0.00
Ab5S 24d	52.26	995	67.62	19.81	10.22	0.00	1.26

Table 3 a) - cont.

Sample	Depth	Age	Psammothidium papilio	Hantzschia cf. amphioxys	Centric unknown	Navicula sp.	Navicula sp. 4c
Ab5S 13a	26.64	515	0.33	0.00	0.00	0.00	0.00
Ab5S 13b	27.11	525	0.33	0.00	0.00	0.00	0.00
Ab5S 13c	27.59	535	1.31	0.00	0.00	0.00	0.00
Ab5S 13d	28.06	545	1.62	0.09	0.00	0.00	0.00
Ab5S 14a	28.84	557	7.11	0.12	0.00	0.00	0.00
Ab5S 14b	29.31	564	3.98	0.00	0.00	0.00	0.00
Ab5S 14c	29.79	571	1.84	0.00	0.00	0.00	0.00
Ab5S 14d	30.26	579	1.27	0.00	0.00	0.00	0.00
Ab5S 15a	31.04	591	1.57	0.00	0.00	0.00	0.00
Ab5S 15b	31.51	598	0.76	0.00	0.00	0.00	0.00
Ab5S 15c	31.99	606	0.00	0.00	0.00	0.00	0.00
Ab5S 15d	32.46	611	0.47	0.00	0.00	0.00	0.00
Ab5S 16a	33.24	620	0.00	0.00	0.00	0.00	0.00
Ab5S 16b	33.71	626	0.00	0.00	0.00	0.00	0.00
Ab5S 16c	34.19	631	0.00	0.00	0.00	0.00	0.00
Ab5S 16d	34.66	637	0.00	0.00	0.00	0.00	0.00
Ab5S 17a	35.44	646	0.00	0.00	0.00	0.00	0.00
Ab5S 17b	35.91	651	0.05	0.00	0.00	0.00	0.00
Ab5S 17c	36.39	659	0.26	0.01	0.00	0.00	0.00
Ab5S 17d	36.86	667	0.25	0.08	0.00	0.00	0.00
Ab5S 18a	37.64	680	0.00	0.00	0.00	0.00	0.00
Ab5S 18b	38.11	688	0.27	0.00	0.00	0.00	0.00
Ab5S 18c	38.59	696	0.63	0.01	0.00	0.00	0.00
Ab5S 18d	39.06	704	0.11	0.00	0.00	0.00	0.00
Ab5S 19a	39.84	717	1.51	0.00	0.00	0.00	0.00
Ab5S 19b	40.31	725	5.80	0.00	0.00	0.00	0.00
Ab5S 19c	40.79	733	1.13	0.00	0.00	0.00	0.00
Ab5S 19d	41.26	741	0.00	0.12	0.00	0.00	0.00
Ab5S 20a	42.04	754	1.40	0.00	0.00	0.00	0.00
Ab5S 20b	42.51	762	3.80	0.00	0.00	0.00	0.00
Ab5S 20c	42.99	770	3.08	0.04	0.00	0.00	0.00
Ab5S 20d	43.46	779	0.66	0.01	0.00	0.00	0.00
Ab5S 21a	44.24	793	5.43	0.25	0.00	0.00	0.00
Ab5S 21b	44.71	805	3.75	0.00	0.00	0.00	0.00
Ab5S 21c	45.19	816	0.01	0.00	0.00	0.00	0.00
Ab5S 21d	45.66	827	0.01	0.00	0.00	0.00	0.00
Ab5S 22a	46.44	845	0.65	0.00	0.00	0.00	0.00
Ab5S 22b	46.91	856	1.88	0.00	0.00	0.00	0.00
Ab5S 22c	47.39	868	0.85	0.01	0.00	0.00	0.00
Ab5S 22d	47.86	879	0.57	0.00	0.00	0.00	0.00
Ab5S 23a	48.64	899	0.00	0.00	0.00	0.00	0.00
Ab5S 23b	49.11	912	0.00	0.00	0.00	0.00	0.00
Ab5S 23c	49.59	924	0.00	0.00	0.00	0.00	0.00
Ab5S 23d	50.06	937	0.00	0.00	0.00	0.00	0.00
Ab5S 24a	50.84	957	0.48	0.00	0.00	0.00	0.00
Ab5S 24b	51.31	970	0.00	0.00	0.00	0.00	0.00
Ab5S 24c	51.79	982	1.60	0.00	0.00	0.00	0.00
Ab5S 24d	52.26	995	1.10	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	small hantzschia	melosira sp.	small cocconeis sp.	Amphora sp. a	Luticola pseudomurrayi
Ab5S 13a	26.64	515	0.00	0.00	0.00	0.00	0.00
Ab5S 13b	27.11	525	0.00	0.00	0.00	0.00	0.00
Ab5S 13c	27.59	535	0.00	0.00	0.00	0.00	0.00
Ab5S 13d	28.06	545	0.00	0.00	0.00	0.00	0.00
Ab5S 14a	28.84	557	0.00	0.00	0.00	0.00	0.00
Ab5S 14b	29.31	564	0.00	0.00	0.00	0.00	0.00
Ab5S 14c	29.79	571	0.00	0.00	0.00	0.00	0.00
Ab5S 14d	30.26	579	0.00	0.00	0.00	0.00	0.00
Ab5S 15a	31.04	591	0.00	0.00	0.00	0.00	0.00
Ab5S 15b	31.51	598	0.00	0.00	0.00	0.00	0.00
Ab5S 15c	31.99	606	0.00	0.00	0.00	0.00	0.00
Ab5S 15d	32.46	611	0.00	0.00	0.00	0.00	0.00
Ab5S 16a	33.24	620	0.00	0.00	0.00	0.00	0.00
Ab5S 16b	33.71	626	0.00	0.00	0.00	0.00	0.00
Ab5S 16c	34.19	631	0.00	0.00	0.00	0.00	0.00
Ab5S 16d	34.66	637	0.00	0.00	0.00	0.00	0.00
Ab5S 17a	35.44	646	0.00	0.00	0.00	0.00	0.00
Ab5S 17b	35.91	651	0.00	0.00	0.00	0.00	0.00
Ab5S 17c	36.39	659	0.00	0.00	0.00	0.00	0.00
Ab5S 17d	36.86	667	0.00	0.00	0.00	0.00	0.00
Ab5S 18a	37.64	680	0.00	0.00	0.00	0.00	0.00
Ab5S 18b	38.11	688	0.00	0.00	0.00	0.00	0.00
Ab5S 18c	38.59	696	0.00	0.00	0.00	0.00	0.00
Ab5S 18d	39.06	704	0.00	0.00	0.00	0.00	0.00
Ab5S 19a	39.84	717	0.00	0.00	0.00	0.00	0.00
Ab5S 19b	40.31	725	0.00	0.00	0.00	0.00	0.00
Ab5S 19c	40.79	733	0.00	0.00	0.00	0.00	0.00
Ab5S 19d	41.26	741	0.00	0.00	0.00	0.00	0.00
Ab5S 20a	42.04	754	0.00	0.00	0.00	0.00	0.00
Ab5S 20b	42.51	762	0.00	0.00	0.00	0.00	0.00
Ab5S 20c	42.99	770	0.00	0.00	0.00	0.00	0.00
Ab5S 20d	43.46	779	0.00	0.00	0.00	0.00	0.00
Ab5S 21a	44.24	793	0.00	0.00	0.00	0.00	0.00
Ab5S 21b	44.71	805	0.00	0.00	0.00	0.00	0.00
Ab5S 21c	45.19	816	0.00	0.00	0.00	0.00	0.00
Ab5S 21d	45.66	827	0.00	0.00	0.00	0.00	0.00
Ab5S 22a	46.44	845	0.00	0.00	0.00	0.00	0.00
Ab5S 22b	46.91	856	0.00	0.00	0.04	0.00	0.00
Ab5S 22c	47.39	868	0.00	0.00	0.59	0.00	0.00
Ab5S 22d	47.86	879	0.00	0.00	0.00	0.00	0.00
Ab5S 23a	48.64	899	0.00	0.00	0.05	0.00	0.00
Ab5S 23b	49.11	912	0.00	0.00	0.00	0.00	0.00
Ab5S 23c	49.59	924	0.00	0.00	0.00	0.00	0.00
Ab5S 23d	50.06	937	0.00	0.00	0.00	0.00	0.00
Ab5S 24a	50.84	957	0.00	0.00	0.41	0.00	0.00
Ab5S 24b	51.31	970	0.00	0.00	0.00	0.00	0.00
Ab5S 24c	51.79	982	0.00	0.00	0.27	0.00	0.00
Ab5S 24d	52.26	995	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Unknown 31a	Unknown 33b	Unknown 43b	Unknown 36c b	Unknown 37a	Unknown 40b
Ab5S 13a	26.64	515	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 13b	27.11	525	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 13c	27.59	535	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 13d	28.06	545	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 14a	28.84	557	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 14b	29.31	564	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 14c	29.79	571	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 14d	30.26	579	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 15a	31.04	591	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 15b	31.51	598	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 15c	31.99	606	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 15d	32.46	611	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 16a	33.24	620	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 16b	33.71	626	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 16c	34.19	631	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 16d	34.66	637	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 17a	35.44	646	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 17b	35.91	651	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 17c	36.39	659	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 17d	36.86	667	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 18a	37.64	680	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 18b	38.11	688	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 18c	38.59	696	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 18d	39.06	704	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 19a	39.84	717	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 19b	40.31	725	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 19c	40.79	733	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 19d	41.26	741	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 20a	42.04	754	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 20b	42.51	762	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 20c	42.99	770	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 20d	43.46	779	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 21a	44.24	793	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 21b	44.71	805	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 21c	45.19	816	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 21d	45.66	827	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 22a	46.44	845	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 22b	46.91	856	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 22c	47.39	868	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 22d	47.86	879	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 23a	48.64	899	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 23b	49.11	912	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 23c	49.59	924	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 23d	50.06	937	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 24a	50.84	957	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 24b	51.31	970	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 24c	51.79	982	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 24d	52.26	995	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Amphora sp. b	Fragilariopsis curta	Navicula directa	Diatom valves/g
Ab5S 13a	26.64	515	0.00	0.00	0.00	29359169
Ab5S 13b	27.11	525	0.00	0.00	0.00	15876390
Ab5S 13c	27.59	535	0.00	0.00	0.00	36461488
Ab5S 13d	28.06	545	0.00	0.00	0.00	44997618
Ab5S 14a	28.84	557	0.00	0.00	0.00	15960166
Ab5S 14b	29.31	564	0.00	0.00	0.00	23527513
Ab5S 14c	29.79	571	0.00	0.00	0.00	42388765
Ab5S 14d	30.26	579	0.00	0.00	0.00	29316596
Ab5S 15a	31.04	591	0.00	0.00	0.00	17572312
Ab5S 15b	31.51	598	0.00	0.00	0.00	27539157
Ab5S 15c	31.99	606	0.00	0.00	0.00	15321108
Ab5S 15d	32.46	611	0.00	0.00	0.00	16165648
Ab5S 16a	33.24	620	0.00	0.00	0.00	1.02E+08
Ab5S 16b	33.71	626	0.00	0.00	0.00	82743317
Ab5S 16c	34.19	631	0.00	0.00	0.00	85118357
Ab5S 16d	34.66	637	0.00	0.00	0.00	59292581
Ab5S 17a	35.44	646	0.00	0.00	0.00	69936638
Ab5S 17b	35.91	651	0.00	0.00	0.00	62956524
Ab5S 17c	36.39	659	0.00	0.00	0.00	21158192
Ab5S 17d	36.86	667	0.00	0.00	0.00	43868892
Ab5S 18a	37.64	680	0.00	0.00	0.00	37790903
Ab5S 18b	38.11	688	0.00	0.00	0.00	52562532
Ab5S 18c	38.59	696	0.00	0.00	0.00	16564337
Ab5S 18d	39.06	704	0.00	0.00	0.00	73053737
Ab5S 19a	39.84	717	0.00	0.00	0.00	9629130
Ab5S 19b	40.31	725	0.00	0.00	0.00	9992025
Ab5S 19c	40.79	733	0.00	0.00	0.00	16948693
Ab5S 19d	41.26	741	0.00	0.00	0.00	24798328
Ab5S 20a	42.04	754	0.00	0.00	0.00	24155457
Ab5S 20b	42.51	762	0.00	0.00	0.00	23229138
Ab5S 20c	42.99	770	0.00	0.00	0.00	19540989
Ab5S 20d	43.46	779	0.00	0.00	0.00	60424469
Ab5S 21a	44.24	793	0.00	0.00	0.00	3888150
Ab5S 21b	44.71	805	0.00	0.00	0.00	5120234
Ab5S 21c	45.19	816	0.00	0.00	0.00	12960999
Ab5S 21d	45.66	827	0.00	0.00	0.00	16621678
Ab5S 22a	46.44	845	0.00	0.00	0.00	15295432
Ab5S 22b	46.91	856	0.00	0.00	0.00	21461813
Ab5S 22c	47.39	868	0.00	0.00	0.00	34139863
Ab5S 22d	47.86	879	0.00	0.00	0.00	6034853
Ab5S 23a	48.64	899	0.00	0.00	0.00	53966150
Ab5S 23b	49.11	912	0.00	0.00	0.00	85062086
Ab5S 23c	49.59	924	0.00	0.00	0.00	38012313
Ab5S 23d	50.06	937	0.00	0.00	0.00	46121202
Ab5S 24a	50.84	957	0.00	0.00	0.00	5754314
Ab5S 24b	51.31	970	0.00	0.00	0.00	77298261
Ab5S 24c	51.79	982	0.00	0.00	0.00	15489077
Ab5S 24d	52.26	995	0.00	0.00	0.00	30076096

Table 3 a) - cont.

Sample	Depth	Age	Humidophila australis	Navicula gregaria	Craticula antarctica	Stauroneis latistauros	Halamphora vyvermaniana
Ab5S 25a	53.04	1016	90.55	7.91	0.72	0.23	0.18
Ab5S 25b	53.51	1029	62.04	29.58	7.70	0.17	0.34
Ab5S 25c	53.99	1041	92.59	4.14	3.02	0.00	0.04
Ab5S 25d	54.46	1054	91.13	1.37	4.52	0.27	0.40
Ab5S 26a	55.24	1075	95.24	3.85	0.18	0.47	0.02
Ab5S 26b	55.71	1088	91.58	6.49	0.46	0.88	0.00
Ab5S 26c	56.19	1100	82.35	14.71	0.50	2.02	0.08
Ab5S 26d	56.66	1110	75.00	22.29	0.99	0.62	0.25
Ab5S 27a	57.44	1127	92.68	5.60	1.01	0.24	0.21
Ab5S 27b	57.91	1137	92.77	4.01	2.17	0.22	0.14
Ab5S 27c	58.39	1147	75.79	10.83	6.57	0.69	3.46
Ab5S 27d	58.86	1157	92.04	5.70	2.02	0.04	0.04
Ab5S 28a	59.64	1174	55.24	40.33	1.21	1.21	0.00
Ab5S 28b	60.11	1183	91.50	4.13	2.19	0.45	0.08
Ab5S 28c	60.59	1191	94.66	4.69	0.29	0.05	0.13
Ab5S 28d	61.06	1198	98.00	1.95	0.02	0.01	0.02
Ab5S 29a	61.84	1210	84.06	14.33	1.12	0.21	0.07
Ab5S 29b	62.31	1218	80.50	16.84	1.81	0.10	0.10
Ab5S 29c	62.79	1225	82.16	11.89	4.74	0.08	0.40
Ab5S 29d	63.26	1232	91.50	5.98	1.94	0.25	0.08
Ab5S 30a	64.04	1245	63.30	34.31	1.19	0.00	0.00
Ab5S 30b	64.51	1252	22.50	75.95	1.55	0.00	0.00
Ab5S 30c	64.99	1260	46.19	51.43	1.06	0.79	0.00
Ab5S 30d	65.46	1267	83.50	13.53	2.56	0.25	0.17
Ab5S 31a	66.24	1280	72.56	23.00	2.61	0.26	0.52
Ab5S 31b	66.71	1288	81.00	15.94	1.53	0.10	0.67
Ab5S 31c	67.19	1295	58.71	34.78	1.22	4.27	0.00
Ab5S 31d	67.66	1303	28.00	68.40	0.72	1.44	0.00
Ab5S 32a	68.44	1318	78.20	18.42	1.74	0.58	0.00
Ab5S 32b	68.91	1328	70.35	22.80	5.13	0.43	0.00
Ab5S 32c	69.39	1339	78.54	13.40	8.06	0.00	0.00
Ab5S 32d	69.86	1349	96.08	1.53	2.19	0.00	0.08
Ab5S 33a	70.64	1367	81.16	8.13	8.22	0.09	1.85
Ab5S 33b	71.11	1377	85.65	4.60	5.71	0.07	1.32
Ab5S 33c	71.59	1388	69.31	30.54	0.15	0.00	0.00
Ab5S 33d	72.06	1398	64.73	29.10	1.54	0.34	1.71
Ab5S 34a	72.84	1415	93.75	4.32	0.42	0.36	0.15
Ab5S 34b	73.31	1425	96.77	2.23	0.20	0.03	0.05
Ab5S 34c	73.79	1436	81.16	18.12	0.36	0.00	0.00
Ab5S 34d	74.26	1446	38.05	50.30	11.38	0.00	0.00
Ab5S 35a	75.04	1463	90.91	4.28	3.42	0.13	0.34
Ab5S 35b	75.51	1473	85.50	4.72	6.54	0.44	0.73
Ab5S 35c	75.99	1484	88.89	9.60	1.51	0.00	0.00
Ab5S 35d	76.46	1496	49.76	46.56	3.19	0.00	0.00
Ab5S 36a	77.24	1517	89.52	5.15	4.90	0.10	0.20
Ab5S 36b	77.71	1529	80.66	6.29	11.75	0.00	0.19
Ab5S 36c	78.19	1542	76.59	10.53	9.88	0.21	0.97
Ab5S 36d	78.66	1555	34.88	5.43	58.73	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Psammothidium papilio	Hantzschia cf. amphioxys	Centric unknown	Navicula sp.	Navicula sp. 4c
Ab5S 25a	53.04	1016	0.14	0.00	0.00	0.00	0.00
Ab5S 25b	53.51	1029	0.17	0.00	0.00	0.00	0.00
Ab5S 25c	53.99	1041	0.22	0.00	0.00	0.00	0.00
Ab5S 25d	54.46	1054	2.31	0.00	0.00	0.00	0.00
Ab5S 26a	55.24	1075	0.20	0.02	0.00	0.00	0.00
Ab5S 26b	55.71	1088	0.46	0.00	0.00	0.00	0.00
Ab5S 26c	56.19	1100	0.00	0.17	0.00	0.00	0.00
Ab5S 26d	56.66	1110	0.74	0.00	0.00	0.00	0.00
Ab5S 27a	57.44	1127	0.21	0.02	0.00	0.00	0.00
Ab5S 27b	57.91	1137	0.69	0.00	0.00	0.00	0.00
Ab5S 27c	58.39	1147	2.54	0.00	0.00	0.00	0.00
Ab5S 27d	58.86	1157	0.12	0.00	0.00	0.00	0.00
Ab5S 28a	59.64	1174	1.81	0.00	0.00	0.00	0.00
Ab5S 28b	60.11	1183	1.61	0.04	0.00	0.00	0.00
Ab5S 28c	60.59	1191	0.16	0.00	0.00	0.00	0.00
Ab5S 28d	61.06	1198	0.00	0.00	0.00	0.00	0.00
Ab5S 29a	61.84	1210	0.21	0.00	0.00	0.00	0.00
Ab5S 29b	62.31	1218	0.67	0.00	0.00	0.00	0.00
Ab5S 29c	62.79	1225	0.72	0.00	0.00	0.00	0.00
Ab5S 29d	63.26	1232	0.25	0.00	0.00	0.00	0.00
Ab5S 30a	64.04	1245	1.02	0.00	0.00	0.00	0.00
Ab5S 30b	64.51	1252	0.00	0.00	0.00	0.00	0.00
Ab5S 30c	64.99	1260	0.26	0.00	0.00	0.00	0.00
Ab5S 30d	65.46	1267	0.00	0.00	0.00	0.00	0.00
Ab5S 31a	66.24	1280	0.78	0.00	0.00	0.00	0.00
Ab5S 31b	66.71	1288	0.76	0.00	0.00	0.00	0.00
Ab5S 31c	67.19	1295	1.02	0.00	0.00	0.00	0.00
Ab5S 31d	67.66	1303	1.44	0.00	0.00	0.00	0.00
Ab5S 32a	68.44	1318	0.87	0.10	0.00	0.00	0.00
Ab5S 32b	68.91	1328	1.28	0.00	0.00	0.00	0.00
Ab5S 32c	69.39	1339	0.00	0.00	0.00	0.00	0.00
Ab5S 32d	69.86	1349	0.12	0.01	0.00	0.00	0.00
Ab5S 33a	70.64	1367	0.55	0.00	0.00	0.00	0.00
Ab5S 33b	71.11	1377	1.81	0.00	0.00	0.00	0.00
Ab5S 33c	71.59	1388	0.00	0.00	0.00	0.00	0.00
Ab5S 33d	72.06	1398	2.57	0.00	0.00	0.00	0.00
Ab5S 34a	72.84	1415	1.01	0.00	0.00	0.00	0.00
Ab5S 34b	73.31	1425	0.70	0.02	0.00	0.00	0.00
Ab5S 34c	73.79	1436	0.36	0.00	0.00	0.00	0.00
Ab5S 34d	74.26	1446	0.26	0.00	0.00	0.00	0.00
Ab5S 35a	75.04	1463	0.90	0.02	0.00	0.00	0.00
Ab5S 35b	75.51	1473	2.04	0.04	0.00	0.00	0.00
Ab5S 35c	75.99	1484	0.00	0.00	0.00	0.00	0.00
Ab5S 35d	76.46	1496	0.49	0.00	0.00	0.00	0.00
Ab5S 36a	77.24	1517	0.10	0.03	0.00	0.00	0.00
Ab5S 36b	77.71	1529	1.11	0.00	0.00	0.00	0.00
Ab5S 36c	78.19	1542	1.61	0.00	0.00	0.00	0.00
Ab5S 36d	78.66	1555	0.96	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	small hantzschia	melosira sp.	small cocconeis sp.	Amphora sp. a	Luticola pseudomurrayi
Ab5S 25a	53.04	1016	0.00	0.00	0.18	0.05	0.04
Ab5S 25b	53.51	1029	0.00	0.00	0.00	0.00	0.00
Ab5S 25c	53.99	1041	0.00	0.00	0.00	0.00	0.00
Ab5S 25d	54.46	1054	0.00	0.00	0.00	0.00	0.00
Ab5S 26a	55.24	1075	0.00	0.00	0.00	0.02	0.00
Ab5S 26b	55.71	1088	0.00	0.00	0.13	0.00	0.00
Ab5S 26c	56.19	1100	0.00	0.00	0.17	0.00	0.00
Ab5S 26d	56.66	1110	0.00	0.00	0.00	0.12	0.00
Ab5S 27a	57.44	1127	0.00	0.00	0.00	0.00	0.03
Ab5S 27b	57.91	1137	0.00	0.00	0.00	0.00	0.00
Ab5S 27c	58.39	1147	0.00	0.00	0.12	0.00	0.00
Ab5S 27d	58.86	1157	0.00	0.00	0.04	0.00	0.00
Ab5S 28a	59.64	1174	0.00	0.00	0.20	0.00	0.00
Ab5S 28b	60.11	1183	0.00	0.00	0.00	0.00	0.00
Ab5S 28c	60.59	1191	0.00	0.00	0.03	0.00	0.00
Ab5S 28d	61.06	1198	0.00	0.00	0.00	0.00	0.00
Ab5S 29a	61.84	1210	0.00	0.00	0.00	0.00	0.00
Ab5S 29b	62.31	1218	0.00	0.00	0.00	0.00	0.00
Ab5S 29c	62.79	1225	0.00	0.00	0.00	0.00	0.00
Ab5S 29d	63.26	1232	0.00	0.00	0.00	0.00	0.00
Ab5S 30a	64.04	1245	0.00	0.00	0.17	0.00	0.00
Ab5S 30b	64.51	1252	0.00	0.00	0.00	0.00	0.00
Ab5S 30c	64.99	1260	0.00	0.00	0.26	0.00	0.00
Ab5S 30d	65.46	1267	0.00	0.00	0.00	0.00	0.00
Ab5S 31a	66.24	1280	0.00	0.00	0.13	0.13	0.00
Ab5S 31b	66.71	1288	0.00	0.00	0.00	0.00	0.00
Ab5S 31c	67.19	1295	0.00	0.00	0.00	0.00	0.00
Ab5S 31d	67.66	1303	0.00	0.00	0.00	0.00	0.00
Ab5S 32a	68.44	1318	0.00	0.00	0.10	0.00	0.00
Ab5S 32b	68.91	1328	0.00	0.00	0.00	0.00	0.00
Ab5S 32c	69.39	1339	0.00	0.00	0.00	0.00	0.00
Ab5S 32d	69.86	1349	0.00	0.00	0.00	0.00	0.00
Ab5S 33a	70.64	1367	0.00	0.00	0.00	0.00	0.00
Ab5S 33b	71.11	1377	0.00	0.00	0.00	0.00	0.00
Ab5S 33c	71.59	1388	0.00	0.00	0.00	0.00	0.00
Ab5S 33d	72.06	1398	0.00	0.00	0.00	0.00	0.00
Ab5S 34a	72.84	1415	0.00	0.00	0.00	0.00	0.00
Ab5S 34b	73.31	1425	0.00	0.00	0.00	0.00	0.00
Ab5S 34c	73.79	1436	0.00	0.00	0.00	0.00	0.00
Ab5S 34d	74.26	1446	0.00	0.00	0.00	0.00	0.00
Ab5S 35a	75.04	1463	0.00	0.00	0.00	0.00	0.00
Ab5S 35b	75.51	1473	0.00	0.00	0.00	0.00	0.00
Ab5S 35c	75.99	1484	0.00	0.00	0.00	0.00	0.00
Ab5S 35d	76.46	1496	0.00	0.00	0.00	0.00	0.00
Ab5S 36a	77.24	1517	0.00	0.00	0.00	0.00	0.00
Ab5S 36b	77.71	1529	0.00	0.00	0.00	0.00	0.00
Ab5S 36c	78.19	1542	0.00	0.00	0.00	0.00	0.00
Ab5S 36d	78.66	1555	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Unknown 31a	Unknown 33b	Unknown 43b	Unknown 36c b	Unknown 37a	Unknown 40b
Ab5S 25a	53.04	1016	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 25b	53.51	1029	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 25c	53.99	1041	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 25d	54.46	1054	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 26a	55.24	1075	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 26b	55.71	1088	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 26c	56.19	1100	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 26d	56.66	1110	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 27a	57.44	1127	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 27b	57.91	1137	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 27c	58.39	1147	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 27d	58.86	1157	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 28a	59.64	1174	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 28b	60.11	1183	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 28c	60.59	1191	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 28d	61.06	1198	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 29a	61.84	1210	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 29b	62.31	1218	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 29c	62.79	1225	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 29d	63.26	1232	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 30a	64.04	1245	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 30b	64.51	1252	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 30c	64.99	1260	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 30d	65.46	1267	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 31a	66.24	1280	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 31b	66.71	1288	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 31c	67.19	1295	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 31d	67.66	1303	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 32a	68.44	1318	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 32b	68.91	1328	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 32c	69.39	1339	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 32d	69.86	1349	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 33a	70.64	1367	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 33b	71.11	1377	0.00	0.84	0.00	0.00	0.00	0.00
Ab5S 33c	71.59	1388	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 33d	72.06	1398	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 34a	72.84	1415	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 34b	73.31	1425	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 34c	73.79	1436	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 34d	74.26	1446	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 35a	75.04	1463	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 35b	75.51	1473	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 35c	75.99	1484	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 35d	76.46	1496	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 36a	77.24	1517	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 36b	77.71	1529	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 36c	78.19	1542	0.00	0.00	0.00	0.21	0.00	0.00
Ab5S 36d	78.66	1555	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Amphora sp. b	Fragilariopsis curta	Navicula directa	Diatom valves/g
Ab5S 25a	53.04	1016	0.00	0.00	0.00	9995149
Ab5S 25b	53.51	1029	0.00	0.00	0.00	15651274
Ab5S 25c	53.99	1041	0.00	0.00	0.00	1.92E+08
Ab5S 25d	54.46	1054	0.00	0.00	0.00	34529633
Ab5S 26a	55.24	1075	0.00	0.00	0.00	1.27E+08
Ab5S 26b	55.71	1088	0.00	0.00	0.00	22234093
Ab5S 26c	56.19	1100	0.00	0.00	0.00	15803869
Ab5S 26d	56.66	1110	0.00	0.00	0.00	8703314
Ab5S 27a	57.44	1127	0.00	0.00	0.00	47605339
Ab5S 27b	57.91	1137	0.00	0.00	0.00	45162071
Ab5S 27c	58.39	1147	0.00	0.00	0.00	26583407
Ab5S 27d	58.86	1157	0.00	0.00	0.00	1.35E+08
Ab5S 28a	59.64	1174	0.00	0.00	0.00	24109417
Ab5S 28b	60.11	1183	0.00	0.00	0.00	5568758
Ab5S 28c	60.59	1191	0.00	0.00	0.00	14407884
Ab5S 28d	61.06	1198	0.00	0.00	0.00	60934539
Ab5S 29a	61.84	1210	0.00	0.00	0.00	1.14E+08
Ab5S 29b	62.31	1218	0.00	0.00	0.00	38184952
Ab5S 29c	62.79	1225	0.00	0.00	0.00	26741996
Ab5S 29d	63.26	1232	0.00	0.00	0.00	37606838
Ab5S 30a	64.04	1245	0.00	0.00	0.00	14588795
Ab5S 30b	64.51	1252	0.00	0.00	0.00	12042138
Ab5S 30c	64.99	1260	0.00	0.00	0.00	30862317
Ab5S 30d	65.46	1267	0.00	0.00	0.00	39048633
Ab5S 31a	66.24	1280	0.00	0.00	0.00	6966033
Ab5S 31b	66.71	1288	0.00	0.00	0.00	6234020
Ab5S 31c	67.19	1295	0.00	0.00	0.00	14733035
Ab5S 31d	67.66	1303	0.00	0.00	0.00	30127607
Ab5S 32a	68.44	1318	0.00	0.00	0.00	24270857
Ab5S 32b	68.91	1328	0.00	0.00	0.00	33979473
Ab5S 32c	69.39	1339	0.00	0.00	0.00	26543180
Ab5S 32d	69.86	1349	0.00	0.00	0.00	34202103
Ab5S 33a	70.64	1367	0.00	0.00	0.00	5121835
Ab5S 33b	71.11	1377	0.00	0.00	0.00	10751374
Ab5S 33c	71.59	1388	0.00	0.00	0.00	5427214
Ab5S 33d	72.06	1398	0.00	0.00	0.00	11186815
Ab5S 34a	72.84	1415	0.00	0.00	0.00	1.03E+08
Ab5S 34b	73.31	1425	0.00	0.00	0.00	1.02E+08
Ab5S 34c	73.79	1436	0.00	0.00	0.00	51752673
Ab5S 34d	74.26	1446	0.00	0.00	0.00	20384720
Ab5S 35a	75.04	1463	0.00	0.00	0.00	33419230
Ab5S 35b	75.51	1473	0.00	0.00	0.00	9587424
Ab5S 35c	75.99	1484	0.00	0.00	0.00	81374269
Ab5S 35d	76.46	1496	0.00	0.00	0.00	38096730
Ab5S 36a	77.24	1517	0.00	0.00	0.00	30574582
Ab5S 36b	77.71	1529	0.00	0.00	0.00	22729045
Ab5S 36c	78.19	1542	0.00	0.00	0.00	17052505
Ab5S 36d	78.66	1555	0.00	0.00	0.00	6466567

Table 3 a) - cont.

Sample	Depth	Age	Humidophila australis	Navicula gregaria	Craticula antarctica	Stauroneis latistauros	Halamphora vyvermaniana
Ab5S 37a	79.44	1575	91.89	0.92	6.84	0.00	0.08
Ab5S 37b	79.91	1588	93.10	3.81	2.99	0.07	0.03
Ab5S 37c	80.39	1599	94.76	1.62	3.49	0.05	0.08
Ab5S 37d	80.86	1611	83.72	12.99	3.07	0.07	0.07
Ab5S 38a	81.64	1629	52.94	37.65	7.26	1.81	0.00
Ab5S 38b	82.11	1640	68.00	23.18	5.53	0.15	0.00
Ab5S 38c	82.59	1652	47.62	47.09	2.77	0.25	0.00
Ab5S 38d	83.06	1663	46.97	45.38	6.33	0.00	0.00
Ab5S 39a	83.84	1682	93.24	3.08	1.21	0.48	0.48
Ab5S 39b	84.31	1692	91.43	5.63	0.29	0.67	0.08
Ab5S 39c	84.79	1703	95.12	3.86	0.26	0.05	0.00
Ab5S 39d	85.26	1714	90.10	9.67	0.09	0.14	0.00
Ab5S 40a	86.04	1731	91.75	7.04	0.44	0.16	0.08
Ab5S 40b	86.51	1742	98.25	1.35	0.13	0.02	0.13
Ab5S 40c	86.99	1752	82.32	15.57	1.20	0.00	0.52
Ab5S 40d	87.46	1763	55.02	44.62	0.36	0.00	0.00
Ab5S 41a	88.24	1781	66.02	29.30	3.32	0.59	0.00
Ab5S 41b	88.71	1793	32.68	56.36	5.09	0.98	2.94
Ab5S 41c	89.19	1805	3.33	82.35	11.76	1.57	0.39
Ab5S 41d	89.66	1817	3.94	89.57	4.92	0.79	0.20
Ab5S 42a	90.44	1836	1.73	83.69	9.40	0.58	3.65
Ab5S 42b	90.91	1848	1.18	74.80	9.84	1.18	7.68
Ab5S 42c	91.39	1860	0.00	84.87	3.17	1.78	3.96
Ab5S 42d	91.86	1873	0.00	83.92	5.10	0.39	10.20
Ab5S 43a	92.64	1903	1.32	71.32	22.26	0.75	2.83
Ab5S 43b	93.11	1923	2.99	13.73	62.69	0.00	17.11
Ab5S 43c	93.59	1943	2.17	12.82	49.51	0.79	33.93
Ab5S 43d	94.06	1964	0.40	49.80	34.66	1.00	8.57
Ab5S 44a	94.84	1996	0.00	32.48	62.99	0.00	4.13
Ab5S 44b	95.31	2017	0.00	78.06	19.37	0.40	2.17
Ab5S 44c	95.79	2037	0.00	92.70	6.11	0.59	0.59
Ab5S 44d	96.26	2056	0.00	97.49	0.97	1.54	0.00
Ab5S 45a	97.04	2087	2.77	86.34	5.74	4.55	0.20
Ab5S 45b	97.51	2106	0.00	94.25	0.20	5.56	0.00
Ab5S 45c	97.99	2125	0.60	91.45	4.77	1.39	1.79
Ab5S 45d	98.46	2144	1.19	38.33	38.33	1.99	16.68
Ab5S 46a	99.24	2175	1.60	81.60	15.20	0.40	1.20
Ab5S 46b	99.71	2194	2.96	59.11	34.88	0.79	1.77
Ab5S 46c	100.19	2209	0.20	52.55	44.90	0.98	0.98
Ab5S 46d	100.66	2219	0.00	86.19	11.95	0.59	0.39
Ab5S 47a	101.44	2234	1.00	48.36	48.16	0.60	0.40
Ab5S 47b	101.91	2244	1.55	24.37	66.92	0.77	2.71
Ab5S 47c	102.39	2253	2.71	85.27	7.17	2.91	1.36
Ab5S 47d	102.86	2263	0.59	75.69	17.98	0.40	3.95
Ab5S 48a	103.64	2278	0.39	96.08	2.35	0.78	0.00
Ab5S 48b	104.11	2288	0.37	77.28	21.04	1.30	0.00
Ab5S 48c	104.59	2300	0.58	65.95	31.32	0.39	0.39
Ab5S 48d	105.06	2311	0.00	68.19	30.62	0.20	0.80

Table 3 a) - cont.

Sample	Depth	Age	Psammothidium papilio	Hantzschia cf. amphioxys	Centric unknown	Navicula sp.	Navicula sp. 4c
Ab5S 37a	79.44	1575	0.23	0.00	0.00	0.00	0.00
Ab5S 37b	79.91	1588	0.00	0.00	0.00	0.00	0.00
Ab5S 37c	80.39	1599	0.00	0.00	0.00	0.00	0.00
Ab5S 37d	80.86	1611	0.07	0.00	0.00	0.00	0.00
Ab5S 38a	81.64	1629	0.23	0.11	0.00	0.00	0.00
Ab5S 38b	82.11	1640	3.14	0.00	0.00	0.00	0.00
Ab5S 38c	82.59	1652	2.27	0.00	0.00	0.00	0.00
Ab5S 38d	83.06	1663	1.32	0.00	0.00	0.00	0.00
Ab5S 39a	83.84	1682	1.28	0.02	0.00	0.00	0.00
Ab5S 39b	84.31	1692	1.89	0.00	0.00	0.00	0.00
Ab5S 39c	84.79	1703	0.70	0.01	0.00	0.00	0.00
Ab5S 39d	85.26	1714	0.00	0.00	0.00	0.00	0.00
Ab5S 40a	86.04	1731	0.53	0.00	0.00	0.00	0.00
Ab5S 40b	86.51	1742	0.11	0.00	0.00	0.00	0.00
Ab5S 40c	86.99	1752	0.34	0.04	0.00	0.00	0.00
Ab5S 40d	87.46	1763	0.00	0.00	0.00	0.00	0.00
Ab5S 41a	88.24	1781	0.78	0.00	0.00	0.00	0.00
Ab5S 41b	88.71	1793	1.96	0.00	0.00	0.00	0.00
Ab5S 41c	89.19	1805	0.59	0.00	0.00	0.00	0.00
Ab5S 41d	89.66	1817	0.20	0.20	0.00	0.00	0.00
Ab5S 42a	90.44	1836	0.96	0.00	0.00	0.00	0.00
Ab5S 42b	90.91	1848	5.31	0.00	0.00	0.00	0.00
Ab5S 42c	91.39	1860	5.74	0.10	0.00	0.00	0.00
Ab5S 42d	91.86	1873	0.00	0.20	0.00	0.00	0.00
Ab5S 43a	92.64	1903	1.51	0.00	0.00	0.00	0.00
Ab5S 43b	93.11	1923	3.18	0.10	0.00	0.00	0.00
Ab5S 43c	93.59	1943	0.79	0.00	0.00	0.00	0.00
Ab5S 43d	94.06	1964	5.38	0.00	0.00	0.00	0.00
Ab5S 44a	94.84	1996	0.39	0.00	0.00	0.00	0.00
Ab5S 44b	95.31	2017	0.00	0.00	0.00	0.00	0.00
Ab5S 44c	95.79	2037	0.00	0.00	0.00	0.00	0.00
Ab5S 44d	96.26	2056	0.00	0.00	0.00	0.00	0.00
Ab5S 45a	97.04	2087	0.40	0.00	0.00	0.00	0.00
Ab5S 45b	97.51	2106	0.00	0.00	0.00	0.00	0.00
Ab5S 45c	97.99	2125	0.00	0.00	0.00	0.00	0.00
Ab5S 45d	98.46	2144	3.38	0.10	0.00	0.00	0.00
Ab5S 46a	99.24	2175	0.00	0.00	0.00	0.00	0.00
Ab5S 46b	99.71	2194	0.39	0.10	0.00	0.00	0.00
Ab5S 46c	100.19	2209	0.39	0.00	0.00	0.00	0.00
Ab5S 46d	100.66	2219	0.78	0.10	0.00	0.00	0.00
Ab5S 47a	101.44	2234	0.40	0.10	0.00	0.00	0.00
Ab5S 47b	101.91	2244	3.48	0.00	0.00	0.00	0.00
Ab5S 47c	102.39	2253	0.19	0.00	0.00	0.00	0.00
Ab5S 47d	102.86	2263	1.38	0.00	0.00	0.00	0.00
Ab5S 48a	103.64	2278	0.39	0.00	0.00	0.00	0.00
Ab5S 48b	104.11	2288	0.00	0.00	0.00	0.00	0.00
Ab5S 48c	104.59	2300	1.36	0.00	0.00	0.00	0.00
Ab5S 48d	105.06	2311	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	small hantzschia	melosira sp.	small cocconeis sp.	Amphora sp. a	Luticola pseudomurrayi
Ab5S 37a	79.44	1575	0.00	0.00	0.00	0.00	0.00
Ab5S 37b	79.91	1588	0.00	0.00	0.00	0.00	0.00
Ab5S 37c	80.39	1599	0.00	0.00	0.00	0.00	0.00
Ab5S 37d	80.86	1611	0.00	0.00	0.00	0.00	0.00
Ab5S 38a	81.64	1629	0.00	0.00	0.00	0.00	0.00
Ab5S 38b	82.11	1640	0.00	0.00	0.00	0.00	0.00
Ab5S 38c	82.59	1652	0.00	0.00	0.00	0.00	0.00
Ab5S 38d	83.06	1663	0.00	0.00	0.00	0.00	0.00
Ab5S 39a	83.84	1682	0.00	0.00	0.03	0.00	0.09
Ab5S 39b	84.31	1692	0.00	0.00	0.00	0.00	0.00
Ab5S 39c	84.79	1703	0.00	0.00	0.00	0.00	0.00
Ab5S 39d	85.26	1714	0.00	0.00	0.00	0.00	0.00
Ab5S 40a	86.04	1731	0.00	0.00	0.00	0.00	0.00
Ab5S 40b	86.51	1742	0.00	0.00	0.00	0.00	0.00
Ab5S 40c	86.99	1752	0.00	0.00	0.00	0.00	0.00
Ab5S 40d	87.46	1763	0.00	0.00	0.00	0.00	0.00
Ab5S 41a	88.24	1781	0.00	0.00	0.00	0.00	0.00
Ab5S 41b	88.71	1793	0.00	0.00	0.00	0.00	0.00
Ab5S 41c	89.19	1805	0.00	0.00	0.00	0.00	0.00
Ab5S 41d	89.66	1817	0.00	0.00	0.20	0.00	0.00
Ab5S 42a	90.44	1836	0.00	0.00	0.00	0.00	0.00
Ab5S 42b	90.91	1848	0.00	0.00	0.00	0.00	0.00
Ab5S 42c	91.39	1860	0.00	0.00	0.00	0.00	0.40
Ab5S 42d	91.86	1873	0.00	0.00	0.20	0.00	0.00
Ab5S 43a	92.64	1903	0.00	0.00	0.00	0.00	0.00
Ab5S 43b	93.11	1923	0.00	0.00	0.00	0.00	0.00
Ab5S 43c	93.59	1943	0.00	0.00	0.00	0.00	0.00
Ab5S 43d	94.06	1964	0.00	0.00	0.00	0.00	0.00
Ab5S 44a	94.84	1996	0.00	0.00	0.00	0.00	0.00
Ab5S 44b	95.31	2017	0.00	0.00	0.00	0.00	0.00
Ab5S 44c	95.79	2037	0.00	0.00	0.00	0.00	0.00
Ab5S 44d	96.26	2056	0.00	0.00	0.00	0.00	0.00
Ab5S 45a	97.04	2087	0.00	0.00	0.00	0.00	0.00
Ab5S 45b	97.51	2106	0.00	0.00	0.00	0.00	0.00
Ab5S 45c	97.99	2125	0.00	0.00	0.00	0.00	0.00
Ab5S 45d	98.46	2144	0.00	0.00	0.00	0.00	0.00
Ab5S 46a	99.24	2175	0.00	0.00	0.00	0.00	0.00
Ab5S 46b	99.71	2194	0.00	0.00	0.00	0.00	0.00
Ab5S 46c	100.19	2209	0.00	0.00	0.00	0.00	0.00
Ab5S 46d	100.66	2219	0.00	0.00	0.00	0.00	0.00
Ab5S 47a	101.44	2234	0.00	0.00	1.00	0.00	0.00
Ab5S 47b	101.91	2244	0.00	0.00	0.00	0.00	0.00
Ab5S 47c	102.39	2253	0.00	0.00	0.19	0.00	0.00
Ab5S 47d	102.86	2263	0.00	0.00	0.00	0.00	0.00
Ab5S 48a	103.64	2278	0.00	0.00	0.00	0.00	0.00
Ab5S 48b	104.11	2288	0.00	0.00	0.00	0.00	0.00
Ab5S 48c	104.59	2300	0.00	0.00	0.00	0.00	0.00
Ab5S 48d	105.06	2311	0.00	0.00	0.20	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Unknown 31a	Unknown 33b	Unknown 43b	Unknown 36c b	Unknown 37a	Unknown 40b
Ab5S 37a	79.44	1575	0.00	0.00	0.00	0.00	0.04	0.00
Ab5S 37b	79.91	1588	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 37c	80.39	1599	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 37d	80.86	1611	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 38a	81.64	1629	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 38b	82.11	1640	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 38c	82.59	1652	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 38d	83.06	1663	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 39a	83.84	1682	0.00	0.00	0.00	0.03	0.00	0.00
Ab5S 39b	84.31	1692	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 39c	84.79	1703	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 39d	85.26	1714	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 40a	86.04	1731	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 40b	86.51	1742	0.00	0.00	0.00	0.00	0.00	0.01
Ab5S 40c	86.99	1752	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 40d	87.46	1763	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 41a	88.24	1781	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 41b	88.71	1793	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 41c	89.19	1805	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 41d	89.66	1817	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 42a	90.44	1836	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 42b	90.91	1848	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 42c	91.39	1860	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 42d	91.86	1873	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 43a	92.64	1903	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 43b	93.11	1923	0.00	0.00	0.20	0.00	0.00	0.00
Ab5S 43c	93.59	1943	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 43d	94.06	1964	0.00	0.00	0.00	0.00	0.00	0.20
Ab5S 44a	94.84	1996	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 44b	95.31	2017	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 44c	95.79	2037	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 44d	96.26	2056	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 45a	97.04	2087	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 45b	97.51	2106	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 45c	97.99	2125	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 45d	98.46	2144	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 46a	99.24	2175	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 46b	99.71	2194	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 46c	100.19	2209	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 46d	100.66	2219	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 47a	101.44	2234	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 47b	101.91	2244	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 47c	102.39	2253	0.00	0.00	0.00	0.19	0.00	0.00
Ab5S 47d	102.86	2263	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 48a	103.64	2278	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 48b	104.11	2288	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 48c	104.59	2300	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 48d	105.06	2311	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Amphora sp. b	Fragilariopsis curta	Navicula directa	Diatom valves/g
Ab5S 37a	79.44	1575	0.00	0.00	0.00	27307730
Ab5S 37b	79.91	1588	0.00	0.00	0.00	9771651
Ab5S 37c	80.39	1599	0.00	0.00	0.00	52554020
Ab5S 37d	80.86	1611	0.00	0.00	0.00	4.4E+08
Ab5S 38a	81.64	1629	0.00	0.00	0.00	20950780
Ab5S 38b	82.11	1640	0.00	0.00	0.00	59296285
Ab5S 38c	82.59	1652	0.00	0.00	0.00	11621047
Ab5S 38d	83.06	1663	0.00	0.00	0.00	11705115
Ab5S 39a	83.84	1682	0.00	0.00	0.00	14198980
Ab5S 39b	84.31	1692	0.00	0.00	0.00	13270662
Ab5S 39c	84.79	1703	0.00	0.00	0.00	17969755
Ab5S 39d	85.26	1714	0.00	0.00	0.00	32033236
Ab5S 40a	86.04	1731	0.00	0.00	0.00	19529825
Ab5S 40b	86.51	1742	0.00	0.00	0.00	39471510
Ab5S 40c	86.99	1752	0.00	0.00	0.00	31349117
Ab5S 40d	87.46	1763	0.00	0.00	0.00	84419074
Ab5S 41a	88.24	1781	0.00	0.00	0.00	1.08E+08
Ab5S 41b	88.71	1793	0.00	0.00	0.00	41429888
Ab5S 41c	89.19	1805	0.00	0.00	0.00	33358835
Ab5S 41d	89.66	1817	0.00	0.00	0.00	15646963
Ab5S 42a	90.44	1836	0.00	0.00	0.00	36081313
Ab5S 42b	90.91	1848	0.00	0.00	0.00	12887662
Ab5S 42c	91.39	1860	0.00	0.00	0.00	24393009
Ab5S 42d	91.86	1873	0.00	0.00	0.00	34642752
Ab5S 43a	92.64	1903	0.00	0.00	0.00	18625604
Ab5S 43b	93.11	1923	0.00	0.00	0.00	3885238
Ab5S 43c	93.59	1943	0.00	0.00	0.00	8641780
Ab5S 43d	94.06	1964	0.00	0.00	0.00	4421722
Ab5S 44a	94.84	1996	0.00	0.00	0.00	9157101
Ab5S 44b	95.31	2017	0.00	0.00	0.00	32654076
Ab5S 44c	95.79	2037	0.00	0.00	0.00	50928970
Ab5S 44d	96.26	2056	0.00	0.00	0.00	77513096
Ab5S 45a	97.04	2087	0.00	0.00	0.00	9090579
Ab5S 45b	97.51	2106	0.00	0.00	0.00	25072945
Ab5S 45c	97.99	2125	0.00	0.00	0.00	16112909
Ab5S 45d	98.46	2144	0.00	0.00	0.00	6379130
Ab5S 46a	99.24	2175	0.00	0.00	0.00	5418176
Ab5S 46b	99.71	2194	0.00	0.00	0.00	13754379
Ab5S 46c	100.19	2209	0.00	0.00	0.00	42108970
Ab5S 46d	100.66	2219	0.00	0.00	0.00	36187093
Ab5S 47a	101.44	2234	0.00	0.00	0.00	5128896
Ab5S 47b	101.91	2244	0.19	0.00	0.00	6327702
Ab5S 47c	102.39	2253	0.00	0.00	0.00	2146608
Ab5S 47d	102.86	2263	0.00	0.00	0.00	3248306
Ab5S 48a	103.64	2278	0.00	0.00	0.00	55283104
Ab5S 48b	104.11	2288	0.00	0.00	0.00	43258152
Ab5S 48c	104.59	2300	0.00	0.00	0.00	44869374
Ab5S 48d	105.06	2311	0.00	0.00	0.00	30516603

Table 3 a) - cont.

Sample	Depth	Age	Humidophila australis	Navicula gregaria	Craticula antarctica	Stauroneis latistauros	Halamphora vyvermaniana
Ab5S 49a	105.84	2330	0.39	70.74	25.78	1.55	0.58
Ab5S 49b	106.31	2342	0.39	73.39	24.07	1.17	0.59
Ab5S 49c	106.79	2354	0.20	45.17	45.76	0.39	0.39
Ab5S 49d	107.26	2365	0.20	81.94	16.87	0.40	0.20
Ab5S 50a	108.04	2385	0.00	58.82	38.24	1.57	0.59
Ab5S 50b	108.51	2397	0.00	70.90	23.63	2.54	1.17
Ab5S 50c	108.99	2409	0.00	76.31	20.02	1.78	0.59
Ab5S 50d	109.46	2422	0.79	92.08	4.55	0.79	0.59
Ab5S 51a	110.24	2442	2.37	85.01	11.05	0.39	0.00
Ab5S 51b	110.71	2455	0.00	52.92	44.55	0.78	0.78
Ab5S 51c	111.19	2467	1.36	92.59	0.39	2.14	0.39
Ab5S 51d	111.66	2479	1.55	85.69	3.29	2.13	0.39
Ab5S 52a	112.44	2499	0.00	40.61	48.24	2.86	0.57
Ab5S 52b	112.91	2512	0.00	65.57	33.75	0.58	0.00
Ab5S 52c	113.39	2524	0.20	77.56	21.46	0.20	0.59
Ab5S 52d	113.86	2536	0.00	96.65	2.56	0.00	0.00
Ab5S 53a	114.64	2556	0.00	96.30	1.36	0.00	0.39
Ab5S 53b	115.11	2568	0.00	38.50	59.23	0.20	0.39
Ab5S 53c	115.59	2580	0.39	33.56	65.55	0.00	0.20
Ab5S 53d	116.06	2592	0.79	79.88	18.45	0.00	0.79
Ab5S 54a	116.78	2608	0.39	82.95	10.08	0.19	4.46
Ab5S 54b	117.31	2621	0.39	66.80	24.88	0.00	2.74
Ab5S 54c	117.79	2632	0.97	35.67	48.34	0.78	4.29
Ab5S 54d	118.26	2643	0.00	44.71	41.57	0.39	7.84
Ab5S 55a	119.04	2661	0.39	94.49	2.17	0.39	0.59
Ab5S 55b	119.51	2672	0.20	89.60	7.80	0.00	2.00
Ab5S 55c	119.99	2683	0.00	67.00	24.63	0.79	5.52
Ab5S 55d	120.46	2694	0.00	70.80	17.70	0.20	8.46
Ab5S 56a	121.24	2712	0.38	6.73	64.23	0.00	24.42
Ab5S 56b	121.71	2723	0.00	28.32	36.52	0.00	31.45
Ab5S 56c	122.19	2734	0.00	37.15	61.66	0.20	0.99
Ab5S 56d	122.66	2745	0.00	77.70	20.61	0.40	0.59
Ab5S 57a	123.44	2763	0.00	86.53	5.70	0.79	5.31
Ab5S 57b	123.91	2775	0.38	86.71	7.16	0.38	0.75
Ab5S 57c	124.39	2786	0.00	92.61	5.52	0.39	0.59
Ab5S 57d	124.86	2797	1.33	65.40	18.44	0.19	11.03
Ab5S 58a	125.64	2815	0.39	37.16	50.78	0.00	8.75
Ab5S 58b	126.11	2826	0.00	44.82	49.56	0.00	2.76
Ab5S 58c	126.59	2837	0.00	47.19	37.31	0.00	14.22
Ab5S 58d	127.06	2848	0.77	28.43	58.03	0.00	9.86

Table 3 a) - cont.

Sample	Depth	Age	Psammothidium papilio	Hantzschia cf. amphioxys	Centric unknown	Navicula sp.	Navicula sp. 4c
Ab5S 49a	105.84	2330	0.97	0.00	0.00	0.00	0.00
Ab5S 49b	106.31	2342	0.39	0.00	0.00	0.00	0.00
Ab5S 49c	106.79	2354	7.50	0.00	0.00	0.00	0.00
Ab5S 49d	107.26	2365	0.40	0.00	0.00	0.00	0.00
Ab5S 50a	108.04	2385	0.78	0.00	0.00	0.00	0.00
Ab5S 50b	108.51	2397	1.37	0.00	0.00	0.00	0.00
Ab5S 50c	108.99	2409	1.19	0.10	0.00	0.00	0.00
Ab5S 50d	109.46	2422	0.99	0.20	0.00	0.00	0.00
Ab5S 51a	110.24	2442	0.99	0.00	0.00	0.00	0.00
Ab5S 51b	110.71	2455	0.97	0.00	0.00	0.00	0.00
Ab5S 51c	111.19	2467	1.95	0.00	0.00	0.00	0.00
Ab5S 51d	111.66	2479	5.22	0.00	0.00	0.00	0.00
Ab5S 52a	112.44	2499	5.72	0.29	0.00	0.00	0.00
Ab5S 52b	112.91	2512	0.00	0.00	0.00	0.00	0.00
Ab5S 52c	113.39	2524	0.00	0.00	0.00	0.00	0.00
Ab5S 52d	113.86	2536	0.39	0.20	0.00	0.00	0.00
Ab5S 53a	114.64	2556	0.58	0.00	0.00	0.00	0.00
Ab5S 53b	115.11	2568	0.99	0.00	0.00	0.00	0.00
Ab5S 53c	115.59	2580	0.00	0.00	0.00	0.00	0.00
Ab5S 53d	116.06	2592	0.00	0.00	0.00	0.00	0.00
Ab5S 54a	116.78	2608	0.58	0.19	0.00	0.00	0.00
Ab5S 54b	117.31	2621	4.11	0.20	0.00	0.00	0.00
Ab5S 54c	117.79	2632	7.21	0.29	0.00	0.00	0.00
Ab5S 54d	118.26	2643	3.73	0.10	0.00	0.00	0.00
Ab5S 55a	119.04	2661	1.18	0.00	0.00	0.00	0.00
Ab5S 55b	119.51	2672	0.00	0.00	0.00	0.00	0.00
Ab5S 55c	119.99	2683	0.99	0.20	0.00	0.00	0.00
Ab5S 55d	120.46	2694	2.16	0.00	0.00	0.00	0.00
Ab5S 56a	121.24	2712	2.88	0.48	0.00	0.00	0.00
Ab5S 56b	121.71	2723	3.32	0.00	0.00	0.00	0.00
Ab5S 56c	122.19	2734	0.00	0.00	0.00	0.00	0.00
Ab5S 56d	122.66	2745	0.00	0.00	0.00	0.00	0.00
Ab5S 57a	123.44	2763	1.18	0.29	0.00	0.00	0.00
Ab5S 57b	123.91	2775	2.64	0.19	0.00	0.00	0.00
Ab5S 57c	124.39	2786	0.39	0.00	0.00	0.00	0.00
Ab5S 57d	124.86	2797	1.71	0.57	0.00	0.00	0.00
Ab5S 58a	125.64	2815	0.39	0.00	0.00	0.00	0.00
Ab5S 58b	126.11	2826	0.00	0.00	0.00	0.00	0.00
Ab5S 58c	126.59	2837	0.00	0.00	0.00	0.00	0.00
Ab5S 58d	127.06	2848	1.74	0.19	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	small hantzschia	melosira sp.	small cocconeis sp.	Amphora sp. a	Luticola pseudomurrayi
Ab5S 49a	105.84	2330	0.00	0.00	0.00	0.00	0.00
Ab5S 49b	106.31	2342	0.00	0.00	0.00	0.00	0.00
Ab5S 49c	106.79	2354	0.00	0.00	0.00	0.00	0.00
Ab5S 49d	107.26	2365	0.00	0.00	0.00	0.00	0.00
Ab5S 50a	108.04	2385	0.00	0.00	0.00	0.00	0.00
Ab5S 50b	108.51	2397	0.00	0.00	0.39	0.00	0.00
Ab5S 50c	108.99	2409	0.00	0.00	0.00	0.00	0.00
Ab5S 50d	109.46	2422	0.00	0.00	0.00	0.00	0.00
Ab5S 51a	110.24	2442	0.00	0.00	0.00	0.00	0.00
Ab5S 51b	110.71	2455	0.00	0.00	0.00	0.00	0.00
Ab5S 51c	111.19	2467	0.00	0.00	0.39	0.00	0.19
Ab5S 51d	111.66	2479	0.00	0.00	0.00	0.00	0.19
Ab5S 52a	112.44	2499	0.00	0.00	0.00	0.00	0.00
Ab5S 52b	112.91	2512	0.00	0.00	0.00	0.00	0.00
Ab5S 52c	113.39	2524	0.00	0.00	0.00	0.00	0.00
Ab5S 52d	113.86	2536	0.00	0.00	0.20	0.00	0.00
Ab5S 53a	114.64	2556	0.00	0.00	0.19	0.00	0.00
Ab5S 53b	115.11	2568	0.00	0.00	0.00	0.00	0.00
Ab5S 53c	115.59	2580	0.00	0.00	0.00	0.00	0.00
Ab5S 53d	116.06	2592	0.00	0.00	0.00	0.00	0.00
Ab5S 54a	116.78	2608	0.00	0.00	0.19	0.00	0.00
Ab5S 54b	117.31	2621	0.00	0.00	0.00	0.00	0.00
Ab5S 54c	117.79	2632	0.00	0.00	0.00	0.00	0.00
Ab5S 54d	118.26	2643	0.00	0.00	0.00	0.00	0.00
Ab5S 55a	119.04	2661	0.00	0.00	0.00	0.00	0.00
Ab5S 55b	119.51	2672	0.00	0.00	0.00	0.00	0.00
Ab5S 55c	119.99	2683	0.00	0.00	0.00	0.00	0.00
Ab5S 55d	120.46	2694	0.00	0.00	0.00	0.00	0.00
Ab5S 56a	121.24	2712	0.00	0.00	0.00	0.00	0.00
Ab5S 56b	121.71	2723	0.00	0.00	0.00	0.00	0.00
Ab5S 56c	122.19	2734	0.00	0.00	0.00	0.00	0.00
Ab5S 56d	122.66	2745	0.00	0.00	0.00	0.00	0.00
Ab5S 57a	123.44	2763	0.00	0.00	0.00	0.00	0.00
Ab5S 57b	123.91	2775	0.00	0.00	0.00	0.00	0.00
Ab5S 57c	124.39	2786	0.00	0.00	0.00	0.00	0.00
Ab5S 57d	124.86	2797	0.00	0.00	0.00	0.00	0.00
Ab5S 58a	125.64	2815	0.00	0.00	0.00	0.00	0.00
Ab5S 58b	126.11	2826	0.00	0.00	0.00	0.00	0.00
Ab5S 58c	126.59	2837	0.00	0.00	0.00	0.00	0.00
Ab5S 58d	127.06	2848	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Unknown 31a	Unknown 33b	Unknown 43b	Unknown 36c b	Unknown 37a	Unknown 40b
Ab5S 49a	105.84	2330	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 49b	106.31	2342	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 49c	106.79	2354	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 49d	107.26	2365	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 50a	108.04	2385	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 50b	108.51	2397	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 50c	108.99	2409	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 50d	109.46	2422	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 51a	110.24	2442	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 51b	110.71	2455	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 51c	111.19	2467	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 51d	111.66	2479	0.00	0.00	0.00	0.00	0.19	0.00
Ab5S 52a	112.44	2499	0.00	0.00	0.19	0.00	0.00	0.00
Ab5S 52b	112.91	2512	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 52c	113.39	2524	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 52d	113.86	2536	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 53a	114.64	2556	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 53b	115.11	2568	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 53c	115.59	2580	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 53d	116.06	2592	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 54a	116.78	2608	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 54b	117.31	2621	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 54c	117.79	2632	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 54d	118.26	2643	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 55a	119.04	2661	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 55b	119.51	2672	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 55c	119.99	2683	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 55d	120.46	2694	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 56a	121.24	2712	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 56b	121.71	2723	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 56c	122.19	2734	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 56d	122.66	2745	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 57a	123.44	2763	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 57b	123.91	2775	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 57c	124.39	2786	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 57d	124.86	2797	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 58a	125.64	2815	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 58b	126.11	2826	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 58c	126.59	2837	0.00	0.00	0.00	0.00	0.00	0.00
Ab5S 58d	127.06	2848	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 a) - cont.

Sample	Depth	Age	Amphora sp. b	Fragilariopsis curta	Navicula directa	Diatom valves/g
Ab5S 49a	105.84	2330	0.00	0.00	0.00	38846169
Ab5S 49b	106.31	2342	0.00	0.00	0.00	7297458
Ab5S 49c	106.79	2354	0.00	0.39	0.20	6525913
Ab5S 49d	107.26	2365	0.00	0.00	0.00	10930593
Ab5S 50a	108.04	2385	0.00	0.00	0.00	17911877
Ab5S 50b	108.51	2397	0.00	0.00	0.00	15586632
Ab5S 50c	108.99	2409	0.00	0.00	0.00	23957058
Ab5S 50d	109.46	2422	0.00	0.00	0.00	24848097
Ab5S 51a	110.24	2442	0.20	0.00	0.00	20103887
Ab5S 51b	110.71	2455	0.00	0.00	0.00	28669285
Ab5S 51c	111.19	2467	0.19	0.39	0.00	6888590
Ab5S 51d	111.66	2479	0.00	1.35	0.00	5056442
Ab5S 52a	112.44	2499	0.00	1.53	0.00	18350381
Ab5S 52b	112.91	2512	0.00	0.10	0.00	30603048
Ab5S 52c	113.39	2524	0.00	0.00	0.00	53997595
Ab5S 52d	113.86	2536	0.00	0.00	0.00	39334380
Ab5S 53a	114.64	2556	0.00	0.78	0.39	18858669
Ab5S 53b	115.11	2568	0.00	0.49	0.20	49999439
Ab5S 53c	115.59	2580	0.00	0.10	0.20	16770617
Ab5S 53d	116.06	2592	0.00	0.10	0.00	4990184
Ab5S 54a	116.78	2608	0.19	0.78	0.00	17890734
Ab5S 54b	117.31	2621	0.00	0.88	0.00	7217924
Ab5S 54c	117.79	2632	0.00	1.27	1.17	5049981
Ab5S 54d	118.26	2643	0.00	0.69	0.98	18621497
Ab5S 55a	119.04	2661	0.00	0.20	0.59	30398815
Ab5S 55b	119.51	2672	0.40	0.00	0.00	13145355
Ab5S 55c	119.99	2683	0.00	0.30	0.59	10584966
Ab5S 55d	120.46	2694	0.00	0.69	0.00	15681736
Ab5S 56a	121.24	2712	0.00	0.29	0.58	9220559
Ab5S 56b	121.71	2723	0.00	0.20	0.20	28492275
Ab5S 56c	122.19	2734	0.00	0.00	0.00	33867713
Ab5S 56d	122.66	2745	0.00	0.50	0.20	16255775
Ab5S 57a	123.44	2763	0.00	0.20	0.00	17648410
Ab5S 57b	123.91	2775	0.00	0.85	0.94	14192154
Ab5S 57c	124.39	2786	0.00	0.30	0.20	31127611
Ab5S 57d	124.86	2797	0.00	0.95	0.38	23851255
Ab5S 58a	125.64	2815	0.00	0.97	1.56	20437468
Ab5S 58b	126.11	2826	0.00	0.89	1.97	18916532
Ab5S 58c	126.59	2837	0.00	0.69	0.59	24133693
Ab5S 58d	127.06	2848	0.00	0.39	0.58	7040777

Table 3 b) Lake Naga

Sample	Depth	Age	Halamphora vyvermaniana	Navicula gregaria	Craticula antarctica	Hantzschia cf. amphioxys	Luticola pseudomurrayi
Ng5S 1a	0.28	-29	82.78	8.95	8.21	0.06	0.00
Ng5S 1b	0.83	-8	72.76	22.16	4.73	0.34	0.00
Ng5S 1c	1.38	13	74.26	18.96	6.66	0.04	0.00
Ng5S 1d	1.93	33	79.63	18.22	2.11	0.04	0.00
Ng5S 2a	2.48	54	85.59	12.73	1.50	0.02	0.14
Ng5S 2b	3.03	75	85.23	13.67	0.99	0.00	0.06
Ng5S 2c	3.58	96	90.13	6.96	2.56	0.02	0.33
Ng5S 2d	4.13	117	91.42	5.42	3.05	0.02	0.07
Ng5S 3a	4.68	137	93.65	3.69	2.28	0.16	0.17
Ng5S 3b	5.23	154	92.59	4.82	2.29	0.15	0.09
Ng5S 3c	5.78	166	94.30	4.80	0.76	0.07	0.07
Ng5S 3d	6.33	179	92.21	4.54	3.08	0.08	0.09
Ng5S 4a	6.89	191	86.21	8.38	5.18	0.04	0.09
Ng5S 4b	7.44	203	79.05	12.04	8.91	0.00	0.00
Ng5S 4c	7.99	215	79.25	12.35	8.40	0.00	0.00
Ng5S 4d	8.54	228	90.41	6.46	3.14	0.00	0.00
Ng5S 5a	9.09	240	92.56	1.09	6.32	0.00	0.02
Ng5S 5b	9.64	252	92.52	3.45	3.94	0.06	0.00
Ng5S 5c	10.19	263	96.53	0.75	2.71	0.00	0.01
Ng5S 5d	10.74	272	96.08	1.53	2.29	0.03	0.08
Ng5S 6a	11.29	280	98.65	0.61	0.72	0.01	0.01
Ng5S 6b	11.84	289	94.78	1.12	4.07	0.03	0.00
Ng5S 6c	12.39	298	94.44	1.52	4.01	0.02	0.00
Ng5S 6d	12.94	306	98.04	0.62	1.31	0.03	0.00
Ng5S 7a	13.50	315	95.37	0.84	3.70	0.06	0.03
Ng5S 7b	14.05	324	95.62	1.46	2.87	0.05	0.00
Ng5S 7c	14.60	332	91.25	2.08	6.53	0.10	0.03
Ng5S 7d	15.15	340	84.27	10.39	5.34	0.00	0.00
Ng5S 8a	15.70	347	80.53	4.24	14.25	0.91	0.00
Ng5S 8b	16.25	353	92.94	2.08	4.85	0.06	0.06
Ng5S 8c	16.80	360	83.64	5.66	10.57	0.13	0.00
Ng5S 8d	17.35	366	90.04	2.19	7.74	0.04	0.00
Ng5S 9a	17.90	372	93.56	3.92	2.38	0.01	0.10
Ng5S 9b	18.45	379	74.91	6.39	18.33	0.19	0.19
Ng5S 9c	19.00	385	87.21	6.47	5.98	0.05	0.20
Ng5S 9d	19.56	392	82.68	10.27	6.92	0.14	0.00
Ng5S 10a	20.11	398	95.80	0.91	2.92	0.00	0.30
Ng5S 10b	20.66	404	84.94	1.15	13.82	0.09	0.00
Ng5S 10c	21.21	409	94.59	0.17	5.16	0.05	0.02
Ng5S 10d	21.76	415	93.75	0.36	5.70	0.19	0.00
Ng5S 11a	22.31	420	96.68	0.31	2.90	0.05	0.03
Ng5S 11b	22.86	426	90.91	0.61	8.43	0.02	0.04
Ng5S 11c	23.41	431	93.07	0.45	6.23	0.09	0.14
Ng5S 11d	23.96	436	88.12	0.70	11.04	0.09	0.00
Ng5S 12a	24.51	442	94.67	1.01	4.21	0.03	0.04
Ng5S 12b	25.06	447	91.62	0.39	7.89	0.07	0.00
Ng5S 12c	25.61	454	92.58	0.09	7.33	0.00	0.00
Ng5S 12d	26.17	461	91.82	0.29	7.80	0.10	0.00

Table 3 b) - cont.

Sample	Depth	Age	Stauroneis latistauros	Unknown 54a	Fragilaropsis sp.	Unknown 55b	Unknown 57a	Amphora sp.
Ng5S 1a	0.28	-29	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1b	0.83	-8	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1c	1.38	13	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1d	1.93	33	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2a	2.48	54	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 2b	3.03	75	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2c	3.58	96	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2d	4.13	117	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3a	4.68	137	0.00	0.02	0.00	0.00	0.00	0.00
Ng5S 3b	5.23	154	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3c	5.78	166	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3d	6.33	179	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4a	6.89	191	0.00	0.00	0.06	0.00	0.00	0.00
Ng5S 4b	7.44	203	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4c	7.99	215	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4d	8.54	228	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5a	9.09	240	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5b	9.64	252	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5c	10.19	263	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5d	10.74	272	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6a	11.29	280	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6b	11.84	289	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6c	12.39	298	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6d	12.94	306	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7a	13.50	315	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7b	14.05	324	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7c	14.60	332	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7d	15.15	340	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8a	15.70	347	0.00	0.07	0.00	0.00	0.00	0.00
Ng5S 8b	16.25	353	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8c	16.80	360	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8d	17.35	366	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9a	17.90	372	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9b	18.45	379	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9c	19.00	385	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9d	19.56	392	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10a	20.11	398	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10b	20.66	404	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10c	21.21	409	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10d	21.76	415	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11a	22.31	420	0.00	0.01	0.00	0.00	0.00	0.00
Ng5S 11b	22.86	426	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11c	23.41	431	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 11d	23.96	436	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12a	24.51	442	0.00	0.02	0.00	0.00	0.00	0.00
Ng5S 12b	25.06	447	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12c	25.61	454	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12d	26.17	461	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Psammothidium papilio	Cocconeis sp.	Humidophila australis	Chamaepinnularia sp.	Unknown 4a
Ng5S 1a	0.28	-29	0.00	0.00	0.00	0.00	0.00
Ng5S 1b	0.83	-8	0.00	0.00	0.00	0.00	0.00
Ng5S 1c	1.38	13	0.00	0.08	0.00	0.00	0.00
Ng5S 1d	1.93	33	0.00	0.00	0.00	0.00	0.00
Ng5S 2a	2.48	54	0.00	0.00	0.00	0.00	0.00
Ng5S 2b	3.03	75	0.00	0.00	0.00	0.00	0.00
Ng5S 2c	3.58	96	0.00	0.00	0.00	0.00	0.00
Ng5S 2d	4.13	117	0.00	0.03	0.00	0.00	0.00
Ng5S 3a	4.68	137	0.00	0.00	0.02	0.02	0.00
Ng5S 3b	5.23	154	0.00	0.00	0.00	0.06	0.00
Ng5S 3c	5.78	166	0.00	0.00	0.00	0.00	0.00
Ng5S 3d	6.33	179	0.00	0.00	0.00	0.00	0.00
Ng5S 4a	6.89	191	0.00	0.00	0.00	0.00	0.04
Ng5S 4b	7.44	203	0.00	0.00	0.00	0.00	0.00
Ng5S 4c	7.99	215	0.00	0.00	0.00	0.00	0.00
Ng5S 4d	8.54	228	0.00	0.00	0.00	0.00	0.00
Ng5S 5a	9.09	240	0.00	0.00	0.00	0.00	0.00
Ng5S 5b	9.64	252	0.00	0.00	0.00	0.00	0.00
Ng5S 5c	10.19	263	0.00	0.00	0.00	0.00	0.00
Ng5S 5d	10.74	272	0.00	0.00	0.00	0.00	0.00
Ng5S 6a	11.29	280	0.00	0.00	0.00	0.00	0.00
Ng5S 6b	11.84	289	0.00	0.00	0.00	0.00	0.00
Ng5S 6c	12.39	298	0.00	0.00	0.00	0.00	0.00
Ng5S 6d	12.94	306	0.00	0.00	0.00	0.00	0.00
Ng5S 7a	13.50	315	0.00	0.00	0.00	0.00	0.00
Ng5S 7b	14.05	324	0.00	0.00	0.00	0.00	0.00
Ng5S 7c	14.60	332	0.00	0.00	0.00	0.00	0.00
Ng5S 7d	15.15	340	0.00	0.00	0.00	0.00	0.00
Ng5S 8a	15.70	347	0.00	0.00	0.00	0.00	0.00
Ng5S 8b	16.25	353	0.03	0.00	0.00	0.00	0.00
Ng5S 8c	16.80	360	0.00	0.00	0.00	0.00	0.00
Ng5S 8d	17.35	366	0.00	0.00	0.00	0.00	0.00
Ng5S 9a	17.90	372	0.00	0.03	0.00	0.00	0.00
Ng5S 9b	18.45	379	0.00	0.00	0.00	0.00	0.00
Ng5S 9c	19.00	385	0.00	0.10	0.00	0.00	0.00
Ng5S 9d	19.56	392	0.00	0.00	0.00	0.00	0.00
Ng5S 10a	20.11	398	0.03	0.03	0.00	0.00	0.00
Ng5S 10b	20.66	404	0.00	0.00	0.00	0.00	0.00
Ng5S 10c	21.21	409	0.00	0.00	0.00	0.00	0.00
Ng5S 10d	21.76	415	0.00	0.00	0.00	0.00	0.00
Ng5S 11a	22.31	420	0.01	0.01	0.00	0.00	0.00
Ng5S 11b	22.86	426	0.00	0.00	0.00	0.00	0.00
Ng5S 11c	23.41	431	0.00	0.00	0.00	0.00	0.00
Ng5S 11d	23.96	436	0.00	0.05	0.00	0.00	0.00
Ng5S 12a	24.51	442	0.02	0.00	0.00	0.00	0.00
Ng5S 12b	25.06	447	0.00	0.00	0.00	0.00	0.00
Ng5S 12c	25.61	454	0.00	0.00	0.00	0.00	0.00
Ng5S 12d	26.17	461	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Unknown 12b	Unknown 37a	Unknown 56c	Unknown 54a	Caloneis sp.	Unknown 55d	Unknown 56b
Ng5S 1a	0.28	-29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1b	0.83	-8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1c	1.38	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 1d	1.93	33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2a	2.48	54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2b	3.03	75	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2c	3.58	96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 2d	4.13	117	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3a	4.68	137	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3b	5.23	154	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3c	5.78	166	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 3d	6.33	179	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4a	6.89	191	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4b	7.44	203	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4c	7.99	215	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 4d	8.54	228	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5a	9.09	240	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5b	9.64	252	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Ng5S 5c	10.19	263	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 5d	10.74	272	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6a	11.29	280	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6b	11.84	289	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6c	12.39	298	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 6d	12.94	306	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7a	13.50	315	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7b	14.05	324	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7c	14.60	332	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 7d	15.15	340	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8a	15.70	347	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8b	16.25	353	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8c	16.80	360	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 8d	17.35	366	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9a	17.90	372	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9b	18.45	379	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9c	19.00	385	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 9d	19.56	392	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10a	20.11	398	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10b	20.66	404	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10c	21.21	409	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 10d	21.76	415	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11a	22.31	420	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11b	22.86	426	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11c	23.41	431	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 11d	23.96	436	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12a	24.51	442	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12b	25.06	447	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12c	25.61	454	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 12d	26.17	461	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Gomphonema sp.	Diatom valves/g
Ng5S 1a	0.28	-29	0.00	106677647
Ng5S 1b	0.83	-8	0.00	99192982
Ng5S 1c	1.38	13	0.00	134778053
Ng5S 1d	1.93	33	0.00	70896130
Ng5S 2a	2.48	54	0.00	63997141
Ng5S 2b	3.03	75	0.00	108641513
Ng5S 2c	3.58	96	0.00	73661550
Ng5S 2d	4.13	117	0.00	103142494
Ng5S 3a	4.68	137	0.00	74530103
Ng5S 3b	5.23	154	0.00	50420168
Ng5S 3c	5.78	166	0.00	115205761
Ng5S 3d	6.33	179	0.00	82591952
Ng5S 4a	6.89	191	0.00	90103860
Ng5S 4b	7.44	203	0.00	53848725
Ng5S 4c	7.99	215	0.00	71946239
Ng5S 4d	8.54	228	0.00	103551889
Ng5S 5a	9.09	240	0.00	74328985
Ng5S 5b	9.64	252	0.00	104041096
Ng5S 5c	10.19	263	0.00	60716846
Ng5S 5d	10.74	272	0.00	119108280
Ng5S 6a	11.29	280	0.00	52741314
Ng5S 6b	11.84	289	0.00	56841579
Ng5S 6c	12.39	298	0.00	69390681
Ng5S 6d	12.94	306	0.00	151250000
Ng5S 7a	13.50	315	0.00	55029214
Ng5S 7b	14.05	324	0.00	60304790
Ng5S 7c	14.60	332	0.00	97039832
Ng5S 7d	15.15	340	0.00	81127503
Ng5S 8a	15.70	347	0.00	126658920
Ng5S 8b	16.25	353	0.00	82090794
Ng5S 8c	16.80	360	0.00	82008062
Ng5S 8d	17.35	366	0.00	159296354
Ng5S 9a	17.90	372	0.00	275521822
Ng5S 9b	18.45	379	0.00	42330975
Ng5S 9c	19.00	385	0.00	45271773
Ng5S 9d	19.56	392	0.00	73596743
Ng5S 10a	20.11	398	0.00	115607279
Ng5S 10b	20.66	404	0.00	57051054
Ng5S 10c	21.21	409	0.00	78406060
Ng5S 10d	21.76	415	0.00	56874788
Ng5S 11a	22.31	420	0.00	70308519
Ng5S 11b	22.86	426	0.00	36475247
Ng5S 11c	23.41	431	0.00	59080389
Ng5S 11d	23.96	436	0.00	56383064
Ng5S 12a	24.51	442	0.00	56860902
Ng5S 12b	25.06	447	0.00	37776831
Ng5S 12c	25.61	454	0.00	37538135
Ng5S 12d	26.17	461	0.00	48054697

Table 3 b) - cont.

Sample	Depth	Age	Halamphora vyvermaniana	Navicula gregaria	Craticula antarctica	Hantzschia cf. amphioxys	Luticola pseudomurrayi
Ng5S 13a	26.72	467	64.95	0.49	34.57	0.00	0.00
Ng5S 13b	27.27	474	64.39	0.97	34.64	0.00	0.00
Ng5S 13c	27.82	481	46.88	3.49	49.63	0.00	0.00
Ng5S 13d	28.37	488	35.38	4.75	59.79	0.08	0.00
Ng5S 14a	28.92	495	87.92	6.79	5.26	0.02	0.00
Ng5S 14b	29.47	502	96.08	1.86	2.00	0.07	0.00
Ng5S 14c	30.02	509	90.07	0.08	9.79	0.06	0.00
Ng5S 14d	30.57	518	88.07	0.19	11.46	0.09	0.19
Ng5S 15a	31.12	528	80.58	0.15	19.27	0.00	0.00
Ng5S 15b	31.67	537	81.44	0.28	18.21	0.07	0.00
Ng5S 15c	32.22	547	92.08	0.18	7.53	0.17	0.03
Ng5S 15d	32.78	556	95.24	0.29	4.26	0.16	0.00
Ng5S 16a	33.33	566	89.76	2.15	7.76	0.33	0.00
Ng5S 16b	33.88	575	85.19	5.40	9.30	0.12	0.00
Ng5S 16c	34.43	584	88.58	2.54	8.70	0.18	0.00
Ng5S 16d	34.98	594	94.67	2.18	3.07	0.07	0.00
Ng5S 17a	35.53	606	93.36	2.49	4.07	0.05	0.00
Ng5S 17b	36.08	618	94.86	1.65	3.35	0.14	0.00
Ng5S 17c	36.63	631	66.30	2.76	30.75	0.19	0.00
Ng5S 17d	37.18	644	91.80	0.29	7.84	0.08	0.00
Ng5S 18a	37.73	657	90.51	0.72	8.61	0.16	0.00
Ng5S 18b	38.28	669	96.46	0.47	3.00	0.07	0.00
Ng5S 18c	38.83	682	90.56	0.74	8.28	0.33	0.00
Ng5S 18d	39.39	695	89.64	0.90	8.85	0.29	0.24
Ng5S 19a	39.94	707	98.52	0.07	1.38	0.02	0.00
Ng5S 19b	40.49	720	98.00	0.36	1.55	0.10	0.00
Ng5S 19c	41.04	733	95.42	0.12	4.43	0.03	0.00
Ng5S 19d	41.59	746	98.81	0.03	1.13	0.02	0.00
Ng5S 20a	42.14	760	92.43	0.00	7.54	0.03	0.00
Ng5S 20b	42.69	773	97.61	0.15	2.14	0.10	0.00
Ng5S 20c	43.24	785	93.75	0.15	6.08	0.02	0.00
Ng5S 20d	43.79	798	94.12	0.05	5.81	0.02	0.00
Ng5S 21a	44.34	811	86.37	0.54	13.01	0.03	0.00
Ng5S 21b	44.89	824	89.52	1.52	8.59	0.29	0.04
Ng5S 21c	45.44	838	93.33	3.30	3.07	0.20	0.03
Ng5S 21d	46.00	852	93.25	1.92	4.59	0.21	0.00
Ng5S 22a	46.55	866	83.18	5.52	11.30	0.00	0.00
Ng5S 22b	47.10	881	90.55	2.15	7.11	0.11	0.07
Ng5S 22c	47.65	895	95.24	1.44	3.25	0.01	0.06
Ng5S 22d	48.20	910	90.20	7.12	2.69	0.00	0.00
Ng5S 23a	48.75	924	84.24	3.44	12.20	0.00	0.13
Ng5S 23b	49.30	938	81.52	8.72	9.51	0.25	0.00
Ng5S 23c	49.85	953	80.42	11.98	6.91	0.61	0.00
Ng5S 23d	50.40	967	90.20	6.51	2.91	0.11	0.27
Ng5S 24a	50.95	982	88.41	2.50	9.05	0.00	0.04
Ng5S 24b	51.50	996	89.46	1.53	8.90	0.02	0.00
Ng5S 24c	52.06	1011	94.31	0.41	5.22	0.00	0.04
Ng5S 24d	52.61	1026	94.34	0.51	4.97	0.18	0.00

Table 3 b) - cont.

Sample	Depth	Age	Stauroneis latistauros	Unknown 54a	Fragilaropsis sp.	Unknown 55b	Unknown 57a	Amphora sp.
Ng5S 13a	26.72	467	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13b	27.27	474	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13c	27.82	481	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13d	28.37	488	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14a	28.92	495	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14b	29.47	502	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14c	30.02	509	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14d	30.57	518	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15a	31.12	528	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15b	31.67	537	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15c	32.22	547	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15d	32.78	556	0.03	0.00	0.00	0.00	0.00	0.00
Ng5S 16a	33.33	566	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16b	33.88	575	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16c	34.43	584	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16d	34.98	594	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17a	35.53	606	0.00	0.00	0.03	0.00	0.00	0.00
Ng5S 17b	36.08	618	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17c	36.63	631	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17d	37.18	644	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18a	37.73	657	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18b	38.28	669	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18c	38.83	682	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18d	39.39	695	0.08	0.00	0.00	0.00	0.00	0.00
Ng5S 19a	39.94	707	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19b	40.49	720	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19c	41.04	733	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19d	41.59	746	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20a	42.14	760	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20b	42.69	773	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20c	43.24	785	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20d	43.79	798	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21a	44.34	811	0.00	0.00	0.05	0.00	0.00	0.00
Ng5S 21b	44.89	824	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21c	45.44	838	0.00	0.00	0.08	0.00	0.00	0.00
Ng5S 21d	46.00	852	0.03	0.00	0.00	0.00	0.00	0.00
Ng5S 22a	46.55	866	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22b	47.10	881	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22c	47.65	895	0.00	0.00	0.01	0.00	0.00	0.00
Ng5S 22d	48.20	910	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23a	48.75	924	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23b	49.30	938	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23c	49.85	953	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23d	50.40	967	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24a	50.95	982	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24b	51.50	996	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24c	52.06	1011	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24d	52.61	1026	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Psammothidium papilio	Cocconeis sp.	Humidophila australis	Chamaepinnularia sp.	Unknown 4a
Ng5S 13a	26.72	467	0.00	0.00	0.00	0.00	0.00
Ng5S 13b	27.27	474	0.00	0.00	0.00	0.00	0.00
Ng5S 13c	27.82	481	0.00	0.00	0.00	0.00	0.00
Ng5S 13d	28.37	488	0.00	0.00	0.00	0.00	0.00
Ng5S 14a	28.92	495	0.00	0.00	0.00	0.00	0.00
Ng5S 14b	29.47	502	0.00	0.00	0.00	0.00	0.00
Ng5S 14c	30.02	509	0.00	0.00	0.00	0.00	0.00
Ng5S 14d	30.57	518	0.00	0.00	0.00	0.00	0.00
Ng5S 15a	31.12	528	0.00	0.00	0.00	0.00	0.00
Ng5S 15b	31.67	537	0.00	0.00	0.00	0.00	0.00
Ng5S 15c	32.22	547	0.00	0.00	0.00	0.00	0.00
Ng5S 15d	32.78	556	0.03	0.00	0.00	0.00	0.00
Ng5S 16a	33.33	566	0.00	0.00	0.00	0.00	0.00
Ng5S 16b	33.88	575	0.00	0.00	0.00	0.00	0.00
Ng5S 16c	34.43	584	0.00	0.00	0.00	0.00	0.00
Ng5S 16d	34.98	594	0.00	0.00	0.00	0.00	0.00
Ng5S 17a	35.53	606	0.00	0.00	0.00	0.00	0.00
Ng5S 17b	36.08	618	0.00	0.00	0.00	0.00	0.00
Ng5S 17c	36.63	631	0.00	0.00	0.00	0.00	0.00
Ng5S 17d	37.18	644	0.00	0.00	0.00	0.00	0.00
Ng5S 18a	37.73	657	0.00	0.00	0.00	0.00	0.00
Ng5S 18b	38.28	669	0.00	0.00	0.00	0.00	0.00
Ng5S 18c	38.83	682	0.00	0.00	0.00	0.00	0.00
Ng5S 18d	39.39	695	0.00	0.00	0.00	0.00	0.00
Ng5S 19a	39.94	707	0.01	0.00	0.00	0.00	0.00
Ng5S 19b	40.49	720	0.00	0.00	0.00	0.00	0.00
Ng5S 19c	41.04	733	0.00	0.00	0.00	0.00	0.00
Ng5S 19d	41.59	746	0.00	0.00	0.00	0.00	0.00
Ng5S 20a	42.14	760	0.00	0.00	0.00	0.00	0.00
Ng5S 20b	42.69	773	0.00	0.00	0.00	0.00	0.00
Ng5S 20c	43.24	785	0.00	0.00	0.00	0.00	0.00
Ng5S 20d	43.79	798	0.00	0.00	0.00	0.00	0.00
Ng5S 21a	44.34	811	0.00	0.00	0.00	0.00	0.00
Ng5S 21b	44.89	824	0.00	0.00	0.00	0.04	0.00
Ng5S 21c	45.44	838	0.00	0.00	0.00	0.00	0.00
Ng5S 21d	46.00	852	0.00	0.00	0.00	0.00	0.00
Ng5S 22a	46.55	866	0.00	0.00	0.00	0.00	0.00
Ng5S 22b	47.10	881	0.00	0.00	0.00	0.00	0.00
Ng5S 22c	47.65	895	0.00	0.00	0.00	0.00	0.00
Ng5S 22d	48.20	910	0.00	0.00	0.00	0.00	0.00
Ng5S 23a	48.75	924	0.00	0.00	0.00	0.00	0.00
Ng5S 23b	49.30	938	0.00	0.00	0.00	0.00	0.00
Ng5S 23c	49.85	953	0.00	0.00	0.00	0.08	0.00
Ng5S 23d	50.40	967	0.00	0.00	0.00	0.00	0.00
Ng5S 24a	50.95	982	0.00	0.00	0.00	0.00	0.00
Ng5S 24b	51.50	996	0.00	0.08	0.00	0.00	0.00
Ng5S 24c	52.06	1011	0.00	0.00	0.00	0.02	0.00
Ng5S 24d	52.61	1026	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Unknown 12b	Unknown 37a	Unknown 56c	Unknown 54a	Caloneis sp.	Unknown 55d	Unknown 56b
Ng5S 13a	26.72	467	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13b	27.27	474	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13c	27.82	481	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 13d	28.37	488	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14a	28.92	495	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14b	29.47	502	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14c	30.02	509	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 14d	30.57	518	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15a	31.12	528	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15b	31.67	537	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15c	32.22	547	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 15d	32.78	556	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16a	33.33	566	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16b	33.88	575	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16c	34.43	584	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 16d	34.98	594	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17a	35.53	606	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17b	36.08	618	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17c	36.63	631	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 17d	37.18	644	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18a	37.73	657	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18b	38.28	669	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18c	38.83	682	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 18d	39.39	695	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19a	39.94	707	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19b	40.49	720	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19c	41.04	733	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 19d	41.59	746	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20a	42.14	760	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20b	42.69	773	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20c	43.24	785	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 20d	43.79	798	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21a	44.34	811	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21b	44.89	824	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21c	45.44	838	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 21d	46.00	852	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22a	46.55	866	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22b	47.10	881	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22c	47.65	895	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 22d	48.20	910	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23a	48.75	924	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23b	49.30	938	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23c	49.85	953	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 23d	50.40	967	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24a	50.95	982	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24b	51.50	996	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24c	52.06	1011	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 24d	52.61	1026	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Gomphonema sp.	Diatom valves/g
Ng5S 13a	26.72	467	0.00	89068488
Ng5S 13b	27.27	474	0.00	49516369
Ng5S 13c	27.82	481	0.00	89650229
Ng5S 13d	28.37	488	0.00	158758865
Ng5S 14a	28.92	495	0.00	71921726
Ng5S 14b	29.47	502	0.00	48852895
Ng5S 14c	30.02	509	0.00	55798419
Ng5S 14d	30.57	518	0.00	84113520
Ng5S 15a	31.12	528	0.00	96014193
Ng5S 15b	31.67	537	0.00	62192629
Ng5S 15c	32.22	547	0.00	95522844
Ng5S 15d	32.78	556	0.00	61312019
Ng5S 16a	33.33	566	0.00	60822255
Ng5S 16b	33.88	575	0.00	38561640
Ng5S 16c	34.43	584	0.00	50589073
Ng5S 16d	34.98	594	0.00	58977576
Ng5S 17a	35.53	606	0.00	158320413
Ng5S 17b	36.08	618	0.00	41113349
Ng5S 17c	36.63	631	0.00	58899676
Ng5S 17d	37.18	644	0.00	87207207
Ng5S 18a	37.73	657	0.00	97481859
Ng5S 18b	38.28	669	0.00	52029795
Ng5S 18c	38.83	682	0.00	52825094
Ng5S 18d	39.39	695	0.00	37327053
Ng5S 19a	39.94	707	0.00	137530795
Ng5S 19b	40.49	720	0.00	49428105
Ng5S 19c	41.04	733	0.00	60192147
Ng5S 19d	41.59	746	0.00	106068638
Ng5S 20a	42.14	760	0.00	106776040
Ng5S 20b	42.69	773	0.00	36557431
Ng5S 20c	43.24	785	0.00	81277744
Ng5S 20d	43.79	798	0.00	78266494
Ng5S 21a	44.34	811	0.00	128991401
Ng5S 21b	44.89	824	0.00	71447852
Ng5S 21c	45.44	838	0.00	56187974
Ng5S 21d	46.00	852	0.00	87361805
Ng5S 22a	46.55	866	0.00	89951081
Ng5S 22b	47.10	881	0.00	48555224
Ng5S 22c	47.65	895	0.00	44235540
Ng5S 22d	48.20	910	0.00	250129199
Ng5S 23a	48.75	924	0.00	140263340
Ng5S 23b	49.30	938	0.00	32732352
Ng5S 23c	49.85	953	0.00	120884872
Ng5S 23d	50.40	967	0.00	119745316
Ng5S 24a	50.95	982	0.00	85028156
Ng5S 24b	51.50	996	0.00	56479355
Ng5S 24c	52.06	1011	0.00	43628991
Ng5S 24d	52.61	1026	0.00	101058058

Table 3 b) - cont.

Sample	Depth	Age	Halamphora vyvermaniana	Navicula gregaria	Craticula antarctica	Hantzschia cf. amphioxys	Luticola pseudomurrayi
Ng5S 25a	53.16	1041	89.21	1.14	9.49	0.04	0.08
Ng5S 25b	53.71	1056	94.12	0.09	5.72	0.07	0.00
Ng5S 25c	54.26	1070	95.06	0.21	4.68	0.03	0.00
Ng5S 25d	54.81	1085	95.79	0.81	3.14	0.18	0.00
Ng5S 26a	55.36	1101	79.79	0.00	19.98	0.00	0.08
Ng5S 26b	55.91	1117	88.93	0.00	10.70	0.18	0.14
Ng5S 26c	56.46	1133	96.46	0.06	3.44	0.04	0.01
Ng5S 26d	57.01	1149	94.23	0.12	5.54	0.02	0.07
Ng5S 27a	57.56	1165	94.18	0.09	5.56	0.07	0.00
Ng5S 27b	58.11	1181	94.23	0.05	5.61	0.00	0.07
Ng5S 27c	58.67	1198	95.33	0.07	4.52	0.00	0.02
Ng5S 27d	59.22	1214	94.49	0.04	5.45	0.02	0.00
Ng5S 28a	59.77	1230	95.02	0.06	4.90	0.00	0.00
Ng5S 28b	60.32	1247	95.51	0.26	4.15	0.06	0.00
Ng5S 28c	60.87	1265	96.90	0.45	2.51	0.12	0.00
Ng5S 28d	61.42	1283	79.05	1.39	19.56	0.00	0.00
Ng5S 29a	61.97	1301	63.65	10.59	25.61	0.14	0.00
Ng5S 29b	62.52	1319	87.04	3.01	9.80	0.10	0.05
Ng5S 29c	63.07	1336	92.16	1.07	6.70	0.04	0.00
Ng5S 29d	63.62	1354	97.61	0.08	2.21	0.07	0.03
Ng5S 30a	64.17	1372	93.17	0.13	6.45	0.17	0.00
Ng5S 30b	64.72	1390	92.52	0.00	7.33	0.03	0.12
Ng5S 30c	65.28	1407	90.07	0.00	9.89	0.04	0.00
Ng5S 30d	65.83	1425	94.12	0.00	5.81	0.05	0.00
Ng5S 31a	66.38	1442	73.02	2.66	24.06	0.15	0.10
Ng5S 31b	66.93	1460	83.33	1.82	14.62	0.10	0.13
Ng5S 31c	67.48	1477	75.00	3.07	21.55	0.10	0.00
Ng5S 31d	68.03	1495	45.30	15.98	38.71	0.00	0.00
Ng5S 32a	68.58	1512	66.04	15.72	18.04	0.19	0.00
Ng5S 32b	69.13	1530	91.40	6.46	2.11	0.00	0.03
Ng5S 32c	69.68	1547	89.18	9.81	0.79	0.17	0.04
Ng5S 32d	70.23	1563	70.61	10.42	18.64	0.33	0.00
Ng5S 33a	70.78	1578	89.77	1.72	8.41	0.10	0.00
Ng5S 33b	71.33	1592	94.70	1.15	4.08	0.08	0.00
Ng5S 33c	71.89	1607	82.55	0.20	17.18	0.07	0.00
Ng5S 33d	72.44	1621	74.95	0.00	24.80	0.25	0.00
Ng5S 34a	72.99	1635	79.93	7.81	12.19	0.08	0.00
Ng5S 34b	73.54	1650	75.19	6.82	17.99	0.00	0.00
Ng5S 34c	74.09	1664	83.66	0.91	15.21	0.16	0.00
Ng5S 34d	74.64	1679	85.15	0.00	14.50	0.29	0.00
Ng5S 35a	75.19	1693	95.54	0.70	3.59	0.04	0.05
Ng5S 35b	75.74	1707	91.42	2.94	5.29	0.26	0.10
Ng5S 35c	76.29	1722	97.47	0.88	1.54	0.10	0.01
Ng5S 35d	76.84	1736	88.76	1.93	9.01	0.30	0.00
Ng5S 36a	77.39	1751	81.60	2.01	15.25	0.80	0.14
Ng5S 36b	77.94	1765	88.80	8.11	2.97	0.11	0.00
Ng5S 36c	78.50	1779	85.07	8.51	6.09	0.17	0.11
Ng5S 36d	79.05	1794	99.64	0.02	0.32	0.01	0.00

Table 3 b) - cont.

Sample	Depth	Age	Stauroneis latistauros	Unknown 54a	Fragilaropsis sp.	Unknown 55b	Unknown 57a	Amphora sp.
Ng5S 25a	53.16	1041	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25b	53.71	1056	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25c	54.26	1070	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25d	54.81	1085	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26a	55.36	1101	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26b	55.91	1117	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26c	56.46	1133	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26d	57.01	1149	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 27a	57.56	1165	0.00	0.00	0.03	0.00	0.00	0.00
Ng5S 27b	58.11	1181	0.00	0.00	0.00	0.02	0.00	0.00
Ng5S 27c	58.67	1198	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 27d	59.22	1214	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28a	59.77	1230	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28b	60.32	1247	0.00	0.00	0.03	0.00	0.00	0.00
Ng5S 28c	60.87	1265	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28d	61.42	1283	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29a	61.97	1301	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29b	62.52	1319	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29c	63.07	1336	0.00	0.00	0.03	0.00	0.00	0.00
Ng5S 29d	63.62	1354	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30a	64.17	1372	0.00	0.00	0.00	0.03	0.00	0.00
Ng5S 30b	64.72	1390	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30c	65.28	1407	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30d	65.83	1425	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31a	66.38	1442	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31b	66.93	1460	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31c	67.48	1477	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31d	68.03	1495	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32a	68.58	1512	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32b	69.13	1530	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32c	69.68	1547	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32d	70.23	1563	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33a	70.78	1578	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33b	71.33	1592	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33c	71.89	1607	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33d	72.44	1621	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34a	72.99	1635	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34b	73.54	1650	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34c	74.09	1664	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34d	74.64	1679	0.00	0.00	0.00	0.06	0.00	0.00
Ng5S 35a	75.19	1693	0.00	0.02	0.04	0.00	0.00	0.00
Ng5S 35b	75.74	1707	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35c	76.29	1722	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35d	76.84	1736	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36a	77.39	1751	0.00	0.00	0.21	0.00	0.00	0.00
Ng5S 36b	77.94	1765	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36c	78.50	1779	0.00	0.00	0.06	0.00	0.00	0.00
Ng5S 36d	79.05	1794	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Psammothidium papilio	Cocconeis sp.	Humidophila australis	Chamaepinnularia sp.	Unknown 4a
Ng5S 25a	53.16	1041	0.04	0.00	0.00	0.00	0.00
Ng5S 25b	53.71	1056	0.00	0.00	0.00	0.00	0.00
Ng5S 25c	54.26	1070	0.00	0.02	0.00	0.00	0.00
Ng5S 25d	54.81	1085	0.05	0.00	0.00	0.00	0.00
Ng5S 26a	55.36	1101	0.08	0.00	0.00	0.00	0.00
Ng5S 26b	55.91	1117	0.05	0.00	0.00	0.00	0.00
Ng5S 26c	56.46	1133	0.00	0.00	0.00	0.00	0.00
Ng5S 26d	57.01	1149	0.00	0.02	0.00	0.00	0.00
Ng5S 27a	57.56	1165	0.00	0.02	0.00	0.00	0.00
Ng5S 27b	58.11	1181	0.00	0.02	0.00	0.00	0.00
Ng5S 27c	58.67	1198	0.04	0.00	0.00	0.00	0.00
Ng5S 27d	59.22	1214	0.00	0.00	0.00	0.00	0.00
Ng5S 28a	59.77	1230	0.00	0.00	0.00	0.00	0.00
Ng5S 28b	60.32	1247	0.00	0.00	0.00	0.00	0.00
Ng5S 28c	60.87	1265	0.00	0.01	0.00	0.00	0.00
Ng5S 28d	61.42	1283	0.00	0.00	0.00	0.00	0.00
Ng5S 29a	61.97	1301	0.00	0.00	0.00	0.00	0.00
Ng5S 29b	62.52	1319	0.00	0.00	0.00	0.00	0.00
Ng5S 29c	63.07	1336	0.00	0.00	0.00	0.00	0.00
Ng5S 29d	63.62	1354	0.00	0.00	0.00	0.00	0.00
Ng5S 30a	64.17	1372	0.00	0.00	0.00	0.00	0.00
Ng5S 30b	64.72	1390	0.00	0.00	0.00	0.00	0.00
Ng5S 30c	65.28	1407	0.00	0.00	0.00	0.00	0.00
Ng5S 30d	65.83	1425	0.00	0.02	0.00	0.00	0.00
Ng5S 31a	66.38	1442	0.00	0.00	0.00	0.00	0.00
Ng5S 31b	66.93	1460	0.00	0.00	0.00	0.00	0.00
Ng5S 31c	67.48	1477	0.29	0.00	0.00	0.00	0.00
Ng5S 31d	68.03	1495	0.00	0.00	0.00	0.00	0.00
Ng5S 32a	68.58	1512	0.00	0.00	0.00	0.00	0.00
Ng5S 32b	69.13	1530	0.00	0.00	0.00	0.00	0.00
Ng5S 32c	69.68	1547	0.00	0.00	0.00	0.00	0.00
Ng5S 32d	70.23	1563	0.00	0.00	0.00	0.00	0.00
Ng5S 33a	70.78	1578	0.00	0.00	0.00	0.00	0.00
Ng5S 33b	71.33	1592	0.00	0.00	0.00	0.00	0.00
Ng5S 33c	71.89	1607	0.00	0.00	0.00	0.00	0.00
Ng5S 33d	72.44	1621	0.00	0.00	0.00	0.00	0.00
Ng5S 34a	72.99	1635	0.00	0.00	0.00	0.00	0.00
Ng5S 34b	73.54	1650	0.00	0.00	0.00	0.00	0.00
Ng5S 34c	74.09	1664	0.00	0.00	0.00	0.00	0.00
Ng5S 34d	74.64	1679	0.00	0.00	0.00	0.00	0.00
Ng5S 35a	75.19	1693	0.00	0.02	0.00	0.00	0.00
Ng5S 35b	75.74	1707	0.00	0.00	0.00	0.00	0.00
Ng5S 35c	76.29	1722	0.00	0.00	0.00	0.00	0.00
Ng5S 35d	76.84	1736	0.00	0.00	0.00	0.00	0.00
Ng5S 36a	77.39	1751	0.00	0.00	0.00	0.00	0.00
Ng5S 36b	77.94	1765	0.00	0.00	0.00	0.00	0.00
Ng5S 36c	78.50	1779	0.00	0.00	0.00	0.00	0.00
Ng5S 36d	79.05	1794	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Unknown 12b	Unknown 37a	Unknown 56c	Unknown 54a	Caloneis sp.	Unknown 55d	Unknown 56b
Ng5S 25a	53.16	1041	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25b	53.71	1056	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25c	54.26	1070	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 25d	54.81	1085	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Ng5S 26a	55.36	1101	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26b	55.91	1117	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26c	56.46	1133	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 26d	57.01	1149	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 27a	57.56	1165	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 27b	58.11	1181	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 27c	58.67	1198	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 27d	59.22	1214	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28a	59.77	1230	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28b	60.32	1247	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28c	60.87	1265	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 28d	61.42	1283	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29a	61.97	1301	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29b	62.52	1319	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29c	63.07	1336	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 29d	63.62	1354	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30a	64.17	1372	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30b	64.72	1390	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30c	65.28	1407	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 30d	65.83	1425	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31a	66.38	1442	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31b	66.93	1460	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31c	67.48	1477	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 31d	68.03	1495	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32a	68.58	1512	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32b	69.13	1530	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32c	69.68	1547	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 32d	70.23	1563	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33a	70.78	1578	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33b	71.33	1592	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33c	71.89	1607	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 33d	72.44	1621	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34a	72.99	1635	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34b	73.54	1650	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34c	74.09	1664	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 34d	74.64	1679	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35a	75.19	1693	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35b	75.74	1707	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35c	76.29	1722	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 35d	76.84	1736	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36a	77.39	1751	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36b	77.94	1765	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36c	78.50	1779	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 36d	79.05	1794	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Gomphonema sp.	Diatom valves/g
Ng5S 25a	53.16	1041	0.00	83137810
Ng5S 25b	53.71	1056	0.00	52581800
Ng5S 25c	54.26	1070	0.00	58784520
Ng5S 25d	54.81	1085	0.00	56059288
Ng5S 26a	55.36	1101	0.00	80797748
Ng5S 26b	55.91	1117	0.00	45111995
Ng5S 26c	56.46	1133	0.00	33240590
Ng5S 26d	57.01	1149	0.00	47173489
Ng5S 27a	57.56	1165	0.00	69866125
Ng5S 27b	58.11	1181	0.00	35380117
Ng5S 27c	58.67	1198	0.00	28125537
Ng5S 27d	59.22	1214	0.00	36666667
Ng5S 28a	59.77	1230	0.00	60418207
Ng5S 28b	60.32	1247	0.00	41368316
Ng5S 28c	60.87	1265	0.00	57359406
Ng5S 28d	61.42	1283	0.00	60380671
Ng5S 29a	61.97	1301	0.00	95284570
Ng5S 29b	62.52	1319	0.00	45681446
Ng5S 29c	63.07	1336	0.00	85998579
Ng5S 29d	63.62	1354	0.00	46226788
Ng5S 30a	64.17	1372	0.00	85037798
Ng5S 30b	64.72	1390	0.00	71433926
Ng5S 30c	65.28	1407	0.00	57295556
Ng5S 30d	65.83	1425	0.00	99335989
Ng5S 31a	66.38	1442	0.00	106794774
Ng5S 31b	66.93	1460	0.00	53477452
Ng5S 31c	67.48	1477	0.00	48556127
Ng5S 31d	68.03	1495	0.00	91969697
Ng5S 32a	68.58	1512	0.00	100875679
Ng5S 32b	69.13	1530	0.00	96267644
Ng5S 32c	69.68	1547	0.00	60146199
Ng5S 32d	70.23	1563	0.00	36514628
Ng5S 33a	70.78	1578	0.00	103009809
Ng5S 33b	71.33	1592	0.00	88868223
Ng5S 33c	71.89	1607	0.00	85665139
Ng5S 33d	72.44	1621	0.00	53478915
Ng5S 34a	72.99	1635	0.00	74410501
Ng5S 34b	73.54	1650	0.00	33411486
Ng5S 34c	74.09	1664	0.00	35880472
Ng5S 34d	74.64	1679	0.00	60886190
Ng5S 35a	75.19	1693	0.00	72328193
Ng5S 35b	75.74	1707	0.00	42607593
Ng5S 35c	76.29	1722	0.00	33025283
Ng5S 35d	76.84	1736	0.00	84885845
Ng5S 36a	77.39	1751	0.00	64079259
Ng5S 36b	77.94	1765	0.00	45350650
Ng5S 36c	78.50	1779	0.00	23653493
Ng5S 36d	79.05	1794	0.00	110264999

Table 3 b) - cont.

Sample	Depth	Age	Halamphora vyvermaniana	Navicula gregaria	Craticula antarctica	Hantzschia cf. amphioxys	Luticola pseudomurrayi
Ng5S 37a	79.60	1808	90.09	0.43	9.29	0.02	0.00
Ng5S 37b	80.15	1823	90.55	0.00	9.37	0.07	0.00
Ng5S 37c	80.70	1839	87.85	0.00	12.03	0.10	0.00
Ng5S 37d	81.25	1854	91.25	2.01	6.55	0.15	0.00
Ng5S 38a	81.80	1870	92.12	4.52	3.21	0.00	0.00
Ng5S 38b	82.35	1885	93.87	4.10	1.64	0.11	0.12
Ng5S 38c	82.90	1901	60.59	21.88	17.53	0.00	0.00
Ng5S 38d	83.45	1917	65.22	29.66	5.12	0.00	0.00
Ng5S 39a	84.00	1932	73.89	8.29	17.61	0.00	0.00
Ng5S 39b	84.56	1948	68.59	16.44	14.72	0.00	0.00
Ng5S 39c	85.11	1965	46.29	31.77	21.77	0.00	0.00
Ng5S 39d	85.66	1984	75.44	4.31	20.11	0.14	0.00
Ng5S 40a	86.21	2003	66.01	2.00	31.93	0.07	0.00
Ng5S 40b	86.76	2022	66.92	5.29	27.79	0.00	0.00
Ng5S 40c	87.31	2041	45.44	14.68	39.88	0.00	0.00
Ng5S 40d	87.86	2061	79.68	5.70	14.54	0.08	0.00
Ng5S 41a	88.41	2080	57.14	7.69	34.69	0.47	0.00
Ng5S 41b	88.96	2100	85.60	8.79	5.15	0.46	0.00
Ng5S 41c	89.51	2119	61.73	4.98	32.93	0.37	0.00
Ng5S 41d	90.06	2138	75.47	5.86	18.57	0.00	0.00
Ng5S 42a	90.61	2152	72.63	15.30	12.07	0.00	0.00
Ng5S 42b	91.17	2165	84.98	8.98	5.84	0.14	0.00
Ng5S 42c	91.72	2179	79.25	11.54	9.06	0.08	0.00
Ng5S 42d	92.27	2192	85.82	5.05	8.86	0.00	0.05
Ng5S 43a	92.82	2206	42.37	0.38	57.25	0.00	0.00
Ng5S 43b	93.37	2219	86.79	2.75	10.43	0.03	0.00
Ng5S 43c	93.92	2233	62.06	14.78	23.16	0.00	0.00
Ng5S 43d	94.47	2246	88.58	0.62	10.34	0.20	0.22
Ng5S 44a	95.02	2260	82.09	9.40	7.82	0.00	0.00
Ng5S 44b	95.57	2273	62.21	23.08	14.22	0.07	0.00
Ng5S 44c	96.12	2287	42.23	19.96	37.81	0.00	0.00
Ng5S 44d	96.67	2300	79.25	4.01	16.43	0.08	0.08
Ng5S 45a	97.22	2314	63.13	5.75	30.84	0.00	0.28
Ng5S 45b	97.78	2328	90.00	1.14	8.63	0.00	0.16
Ng5S 45c	98.33	2341	69.23	0.23	30.30	0.00	0.00
Ng5S 45d	98.88	2355	51.22	0.00	48.78	0.00	0.00
Ng5S 46a	99.43	2369	72.93	2.78	23.15	1.13	0.00
Ng5S 46b	99.98	2383	88.24	2.41	9.28	0.07	0.00
Ng5S 46c	100.53	2405	85.23	3.89	10.71	0.00	0.06
Ng5S 46d	101.08	2427	64.71	21.20	13.67	0.14	0.14
Ng5S 47a	101.63	2449	68.91	6.58	23.92	0.24	0.00
Ng5S 47b	102.18	2472	67.44	5.70	26.61	0.13	0.13
Ng5S 47c	102.73	2494	44.04	21.35	34.04	0.00	0.58
Ng5S 47d	103.28	2517	68.44	13.60	17.40	0.55	0.00
Ng5S 48a	103.83	2539	68.02	1.33	30.28	0.36	0.00
Ng5S 48b	104.39	2562	80.61	0.29	18.81	0.22	0.00
Ng5S 48c	104.94	2584	46.05	7.31	46.44	0.20	0.00
Ng5S 48d	105.49	2599	49.43	5.58	44.66	0.33	0.00

Table 3 b) - cont.

Sample	Depth	Age	Stauroneis latistauros	Unknown 54a	Fragilaropsis sp.	Unknown 55b	Unknown 57a	Amphora sp.
Ng5S 37a	79.60	1808	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 37b	80.15	1823	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 37c	80.70	1839	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 37d	81.25	1854	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 38a	81.80	1870	0.00	0.00	0.09	0.00	0.00	0.00
Ng5S 38b	82.35	1885	0.00	0.02	0.07	0.00	0.00	0.00
Ng5S 38c	82.90	1901	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 38d	83.45	1917	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39a	84.00	1932	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39b	84.56	1948	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39c	85.11	1965	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39d	85.66	1984	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40a	86.21	2003	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40b	86.76	2022	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40c	87.31	2041	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40d	87.86	2061	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41a	88.41	2080	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41b	88.96	2100	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41c	89.51	2119	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41d	90.06	2138	0.00	0.00	0.00	0.10	0.00	0.00
Ng5S 42a	90.61	2152	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 42b	91.17	2165	0.00	0.06	0.00	0.00	0.00	0.00
Ng5S 42c	91.72	2179	0.00	0.08	0.00	0.00	0.00	0.00
Ng5S 42d	92.27	2192	0.00	0.00	0.00	0.16	0.00	0.00
Ng5S 43a	92.82	2206	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43b	93.37	2219	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43c	93.92	2233	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43d	94.47	2246	0.00	0.00	0.04	0.00	0.00	0.00
Ng5S 44a	95.02	2260	0.00	0.07	0.07	0.00	0.00	0.00
Ng5S 44b	95.57	2273	0.00	0.14	0.14	0.00	0.00	0.00
Ng5S 44c	96.12	2287	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 44d	96.67	2300	0.00	0.00	0.08	0.08	0.00	0.00
Ng5S 45a	97.22	2314	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45b	97.78	2328	0.00	0.00	0.04	0.04	0.00	0.00
Ng5S 45c	98.33	2341	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45d	98.88	2355	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46a	99.43	2369	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46b	99.98	2383	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46c	100.53	2405	0.00	0.00	0.06	0.00	0.00	0.00
Ng5S 46d	101.08	2427	0.00	0.00	0.14	0.00	0.00	0.00
Ng5S 47a	101.63	2449	0.00	0.24	0.12	0.00	0.00	0.00
Ng5S 47b	102.18	2472	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47c	102.73	2494	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47d	103.28	2517	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48a	103.83	2539	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48b	104.39	2562	0.00	0.00	0.00	0.07	0.00	0.00
Ng5S 48c	104.94	2584	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48d	105.49	2599	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Psammothidium papilio	Cocconeis sp.	Humidophila australis	Chamaepinnularia sp.	Unknown 4a
Ng5S 37a	79.60	1808	0.00	0.08	0.00	0.00	0.00
Ng5S 37b	80.15	1823	0.00	0.00	0.00	0.00	0.00
Ng5S 37c	80.70	1839	0.00	0.00	0.00	0.00	0.00
Ng5S 37d	81.25	1854	0.00	0.03	0.00	0.00	0.00
Ng5S 38a	81.80	1870	0.00	0.03	0.00	0.00	0.00
Ng5S 38b	82.35	1885	0.00	0.00	0.00	0.00	0.00
Ng5S 38c	82.90	1901	0.00	0.00	0.00	0.00	0.00
Ng5S 38d	83.45	1917	0.00	0.00	0.00	0.00	0.00
Ng5S 39a	84.00	1932	0.21	0.00	0.00	0.00	0.00
Ng5S 39b	84.56	1948	0.25	0.00	0.00	0.00	0.00
Ng5S 39c	85.11	1965	0.00	0.00	0.00	0.16	0.00
Ng5S 39d	85.66	1984	0.00	0.00	0.00	0.00	0.00
Ng5S 40a	86.21	2003	0.00	0.00	0.00	0.00	0.00
Ng5S 40b	86.76	2022	0.00	0.00	0.00	0.00	0.00
Ng5S 40c	87.31	2041	0.00	0.00	0.00	0.00	0.00
Ng5S 40d	87.86	2061	0.00	0.00	0.00	0.00	0.00
Ng5S 41a	88.41	2080	0.00	0.00	0.00	0.00	0.00
Ng5S 41b	88.96	2100	0.00	0.00	0.00	0.00	0.00
Ng5S 41c	89.51	2119	0.00	0.00	0.00	0.00	0.00
Ng5S 41d	90.06	2138	0.00	0.00	0.00	0.00	0.00
Ng5S 42a	90.61	2152	0.00	0.00	0.00	0.00	0.00
Ng5S 42b	91.17	2165	0.00	0.00	0.00	0.00	0.00
Ng5S 42c	91.72	2179	0.00	0.00	0.00	0.00	0.00
Ng5S 42d	92.27	2192	0.00	0.05	0.00	0.00	0.00
Ng5S 43a	92.82	2206	0.00	0.00	0.00	0.00	0.00
Ng5S 43b	93.37	2219	0.00	0.00	0.00	0.00	0.00
Ng5S 43c	93.92	2233	0.00	0.00	0.00	0.00	0.00
Ng5S 43d	94.47	2246	0.00	0.00	0.00	0.00	0.00
Ng5S 44a	95.02	2260	0.27	0.14	0.00	0.00	0.00
Ng5S 44b	95.57	2273	0.00	0.00	0.00	0.00	0.00
Ng5S 44c	96.12	2287	0.00	0.00	0.00	0.00	0.00
Ng5S 44d	96.67	2300	0.00	0.00	0.00	0.00	0.00
Ng5S 45a	97.22	2314	0.00	0.00	0.00	0.00	0.00
Ng5S 45b	97.78	2328	0.00	0.00	0.00	0.00	0.00
Ng5S 45c	98.33	2341	0.00	0.00	0.00	0.23	0.00
Ng5S 45d	98.88	2355	0.00	0.00	0.00	0.00	0.00
Ng5S 46a	99.43	2369	0.00	0.00	0.00	0.00	0.00
Ng5S 46b	99.98	2383	0.00	0.00	0.00	0.00	0.00
Ng5S 46c	100.53	2405	0.00	0.06	0.00	0.00	0.00
Ng5S 46d	101.08	2427	0.00	0.00	0.00	0.00	0.00
Ng5S 47a	101.63	2449	0.00	0.00	0.00	0.00	0.00
Ng5S 47b	102.18	2472	0.00	0.00	0.00	0.00	0.00
Ng5S 47c	102.73	2494	0.00	0.00	0.00	0.00	0.00
Ng5S 47d	103.28	2517	0.00	0.00	0.00	0.00	0.00
Ng5S 48a	103.83	2539	0.00	0.00	0.00	0.00	0.00
Ng5S 48b	104.39	2562	0.00	0.00	0.00	0.00	0.00
Ng5S 48c	104.94	2584	0.00	0.00	0.00	0.00	0.00
Ng5S 48d	105.49	2599	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Unknown 12b	Unknown 37a	Unknown 56c	Unknown 54a	Caloneis sp.	Unknown 55d	Unknown 56b
Ng5S 37a	79.60	1808	0.04	0.04	0.00	0.00	0.00	0.00	0.00
Ng5S 37b	80.15	1823	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 37c	80.70	1839	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 37d	81.25	1854	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 38a	81.80	1870	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Ng5S 38b	82.35	1885	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Ng5S 38c	82.90	1901	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 38d	83.45	1917	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39a	84.00	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39b	84.56	1948	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39c	85.11	1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 39d	85.66	1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40a	86.21	2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40b	86.76	2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40c	87.31	2041	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 40d	87.86	2061	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41a	88.41	2080	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41b	88.96	2100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41c	89.51	2119	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 41d	90.06	2138	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 42a	90.61	2152	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 42b	91.17	2165	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 42c	91.72	2179	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 42d	92.27	2192	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43a	92.82	2206	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43b	93.37	2219	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43c	93.92	2233	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 43d	94.47	2246	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 44a	95.02	2260	0.00	0.14	0.00	0.00	0.00	0.00	0.00
Ng5S 44b	95.57	2273	0.00	0.00	0.14	0.00	0.00	0.00	0.00
Ng5S 44c	96.12	2287	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 44d	96.67	2300	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45a	97.22	2314	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45b	97.78	2328	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45c	98.33	2341	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 45d	98.88	2355	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46a	99.43	2369	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46b	99.98	2383	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46c	100.53	2405	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 46d	101.08	2427	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47a	101.63	2449	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47b	102.18	2472	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47c	102.73	2494	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 47d	103.28	2517	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48a	103.83	2539	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48b	104.39	2562	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48c	104.94	2584	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 48d	105.49	2599	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Gomphonema sp.	Diatom valves/g
Ng5S 37a	79.60	1808	0.00	63024382
Ng5S 37b	80.15	1823	0.00	101652506
Ng5S 37c	80.70	1839	0.00	41767480
Ng5S 37d	81.25	1854	0.00	79682003
Ng5S 38a	81.80	1870	0.00	52378241
Ng5S 38b	82.35	1885	0.00	72380830
Ng5S 38c	82.90	1901	0.00	94716243
Ng5S 38d	83.45	1917	0.00	81829011
Ng5S 39a	84.00	1932	0.00	149155939
Ng5S 39b	84.56	1948	0.00	55748428
Ng5S 39c	85.11	1965	0.00	170709972
Ng5S 39d	85.66	1984	0.00	56436647
Ng5S 40a	86.21	2003	0.00	113922368
Ng5S 40b	86.76	2022	0.00	80766473
Ng5S 40c	87.31	2041	0.00	134411984
Ng5S 40d	87.86	2061	0.00	76232430
Ng5S 41a	88.41	2080	0.00	107629900
Ng5S 41b	88.96	2100	0.00	71647947
Ng5S 41c	89.51	2119	0.00	68175947
Ng5S 41d	90.06	2138	0.00	58078904
Ng5S 42a	90.61	2152	0.00	72948502
Ng5S 42b	91.17	2165	0.00	77183738
Ng5S 42c	91.72	2179	0.00	28492250
Ng5S 42d	92.27	2192	0.00	89853145
Ng5S 43a	92.82	2206	0.00	141986340
Ng5S 43b	93.37	2219	0.00	56552028
Ng5S 43c	93.92	2233	0.00	37039322
Ng5S 43d	94.47	2246	0.00	39253006
Ng5S 44a	95.02	2260	0.00	83251181
Ng5S 44b	95.57	2273	0.00	66352323
Ng5S 44c	96.12	2287	0.00	74627874
Ng5S 44d	96.67	2300	0.00	90612692
Ng5S 45a	97.22	2314	0.00	93598787
Ng5S 45b	97.78	2328	0.00	44711316
Ng5S 45c	98.33	2341	0.00	39262119
Ng5S 45d	98.88	2355	0.00	46746394
Ng5S 46a	99.43	2369	0.00	90473234
Ng5S 46b	99.98	2383	0.00	46450447
Ng5S 46c	100.53	2405	0.00	69765766
Ng5S 46d	101.08	2427	0.00	83852229
Ng5S 47a	101.63	2449	0.00	117959569
Ng5S 47b	102.18	2472	0.00	114869215
Ng5S 47c	102.73	2494	0.00	76708321
Ng5S 47d	103.28	2517	0.00	57793387
Ng5S 48a	103.83	2539	0.00	159382347
Ng5S 48b	104.39	2562	0.00	81202431
Ng5S 48c	104.94	2584	0.00	215375956
Ng5S 48d	105.49	2599	0.00	260020510

Table 3 b) - cont.

Sample	Depth	Age	Halamphora vyvermaniana	Navicula gregaria	Craticula antarctica	Hantzschia cf. amphioxys	Luticola pseudomurrayi
Ng5S 49a	106.04	2612	91.09	1.30	7.20	0.33	0.07
Ng5S 49b	106.59	2625	50.47	3.00	46.53	0.00	0.00
Ng5S 49c	107.14	2639	36.24	22.08	41.68	0.00	0.00
Ng5S 49d	107.69	2652	57.81	20.12	21.47	0.60	0.00
Ng5S 50a	108.24	2666	44.83	16.15	39.02	0.00	0.00
Ng5S 50b	108.79	2679	58.80	20.37	20.52	0.16	0.16
Ng5S 50c	109.34	2692	67.31	11.32	20.99	0.13	0.25
Ng5S 50d	109.89	2705	39.15	20.97	38.98	0.74	0.00
Ng5S 51a	110.44	2717	47.44	2.99	49.57	0.00	0.00
Ng5S 51b	111.00	2729	83.33	4.70	11.50	0.09	0.00
Ng5S 51c	111.55	2742	62.50	4.49	32.58	0.36	0.00
Ng5S 51d	112.10	2754	41.46	7.63	50.58	0.25	0.00
Ng5S 52a	112.65	2766	59.66	18.72	21.16	0.00	0.30
Ng5S 52b	113.20	2779	62.07	20.60	17.12	0.07	0.00
Ng5S 52c	113.75	2791	59.82	11.93	26.68	1.26	0.00
Ng5S 52d	114.30	2803	77.82	3.04	18.59	0.13	0.00
Ng5S 53a	114.85	2816	89.78	0.74	9.15	0.02	0.00
Ng5S 53b	115.40	2827	63.77	10.01	25.73	0.00	0.00
Ng5S 53c	115.95	2839	64.64	4.59	30.37	0.00	0.00
Ng5S 53d	116.50	2850	58.14	7.45	33.92	0.17	0.17
Ng5S 54a	117.06	2862	70.74	2.63	26.34	0.00	0.00
Ng5S 54b	117.61	2874	46.98	12.27	39.61	0.35	0.00
Ng5S 54c	118.16	2885	57.47	14.01	28.02	0.00	0.00
Ng5S 54d	118.71	2897	53.51	10.01	35.49	0.00	0.00
Ng5S 55a	119.26	2908	64.81	3.93	30.51	0.07	0.27
Ng5S 55b	119.81	2920	62.14	7.53	29.68	0.00	0.00
Ng5S 55c	120.36	2931	65.13	12.32	22.34	0.00	0.00
Ng5S 55d	120.91	2942	59.89	8.22	30.45	0.00	0.00
Ng5S 56a	121.46	2953	85.07	1.17	10.21	0.00	0.00
Ng5S 56b	122.01	2964	77.36	1.20	16.92	0.00	0.60
Ng5S 56c	122.56	2975	78.67	1.41	15.61	0.00	0.00
Ng5S 56d	123.11	2987	64.52	2.44	31.83	0.00	0.00
Ng5S 57a	123.67	2997	84.77	0.00	0.00	0.00	0.00
Ng5S 57b	124.22	3008	86.87	0.71	10.59	0.00	0.00
Ng5S 57c	124.77	3019	90.38	1.13	7.50	0.02	0.00
Ng5S 57d	125.32	3030	61.57	7.57	28.75	0.14	0.00
Ng5S 58a	125.87	3040	39.10	10.77	47.96	0.09	0.00
Ng5S 58b	126.42	3051	55.92	0.50	41.58	0.17	0.00
Ng5S 58c	126.97	3061	65.89	1.01	31.39	0.13	0.00
Ng5S 58d	127.52	3072	67.65	5.12	25.26	0.06	0.00
Ng5S 59a	128.07	3082	64.71	1.94	31.87	0.71	0.00
Ng5S 59b	128.62	3093	59.33	1.34	37.14	0.08	0.00
Ng5S 59c	129.17	3103	51.61	1.35	44.34	0.48	0.00
Ng5S 59d	129.72	3114	57.56	4.02	36.17	0.16	0.00

Table 3 b) - cont.

Sample	Depth	Age	Stauroneis latistauros	Unknown 54a	Fragilaropsis sp.	Unknown 55b	Unknown 57a	Amphora sp.
Ng5S 49a	106.04	2612	0.00	0.00	0.02	0.00	0.00	0.00
Ng5S 49b	106.59	2625	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 49c	107.14	2639	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 49d	107.69	2652	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50a	108.24	2666	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50b	108.79	2679	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50c	109.34	2692	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50d	109.89	2705	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 51a	110.44	2717	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 51b	111.00	2729	0.12	0.00	0.00	0.00	0.00	0.00
Ng5S 51c	111.55	2742	0.00	0.00	0.07	0.00	0.00	0.00
Ng5S 51d	112.10	2754	0.00	0.00	0.08	0.00	0.00	0.00
Ng5S 52a	112.65	2766	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 52b	113.20	2779	0.00	0.00	0.15	0.00	0.00	0.00
Ng5S 52c	113.75	2791	0.00	0.31	0.00	0.00	0.00	0.00
Ng5S 52d	114.30	2803	0.00	0.08	0.25	0.00	0.00	0.00
Ng5S 53a	114.85	2816	0.00	0.06	0.18	0.03	0.00	0.00
Ng5S 53b	115.40	2827	0.00	0.00	0.49	0.00	0.00	0.00
Ng5S 53c	115.95	2839	0.00	0.00	0.27	0.13	0.00	0.00
Ng5S 53d	116.50	2850	0.00	0.00	0.17	0.00	0.00	0.00
Ng5S 54a	117.06	2862	0.00	0.19	0.09	0.00	0.00	0.00
Ng5S 54b	117.61	2874	0.00	0.35	0.09	0.35	0.00	0.00
Ng5S 54c	118.16	2885	0.00	0.00	0.16	0.00	0.00	0.00
Ng5S 54d	118.71	2897	0.00	0.00	0.45	0.18	0.00	0.00
Ng5S 55a	119.26	2908	0.00	0.00	0.41	0.00	0.00	0.00
Ng5S 55b	119.81	2920	0.00	0.00	0.51	0.00	0.00	0.00
Ng5S 55c	120.36	2931	0.00	0.14	0.07	0.00	0.00	0.00
Ng5S 55d	120.91	2942	0.00	0.46	0.99	0.00	0.00	0.00
Ng5S 56a	121.46	2953	0.00	1.58	1.05	0.23	0.00	0.00
Ng5S 56b	122.01	2964	0.00	0.98	2.33	0.00	0.00	0.00
Ng5S 56c	122.56	2975	0.00	1.19	2.30	0.00	0.00	0.00
Ng5S 56d	123.11	2987	0.00	0.41	0.54	0.14	0.00	0.00
Ng5S 57a	123.67	2997	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 57b	124.22	3008	0.00	0.89	0.56	0.05	0.00	0.00
Ng5S 57c	124.77	3019	0.00	0.40	0.30	0.07	0.07	0.00
Ng5S 57d	125.32	3030	0.00	0.56	0.98	0.00	0.00	0.00
Ng5S 58a	125.87	3040	0.00	0.87	1.22	0.00	0.00	0.00
Ng5S 58b	126.42	3051	0.00	0.33	0.50	0.17	0.00	0.00
Ng5S 58c	126.97	3061	0.00	0.51	0.95	0.00	0.00	0.00
Ng5S 58d	127.52	3072	0.00	0.12	0.83	0.12	0.00	0.00
Ng5S 59a	128.07	3082	0.00	0.26	0.52	0.00	0.00	0.00
Ng5S 59b	128.62	3093	0.00	1.18	0.25	0.17	0.00	0.00
Ng5S 59c	129.17	3103	0.00	0.00	2.02	0.00	0.00	0.00
Ng5S 59d	129.72	3114	0.00	0.80	0.48	0.00	0.00	0.00

Table 3 b) - cont.

Sample	Depth	Age	Psammothidium papilio	Cocconeis sp.	Humidophila australis	Chamaepinnularia sp.	Unknown 4a
Ng5S 49a	106.04	2612	0.00	0.00	0.00	0.00	0.00
Ng5S 49b	106.59	2625	0.00	0.00	0.00	0.00	0.00
Ng5S 49c	107.14	2639	0.00	0.00	0.00	0.00	0.00
Ng5S 49d	107.69	2652	0.00	0.00	0.00	0.00	0.00
Ng5S 50a	108.24	2666	0.00	0.00	0.00	0.00	0.00
Ng5S 50b	108.79	2679	0.00	0.00	0.00	0.00	0.00
Ng5S 50c	109.34	2692	0.00	0.00	0.00	0.00	0.00
Ng5S 50d	109.89	2705	0.00	0.16	0.00	0.00	0.00
Ng5S 51a	110.44	2717	0.00	0.00	0.00	0.00	0.00
Ng5S 51b	111.00	2729	0.12	0.00	0.00	0.00	0.00
Ng5S 51c	111.55	2742	0.00	0.00	0.00	0.00	0.00
Ng5S 51d	112.10	2754	0.00	0.00	0.00	0.00	0.00
Ng5S 52a	112.65	2766	0.00	0.00	0.00	0.15	0.00
Ng5S 52b	113.20	2779	0.00	0.00	0.00	0.00	0.00
Ng5S 52c	113.75	2791	0.00	0.00	0.00	0.00	0.00
Ng5S 52d	114.30	2803	0.00	0.00	0.00	0.08	0.00
Ng5S 53a	114.85	2816	0.00	0.03	0.00	0.00	0.00
Ng5S 53b	115.40	2827	0.00	0.00	0.00	0.00	0.00
Ng5S 53c	115.95	2839	0.00	0.00	0.00	0.00	0.00
Ng5S 53d	116.50	2850	0.00	0.00	0.00	0.00	0.00
Ng5S 54a	117.06	2862	0.00	0.00	0.00	0.00	0.00
Ng5S 54b	117.61	2874	0.00	0.00	0.00	0.00	0.00
Ng5S 54c	118.16	2885	0.00	0.00	0.00	0.00	0.00
Ng5S 54d	118.71	2897	0.00	0.00	0.00	0.36	0.00
Ng5S 55a	119.26	2908	0.00	0.00	0.00	0.00	0.00
Ng5S 55b	119.81	2920	0.00	0.00	0.00	0.00	0.00
Ng5S 55c	120.36	2931	0.00	0.00	0.00	0.00	0.00
Ng5S 55d	120.91	2942	0.00	0.00	0.00	0.00	0.00
Ng5S 56a	121.46	2953	0.00	0.06	0.00	0.00	0.00
Ng5S 56b	122.01	2964	0.00	0.08	0.00	0.00	0.00
Ng5S 56c	122.56	2975	0.00	0.22	0.00	0.07	0.00
Ng5S 56d	123.11	2987	0.00	0.00	0.00	0.00	0.00
Ng5S 57a	123.67	2997	0.00	0.00	0.00	0.00	0.00
Ng5S 57b	124.22	3008	0.00	0.14	0.00	0.00	0.00
Ng5S 57c	124.77	3019	0.00	0.13	0.00	0.00	0.00
Ng5S 57d	125.32	3030	0.00	0.00	0.00	0.00	0.00
Ng5S 58a	125.87	3040	0.00	0.00	0.00	0.00	0.00
Ng5S 58b	126.42	3051	0.00	0.50	0.00	0.00	0.00
Ng5S 58c	126.97	3061	0.00	0.00	0.00	0.00	0.00
Ng5S 58d	127.52	3072	0.12	0.12	0.00	0.00	0.00
Ng5S 59a	128.07	3082	0.00	0.00	0.00	0.00	0.00
Ng5S 59b	128.62	3093	0.00	0.17	0.00	0.34	0.00
Ng5S 59c	129.17	3103	0.00	0.00	0.00	0.00	0.00
Ng5S 59d	129.72	3114	0.00	0.00	0.00	0.32	0.00

Table 3 b) - cont.

Sample	Depth	Age	Unknown 12b	Unknown 37a	Unknown 56c	Unknown 54a	Caloneis sp.	Unknown 55d	Unknown 56b
Ng5S 49a	106.04	2612	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 49b	106.59	2625	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 49c	107.14	2639	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 49d	107.69	2652	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50a	108.24	2666	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50b	108.79	2679	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50c	109.34	2692	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 50d	109.89	2705	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 51a	110.44	2717	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 51b	111.00	2729	0.00	0.06	0.06	0.00	0.00	0.00	0.00
Ng5S 51c	111.55	2742	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 51d	112.10	2754	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 52a	112.65	2766	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 52b	113.20	2779	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 52c	113.75	2791	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 52d	114.30	2803	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 53a	114.85	2816	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 53b	115.40	2827	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 53c	115.95	2839	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 53d	116.50	2850	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 54a	117.06	2862	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 54b	117.61	2874	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 54c	118.16	2885	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 54d	118.71	2897	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 55a	119.26	2908	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 55b	119.81	2920	0.00	0.14	0.00	0.00	0.00	0.00	0.00
Ng5S 55c	120.36	2931	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 55d	120.91	2942	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 56a	121.46	2953	0.00	0.00	0.00	0.00	0.00	0.41	0.00
Ng5S 56b	122.01	2964	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Ng5S 56c	122.56	2975	0.00	0.22	0.30	0.00	0.00	0.00	0.00
Ng5S 56d	123.11	2987	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 57a	123.67	2997	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 57b	124.22	3008	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Ng5S 57c	124.77	3019	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 57d	125.32	3030	0.00	0.00	0.00	0.00	0.00	0.42	0.00
Ng5S 58a	125.87	3040	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 58b	126.42	3051	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Ng5S 58c	126.97	3061	0.00	0.13	0.00	0.00	0.00	0.00	0.00
Ng5S 58d	127.52	3072	0.00	0.00	0.00	0.00	0.00	0.60	0.00
Ng5S 59a	128.07	3082	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 59b	128.62	3093	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ng5S 59c	129.17	3103	0.00	0.19	0.00	0.00	0.00	0.00	0.00
Ng5S 59d	129.72	3114	0.00	0.00	0.00	0.00	0.16	0.32	0.00

Table 3 b) - cont.

Sample	Depth	Age	Gomphonema sp.	Diatom valves/g
Ng5S 49a	106.04	2612	0.00	51617063
Ng5S 49b	106.59	2625	0.00	257564579
Ng5S 49c	107.14	2639	0.00	94239843
Ng5S 49d	107.69	2652	0.00	58854768
Ng5S 50a	108.24	2666	0.00	74877583
Ng5S 50b	108.79	2679	0.00	75710610
Ng5S 50c	109.34	2692	0.00	63748734
Ng5S 50d	109.89	2705	0.00	217923151
Ng5S 51a	110.44	2717	0.00	211614350
Ng5S 51b	111.00	2729	0.00	67279930
Ng5S 51c	111.55	2742	0.00	111927733
Ng5S 51d	112.10	2754	0.00	111897861
Ng5S 52a	112.65	2766	0.00	95426432
Ng5S 52b	113.20	2779	0.00	79185106
Ng5S 52c	113.75	2791	0.00	71668468
Ng5S 52d	114.30	2803	0.00	53726676
Ng5S 53a	114.85	2816	0.00	80645444
Ng5S 53b	115.40	2827	0.00	60671712
Ng5S 53c	115.95	2839	0.00	79899570
Ng5S 53d	116.50	2850	0.00	78395329
Ng5S 54a	117.06	2862	0.00	86678270
Ng5S 54b	117.61	2874	0.00	104078371
Ng5S 54c	118.16	2885	0.33	118192365
Ng5S 54d	118.71	2897	0.00	42226107
Ng5S 55a	119.26	2908	0.00	107030687
Ng5S 55b	119.81	2920	0.00	117813321
Ng5S 55c	120.36	2931	0.00	120885657
Ng5S 55d	120.91	2942	0.00	87487745
Ng5S 56a	121.46	2953	0.23	76604733
Ng5S 56b	122.01	2964	0.38	50984835
Ng5S 56c	122.56	2975	0.00	98984911
Ng5S 56d	123.11	2987	0.14	56066455
Ng5S 57a	123.67	2997	0.00	82558845
Ng5S 57b	124.22	3008	0.09	41602283
Ng5S 57c	124.77	3019	0.00	44399058
Ng5S 57d	125.32	3030	0.00	94229625
Ng5S 58a	125.87	3040	0.00	87881169
Ng5S 58b	126.42	3051	0.00	41479386
Ng5S 58c	126.97	3061	0.00	81975116
Ng5S 58d	127.52	3072	0.00	78198569
Ng5S 59a	128.07	3082	0.00	173600232
Ng5S 59b	128.62	3093	0.00	126898551
Ng5S 59c	129.17	3103	0.00	64479904
Ng5S 59d	129.72	3114	0.00	101633159

Table 4a - Stable isotope data - Lake Hamagiku, non-acidified

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
1a	-60	2591	0.27	0.06	-18.83	0.18	0.40	0.07	5.02	0.34	14.70
1b	-43	2512	1.35	0.27	-16.46	0.20	0.78	0.04	9.77	0.14	14.61
1c	-26	2335	1.56	0.08	-16.21	0.15	0.78	0.15	8.08	0.64	12.05
1d	-9	2823	NA	NA	-16.00	0.22	0.66	0.04	7.48	0.23	13.18
2a	18	2260	NA	0.06	-20.26	0.18	0.40	0.07	5.64	0.38	16.47
2b	35	2554	0.37	0.27	-21.49	0.20	0.50	0.02	6.10	0.09	14.24
2c	52	2426	0.42	0.08	-22.27	0.15	0.60	0.11	7.02	0.55	13.54
2d	68	2852	NA	NA	-21.59	0.22	0.63	0.04	8.11	0.25	15.13
3a	93	2211	NA	0.06	-17.53	0.18	0.37	0.06	5.47	0.37	17.12
3b	108	2850	-0.04	0.27	-17.18	0.20	0.41	0.02	4.15	0.06	11.87
3c	122	2766	NA	0.08	-18.05	0.15	0.41	0.08	3.65	0.29	10.44
3d	137	2913	NA	NA	-18.67	0.22	0.40	0.03	4.49	0.14	13.23
4a	161	2177	NA	0.06	-16.94	0.18	0.25	0.04	4.00	0.27	18.81
4b	176	2737	2.38	0.27	-16.96	0.20	0.41	0.02	5.33	0.08	15.14
4c	191	2202	0.57	0.08	-16.83	0.15	0.79	0.15	9.40	0.74	13.92
4d	204	3014	NA	NA	-18.54	0.22	1.08	0.07	14.16	0.43	15.26
5a	226	2215	-0.51	0.06	-17.27	0.18	0.62	0.11	7.91	0.54	14.93
5b	238	2531	0.62	0.27	-16.95	0.20	0.56	0.03	6.29	0.09	13.02
5c	251	2598	NA	0.08	-17.40	0.15	0.46	0.09	7.03	0.55	17.75
5d	264	3063	NA	NA	-17.49	0.22	0.77	0.05	8.50	0.26	12.91
6a	285	2331	0.25	0.06	-19.54	0.18	0.62	0.11	7.74	0.52	14.58
6b	298	2583	-0.31	0.27	-17.93	0.20	0.73	0.03	7.81	0.11	12.46
6c	309	2607	0.33	0.08	-17.71	0.15	1.27	0.24	15.98	1.26	14.67
6d	316	2763	NA	NA	-20.01	0.22	1.38	0.09	18.42	0.56	15.54
7a	327	2312	-0.30	0.06	-17.72	0.18	0.78	0.13	10.19	0.69	15.25
7b	333	2509	0.16	0.27	-18.68	0.20	0.65	0.03	7.93	0.11	14.34
7c	340	2357	NA	0.08	-21.74	0.15	0.53	0.10	5.09	0.40	11.23
7d	347	2957	NA	NA	-20.94	0.22	0.54	0.03	6.13	0.19	13.34
8a	358	2265	-0.02	0.06	-16.22	0.18	0.53	0.09	7.38	0.50	16.13
8b	364	2871	-0.28	0.27	-17.58	0.20	0.36	0.02	4.15	0.06	13.31
8c	369	2367	0.55	0.08	-17.00	0.15	0.59	0.11	5.47	0.43	10.76
8d	375	3016	NA	NA	-18.57	0.22	0.45	0.03	4.49	0.14	11.71
9a	383	2176	0.81	0.06	-16.83	0.18	0.73	0.13	9.51	0.64	15.20
9b	388	2505	0.95	0.27	-7.66	0.20	0.83	0.04	5.95	0.09	8.38
9c	394	2287	0.78	0.08	-17.41	0.15	0.59	0.11	5.93	0.47	11.64
9d	399	2834	NA	NA	-17.19	0.22	0.52	0.03	5.91	0.18	13.29
10a	407	2371	0.48	0.06	-16.60	0.18	0.87	0.15	11.91	0.81	15.97
10b	414	2713	-0.11	0.27	-16.60	0.20	0.93	0.04	11.37	0.16	14.26
10c	420	2178	0.96	0.08	-16.84	0.15	1.18	0.22	13.29	1.05	13.10
10d	427	3113	NA	NA	-17.20	0.22	1.02	0.07	12.30	0.38	14.12
11a	437	2238	0.69	0.06	-19.81	0.18	0.56	0.10	7.94	0.54	16.67
11b	444	2585	1.59	0.27	-19.33	0.20	0.45	0.02	5.21	0.08	13.43
11c	450	2279	1.30	0.08	-19.27	0.15	0.76	0.14	7.93	0.63	12.10
11d	457	2865	NA	NA	-20.48	0.22	0.49	0.03	5.76	0.18	13.84
12a	470	2233	0.34	0.06	-19.30	0.18	0.70	0.12	10.01	0.68	16.73
12b	480	2648	1.08	0.27	-19.89	0.20	0.52	0.02	6.43	0.09	14.51
12c	490	2528	0.46	0.08	-19.01	0.15	0.69	0.13	8.75	0.69	14.70
12d	500	2743	NA	NA	-18.34	0.22	0.67	0.04	8.66	0.27	15.02
13a	515	2523	-0.30	0.06	-14.78	0.18	0.43	0.07	7.56	0.51	20.31

Table 4a - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
13b	525	2572	-0.82	0.27	-17.14	0.20	0.29	0.01	3.62	0.05	14.45
13c	535	2555	NA	0.08	-18.15	0.15	0.50	0.09	4.84	0.38	11.35
13d	545	3123	NA	NA	-19.13	0.22	0.65	0.04	7.39	0.23	13.29
14a	557	2502	1.71	0.06	-17.13	0.18	0.57	0.10	7.11	0.48	14.44
14b	564	2488	1.77	0.27	-17.76	0.20	0.66	0.03	6.70	0.10	11.87
14c	571	2271	1.62	0.08	-18.65	0.15	0.84	0.16	8.68	0.68	12.11
14d	579	3020	NA	NA	-19.27	0.22	0.79	0.05	9.80	0.30	14.41
15a	591	2291	0.51	0.06	-17.11	0.18	0.49	0.08	7.27	0.49	17.30
15b	598	2712	0.19	0.27	-17.86	0.20	0.62	0.03	7.37	0.11	13.88
15c	606	2558	0.96	0.08	-17.06	0.15	0.75	0.14	7.85	0.62	12.14
15d	611	3004	NA	NA	-15.95	0.22	0.87	0.06	10.78	0.33	14.48
16a	620	2283	1.26	0.06	-20.06	0.18	0.48	0.08	6.74	0.46	16.55
16b	626	2470	1.29	0.27	-19.87	0.20	0.62	0.03	6.87	0.10	12.92
16c	631	2165	NA	0.08	-18.30	0.15	0.58	0.11	4.79	0.38	9.59
16d	637	2718	NA	NA	-18.64	0.22	0.35	0.02	4.42	0.14	14.73
17a	646	2272	NA	0.06	-17.52	0.18	0.26	0.04	3.63	0.25	16.41
17b	651	2602	-0.25	0.27	-19.58	0.20	0.37	0.02	4.60	0.07	14.47
17c	659	2213	NA	0.08	-17.34	0.15	0.37	0.07	3.48	0.27	10.82
17d	667	2844	NA	NA	-16.33	0.22	0.74	0.05	9.41	0.29	14.89
18a	680	2404	NA	0.06	-14.60	0.18	0.34	0.06	4.80	0.33	16.36
18b	688	2553	0.09	0.27	-15.94	0.20	0.51	0.02	6.27	0.09	14.46
18c	696	2780	NA	0.08	-16.36	0.15	0.36	0.07	3.32	0.26	10.84
18d	704	2753	NA	NA	-19.98	0.22	0.33	0.02	4.05	0.12	14.25
19a	717	2277	NA	0.06	-21.21	0.18	0.27	0.05	4.05	0.27	17.44
19b	725	2417	1.55	0.27	-21.21	0.20	0.50	0.02	5.94	0.09	13.98
19c	733	2385	0.85	0.08	-17.46	0.15	0.61	0.11	7.18	0.57	13.81
19d	741	2960	NA	NA	-17.74	0.22	0.38	0.02	6.15	0.19	18.68
20a	754	2371	2.87	0.06	-19.22	0.18	0.42	0.07	5.30	0.36	14.86
20b	762	2715	1.64	0.27	-17.73	0.20	0.47	0.02	5.83	0.08	14.58
20c	770	2351	NA	0.08	-18.42	0.15	0.57	0.11	5.79	0.46	11.78
20d	779	2569	NA	NA	-17.75	0.22	0.84	0.05	11.43	0.35	15.93
21a	793	2619	0.37	0.06	-17.82	0.18	0.80	0.14	9.94	0.67	14.54
21b	805	2570	0.54	0.27	-17.57	0.20	0.65	0.03	7.52	0.11	13.59
21c	816	2230	0.68	0.08	-17.24	0.15	0.81	0.15	8.44	0.67	12.21
21d	827	2531	NA	NA	-17.78	0.22	0.75	0.05	9.78	0.30	15.25
22a	845	2128	NA	0.06	-20.31	0.18	0.36	0.06	5.38	0.36	17.48
22b	856	2477	1.35	0.27	-20.25	0.20	0.71	0.03	8.44	0.12	13.87
22c	868	2309	1.05	0.08	-19.86	0.15	0.93	0.17	10.60	0.84	13.36
22d	879	2875	NA	NA	-19.26	0.22	0.51	0.03	7.00	0.21	15.92
23a	899	2359	NA	0.06	-19.79	0.18	0.28	0.05	3.76	0.25	15.75
23b	912	2499	0.26	0.27	-22.63	0.20	0.26	0.01	3.03	0.04	13.79
23c	924	2790	NA	0.08	-22.16	0.15	0.45	0.08	4.66	0.37	12.10
23d	937	3011	NA	NA	-21.97	0.22	0.24	0.02	3.19	0.10	15.20
24a	957	2409	0.38	0.06	-20.59	0.18	0.88	0.15	13.39	0.91	17.79
24b	970	2537	0.66	0.27	-20.46	0.20	0.95	0.04	13.12	0.19	16.03
24c	982	2553	NA	0.08	-17.17	0.15	0.51	0.10	5.10	0.40	11.58
24d	995	2746	NA	NA	-20.30	0.22	0.35	0.02	4.68	0.14	15.53
25a	1016	2390	-0.22	0.06	-16.07	0.18	0.70	0.12	9.51	0.64	15.84
25b	1029	2623	-0.30	0.27	-17.47	0.20	0.44	0.02	5.13	0.07	13.68

Table 4a - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
25c	1041	2360	NA	0.08	-17.02	0.15	0.51	0.10	5.49	0.43	12.50
25d	1054	2667	NA	NA	-17.40	0.22	0.41	0.03	5.88	0.18	16.67
26a	1075	2352	0.04	0.06	-18.22	0.18	0.54	0.09	7.15	0.48	15.39
26b	1088	2359	-0.14	0.27	-18.37	0.20	0.63	0.03	7.16	0.10	13.25
26c	1100	2395	0.52	0.08	-17.17	0.15	0.88	0.17	9.59	0.76	12.65
26d	1110	2614	NA	NA	-18.17	0.22	0.49	0.03	6.60	0.20	15.60
27a	1127	2395	-0.35	0.06	-20.23	0.18	0.56	0.10	7.59	0.51	15.71
27b	1137	2621	0.46	0.27	-20.06	0.20	0.76	0.03	8.81	0.13	13.45
27c	1147	2288	-0.54	0.08	-18.06	0.15	0.92	0.17	9.60	0.76	12.23
27d	1157	2684	NA	NA	-19.67	0.22	0.47	0.03	5.03	0.15	12.55
28a	1174	2245	0.10	0.06	-21.29	0.18	0.67	0.12	7.79	0.53	13.54
28b	1183	2774	-0.61	0.27	-18.56	0.20	0.44	0.02	4.90	0.07	12.93
28c	1191	2253	0.24	0.08	-16.42	0.15	0.97	0.18	10.02	0.79	11.99
28d	1198	3003	1.25	0.09	-15.67	0.34	1.05	0.21	13.29	0.97	14.75
29a	1210	2408	0.14	0.06	-17.20	0.18	0.54	0.09	6.49	0.44	14.14
29b	1218	2458	0.53	0.27	-18.10	0.20	0.66	0.03	7.92	0.11	14.09
29c	1225	2225	0.38	0.08	-18.09	0.15	0.66	0.12	6.94	0.55	12.33
29d	1232	2924	1.01	0.09	-19.51	0.34	0.46	0.09	6.67	0.48	16.99
30a	1245	2575	NA	0.06	-17.57	0.18	0.26	0.04	4.45	0.30	20.12
30b	1252	2630	0.71	0.27	-17.77	0.20	0.35	0.02	4.29	0.06	14.43
30c	1260	2613	1.09	0.08	-16.87	0.15	0.54	0.10	5.98	0.47	13.03
30d	1267	2735	1.47	0.09	-16.86	0.34	0.34	0.07	5.97	0.43	20.17
31a	1280	2634	1.18	0.06	-17.00	0.18	0.69	0.12	8.62	0.58	14.55
31b	1288	2475	-0.01	0.27	-16.75	0.20	0.53	0.02	6.88	0.10	15.14
31c	1295	2759	NA	0.08	-17.10	0.15	0.46	0.09	4.25	0.33	10.84
31d	1303	3165	0.91	0.09	-17.56	0.34	0.31	0.06	4.09	0.30	15.56
32a	1318	2354	-1.27	0.06	-19.16	0.18	0.94	0.16	11.25	0.76	13.89
32b	1328	2839	-0.41	0.27	-18.39	0.20	0.78	0.04	9.49	0.14	14.20
32c	1339	2406	0.16	0.08	-16.90	0.15	0.75	0.14	8.13	0.64	12.60
32d	1349	2809	0.78	0.09	-16.42	0.34	0.48	0.10	6.96	0.51	16.75
33a	1367	2243	-0.07	0.06	-18.18	0.18	1.52	0.26	20.81	1.41	15.93
33b	1377	2523	-0.59	0.27	-17.75	0.20	0.95	0.04	13.02	0.19	15.93
33c	1388	2358	-0.29	0.08	-17.10	0.15	1.22	0.23	14.71	1.16	14.01
33d	1398	2985	-0.23	0.09	-18.73	0.34	0.82	0.16	11.70	0.85	16.69
34a	1415	2420	NA	0.06	-18.76	0.18	0.38	0.07	4.85	0.33	14.79
34b	1425	2814	-0.18	0.27	-19.95	0.20	0.71	0.03	8.59	0.12	14.10
34c	1436	2283	NA	0.08	-18.43	0.15	0.59	0.11	6.17	0.49	12.13
34d	1446	2956	0.77	0.09	-16.88	0.34	0.24	0.05	4.00	0.29	19.20
35a	1463	2520	1.04	0.06	-17.85	0.18	0.61	0.10	8.26	0.56	15.86
35b	1473	2639	1.38	0.27	-16.96	0.20	0.29	0.01	2.98	0.04	12.17
35c	1484	2529	NA	0.08	-19.68	0.15	0.41	0.08	3.93	0.31	11.07
35d	1496	3060	1.21	0.09	-19.43	0.34	0.16	0.03	3.21	0.23	23.00
36a	1517	2399	1.04	0.06	-17.85	0.18	0.64	0.11	8.67	0.59	15.86
36b	1529	2550	1.12	0.27	-17.82	0.20	0.76	0.03	8.91	0.13	13.77
36c	1542	2534	0.14	0.08	-18.94	0.15	0.72	0.13	7.30	0.57	11.83
36d	1555	2662	0.77	0.09	-17.10	0.34	0.60	0.12	9.48	0.69	18.38
37a	1575	2257	-0.09	0.06	-17.38	0.18	0.50	0.09	7.64	0.52	17.73
37b	1588	2691	2.00	0.11	-16.25	0.29	0.39	0.10	6.95	0.71	20.64
37c	1599	2210	NA	0.08	-15.46	0.15	0.60	0.11	6.85	0.54	13.40

Table 4a - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
37d	1611	2763	0.85	0.09	-19.07	0.34	0.18	0.04	3.16	0.23	20.64
38a	1629	2362	0.12	0.06	-18.97	0.18	0.49	0.08	7.32	0.50	17.33
38b	1640	2885	0.61	0.11	-19.98	0.29	0.41	0.10	6.53	0.67	18.45
38c	1652	2390	NA	0.08	-17.05	0.15	0.47	0.09	4.22	0.33	10.46
38d	1663	2683	0.93	0.09	-18.45	0.34	0.40	0.08	6.39	0.46	18.44
39a	1682	2351	0.72	0.06	-16.28	0.18	0.67	0.11	8.78	0.60	15.33
39b	1692	2661	0.98	0.11	-17.32	0.29	0.56	0.14	8.47	0.87	17.79
39c	1703	2602	0.59	0.08	-16.23	0.15	0.85	0.16	8.61	0.68	11.89
39d	1714	2610	0.52	0.09	-15.40	0.34	0.72	0.14	9.74	0.71	15.84
40a	1731	2475	-0.14	0.06	-17.78	0.18	0.78	0.13	10.93	0.74	16.43
40b	1742	3705	0.69	0.10	-17.40	0.07	0.79	0.00	5.64	0.17	8.30
40c	1752	3472	-0.01	0.10	-21.65	0.07	1.50	0.00	10.17	0.30	7.93
40d	1763	2855	0.00	0.10	-17.50	0.07	0.89	0.00	6.09	0.18	7.99
41a	1781	2324	NA	0.06	-21.63	0.05	0.39	0.07	5.21	0.35	15.67
41b	1793	2755	0.86	0.11	-17.76	0.05	0.46	0.11	7.04	0.72	17.81
41c	1805	2701	0.15	0.08	-17.37	0.15	0.52	0.10	5.10	0.40	11.53
41d	1817	2738	-0.08	0.09	-17.18	0.34	0.60	0.12	8.49	0.62	16.61
42a	1836	2443	0.41	0.06	-17.31	0.18	0.61	0.10	8.04	0.54	15.37
42b	1848	2771	NA	0.11	-19.27	0.29	0.22	0.05	3.82	0.39	19.97
42c	1860	2600	NA	0.08	-18.59	0.15	0.46	0.09	4.53	0.36	11.60
42d	1873	2709	1.40	0.09	-18.82	0.34	0.25	0.05	3.77	0.27	17.27
43a	1903	2833	NA	0.06	-19.44	0.18	0.23	0.04	3.01	0.20	15.05
43b	1923	2733	1.38	0.11	-18.88	0.29	0.47	0.11	6.42	0.66	16.00
43c	1943	2342	-0.70	0.08	-20.67	0.15	0.64	0.12	6.65	0.52	12.09
43d	1964	2781	0.22	0.09	-19.92	0.34	0.70	0.14	10.09	0.73	16.73
44a	1996	2508	0.90	0.06	-17.38	0.18	0.47	0.08	7.38	0.50	18.16
44b	2017	2979	0.91	0.11	-17.47	0.29	0.40	0.10	6.50	0.67	18.92
44c	2037	2357	NA	0.08	-16.38	0.15	0.46	0.09	4.49	0.35	11.40
44d	2056	2642	1.07	0.09	-16.02	0.34	0.47	0.10	6.81	0.49	16.74
45a	2087	2492	-0.17	0.06	-16.12	0.18	0.75	0.13	10.12	0.69	15.74
45b	2106	2565	0.44	0.11	-17.28	0.29	0.84	0.20	12.50	1.28	17.42
45c	2125	2384	0.05	0.08	-17.94	0.15	1.08	0.20	12.55	0.99	13.55
45d	2144	2579	0.06	0.09	-19.07	0.34	0.61	0.12	9.18	0.67	17.47
46a	2175	2607	0.04	0.06	-15.46	0.18	0.44	0.08	6.40	0.43	16.81
46b	2194	2679	NA	0.11	-18.87	0.29	0.16	0.04	3.45	0.35	24.37
46c	2209	2865	NA	0.15	-18.91	0.10	0.38	0.06	5.53	0.50	17.05
46d	2219	2751	1.00	0.09	-20.27	0.34	0.21	0.04	3.68	0.27	19.97
47a	2234	2424	NA	0.06	-16.59	0.18	0.36	0.06	5.67	0.38	18.33
47b	2244	2660	NA	0.11	-16.69	0.29	0.26	0.06	4.89	0.50	21.70
47c	2253	2276	1.92	0.15	-16.23	0.10	0.81	0.13	11.20	1.02	16.15
47d	2263	2672	1.63	0.09	-16.98	0.34	0.49	0.10	7.03	0.51	16.79
48a	2278	2948	-0.37	0.06	-14.94	0.18	1.23	0.21	14.93	1.01	14.18
48b	2288	2714	0.59	0.11	-16.85	0.29	0.68	0.17	10.70	1.10	18.40
48c	2300	2228	-0.25	0.15	-16.12	0.10	0.88	0.14	10.87	0.99	14.46
48d	2311	2840	0.85	0.09	-16.41	0.34	0.46	0.09	6.97	0.51	17.74
49a	2330	2440	0.69	0.06	-19.91	0.18	0.40	0.07	6.30	0.43	18.37
49b	2342	2629	0.15	0.11	-18.06	0.29	0.50	0.12	9.30	0.96	21.84
49c	2354	2381	0.20	0.15	-15.41	0.10	0.67	0.11	8.74	0.79	15.31
49d	2365	2617	1.61	0.09	-17.32	0.34	0.64	0.13	9.20	0.67	16.88

Table 4a - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
50a	2385	2475	0.57	0.06	-17.52	0.18	0.43	0.07	7.02	0.48	18.84
50b	2397	2680	0.87	0.11	-17.91	0.29	0.48	0.12	9.63	0.99	23.37
50c	2409	2806	NA	0.15	-16.71	0.10	0.32	0.05	4.40	0.40	16.07
50d	2422	2804	0.43	0.09	-16.73	0.34	0.34	0.07	5.47	0.40	18.72
51a	2442	2516	1.56	0.06	-16.61	0.18	0.38	0.06	6.27	0.42	19.48
51b	2455	2730	1.07	0.11	-16.76	0.29	0.39	0.09	7.04	0.72	21.20
51c	2467	2162	NA	0.15	-18.49	0.10	0.45	0.07	5.31	0.48	13.78
51d	2479	2786	0.59	0.09	-19.95	0.34	0.22	0.04	3.55	0.26	19.17
52a	2499	2545	NA	0.06	-16.96	0.18	0.35	0.06	6.13	0.42	20.27
52b	2512	2801	1.11	0.11	-17.00	0.29	0.38	0.09	6.06	0.62	18.82
52c	2524	2276	NA	0.15	-17.13	0.10	0.49	0.08	5.30	0.48	12.68
52d	2536	2754	0.66	0.09	-16.87	0.34	0.31	0.06	5.01	0.36	18.69
53a	2556	2562	NA	0.06	-18.86	0.18	0.25	0.04	3.68	0.25	17.12
53b	2568	2757	NA	0.11	-18.53	0.29	0.31	0.08	5.28	0.54	20.00
53c	2580	2568	NA	0.15	-17.33	0.10	0.46	0.07	5.48	0.50	14.02
53d	2592	2734	0.77	0.09	-17.61	0.34	0.43	0.09	7.61	0.55	20.49
54a	2608	2504	-0.10	0.06	-17.89	0.18	0.63	0.11	9.75	0.66	17.97
54b	2621	2600	1.29	0.11	-16.64	0.29	0.45	0.11	8.82	0.91	22.74
54c	2632	2290	NA	0.15	-19.76	0.10	0.45	0.07	4.74	0.43	12.27
54d	2643	2713	0.91	0.09	-19.83	0.34	0.26	0.05	4.30	0.31	19.53
55a	2661	2302	NA	0.04	-18.60	0.12	0.35	0.05	5.19	0.36	17.10
55b	2672	2860	NA	0.11	-18.16	0.29	0.12	0.03	2.62	0.27	24.95
55c	2683	2396	NA	0.15	-21.55	0.10	0.27	0.04	2.74	0.25	11.72
55d	2694	2867	-0.94	0.09	-19.72	0.34	0.18	0.04	3.43	0.25	22.15
56a	2712	2660	0.44	0.04	-18.44	0.12	0.43	0.07	6.07	0.42	16.27
56b	2723	2694	1.37	0.11	-19.89	0.29	0.40	0.10	6.14	0.63	17.80
56c	2734	2292	1.51	0.15	-18.42	0.10	0.71	0.11	8.20	0.74	13.48
56d	2745	2697	1.92	0.09	-17.56	0.34	0.48	0.10	6.92	0.50	16.86
57a	2763	2475	0.34	0.04	-19.75	0.12	0.66	0.10	8.38	0.58	14.76
57b	2775	2595	0.67	0.11	-17.66	0.29	0.50	0.12	8.26	0.85	19.21
57c	2786	2574	2.32	0.15	-16.56	0.10	0.58	0.09	6.97	0.63	13.94
57d	2797	2645	0.44	0.09	-18.79	0.34	0.39	0.08	5.90	0.43	17.81
58a	2815	2780	NA	0.04	-18.87	0.12	0.33	0.05	4.45	0.31	15.70
58b	2826	2950	NA	0.11	-17.33	0.29	0.31	0.08	4.80	0.49	17.80
58c	2837	2744	NA	0.15	-17.00	0.10	0.46	0.07	4.61	0.42	11.78
58d	2848	2545	-0.38	0.09	-17.04	0.34	0.55	0.11	8.30	0.60	17.73

Table 4b - Stable isotope data - Lake Hamagiku, acidified

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
1a	-60	3925	0.81	0.05	-18.73	0.10	0.33	0.04	4.97	0.08	17.58
1b	-43	2887	1.23	0.05	-16.75	0.10	0.70	0.09	10.53	0.16	17.56
1c	-26	2961	0.93	0.05	-16.21	0.10	0.58	0.07	8.19	0.13	16.59
1d	-9	3556	0.78	0.05	-16.16	0.10	0.60	0.08	8.37	0.13	16.21
2a	18	3945	0.23	0.05	-20.20	0.10	0.37	0.05	6.02	0.09	19.02
2b	35	2258	-0.63	0.05	-21.33	0.10	0.38	0.05	7.22	0.11	22.39
2c	52	2609	-0.41	0.05	-22.07	0.10	0.31	0.04	6.32	0.10	23.79
2d	68	2338	-0.60	0.05	-21.62	0.10	0.44	0.06	8.26	0.13	21.79
3a	93	2327	-0.54	0.05	-17.50	0.10	0.27	0.04	5.97	0.09	25.57
3b	108	2661	-0.44	0.05	-16.86	0.10	0.29	0.04	4.72	0.07	19.33
3c	122	2329	-0.25	0.05	-18.04	0.10	0.14	0.02	3.34	0.05	28.37
3d	137	2609	0.59	0.05	-18.64	0.10	0.22	0.03	4.45	0.07	23.33
4a	161	2487	-0.42	0.05	-16.94	0.10	0.26	0.03	6.12	0.09	27.85
4b	176	2615	0.40	0.05	-17.31	0.10	0.24	0.03	4.86	0.08	23.61
4c	191	2642	-0.33	0.05	-16.96	0.10	0.31	0.04	6.11	0.09	23.31
4d	204	2453	-0.66	0.05	-19.11	0.10	0.82	0.11	12.56	0.19	17.80
5a	226	2615	-0.45	0.05	-18.93	0.10	0.84	0.11	12.78	0.20	17.74
5b	238	2932	-0.40	0.05	-17.01	0.10	0.35	0.04	5.80	0.09	19.44
5c	251	2325	-0.17	0.05	-17.63	0.10	0.38	0.05	6.32	0.10	19.57
5d	264	2461	0.16	0.05	-17.81	0.10	0.55	0.07	8.06	0.12	17.16
6a	285	2712	0.14	0.05	-19.60	0.10	0.30	0.04	5.28	0.08	20.38
6b	298	2834	-0.68	0.05	-18.08	0.10	0.35	0.05	5.23	0.08	17.45
6c	309	2517	0.53	0.05	-18.17	0.10	1.11	0.14	16.71	0.26	17.49
6d	316	2472	0.94	0.05	-20.18	0.10	1.09	0.14	16.59	0.26	17.67
7a	327	2534	-0.40	0.05	-17.76	0.10	0.59	0.08	9.48	0.15	18.64
7b	333	2774	-0.35	0.05	-18.57	0.10	0.52	0.07	8.76	0.14	19.60
7c	340	2424	-0.59	0.05	-21.60	0.10	0.28	0.04	5.46	0.08	23.02
7d	347	3100	-1.13	0.05	-20.90	0.10	0.34	0.04	5.67	0.09	19.39
8a	358	2782	-0.69	0.05	-16.47	0.10	0.38	0.05	7.05	0.11	21.68
8b	364	2558	-1.76	0.05	-17.35	0.10	0.11	0.01	3.48	0.05	35.94
8c	369	2643	-0.89	0.05	-17.11	0.10	0.30	0.04	5.00	0.08	19.64
8d	375	2654	-1.01	0.05	-18.92	0.10	0.35	0.05	5.56	0.09	18.44
9a	383	3208	0.22	0.05	-16.83	0.10	0.64	0.08	9.65	0.15	17.66
9b	388	3068	0.51	0.05	-16.19	0.10	0.55	0.07	9.45	0.15	19.97
9c	394	2744	-0.94	0.05	-17.49	0.10	0.39	0.05	7.36	0.11	22.00
9d	399	2250	-0.83	0.05	-17.37	0.10	0.40	0.05	7.65	0.12	22.11
10a	407	2232	0.20	0.05	-16.41	0.10	0.63	0.08	11.72	0.18	21.77
10b	414	2402	0.04	0.05	-16.52	0.10	0.60	0.08	10.44	0.16	20.16
10c	420	2549	0.69	0.05	-17.09	0.10	1.05	0.13	15.96	0.25	17.77
10d	427	2306	0.29	0.05	-17.42	0.10	0.91	0.12	15.05	0.23	19.23
11a	437	2808	-0.15	0.05	-19.60	0.10	0.20	0.03	5.30	0.08	31.44
11b	444	2836	0.44	0.05	-19.17	0.10	0.29	0.04	6.45	0.10	26.15
11c	450	2772	1.21	0.05	-19.26	0.10	0.54	0.07	10.06	0.16	21.74
11d	457	3272	0.39	0.05	-20.42	0.10	0.24	0.03	5.26	0.08	25.94
12a	470	2530	0.44	0.05	-19.18	0.10	0.38	0.05	8.78	0.14	27.16
12b	480	3113	2.53	0.05	-19.67	0.10	0.25	0.03	6.80	0.10	32.31
12c	490	2372	1.74	0.05	-19.14	0.10	0.31	0.04	9.00	0.14	33.96
12d	500	3681	3.25	0.05	-18.33	0.10	0.28	0.04	6.67	0.10	28.00
13a	515	2823	3.87	0.05	-14.66	0.10	0.14	0.02	6.82	0.11	57.73
13b	525	3161	NA	0.05	-17.11	0.10	0.00	0.00	2.68	0.04	NA

Table 4b - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
13c	535	3409	5.74	0.05	-17.97	0.10	0.15	0.02	5.04	0.08	40.20
13d	545	2703	6.19	0.05	-19.12	0.10	0.21	0.03	6.55	0.10	36.42
14a	557	2870	5.17	0.05	-16.97	0.10	0.18	0.02	5.48	0.08	34.62
14b	564	2191	3.04	0.05	-17.58	0.10	0.23	0.03	5.66	0.09	28.82
14c	571	2412	NA	0.13	-18.97	0.15	0.63	0.06	8.11	0.28	15.12
14d	579	2604	1.00	0.13	-19.36	0.15	0.68	0.06	8.80	0.30	15.05
15a	591	3388	NA	0.13	-17.35	0.15	0.42	0.04	6.27	0.22	17.36
15b	598	3112	0.02	0.13	-17.94	0.15	0.60	0.06	8.05	0.28	15.56
15c	606	3435	1.05	0.13	-17.36	0.15	0.55	0.05	7.12	0.25	15.05
15d	611	2248	0.04	0.13	-16.56	0.15	0.71	0.07	9.76	0.34	15.92
16a	620	3118	NA	0.13	-20.42	0.15	0.33	0.03	4.86	0.17	17.16
16b	626	2601	NA	0.13	-20.42	0.15	0.47	0.04	6.12	0.21	15.18
16c	631	2778	NA	0.13	-18.70	0.15	0.48	0.04	5.48	0.19	13.45
16d	637	2436	NA	0.13	-18.91	0.15	0.24	0.02	3.70	0.13	18.29
17a	646	2393	NA	0.13	-17.92	0.15	0.27	0.02	4.31	0.15	18.55
17b	651	3157	NA	0.13	-19.70	0.15	0.27	0.03	4.57	0.16	19.48
17c	659	3508	NA	0.13	-18.07	0.15	0.19	0.02	3.16	0.11	19.80
17d	667	2760	NA	0.13	-17.00	0.15	0.54	0.05	7.37	0.26	15.98
18a	680	2534	NA	0.13	-14.79	0.15	0.36	0.03	5.62	0.19	18.20
18b	688	3074	NA	0.13	-16.15	0.15	0.40	0.04	6.14	0.21	17.81
18c	696	3563	NA	0.13	-17.01	0.15	0.20	0.02	3.22	0.11	18.40
18d	704	3324	NA	0.13	-20.18	0.15	0.26	0.02	3.75	0.13	16.95
19a	717	3547	NA	0.13	-21.70	0.15	0.24	0.02	3.48	0.12	16.84
19b	725	2488	NA	0.13	-21.19	0.15	0.47	0.04	6.79	0.24	16.92
19c	733	2961	NA	0.13	-18.19	0.15	0.44	0.04	6.93	0.24	18.35
19d	741	2268	NA	0.13	-17.78	0.15	0.35	0.03	6.82	0.24	22.73
20a	754	2975	NA	0.13	-19.37	0.15	0.40	0.04	5.22	0.18	15.20
20b	762	2482	NA	0.13	-17.88	0.15	0.38	0.03	5.90	0.20	18.21
20c	770	3181	NA	0.13	-19.36	0.15	0.38	0.03	5.38	0.19	16.60
20d	779	2521	0.39	0.13	-17.84	0.15	0.78	0.07	11.44	0.40	17.08
21a	793	2998	0.77	0.13	-17.97	0.15	0.81	0.07	10.58	0.37	15.24
21b	805	2385	-0.16	0.12	-17.65	0.15	0.71	0.05	8.00	0.20	13.06
21c	816	3002	0.67	0.12	-17.54	0.15	0.80	0.05	9.28	0.23	13.58
21d	827	2675	0.64	0.12	-17.67	0.15	0.88	0.06	10.14	0.26	13.45
22a	845	2313	NA	0.12	-20.29	0.15	0.55	0.04	6.48	0.16	13.63
22b	856	2697	1.80	0.12	-19.91	0.15	0.81	0.05	9.25	0.23	13.35
22c	868	3094	0.68	0.12	-20.30	0.15	0.87	0.06	10.26	0.26	13.81
22d	879	2385	NA	0.12	-19.16	0.15	0.63	0.04	7.17	0.18	13.19
23a	899	3652	NA	0.12	-19.86	0.15	0.36	0.02	3.75	0.09	11.98
23b	912	2806	NA	0.12	-22.45	0.15	0.37	0.02	3.95	0.10	12.60
23c	924	3438	NA	0.12	-22.18	0.15	0.37	0.02	4.11	0.10	12.89
23d	937	3244	NA	0.12	-22.03	0.15	0.31	0.02	3.04	0.08	11.52
24a	957	2225	-0.17	0.12	-20.63	0.15	0.95	0.06	12.28	0.31	15.11
24b	970	2312	-0.02	0.12	-20.13	0.15	0.97	0.06	12.33	0.31	14.87
24c	982	2551	NA	0.12	-17.42	0.15	0.52	0.03	5.55	0.14	12.38
24d	995	3110	NA	0.12	-19.96	0.15	0.46	0.03	4.95	0.12	12.63
25a	1016	2289	-1.33	0.12	-15.89	0.15	0.78	0.05	8.80	0.22	13.08
25b	1029	2402	NA	0.12	-16.95	0.15	0.57	0.04	6.03	0.15	12.41
25c	1041	3469	NA	0.12	-7.64	0.15	0.47	0.03	2.93	0.07	7.35
25d	1054	2457	NA	0.12	-17.16	0.15	0.60	0.04	7.20	0.18	14.10

Table 4b - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
26a	1075	2303	NA	0.12	-18.27	0.15	0.66	0.04	7.06	0.18	12.43
26b	1088	2663	-0.44	0.12	-17.77	0.15	0.68	0.05	7.65	0.19	13.09
26c	1100	2166	-0.31	0.12	-17.63	0.15	0.85	0.06	9.49	0.24	13.05
26d	1110	3402	-0.05	0.12	-17.93	0.15	0.68	0.05	7.89	0.20	13.48
27a	1127	3015	-0.39	0.12	-20.27	0.15	0.68	0.05	7.67	0.19	13.18
27b	1137	2745	0.49	0.12	-19.82	0.15	0.77	0.05	8.08	0.20	12.23
27c	1147	2574	-0.26	0.12	-18.12	0.15	1.10	0.07	12.40	0.31	13.16
27d	1157	2438	NA	0.12	-19.75	0.15	0.62	0.04	5.68	0.14	10.76
28a	1174	2524	0.13	0.13	-21.36	0.27	0.85	0.11	9.10	0.53	12.41
28b	1183	2505	-0.01	0.13	-18.03	0.27	0.62	0.08	7.04	0.41	13.33
28c	1191	3117	-0.29	0.13	-16.59	0.27	0.81	0.10	9.08	0.53	13.11
28d	1198	2363	-0.81	0.13	-15.72	0.27	0.98	0.13	10.45	0.61	12.49
29a	1210	3124	0.00	0.13	-17.23	0.27	0.62	0.08	6.77	0.39	12.74
29b	1218	2542	0.19	0.13	-17.95	0.27	0.67	0.09	7.76	0.45	13.60
29c	1225	2484	0.02	0.13	-18.32	0.27	0.64	0.08	7.87	0.46	14.26
29d	1232	2492	0.64	0.13	-19.49	0.27	0.62	0.08	7.18	0.42	13.57
30a	1245	2684	NA	0.13	-18.06	0.27	0.31	0.04	3.66	0.21	13.60
30b	1252	2279	NA	0.13	-17.49	0.27	0.45	0.06	5.83	0.34	15.17
30c	1260	2560	NA	0.13	-17.76	0.27	0.35	0.04	4.35	0.25	14.67
30d	1267	3084	0.28	0.13	-16.96	0.27	0.52	0.07	6.72	0.39	14.97
31a	1280	2364	1.01	0.13	-17.37	0.27	0.66	0.09	7.42	0.43	13.12
31b	1288	2264	NA	0.13	-16.62	0.27	0.51	0.07	6.67	0.39	15.39
31c	1295	2300	NA	0.13	-17.91	0.27	0.49	0.06	5.61	0.33	13.30
31d	1303	3112	NA	0.13	-17.49	0.27	0.39	0.05	4.16	0.24	12.46
32a	1318	2285	-1.23	0.13	-19.41	0.27	1.06	0.14	11.68	0.68	12.89
32b	1328	2138	-0.31	0.13	-17.99	0.27	0.79	0.10	9.57	0.56	14.17
32c	1339	2504	0.22	0.13	-17.20	0.27	0.76	0.10	9.40	0.55	14.40
32d	1349	2260	NA	0.13	-16.67	0.27	0.48	0.06	5.74	0.33	13.83
33a	1367	2184	0.24	0.13	-15.41	0.27	1.03	0.13	14.78	0.86	16.69
33b	1377	2238	-0.52	0.13	-17.84	0.27	0.93	0.12	12.03	0.70	15.16
33c	1388	2667	-0.25	0.13	-17.60	0.27	1.08	0.14	13.63	0.79	14.71
33d	1398	2391	0.04	0.13	-19.02	0.27	0.84	0.11	10.31	0.60	14.30
34a	1415	2193	0.07	0.13	-22.35	0.27	0.91	0.12	10.32	0.60	13.19
34b	1425	2634	0.45	0.13	-20.26	0.27	0.71	0.09	8.43	0.49	13.79
34c	1436	3083	1.74	0.13	-18.79	0.27	0.50	0.07	6.29	0.37	14.57
34d	1446	3083	0.26	0.13	-16.61	0.27	0.43	0.06	5.35	0.31	14.47
35a	1463	2828	NA	0.13	-19.03	0.27	0.39	0.05	4.44	0.26	13.17
35b	1473	2502	NA	0.13	-16.63	0.27	0.29	0.04	3.22	0.19	13.18
35c	1484	3258	NA	0.13	-19.88	0.27	0.29	0.04	3.49	0.20	14.14
35d	1496	2945	NA	0.13	-19.29	0.27	0.33	0.04	4.24	0.25	15.22
36a	1517	2888	0.13	0.13	-18.16	0.27	0.71	0.09	8.89	0.52	14.65
36b	1529	2242	0.49	0.13	-17.69	0.27	0.70	0.09	8.53	0.50	14.12
36c	1542	2567	-0.66	0.13	-19.46	0.27	0.55	0.07	6.14	0.36	13.02
36d	1555	2353	-0.48	0.13	-17.48	0.27	0.68	0.09	8.89	0.52	15.18
37a	1575	2287	NA	0.13	-17.98	0.27	0.54	0.07	7.44	0.43	16.11
37b	1588	2319	NA	0.13	-16.64	0.27	0.52	0.07	6.90	0.40	15.50
37c	1599	2342	NA	0.13	-16.44	0.27	0.45	0.06	6.19	0.36	16.12
37d	1611	3395	NA	0.13	-18.87	0.27	0.30	0.04	3.71	0.22	14.49
38a	1629	2456	NA	0.13	-19.21	0.27	0.50	0.06	6.77	0.39	15.88
38b	1640	2273	NA	0.13	-20.05	0.27	0.53	0.07	6.48	0.38	14.32

Table 4b - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
38c	1652	3009	-0.50	0.13	-17.64	0.27	0.45	0.06	5.08	0.30	13.13
38d	1663	3315	NA	0.13	-18.68	0.27	0.38	0.05	4.68	0.27	14.34
39a	1682	2407	0.29	0.13	-16.93	0.27	0.78	0.10	9.41	0.55	14.14
39b	1692	2188	3.52	0.16	-16.51	0.08	0.72	0.04	7.44	0.19	12.09
39c	1703	2331	3.11	0.16	-15.82	0.08	0.85	0.05	9.01	0.23	12.36
39d	1714	2257	6.06	0.16	-14.49	0.08	0.93	0.06	11.06	0.29	13.93
40a	1731	2608	6.57	0.16	-17.52	0.08	0.81	0.05	10.90	0.28	15.68
40b	1742	3697	0.34	0.10	-17.18	0.07	0.73	0.00	5.06	0.15	8.14
40c	1752	4016	-0.22	0.10	-21.78	0.07	1.50	0.00	9.00	0.26	6.99
40d	1763	2615	-0.39	0.10	-17.55	0.07	0.87	0.00	5.20	0.15	6.99
41a	1781	2309	NA	0.16	-18.10	0.08	0.55	0.03	5.46	0.14	11.52
41b	1793	2284	NA	0.16	-18.10	0.08	0.58	0.04	6.54	0.17	13.06
41c	1805	2349	NA	0.75	-17.71	0.34	0.33	0.02	6.29	0.18	22.03
41d	1817	2274	-0.82	0.75	-16.79	0.34	0.57	0.04	8.83	0.25	18.14
42a	1836	2470	-4.09	0.75	-17.63	0.34	0.60	0.04	8.84	0.25	17.30
42b	1848	2450	NA	0.75	-19.01	0.34	0.14	0.01	4.43	0.13	37.31
42c	1860	2349	NA	0.75	-19.02	0.34	-0.05	0.00	3.34	0.10	-82.02
42d	1873	2645	NA	0.75	-18.38	0.34	0.13	0.01	4.26	0.12	37.06
43a	1903	2516	NA	0.75	-19.74	0.34	0.13	0.01	4.39	0.13	40.36
43b	1923	2208	NA	0.75	-18.71	0.34	0.31	0.02	5.85	0.17	21.90
43c	1943	2223	NA	0.75	-20.62	0.34	0.33	0.02	6.57	0.19	23.15
43d	1964	2377	-1.37	0.75	-19.86	0.34	0.53	0.04	8.58	0.24	18.89
44a	1996	2466	NA	0.75	-17.91	0.34	0.30	0.02	7.12	0.20	27.79
44b	2017	2587	NA	0.75	-17.39	0.34	0.24	0.02	5.75	0.16	28.31
44c	2037	2536	NA	0.75	-16.73	0.34	0.21	0.01	5.31	0.15	29.60
44d	2056	2394	-1.91	0.75	-15.75	0.34	0.55	0.04	8.26	0.24	17.50
45a	2087	2203	-1.87	0.75	-16.48	0.34	0.68	0.05	10.31	0.29	17.64
45b	2106	2359	0.30	0.75	-17.14	0.34	0.92	0.07	13.17	0.38	16.64
45c	2125	2339	1.05	0.75	-18.01	0.34	1.02	0.07	13.78	0.39	15.79
45d	2144	2345	1.10	0.75	-18.83	0.34	0.60	0.04	9.25	0.26	17.86
46a	2175	2641	NA	0.75	-16.04	0.34	0.23	0.02	5.71	0.16	28.80
46b	2194	2943	NA	0.75	-18.49	0.34	-0.01	0.00	3.63	0.10	NA
46c	2209	2399	NA	0.75	-18.86	0.34	0.05	0.00	4.20	0.12	102.51
46d	2219	2590	NA	0.75	-19.79	0.34	0.02	0.00	3.72	0.11	189.18
47a	2234	2197	NA	0.75	-17.24	0.34	0.13	0.01	5.50	0.16	47.84
47b	2244	2240	-2.29	0.75	-16.81	0.34	0.47	0.03	8.84	0.25	22.01
47c	2253	2663	1.80	0.75	-15.94	0.34	0.68	0.05	10.74	0.31	18.32
47d	2263	2420	NA	0.75	-17.18	0.34	0.27	0.02	5.93	0.17	25.57
48a	2278	2384	1.61	0.75	-15.55	0.34	1.15	0.08	14.23	0.41	14.48
48b	2288	2408	0.11	0.75	-16.95	0.34	0.66	0.05	10.49	0.30	18.51
48c	2300	2224	1.91	0.75	-15.61	0.34	0.79	0.06	11.28	0.32	16.74
48d	2311	2686	NA	0.75	-16.14	0.34	0.23	0.02	5.58	0.16	28.24
49a	2330	3012	NA	0.75	-20.20	0.34	0.11	0.01	4.85	0.14	51.71
49b	2342	2313	-2.14	0.75	-17.58	0.34	0.54	0.04	10.44	0.30	22.50
49c	2354	2559	-1.20	0.75	-15.01	0.34	0.60	0.04	9.63	0.27	18.87
49d	2365	2399	1.11	0.75	-17.10	0.34	0.60	0.04	9.10	0.26	17.67
50a	2385	2323	NA	0.75	-17.91	0.34	0.26	0.02	6.94	0.20	30.75
50b	2397	2718	0.19	0.75	-17.32	0.34	0.44	0.03	9.39	0.27	24.72
50c	2409	2190	NA	0.75	-16.18	0.34	-0.05	0.00	4.37	0.12	NA
50d	2422	2368	NA	0.75	-16.13	0.34	0.16	0.01	5.25	0.15	37.67

Table 4b - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
51a	2442	3473	-2.08	0.75	-16.97	0.34	0.22	0.02	6.08	0.17	31.85
51b	2455	3405	-0.11	0.75	-16.17	0.34	0.42	0.03	8.35	0.24	23.43
51c	2467	2784	NA	0.75	-18.36	0.34	0.16	0.01	5.22	0.15	37.22
51d	2479	2580	NA	0.75	-19.77	0.34	0.07	0.01	4.22	0.12	65.66
52a	2499	2474	NA	0.75	-17.34	0.34	0.04	0.00	4.65	0.13	NA
52b	2512	2455	NA	0.75	-16.38	0.34	0.34	0.02	7.03	0.20	24.05
52c	2524	2205	NA	0.75	-16.55	0.34	0.21	0.02	5.79	0.17	31.77
52d	2536	2396	NA	0.16	-15.07	0.08	0.53	0.03	5.66	0.15	12.44
53a	2556	2202	NA	0.16	-17.75	0.08	0.39	0.02	3.43	0.09	10.15
53b	2568	2204	NA	0.16	-17.32	0.08	0.49	0.03	5.09	0.13	12.20
53c	2580	2254	NA	0.16	-15.86	0.08	0.49	0.03	5.94	0.15	14.03
53d	2592	2284	NA	0.16	-16.08	0.08	0.61	0.04	8.79	0.23	16.89
54a	2608	2257	NA	0.75	-18.04	0.34	0.39	0.03	9.11	0.26	27.55
54b	2621	2339	NA	0.75	-16.29	0.34	0.26	0.02	8.26	0.24	36.95
54c	2632	2349	NA	0.75	-19.03	0.34	0.01	0.00	4.35	0.12	NA
54d	2643	2436	NA	0.75	-19.54	0.34	0.07	0.01	5.18	0.15	82.13
55a	2661	2327	0.11	0.06	-18.01	0.15	0.51	0.06	6.52	0.34	14.95
55b	2672	2362	NA	0.06	-17.18	0.15	0.28	0.03	3.43	0.18	14.10
55c	2683	2794	NA	0.06	-21.14	0.15	0.22	0.03	2.31	0.12	12.45
55d	2694	2189	NA	0.06	-19.02	0.15	0.23	0.03	3.01	0.16	14.98
56a	2712	2186	0.19	0.06	-18.08	0.15	0.56	0.07	6.82	0.36	14.24
56b	2723	2204	0.39	0.06	-19.12	0.15	0.62	0.07	8.08	0.42	15.10
56c	2734	2302	1.21	0.06	-18.03	0.15	0.66	0.08	8.54	0.45	15.02
56d	2745	2363	1.56	0.06	-16.61	0.15	0.73	0.09	9.20	0.48	14.74
57a	2763	2380	-0.06	0.06	-19.23	0.15	0.70	0.08	8.21	0.43	13.71
57b	2775	2129	0.21	0.06	-16.91	0.15	0.65	0.08	9.04	0.47	16.13
57c	2786	2264	0.73	0.06	-15.94	0.15	0.64	0.08	8.11	0.42	14.81
57d	2797	2199	0.49	0.06	-18.48	0.15	0.61	0.07	7.86	0.41	15.06
58a	2815	2331	NA	0.06	-18.42	0.15	0.40	0.05	4.82	0.25	13.87
58b	2826	2452	0.75	0.06	-16.52	0.15	0.52	0.06	6.41	0.34	14.28
58c	2837	2925	0.47	0.06	-15.97	0.15	0.43	0.05	5.18	0.27	13.91
58d	2848	2389	-0.31	0.06	-16.36	0.15	0.64	0.08	8.33	0.44	15.27

Table 4c - Stable isotope data - Lake Naga, non-acidified

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
1a	-28.6	2721	NA	0.04	-23.05	0.12	0.31	0.05	2.79	0.19	10.33
1b	-8	2814	NA	0.11	-23.82	0.29	0.34	0.08	3.04	0.31	10.54
1c	12.6	2309	2.33	0.15	-25.33	0.10	0.56	0.09	3.91	0.36	8.13
1d	33.3	2942	0.92	0.09	-24.87	0.34	0.33	0.07	2.88	0.21	10.14
2a	54.2	2526	NA	0.04	-24.76	0.12	0.15	0.02	1.49	0.10	11.96
2b	75.2	2756	NA	0.11	-24.62	0.29	0.15	0.04	1.92	0.20	14.79
2c	95.8	2699	NA	0.15	-24.36	0.10	0.43	0.07	3.18	0.29	8.61
2d	116.5	2810	1.08	0.09	-24.12	0.34	0.25	0.05	2.81	0.20	13.12
3a	137.1	2234	NA	0.04	-23.85	0.12	0.17	0.03	1.88	0.13	13.12
3b	154.2	2850	NA	0.11	-24.28	0.29	0.17	0.04	2.29	0.23	15.85
3c	166.3				data missing						
3d	178.5	2697	0.11	0.09	-25.50	0.34	0.22	0.05	3.37	0.25	17.52
4a	190.9	2883	NA	0.04	-23.90	0.12	0.28	0.04	2.57	0.18	10.57
4b	203.1	2523	NA	0.11	-24.63	0.29	0.31	0.08	3.06	0.31	11.42
4c	215.3				data missing						
4d	227.6	3047	1.97	0.09	-24.64	0.34	0.17	0.03	1.96	0.14	13.71
5a	239.8	2461	NA	0.04	-23.52	0.12	0.27	0.04	2.83	0.20	12.28
5b	252	2980	NA	0.11	-23.96	0.29	0.24	0.06	3.09	0.32	15.05
5c	263.1				data missing						
5d	271.7	2927	0.62	0.09	-24.96	0.34	0.12	0.02	1.61	0.12	16.12
6a	280.4	2340	-1.33	0.04	-24.51	0.12	0.58	0.09	5.97	0.41	12.05
6b	288.9	2771	-1.85	0.11	-24.51	0.29	0.57	0.14	6.33	0.65	13.05
6c	297.7	2837	-1.21	0.15	-24.27	0.10	0.60	0.10	5.14	0.47	9.92
6d	306.4	2802	-1.53	0.09	-24.74	0.34	0.86	0.17	8.61	0.63	11.75
7a	315	2301	-1.59	0.04	-25.78	0.12	0.63	0.10	5.55	0.38	10.21
7b	323.6	2848	-0.17	0.11	-25.67	0.29	0.71	0.17	6.31	0.65	10.31
7c	332.1	2861	-0.67	0.15	-25.22	0.10	0.56	0.09	3.82	0.35	8.01
7d	340.2	2631	-2.64	0.09	-25.67	0.34	0.14	0.03	1.59	0.12	13.31
8a	346.6	2798	NA	0.04	-23.72	0.12	0.28	0.04	3.44	0.24	14.13
8b	353.1	2777	2.80	0.11	-23.31	0.29	0.70	0.17	7.44	0.76	12.43
8c	359.5	2457	1.76	0.15	-24.00	0.10	0.67	0.11	5.60	0.51	9.77
8d	366	2874	2.16	0.09	-23.01	0.34	0.30	0.06	3.34	0.24	13.16
9a	372.4	2782	NA	0.04	-21.07	0.12	0.03	0.00	0.69	0.05	26.61
9b	378.9	6972	1.97	0.15	-20.72	0.16	0.10	0.01	0.96	0.02	10.92
9c	385.3	2842	NA	0.15	-21.46	0.10	0.17	0.03	1.36	0.12	9.50
9d	391.9	3079	0.96	0.09	-21.33	0.34	0.14	0.03	2.71	0.20	22.86
10a	398.1	2672	NA	0.04	-19.79	0.12	0.22	0.03	3.15	0.22	16.60
10b	403.5	2805	NA	0.11	-18.56	0.29	0.22	0.05	4.03	0.41	21.78
10c	409	2754	NA	0.15	-20.42	0.10	0.34	0.05	3.23	0.29	11.23
10d	414.5	2781	0.99	0.09	-22.27	0.34	0.46	0.09	6.31	0.46	16.09
11a	420	2257	NA	0.04	-23.08	0.12	0.16	0.02	2.15	0.15	15.73
11b	425.6	2705	NA	0.11	-22.69	0.29	0.24	0.06	3.38	0.35	16.13
11c	431.1	2785	NA	0.15	-23.02	0.10	0.33	0.05	2.84	0.26	9.97
11d	436.3	2723	-0.03	0.09	-23.22	0.34	0.11	0.02	1.97	0.14	21.88
12a	441.7	3051	1.21	0.15	-26.16	0.16	0.41	0.03	3.74	0.09	10.72
12b	447.1	2839	NA	0.11	-23.72	0.29	0.31	0.08	4.59	0.47	17.37
12c	453.9	2851	NA	0.15	-23.66	0.10	0.28	0.04	3.67	0.33	15.49
12d	460.7	3056	0.14	0.09	-24.01	0.34	0.33	0.07	4.31	0.31	15.15
13a	467.3	2165	NA	0.04	-24.91	0.12	0.19	0.03	2.41	0.17	15.10

Table 4c - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
13b	474.1	2844	1.81	0.11	-22.91	0.29	0.67	0.16	7.45	0.77	12.93
13c	481	2743	2.18	0.15	-22.79	0.10	0.56	0.09	4.82	0.44	10.10
13d	487.9	2943	0.42	0.09	-23.41	0.34	0.19	0.04	2.94	0.21	18.47
14a	494.7	2505	NA	0.04	-24.07	0.12	0.30	0.05	3.05	0.21	11.99
14b	501.6	3029	0.18	0.11	-25.10	0.29	0.45	0.11	4.83	0.50	12.57
14c	508.6	2570	-0.33	0.15	-25.30	0.10	0.69	0.11	5.97	0.54	10.15
14d	518.1	2539	-0.48	0.09	-23.96	0.34	0.64	0.13	6.61	0.48	12.11
15a	527.6	2202	-1.87	0.04	-23.64	0.12	1.11	0.17	10.61	0.73	11.17
15b	537.2	2700	-0.69	0.11	-22.43	0.29	0.45	0.11	4.80	0.49	12.44
15c	546.8	2849	-1.18	0.15	-22.32	0.10	0.70	0.11	5.34	0.49	8.94
15d	556.4	2706	-1.71	0.09	-23.41	0.34	0.39	0.08	4.86	0.35	14.41
16a	565.7	2630	NA	0.04	-22.93	0.12	0.25	0.04	3.12	0.22	14.47
16b	574.9	2864	NA	0.11	-24.69	0.29	0.08	0.02	1.22	0.13	18.87
16c	584.3	2766	0.04	0.15	-23.60	0.10	0.56	0.09	4.34	0.39	8.99
16d	593.6	2856	-1.31	0.09	-23.49	0.34	0.39	0.08	4.12	0.30	12.24
17a	605.8	2724	NA	0.04	-23.45	0.12	0.38	0.06	3.85	0.27	11.86
17b	618.4	2768	-0.30	0.11	-22.79	0.29	0.40	0.10	4.25	0.44	12.30
17c	631.1	2546	-0.44	0.15	-23.45	0.10	0.53	0.08	4.35	0.40	9.52
17d	643.7	2756	-0.75	0.09	-25.03	0.34	0.28	0.06	3.35	0.24	14.07
18a	656.5	2732	NA	0.04	-22.49	0.12	0.34	0.05	3.65	0.25	12.65
18b	669.2	2730	NA	0.11	-22.39	0.29	0.21	0.05	2.67	0.27	14.93
18c	682	2862	NA	0.15	-22.02	0.10	0.31	0.05	2.56	0.23	9.53
18d	694.7	2689	0.44	0.09	-21.62	0.34	0.14	0.03	2.74	0.20	22.80
19a	707.1	2388	NA	0.04	-21.82	0.12	0.23	0.04	2.78	0.19	13.92
19b	720.1	2740	NA	0.11	-21.32	0.29	0.22	0.05	2.92	0.30	15.55
19c	733.3	2839	NA	0.15	-21.43	0.10	0.38	0.06	3.17	0.29	9.61
19d	746.4	2453	1.25	0.09	-22.11	0.34	0.47	0.09	7.00	0.51	17.25
20a	759.5	2707	-0.41	0.04	-23.30	0.12	0.52	0.08	5.01	0.35	11.26
20b	772.5	2868	NA	0.11	-23.44	0.29	0.34	0.08	3.97	0.41	13.57
20c	785.3	2304	-0.24	0.15	-22.70	0.10	1.01	0.16	8.92	0.81	10.28
20d	798.3	2995	1.82	0.09	-22.44	0.34	0.65	0.13	6.68	0.49	12.07
21a	811.3	2214	NA	0.04	-25.51	0.12	0.49	0.07	4.46	0.31	10.69
21b	824.2	2870	NA	0.11	-25.45	0.29	0.16	0.04	1.86	0.19	13.72
21c	838	2863	NA	0.15	-24.18	0.10	0.35	0.05	2.37	0.22	7.99
21d	852.2	2632	10.72	0.09	-23.96	0.34	0.18	0.04	2.51	0.18	16.33
22a	866.4	2397	NA	0.04	-25.25	0.12	0.16	0.02	1.68	0.12	12.04
22b	880.7	2973	NA	0.11	-24.19	0.29	0.12	0.03	1.56	0.16	14.99
22c	895.2	2802	NA	0.15	-24.92	0.10	0.23	0.04	1.47	0.13	7.41
22d	909.6	3051	31.06	0.09	-24.86	0.34	0.07	0.01	1.28	0.09	20.88
23a	924	2246	NA	0.04	-23.83	0.12	0.22	0.03	2.05	0.14	10.85
23b	938.4	2530	NA	0.11	-23.66	0.29	0.20	0.05	2.30	0.24	13.37
23c	952.9	2561	NA	0.15	-22.02	0.10	0.34	0.05	2.50	0.23	8.59
23d	967.1	2560	56.95	0.09	-20.89	0.34	0.10	0.02	2.04	0.15	23.64
24a	981.6	2442	NA	0.04	-21.42	0.12	0.20	0.03	2.77	0.19	15.82
24b	996.4	2568	NA	0.11	-21.25	0.29	0.20	0.05	3.47	0.36	20.35
24c	1011.2	2829	NA	0.15	-21.45	0.10	0.37	0.06	3.37	0.31	10.53
24d	1026	2671	1.85	0.15	-22.51	0.16	0.55	0.04	5.22	0.12	11.03
25a	1040.8	2361	-1.16	0.04	-23.02	0.12	0.50	0.08	5.85	0.40	13.74
25b	1055.6	2806	-0.51	0.11	-22.19	0.29	0.37	0.09	4.44	0.46	14.06

Table 4c - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
25c	1070.3	2715	NA	0.15	-23.55	0.10	0.40	0.06	3.31	0.30	9.57
25d	1084.9	2907	-1.90	0.15	-25.13	0.16	0.40	0.03	3.62	0.09	10.54
26a	1100.5	2412	NA	0.04	-21.23	0.12	0.31	0.05	4.29	0.30	15.95
26b	1116.5	2763	NA	0.11	-21.68	0.29	0.33	0.08	4.56	0.47	16.11
26c	1132.6	2430	NA	0.15	-22.21	0.10	0.36	0.06	3.35	0.30	10.77
26d	1148.7	3090	NA	0.15	-23.06	0.16	0.17	0.01	1.55	0.04	10.43
27a	1165.1	2582	NA	0.04	-21.69	0.12	0.19	0.03	2.15	0.15	12.97
27b	1181.4	2902	NA	0.11	-22.31	0.29	0.23	0.06	3.12	0.32	15.89
27c	1197.7	2555	NA	0.15	-22.45	0.10	0.39	0.06	3.77	0.34	11.17
27d	1214	2589	NA	0.15	-22.60	0.16	0.24	0.02	2.17	0.05	10.43
28a	1229.9	2509	-1.16	0.04	-22.24	0.12	0.49	0.07	5.51	0.38	13.22
28b	1247	2780	-0.53	0.11	-22.85	0.29	0.39	0.10	4.59	0.47	13.60
28c	1264.7	2673	NA	0.15	-24.77	0.10	0.39	0.06	2.92	0.27	8.68
28d	1282.6	2587	-1.69	0.15	-24.30	0.16	0.50	0.03	4.16	0.10	9.80
29a	1300.5	2439	NA	0.04	-21.32	0.12	0.26	0.04	3.07	0.21	13.81
29b	1318.5	2973	NA	0.11	-21.56	0.29	0.22	0.05	3.15	0.32	16.36
29c	1336.4	2530	NA	0.15	-22.46	0.10	0.36	0.06	3.27	0.30	10.56
29d	1354.3	2653	1.02	0.15	-22.77	0.16	0.38	0.02	4.01	0.10	12.14
30a	1372	2608	NA	0.04	-22.56	0.12	0.19	0.03	2.33	0.16	14.35
30b	1389.8	2975	NA	0.11	-21.95	0.29	0.21	0.05	3.01	0.31	16.95
30c	1407.3	2566	2.31	0.15	-22.20	0.10	0.53	0.08	4.35	0.39	9.65
30d	1424.6	2679	0.60	0.15	-24.18	0.16	0.37	0.02	3.18	0.08	9.95
31a	1442.1	2257	NA	0.04	-24.18	0.12	0.45	0.07	4.68	0.32	12.25
31b	1459.8	2842	NA	0.11	-23.33	0.29	0.23	0.06	2.89	0.30	14.78
31c	1477.3	2815	2.04	0.15	-24.96	0.10	0.55	0.09	4.46	0.40	9.39
31d	1495.2	2818	-1.10	0.15	-25.04	0.16	0.25	0.02	1.96	0.05	9.00
32a	1512.4	2280	NA	0.04	-23.59	0.12	0.09	0.01	1.11	0.08	14.97
32b	1529.8	2612	NA	0.11	-23.81	0.29	0.12	0.03	1.74	0.18	16.30
32c	1547.2	2895	NA	0.15	-21.69	0.10	0.24	0.04	1.81	0.16	8.76
32d	1563.3	2935	0.38	0.15	-20.54	0.16	0.40	0.03	4.22	0.10	12.45
33a	1577.6	2469	1.24	0.04	-22.22	0.12	0.54	0.08	5.73	0.40	12.29
33b	1592.1	2776	NA	NA	-22.19	0.22	0.53	0.03	5.13	0.16	11.33
33c	1606.5	2587	2.00	0.15	-23.70	0.10	0.55	0.09	4.49	0.41	9.52
33d	1621	2973	1.39	0.15	-23.53	0.16	0.60	0.04	6.09	0.15	11.86
34a	1635.4	2579	0.71	0.04	-24.46	0.12	0.46	0.07	4.40	0.30	11.22
34b	1649.8	2953	NA	NA	-22.21	0.22	0.33	0.02	3.14	0.10	11.15
34c	1664.2	2486	1.58	0.15	-22.91	0.10	0.83	0.13	7.28	0.66	10.18
34d	1678.6	2792	2.80	0.15	-22.15	0.16	0.37	0.02	3.34	0.08	10.61
35a	1692.8	2361	NA	0.04	-22.02	0.12	0.34	0.05	3.47	0.24	12.07
35b	1707.2	4360	0.53	0.10	-22.35	0.07	0.44	0.00	2.39	0.07	6.37
35c	1721.7	4248	0.31	0.10	-23.01	0.07	0.44	0.00	2.23	0.07	5.95
35d	1736.1	4193	-0.07	0.10	-23.06	0.07	0.42	0.00	2.06	0.06	5.67
36a	1750.5	2193	NA	0.04	-24.70	0.12	0.50	0.08	4.38	0.30	10.12
36b	1764.9	2555	NA	NA	-24.01	0.22	0.65	0.04	5.38	0.16	9.63
36c	1779.3	2663	1.56	0.15	-25.62	0.10	0.53	0.08	3.77	0.34	8.21
36d	1793.8	2945	0.87	0.15	-25.16	0.16	0.33	0.02	2.57	0.06	8.97
37a	1808.3	2486	NA	0.04	-24.10	0.12	0.25	0.04	2.43	0.17	11.22
37b	1823.1	2794	NA	NA	-24.70	0.22	0.65	0.04	5.15	0.16	9.27
37c	1838.6	2402	0.46	0.15	-25.12	0.10	0.71	0.11	5.08	0.46	8.29

Table 4c - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
37d	1854.1	2846	1.67	0.15	-24.10	0.16	0.36	0.02	2.65	0.06	8.68
38a	1869.6	2743	NA	0.04	-24.33	0.12	0.27	0.04	2.33	0.16	9.87
38b	1885.4	2755	NA	NA	-21.38	0.22	0.50	0.03	3.95	0.12	9.21
38c	1901	2407	NA	0.15	-19.16	0.10	0.47	0.07	3.50	0.32	8.77
38d	1916.7	2928	0.85	0.15	-19.77	0.16	0.35	0.02	3.15	0.08	10.41
39a	1932.2	2475	NA	0.04	-19.29	0.12	0.30	0.05	3.41	0.24	13.16
39b	1948	2807	NA	NA	-19.07	0.22	0.22	0.01	2.26	0.07	11.76
39c	1964.5	2666	NA	0.15	-20.79	0.10	0.37	0.06	3.31	0.30	10.37
39d	1983.7	3094	1.32	0.15	-23.36	0.16	0.52	0.03	4.83	0.12	10.77
40a	2002.7	2261	0.84	0.04	-21.24	0.12	0.63	0.10	6.62	0.46	12.18
40b	2022.1	2743	NA	NA	-18.96	0.22	0.42	0.03	4.29	0.13	12.00
40c	2041.4	2475	NA	0.15	-22.19	0.10	0.45	0.07	3.95	0.36	10.30
40d	2060.7	3202	1.61	0.15	-22.70	0.16	0.47	0.03	4.59	0.11	11.33
41a	2080.3	2337	1.58	0.04	-21.70	0.12	0.68	0.10	7.29	0.50	12.52
41b	2099.6	2929	NA	NA	-21.64	0.22	0.94	0.06	9.25	0.28	11.49
41c	2119.1	2850	1.57	0.15	-20.36	0.10	0.59	0.09	5.27	0.48	10.43
41d	2137.7	2917	1.29	0.15	-20.12	0.16	0.73	0.05	7.36	0.18	11.74
42a	2151.5	2611	NA	0.04	-19.37	0.12	0.19	0.03	2.32	0.16	14.00
42b	2165.1	2782	NA	NA	-19.79	0.22	0.18	0.01	1.77	0.05	11.19
42c	2178.6	2804	-0.87	0.27	-20.49	0.20	0.22	0.01	2.12	0.03	11.25
42d	2192.2	2720	-0.54	0.15	-22.07	0.16	0.27	0.02	2.58	0.06	11.33
43a	2205.9	2371	1.01	0.04	-20.72	0.12	0.82	0.13	9.39	0.65	13.40
43b	2219.4	2767	NA	NA	-20.23	0.22	0.99	0.06	9.59	0.29	11.29
43c	2232.9	2757	2.46	0.27	-21.74	0.20	0.57	0.03	4.95	0.07	10.20
43d	2246.4	2878	2.01	0.15	-23.49	0.16	0.59	0.04	4.84	0.12	9.62
44a	2259.9	2268	NA	0.04	-22.04	0.12	0.40	0.06	3.62	0.25	10.66
44b	2273.2	2905	NA	NA	-20.71	0.22	0.21	0.01	1.85	0.06	10.26
44c	2286.7	2757	1.50	0.27	-13.61	0.20	0.30	0.01	2.81	0.04	10.81
44d	2300.2	2626	1.17	0.15	-13.97	0.16	0.58	0.04	6.62	0.16	13.29
45a	2314	2260	1.06	0.04	-19.00	0.12	0.50	0.08	5.59	0.39	12.92
45b	2327.7	2931	NA	NA	-18.25	0.22	0.18	0.01	1.98	0.06	12.71
45c	2341.4	2782	1.59	0.27	-15.80	0.20	0.45	0.02	5.45	0.08	14.27
45d	2355.3	3074	1.87	0.15	-19.59	0.16	0.72	0.05	8.02	0.19	13.00
46a	2369	2649	NA	0.04	-22.58	0.12	0.12	0.02	1.57	0.11	15.25
46b	2382.7	2905	NA	NA	-21.09	0.22	0.57	0.04	5.65	0.17	11.51
46c	2404.6	2574	2.08	0.27	-19.76	0.20	0.59	0.03	6.31	0.09	12.46
46d	2427	3015	2.42	0.15	-20.79	0.16	0.64	0.04	6.75	0.16	12.31
47a	2449.3	2459	1.75	0.04	-22.88	0.12	0.46	0.07	5.03	0.35	12.71
47b	2471.7	3009	NA	NA	-20.70	0.22	0.57	0.04	5.21	0.16	10.75
47c	2494.1	2635	1.21	0.27	-17.19	0.20	0.67	0.03	6.48	0.09	11.32
47d	2516.6	2916	1.48	0.15	-19.93	0.16	0.57	0.04	5.59	0.13	11.44
48a	2539.1	2839	NA	0.04	-21.95	0.12	0.30	0.05	3.02	0.21	11.90
48b	2561.6				data missing						
48c	2584.1	2691	3.85	0.27	-21.54	0.20	0.47	0.02	3.99	0.06	9.96
48d	2598.5	2906	1.51	0.15	-22.50	0.16	0.85	0.06	7.14	0.17	9.77
49a	2611.9	2620	1.56	0.04	-21.56	0.12	0.62	0.09	5.78	0.40	10.86
49b	2625.4	2811	NA	NA	-20.06	0.22	1.19	0.08	10.17	0.31	9.94
49c	2638.8	2716	-5.84	0.27	-15.88	0.20	0.38	0.02	3.07	0.04	9.36
49d	2652.2	2990	0.08	0.15	-18.38	0.16	0.25	0.02	2.01	0.05	9.36

Table 4c - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
50a	2665.5	2370	NA	0.04	-15.12	0.12	0.41	0.06	4.45	0.31	12.70
50b	2678.7	2895	NA	NA	-12.40	0.22	0.31	0.02	3.38	0.10	12.72
50c	2691.9	2590	0.78	0.27	-13.28	0.20	0.37	0.02	4.03	0.06	12.80
50d	2704.9	2726	1.72	0.15	-19.58	0.16	0.45	0.03	4.63	0.11	11.98
51a	2717.1	2505	1.95	0.08	-21.55	0.15	0.62	0.12	5.04	0.40	9.44
51b	2729.3	2838	NA	NA	-19.45	0.22	0.43	0.03	4.21	0.13	11.52
51c	2741.6	2569	1.79	0.27	-20.60	0.20	0.50	0.02	4.43	0.06	10.26
51d	2754.1	2743	1.70	0.15	-19.80	0.16	0.47	0.03	4.17	0.10	10.43
52a	2766.2	2291	1.59	0.08	-20.12	0.15	0.70	0.13	5.47	0.43	9.11
52b	2778.8	2869	NA	NA	-18.87	0.22	0.41	0.03	3.96	0.12	11.32
52c	2790.9	2904	1.15	0.27	-19.81	0.20	0.26	0.01	2.25	0.03	10.29
52d	2803.2	2790	NA	0.15	-23.00	0.16	0.11	0.01	0.69	0.02	6.99
53a	2815.5	2566	NA	0.08	-22.39	0.15	0.29	0.05	1.77	0.14	7.12
53b	2827.1	2638	NA	NA	-22.04	0.22	0.55	0.04	5.20	0.16	11.03
53c	2838.8	2748	1.69	0.27	-18.74	0.20	0.44	0.02	3.78	0.05	9.94
53d	2850.4	3146	1.66	0.15	-14.84	0.16	0.35	0.02	3.56	0.09	11.79
54a	2861.9	2661	NA	0.08	-14.07	0.15	0.37	0.07	2.78	0.22	8.69
54b	2873.5	2815	NA	NA	-15.16	0.22	0.61	0.04	5.54	0.17	10.66
54c	2885	2451	1.53	0.27	-17.13	0.20	0.35	0.02	2.81	0.04	9.43
54d	2896.5	3078	1.18	0.15	-21.38	0.16	0.37	0.02	2.95	0.07	9.22
55a	2908.2	2727	2.09	0.08	-22.02	0.15	0.50	0.09	3.40	0.27	7.92
55b	2920.1	3019	NA	NA	-19.81	0.22	0.41	0.03	3.54	0.11	9.95
55c	2931.2	2489	0.94	0.27	-15.75	0.20	0.40	0.02	3.45	0.05	10.02
55d	2942.1	3080	1.43	0.15	-15.35	0.16	0.41	0.03	3.78	0.09	10.75
56a	2953.3	2303	NA	0.08	-13.97	0.15	0.31	0.06	2.42	0.19	9.00
56b	2964.4	2988	NA	NA	-16.13	0.22	0.23	0.01	2.52	0.08	13.00
56c	2975.4	2842	2.23	0.27	-15.98	0.20	0.24	0.01	2.24	0.03	11.07
56d	2986.5	2750	NA	0.15	-16.57	0.16	0.26	0.02	2.34	0.06	10.64
57a	2997.3	2769	NA	0.08	-20.34	0.15	0.31	0.06	2.45	0.19	9.12
57b	3008.2	2826	NA	NA	-19.83	0.22	0.26	0.02	2.55	0.08	11.65
57c	3019	2951	1.47	0.27	-18.95	0.20	0.28	0.01	2.60	0.04	10.80
57d	3029.7	3042	NA	0.15	-17.40	0.16	0.20	0.01	1.58	0.04	9.26
58a	3040.2	2675	NA	0.08	-19.74	0.15	0.28	0.05	1.68	0.13	7.08
58b	3050.5	2964	NA	NA	-23.71	0.22	0.25	0.02	2.17	0.07	10.13
58c	3061.1	2641	1.08	0.27	-24.00	0.20	0.30	0.01	2.52	0.04	9.85
58d	3071.5	3125	1.66	0.15	-24.21	0.16	0.30	0.02	2.38	0.06	9.11
59a	3082.1	2536	NA	0.08	-22.42	0.15	0.36	0.07	2.26	0.18	7.27
59b	3092.6	2806	NA	NA	-21.04	0.22	0.26	0.02	2.23	0.07	9.90
59c	3103	2544	2.17	0.27	-20.50	0.20	0.30	0.01	2.64	0.04	10.17
59d	3113.5	2899	1.78	0.15	-17.48	0.16	0.36	0.02	3.46	0.08	11.22

Table 4d - Stable isotope data - Lake Naga, acidified

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
1a	-28.6	3019	NA	0.06	-22.77	0.15	0.33	0.04	2.67	0.14	9.50
1b	-8	2251	1.95	0.06	-23.33	0.15	0.50	0.06	3.71	0.19	8.66
1c	12.6	2732	1.09	0.06	-24.78	0.15	0.52	0.06	4.09	0.21	9.21
1d	33.3	2149	NA	0.06	-24.12	0.15	0.42	0.05	3.16	0.17	8.84
2a	54.2	2603	NA	0.06	-24.77	0.15	0.22	0.03	1.79	0.09	9.64
2b	75.2	2710	NA	0.06	-24.19	0.15	0.25	0.03	2.25	0.12	10.41
2c	95.8	2676	NA	0.06	-23.70	0.15	0.33	0.04	2.79	0.15	9.86
2d	116.5	2524	NA	0.06	-23.51	0.15	0.35	0.04	3.14	0.16	10.59
3a	137.1	2505	NA	0.06	-24.12	0.15	0.23	0.03	2.32	0.12	11.66
3b	154.2	2384	NA	0.06	-24.05	0.15	0.25	0.03	2.38	0.12	10.92
3c	166.3	2615	NA	0.06	-24.48	0.15	0.21	0.03	2.03	0.11	11.16
3d	178.5	2826	NA	0.06	-24.93	0.15	0.28	0.03	3.07	0.16	12.62
4a	190.9	2200	NA	0.06	-23.47	0.15	0.45	0.05	3.62	0.19	9.48
4b	203.1	2283	NA	0.06	-23.89	0.15	0.42	0.05	3.38	0.18	9.34
4c	215.3	2186	NA	0.06	-24.05	0.15	0.30	0.04	2.51	0.13	9.83
4d	227.6	2375	NA	0.06	-23.90	0.15	0.24	0.03	2.05	0.11	10.02
5a	239.8	2718	NA	0.06	-23.26	0.15	0.34	0.04	3.11	0.16	10.78
5b	252	2226	NA	0.06	-23.77	0.15	0.38	0.04	3.71	0.19	11.52
5c	263.1	2874	NA	0.06	-23.93	0.15	0.30	0.04	2.72	0.14	10.57
5d	271.7	2906	NA	0.06	-24.48	0.15	0.19	0.02	1.67	0.09	10.45
6a	280.4	2086	0.03	0.06	-23.84	0.15	0.64	0.08	6.13	0.32	11.23
6b	288.9	2358	-0.99	0.06	-23.94	0.15	0.69	0.08	6.63	0.35	11.22
6c	297.7	2597	-0.77	0.06	-23.43	0.15	0.69	0.08	5.92	0.31	9.94
6d	306.4	2252	-0.86	0.06	-24.09	0.15	1.11	0.13	8.76	0.46	9.22
7a	315	2305	-1.97	0.06	-24.63	0.15	0.92	0.11	5.89	0.31	7.44
7b	323.6	2330	-0.32	0.11	-25.49	0.10	0.17	0.22	1.98	1.45	13.45
7c	332.1	2473	-1.03	0.11	-24.82	0.10	-0.07	-0.09	0.87	0.64	-15.44
7d	340.2	2748	-1.20	0.11	-25.21	0.10	-0.18	-0.23	0.27	0.20	-1.78
8a	346.6	2385	1.61	0.11	-23.83	0.10	-0.19	-0.24	2.80	2.05	-17.62
8b	353.1	2676	1.63	0.11	-23.35	0.10	0.25	0.32	6.21	4.55	29.30
8c	359.5	2292	0.26	0.11	-23.74	0.10	-0.02	-0.02	4.16	3.05	NA
8d	366	2701	1.64	0.11	-23.10	0.10	-0.16	-0.21	2.09	1.53	-15.32
9a	372.4	2643	-1.95	0.11	-22.11	0.10	-0.40	-0.52	-0.08	-0.06	0.23
9b	378.9	2300	-2.49	0.11	-21.70	0.10	-0.43	-0.57	0.24	0.17	-0.63
9c	385.3	2158	-0.01	0.11	-22.30	0.10	-0.48	-0.62	0.17	0.13	-0.42
9d	391.9	2024	0.45	0.11	-22.18	0.10	-0.40	-0.53	1.67	1.23	-4.84
10a	398.1	2319	0.21	0.11	-20.21	0.10	-0.27	-0.35	2.10	1.54	-9.12
10b	403.5	2256	0.38	0.11	-19.29	0.10	-0.28	-0.37	2.65	1.94	-10.90
10c	409	2131	0.18	0.18	-20.96	0.21	0.47	0.04	4.22	0.17	10.50
10d	414.5	2548	1.23	0.18	-22.83	0.21	0.58	0.05	6.13	0.24	12.23
11a	420	2858	2.58	0.18	-23.20	0.21	0.27	0.02	1.94	0.08	8.53
11b	425.6	2153	2.73	0.18	-23.20	0.21	0.46	0.04	3.77	0.15	9.52
11c	431.1	2742	2.97	0.18	-23.33	0.21	0.39	0.03	3.34	0.13	9.93
11d	436.3	2191	4.31	0.18	-23.82	0.21	0.34	0.03	2.63	0.10	9.08
12a	441.7	2470	1.88	0.18	-25.85	0.21	0.48	0.04	3.76	0.15	9.11
12b	447.1	2173	3.27	0.18	-24.09	0.21	0.53	0.05	5.18	0.21	11.30
12c	453.9	2185	3.29	0.18	-23.96	0.21	0.42	0.04	3.73	0.15	10.40
12d	460.7	2523	2.43	0.18	-24.23	0.21	0.51	0.04	4.65	0.19	10.68
13a	467.3	2589	2.83	0.18	-24.98	0.21	0.45	0.04	3.67	0.15	9.54

Table 4d - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
13b	474.1	2313	2.14	0.18	-23.31	0.21	0.87	0.08	8.24	0.33	10.99
13c	481	2120	2.26	0.18	-23.28	0.21	0.64	0.06	5.63	0.22	10.21
13d	487.9	2933	3.44	0.18	-23.95	0.21	0.30	0.03	2.60	0.10	10.00
14a	494.7	2353	2.46	0.18	-24.45	0.21	0.44	0.04	3.30	0.13	8.72
14b	501.6	2221	1.69	0.18	-25.34	0.21	0.66	0.06	5.40	0.22	9.48
14c	508.6	2557	1.04	0.18	-25.45	0.21	0.71	0.06	6.25	0.25	10.30
14d	518.1	2390	1.55	0.18	-24.12	0.21	0.83	0.07	7.35	0.29	10.36
15a	527.6	2195	-0.89	0.18	-23.62	0.21	1.12	0.10	9.77	0.39	10.19
15b	537.2	2700	0.17	0.18	-22.33	0.21	0.63	0.06	5.21	0.21	9.65
15c	546.8	2380	0.84	0.18	-22.65	0.21	0.68	0.06	5.23	0.21	8.96
15d	556.4	2848	0.80	0.18	-23.48	0.21	0.52	0.05	4.67	0.19	10.41
16a	565.7	2097	2.08	0.18	-23.01	0.21	0.44	0.04	3.81	0.15	9.99
16b	574.9	2329	-10.49	0.18	-24.69	0.21	0.27	0.02	1.48	0.06	6.38
16c	584.3	2814	-0.04	0.18	-23.69	0.21	0.55	0.05	4.19	0.17	8.88
16d	593.6	2625	0.68	0.18	-23.59	0.21	0.52	0.05	4.00	0.16	8.95
17a	605.8	2290	1.78	0.18	-23.49	0.21	0.54	0.05	4.33	0.17	9.37
17b	618.4					data missing					
17c	631.1					data missing					
17d	643.7					data missing					
18a	656.5					data missing					
18b	669.2					data missing					
18c	682					data missing					
18d	694.7					data missing					
19a	707.1					data missing					
19b	720.1					data missing					
19c	733.3					data missing					
19d	746.4					data missing					
20a	759.5	2437	-0.06	0.08	-21.88	0.09	0.58	0.02	4.86	0.12	9.75
20b	772.5	2908	-0.37	0.08	-22.22	0.09	0.45	0.02	3.87	0.09	10.06
20c	785.3	2372	0.05	0.08	-21.41	0.09	1.00	0.04	9.36	0.22	10.87
20d	798.3	2263	-0.14	0.08	-20.88	0.09	0.89	0.03	7.42	0.18	9.71
21a	811.3	2237	-0.29	0.08	-24.16	0.09	0.77	0.03	5.74	0.14	8.73
21b	824.2	2821	-0.13	0.08	-23.94	0.09	0.30	0.01	1.90	0.05	7.29
21c	838	2198	-0.51	0.08	-22.66	0.09	0.34	0.01	2.11	0.05	7.29
21d	852.2	2230	-0.92	0.08	-22.69	0.09	0.41	0.02	2.88	0.07	8.14
22a	866.4	2371	-1.53	0.08	-24.54	0.09	0.27	0.01	1.60	0.04	6.99
22b	880.7	2526	-0.46	0.08	-23.41	0.09	0.27	0.01	1.64	0.04	7.07
22c	895.2	2231	-0.86	0.08	-23.87	0.09	0.24	0.01	1.33	0.03	6.52
22d	909.6	2429	-2.70	0.08	-23.96	0.09	0.23	0.01	1.37	0.03	6.87
23a	924	2335	-1.97	0.08	-22.95	0.09	0.33	0.01	1.96	0.05	7.03
23b	938.4	2123	0.24	0.08	-22.74	0.09	0.42	0.02	2.81	0.07	7.76
23c	952.9	2701	-0.14	0.08	-20.74	0.09	0.32	0.01	2.21	0.05	8.16
23d	967.1	2426	-2.38	0.08	-20.00	0.09	0.24	0.01	1.66	0.04	7.94
24a	981.6	2415	0.44	0.04	-23.44	0.08	0.60	0.10	3.88	0.26	7.53
24b	996.4	2119	NA	0.04	-22.02	0.08	0.58	0.10	3.58	0.24	7.21
24c	1011.2	2455	1.34	0.04	-21.18	0.08	0.65	0.11	4.62	0.31	8.30
24d	1026	2489	1.84	0.04	-22.14	0.08	0.80	0.14	5.85	0.40	8.52
25a	1040.8	2237	-0.87	0.04	-22.80	0.08	0.95	0.16	7.55	0.51	9.27
25b	1055.6	2398	-0.28	0.04	-21.53	0.08	0.79	0.13	5.58	0.38	8.27

Table 4d - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
25c	1070.3	2721	NA	0.04	-22.90	0.08	0.51	0.09	2.85	0.19	6.57
25d	1084.9	2155	NA	0.04	-24.68	0.08	0.64	0.11	3.75	0.25	6.84
26a	1100.5	2284	-0.86	0.04	-21.02	0.08	0.65	0.11	4.93	0.33	8.83
26b	1116.5	2314	-3.50	0.04	-20.60	0.08	0.66	0.11	4.63	0.31	8.24
26c	1132.6	2329	NA	0.04	-21.60	0.08	0.55	0.09	3.40	0.23	7.25
26d	1148.7	2337	NA	0.04	-22.72	0.08	0.42	0.07	1.88	0.13	5.26
27a	1165.1	2154	NA	0.04	-21.52	0.08	0.60	0.10	3.20	0.22	6.25
27b	1181.4	2398	-1.07	0.04	-21.95	0.08	1.05	0.18	8.83	0.60	9.84
27c	1197.7	2295	-1.08	0.04	-21.95	0.08	1.09	0.19	9.22	0.63	9.84
27d	1214	2839	-1.06	0.04	-21.88	0.08	0.91	0.16	7.35	0.50	9.43
28a	1229.9	2179	-1.07	0.04	-21.89	0.08	1.18	0.20	9.57	0.65	9.43
28b	1247	2196	-1.02	0.04	-22.46	0.08	0.79	0.14	5.35	0.36	7.88
28c	1264.7	2399	-0.93	0.04	-24.08	0.08	0.64	0.11	3.73	0.25	6.78
28d	1282.6	2045	0.05	0.04	-23.54	0.08	0.75	0.13	4.48	0.30	6.96
29a	1300.5	2338	1.41	0.04	-21.53	0.08	0.61	0.10	3.78	0.26	7.21
29b	1318.5	2452	2.19	0.04	-21.39	0.08	0.66	0.11	4.53	0.31	8.04
29c	1336.4	2109	NA	0.04	-22.32	0.08	0.66	0.11	4.52	0.31	7.95
29d	1354.3	2155	2.04	0.04	-22.75	0.08	0.69	0.12	4.84	0.33	8.19
30a	1372	2084	NA	0.04	-23.79	0.08	0.52	0.09	2.63	0.18	5.89
30b	1389.8	2203	NA	0.04	-21.84	0.08	0.57	0.10	3.52	0.24	7.24
30c	1407.3	2138	1.73	0.04	-21.65	0.08	0.77	0.13	5.01	0.34	7.62
30d	1424.6	2264	1.71	0.04	-23.99	0.08	0.76	0.13	5.15	0.35	7.87
31a	1442.1	2154	NA	0.04	-22.80	0.08	0.63	0.11	3.73	0.25	6.92
31b	1459.8	2170	1.26	0.04	-24.31	0.08	0.80	0.14	5.06	0.34	7.35
31c	1477.3	2163	NA	0.04	-23.79	0.08	0.47	0.08	1.94	0.13	4.85
31d	1495.2	2556	NA	0.04	-23.30	0.08	0.40	0.07	1.76	0.12	5.08
32a	1512.4	2376	NA	0.04	-24.50	0.08	0.49	0.08	2.26	0.15	5.34
32b	1529.8	2451	NA	0.04	-24.41	0.08	0.44	0.08	1.98	0.13	5.26
32c	1547.2	2320	NA	0.04	-24.08	0.08	0.60	0.10	3.72	0.25	7.24
32d	1563.3	2950	1.01	0.16	-24.88	0.77	0.43	0.07	4.11	0.25	11.11
33a	1577.6	2125	0.72	0.04	-24.46	0.08	1.03	0.18	7.31	0.50	8.25
33b	1592.1	2190	0.84	0.04	-24.09	0.08	0.83	0.14	5.63	0.38	7.87
33c	1606.5	2296	1.07	0.04	-23.75	0.08	0.77	0.13	4.82	0.33	7.34
33d	1621	2526	1.20	0.04	-23.37	0.08	0.96	0.16	7.60	0.52	9.24
34a	1635.4	2173	-0.24	0.04	-24.55	0.08	0.85	0.15	5.53	0.38	7.56
34b	1649.8	2448	NA	0.04	-24.07	0.08	0.56	0.10	3.24	0.22	6.73
34c	1664.2	2092	0.72	0.04	-22.31	0.08	0.91	0.16	6.69	0.45	8.62
34d	1678.6	2510	1.40	0.04	-21.46	0.08	0.59	0.10	3.61	0.25	7.16
35a	1692.8	2790	1.08	0.04	-21.74	0.08	0.60	0.10	3.72	0.25	7.23
35b	1707.2	3972	0.00	0.10	-22.51	0.07	0.51	0.00	2.33	0.07	5.38
35c	1721.7	3832	-0.53	0.10	-23.02	0.07	0.50	0.00	2.15	0.06	4.98
35d	1736.1	4247	-0.49	0.10	-23.05	0.07	0.44	0.00	1.83	0.05	4.83
36a	1750.5	2384	0.73	0.04	-24.31	0.08	0.73	0.13	4.19	0.28	6.68
36b	1764.9	2298	0.62	0.04	-23.95	0.08	0.81	0.14	4.98	0.34	7.18
36c	1779.3	2712	0.55	0.04	-24.87	0.08	0.66	0.11	3.83	0.26	6.74
36d	1793.8	2302	1.72	0.04	-24.44	0.08	0.63	0.11	3.40	0.23	6.33
37a	1808.3	2799	1.79	0.04	-23.62	0.08	0.52	0.09	3.00	0.20	6.71
37b	1823.1	2210	0.71	0.04	-24.68	0.08	0.89	0.15	5.31	0.36	6.98
37c	1838.6	2099	0.75	0.04	NA	0.14	0.55	0.08	-0.24	-0.02	-0.52

Table 4d - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
37d	1854.1	2247	0.28	0.04	-24.41	0.14	0.28	0.04	2.56	0.19	10.62
38a	1869.6	2415	0.43	0.04	-23.63	0.14	0.26	0.04	2.45	0.18	10.82
38b	1885.4	2220	0.87	0.04	-22.91	0.14	0.28	0.04	2.68	0.19	11.22
38c	1901	2297	0.95	0.04	-23.16	0.14	0.27	0.04	2.87	0.21	12.18
38d	1916.7	2297	0.95	0.04	-23.16	0.14	0.27	0.04	2.87	0.21	12.18
39a	1932.2	2230	2.14	0.04	-23.51	0.14	0.24	0.04	2.73	0.20	13.06
39b	1948	2242	2.12	0.04	-23.30	0.14	0.25	0.04	2.94	0.21	13.51
39c	1964.5	2471	1.06	0.04	-23.42	0.14	0.18	0.03	2.39	0.17	15.55
39d	1983.7	2108	1.22	0.04	-23.23	0.14	0.34	0.05	4.13	0.30	14.03
40a	2002.7	2048	0.85	0.04	-21.95	0.14	0.57	0.08	6.19	0.45	12.60
40b	2022.1	2195	0.38	0.04	-22.03	0.14	0.29	0.04	3.58	0.26	14.22
40c	2041.4	2085	1.26	0.04	-22.95	0.14	0.35	0.05	4.16	0.30	13.79
40d	2060.7	2355	1.85	0.04	-22.59	0.14	0.41	0.06	4.69	0.34	13.40
41a	2080.3	2468	1.38	0.04	-21.51	0.14	0.75	0.11	8.26	0.60	12.84
41b	2099.6	2258	1.25	0.04	-21.62	0.14	0.85	0.12	9.26	0.67	12.63
41c	2119.1	2181	0.76	0.04	-20.09	0.14	0.55	0.08	6.30	0.46	13.35
41d	2137.7	2188	0.79	0.04	-19.75	0.14	0.57	0.08	6.49	0.47	13.29
42a	2151.5	2596	1.46	0.04	-20.22	0.14	0.17	0.02	2.16	0.16	15.04
42b	2165.1	2536	NA	0.04	-21.91	0.14	0.06	0.01	1.06	0.08	21.37
42c	2178.6	2552	1.37	0.04	-22.95	0.14	0.14	0.02	2.08	0.15	17.16
42d	2192.2	2103	1.88	0.04	-23.14	0.14	0.15	0.02	2.31	0.17	17.54
43a	2205.9	2179	1.58	0.04	-19.73	0.14	0.75	0.11	8.92	0.65	13.88
43b	2219.4	2176	1.58	0.04	-19.36	0.14	0.81	0.12	8.93	0.65	12.85
43c	2232.9	2288	2.14	0.04	-21.50	0.14	0.35	0.05	3.93	0.29	13.10
43d	2246.4	2186	2.08	0.04	-22.80	0.14	0.43	0.06	4.48	0.33	12.03
44a	2259.9	2325	2.99	0.04	-22.01	0.14	0.57	0.08	5.14	0.37	10.60
44b	2273.2	2092	0.53	0.04	-21.80	0.14	0.12	0.02	1.68	0.12	16.22
44c	2286.7	2384	1.34	0.04	-15.28	0.14	0.13	0.02	1.92	0.14	17.41
44d	2300.2	2366	0.65	0.04	-12.08	0.14	0.57	0.08	8.17	0.59	16.78
45a	2314	2494	0.76	0.04	-18.58	0.14	0.59	0.09	6.92	0.50	13.64
45b	2327.7	2389	1.87	0.04	-18.96	0.14	0.09	0.01	1.89	0.14	23.94
45c	2341.4	2463	1.41	0.04	-17.49	0.14	0.25	0.04	3.99	0.29	18.24
45d	2355.3	2105	1.16	0.04	-19.45	0.14	0.54	0.08	7.08	0.51	15.41
46a	2369	2206	0.90	0.04	-22.24	0.14	0.12	0.02	1.94	0.14	19.35
46b	2382.7	2247	1.86	0.04	-21.23	0.14	0.41	0.06	5.08	0.37	14.50
46c	2404.6	2360	1.85	0.04	-20.05	0.14	0.54	0.08	6.99	0.51	15.11
46d	2427	2660	1.61	0.04	-20.39	0.14	0.42	0.06	5.27	0.38	14.52
47a	2449.3	2319	1.81	0.04	-22.25	0.14	0.45	0.07	5.67	0.41	14.53
47b	2471.7	2421	0.42	0.04	-20.31	0.14	0.42	0.06	4.57	0.33	12.79
47c	2494.1	2417	1.29	0.04	-17.39	0.14	0.47	0.07	5.65	0.41	14.03
47d	2516.6	2261	0.78	0.04	-19.92	0.14	0.47	0.07	5.46	0.40	13.64
48a	2539.1	2235	2.17	0.04	-21.58	0.14	0.31	0.05	3.76	0.27	13.95
48b	2561.6	2286	1.66	0.04	-20.76	0.14	0.29	0.04	3.52	0.26	14.06
48c	2584.1	2189	2.59	0.04	-21.49	0.14	0.37	0.05	4.17	0.30	13.19
48d	2598.5	2188	1.14	0.04	-21.83	0.14	0.73	0.11	7.10	0.52	11.32
49a	2611.9	2737	1.10	0.04	-20.91	0.14	0.45	0.07	4.61	0.34	11.89
49b	2625.4	2190	0.46	0.04	-19.49	0.14	0.97	0.14	9.27	0.67	11.09
49c	2638.8	2300	-0.35	0.04	-17.33	0.14	0.13	0.02	1.77	0.13	16.08
49d	2652.2	2577	0.58	0.04	-20.62	0.14	0.16	0.02	1.84	0.13	13.62

Table 4d - cont.

Sample	Age	Weight	d15N	d15N error	d13C	d13Cerror	%N	%N error	%C	%C error	C:N
50a	2665.5	2216	-0.11	0.04	-19.12	0.14	0.31	0.04	3.39	0.25	12.91
50b	2678.7	2558	0.36	0.04	-19.01	0.14	0.28	0.04	3.45	0.25	14.19
50c	2691.9	2636	0.04	0.04	-21.52	0.14	0.16	0.02	2.06	0.15	15.43
50d	2704.9	2417	0.75	0.04	-21.68	0.14	0.34	0.05	4.26	0.31	14.50
51a	2717.1	2296	0.78	0.16	-21.47	0.08	0.68	0.04	4.57	0.12	7.81
51b	2729.3	2320	1.56	0.16	-21.77	0.08	0.61	0.04	4.16	0.11	7.99
51c	2741.6	2065	1.24	0.16	-22.55	0.08	0.72	0.04	4.76	0.12	7.68
51d	2754.1	2102	0.97	0.16	-21.67	0.08	0.61	0.04	3.72	0.10	7.16
52a	2766.2	2343	0.04	0.16	-22.61	0.08	0.73	0.04	4.72	0.12	7.59
52b	2778.8	2092	0.73	0.16	-22.26	0.08	0.56	0.03	3.37	0.09	6.97
52c	2790.9	2722	2.22	0.16	-23.21	0.08	0.45	0.03	2.74	0.07	7.08
52d	2803.2	2124	NA	0.16	-23.25	0.08	0.29	0.02	0.68	0.02	2.75
53a	2815.5	2179	1.49	0.16	-22.17	0.08	0.41	0.03	1.92	0.05	5.51
53b	2827.1	2367	1.69	0.16	-21.67	0.08	0.70	0.04	5.25	0.14	8.77
53c	2838.8	2399	1.41	0.16	-20.42	0.08	0.58	0.04	3.69	0.10	7.39
53d	2850.4	2281	1.53	0.16	-19.51	0.08	0.51	0.03	3.12	0.08	7.16
54a	2861.9	2346	1.18	0.16	-22.73	0.08	0.48	0.03	2.62	0.07	6.39
54b	2873.5	2270	0.66	0.16	-27.64	0.08	0.68	0.04	3.01	0.08	5.20
54c	2885	2058	0.94	0.16	-21.28	0.08	0.56	0.03	2.95	0.08	6.14
54d	2896.5	2571	0.95	0.16	-21.65	0.08	0.40	0.02	2.03	0.05	5.88
55a	2908.2	2351	1.46	0.16	-21.90	0.08	0.56	0.03	3.27	0.08	6.78
55b	2920.1	2335	0.76	0.16	-20.94	0.08	0.51	0.03	2.90	0.07	6.62
55c	2931.2	2514	1.12	0.16	-20.03	0.08	0.48	0.03	2.69	0.07	6.58
55d	2942.1	2504	1.98	0.16	-21.01	0.08	0.44	0.03	2.31	0.06	6.13
56a	2953.3	2615	1.87	0.16	-22.40	0.08	0.36	0.02	1.88	0.05	6.18
56b	2964.4	2484	2.68	0.16	-22.31	0.08	0.39	0.02	2.29	0.06	6.79
56c	2975.4	2115	0.67	0.16	-22.71	0.08	0.41	0.03	1.94	0.05	5.59
56d	2986.5	2239	1.15	0.16	-22.31	0.08	0.41	0.03	1.96	0.05	5.59
57a	2997.3	2696	1.44	0.16	-21.67	0.08	0.35	0.02	2.15	0.06	7.08
57b	3008.2	2282	1.13	0.16	-21.97	0.08	0.39	0.02	2.08	0.05	6.17
57c	3019	2550	1.66	0.16	-21.79	0.08	0.36	0.02	1.92	0.05	6.16
57d	3029.7	2280	-4.51	0.16	-22.50	0.08	0.40	0.02	1.44	0.04	4.24
58a	3040.2	2728	-2.42	0.16	-22.84	0.08	0.34	0.02	1.51	0.04	5.20
58b	3050.5	2540	1.97	0.16	-23.48	0.08	0.39	0.02	2.18	0.06	6.56
58c	3061.1	2704	1.51	0.16	-24.03	0.08	0.40	0.02	2.37	0.06	6.90
58d	3071.5	2121	1.25	0.16	-23.44	0.08	0.44	0.03	2.16	0.06	5.74
59a	3082.1	2306	2.18	0.16	-23.25	0.08	0.47	0.03	2.56	0.07	6.38
59b	3092.6	2291	2.51	0.16	-22.54	0.08	0.42	0.03	2.30	0.06	6.43
59c	3103	2420	3.58	0.16	-22.89	0.08	0.42	0.03	2.58	0.07	7.15
59d	3113.5	2460	3.16	0.16	-23.23	0.08	0.39	0.02	2.25	0.06	6.76