USING DIATOMS (CLASS BACILLARIOPHYCEAE) AS A BIOLOGICAL PROXY FOR ENVIRONMENTAL CHANGES IN THE CANTERBURY HIGH COUNTRY, LAKE HAWDON, NEW ZEALAND.

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Abstract

This study examined samples part of a larger project exploring environmental changes at Lake Hawdon, mid Canterbury, involving Queen's University Belfast and the University of Canterbury. The author was responsible for the analysis of 85 fossil diatom samples from Lake Hawdon to create a high resolution study to assess their use as a biological proxy of past environmental changes through the Late Glacial Inter-Glacial Transition. Qualitative interpretations suggest three main phases of environmental change in Lake Hawdon during ~17,000 to 10,000 cal. BP. The first is a cool stage where taxa such as *Cocconeis placentula* and fragilarioid complex taxa *Staurosirella pinnata* and *Pseudostaurosira brevistriata* suggest a cool shallow lake with increasing macrophyte growth. The second phase suggests cold deepening water from at 13,928 +/- 142 to 12,686 +/- 166 cal. BP, dominated by *Pseudostaurosira brevistriata,* which coincides with the Antarctic Cold Reversal. The third phase represents a warm deep water phase after 12,686 +/- 166 cal. BP, dominated by planktonic taxon *Cyclotella stelligera* and epiphytic taxon *Epithemia sorex*, suggesting that Lake Hawdon does not exhibit the Younger Dryas event. Pollen and chironomid data from Lake Hawdon, generated by other project members, are included in the quantitative analyses to further inform palaeoenvironmental inferences generated from diatom data. Chironomid temperature reconstructions complement diatom interpretations for all three phases of change in the lake however diatom resolution allows changes to be detected earlier than other proxies suggest. Stabilisation of the landscape ~12, 686 +/- 166 cal. BP is suggested by tree pollen appearing near the end of the diatom cold phase, confirming with the diatoms and chironomid data that there was a warming out of the cold phase. Interpretations from Lake Hawdon add to other proxy studies in New Zealand that suggest an Antarctic Cold Reversal type event, but fail to highlight the Younger Dryas event. The generation of a transfer function was attempted with the diatom data based on Northern Hemisphere datasets, but a Principal Component Analysis plot highlighted major dissimilarities between the New Zealand fossil data and modern European data. This raised the issue of having morphologically similar but genetically separate taxa, potentially displaying convergent environmental adaptation, a crucial area for further research globally, and particularly in isolated areas like New Zealand.

1 Introduction

1.1 Introduction to diatoms

Diatoms (class Bacillariophyceae) (Table 1) are unicellular eukaryotic micro-organisms (Kilroy, 2007; Round et al., 1990) classed by molecular data sequencing as Heterokont algae (Sims et al., 2006). Diatoms are amongst the most abundant and best preserved algal remains in oceanic and freshwater sediments (Round, 1981), as their cell walls are composed of silica (Battarbee et al., 2001; Round et al., 1990). Diatoms can be found in almost all aquatic environments, in both benthic and planktonic habitats (Battarbee, 2000; Mann, 1999; Reid et al., 1995; Round et al., 1990; Sims et al., 2006). The diatom skeleton consists of two thecae, one being slightly larger than the other, and the larger thecae becomes the dominant distinguishing feature in identifying diatoms (Figure 1) (Battarbee et al., 2001). Most diatoms have a relatively simple shape with the valves being radially or at least bilaterally symmetrical (Round, 1981), but there are exceptions to this e.g. *Nitzschia* species with their asymmetry along the apical axis. For an in-depth account of the diatom structure and physiology see Edlund and Stoermer (1997) and Round et al (1990).

The geographic distribution of diatoms is generally considered to be cosmopolitan (Charles and Smol, 1988; Cochran, 2002; Reid et al., 1995). Other studies have argued against the term ‘ubiquity’ with identification of extant endemic taxa in continental regions (Finlay et al., 2002; Kilroy et al., 2007; Vanormelingen et al., 2008). Both modern and fossil diatoms have been used as a proxy for many environmental variables in water bodies across the globe. Nutrient and chemical studies (Augustinus et al., 2006; Birks et al., 1990; Cumming and Smol, 1993; Hawes and Smith, 1994; Reid, 2005; Reid et al., 1995; Renberg and Hellberg, 1982; Tibby, 2004; Van Dam et al., 1994) and physical factor studies (such as temperature, light, ice cover, turbidity) (Bigler and Hall, 2002; Birks and Wright, 2000; Bradbury, 1986; Larocque and Bigler, 2004; Lotter and Bigler, 2000; Lotter et al., 1997; Lowe, 1996; Rosen et al., 2003; Rosen et al., 2001; Smol et al., 2005) are some of the many studies carried out with diatoms as a proxy.

BACILLARIOPHYTA

- COSCINODISCOPHYCEAE
  - THALASSIOSIRALES
    - Stephanodiscaceae – *Cyclotella*
- FRAGILARIOPHYCEAE
  - FRAGILARIALES
    - Fragilariaceae – *Fragilaria, Staurosirella, Staurosira, Pseudostaurosira, Martyana, Synedra, Fragilariaforma*
  - TABELLARIALES
    - Tabellariaceae – *Tabellaria*
- BACILLARIOPHYCEAE
  - EUNOTIALES
    - Eunotiaceae – *Eunotia*
  - CYMBELLALES
    - Cymbellaceae – *Cymbella, Encyonema, Encyonopsis*
    - Gomphonemataceae – *Gomphonema, Reimeria*
  - ACHNANTHALES
    - Achnanthaceae – *Achnanthes*
    - Cocconeidaceae – *Cocconeis*
    - Achnanthidiaceae – *Achnanthidium, Planothidium, Karayevia, Lemnicola*
  - NAVICULALES
    - Cavinulaceae – *Cavinula*
    - Neidiaceae – *Neidium*
    - Sellaphoraceae – *Sellaphora*
    - Pinnulariaceae – *Pinnularia, Caloneis, Diatomella*
    - Pleurosigmataceae – *Gyrosigma*
    - Diploneidaceae – *Diploneis*
    - Naviculaceae – *Navicula*
    - Stauroneidaceae – *Stauroneis, Craticula*
  - THALASSIOPHYSALES
    - Catenulaceae – *Amphora*
  - BACILLARIALES
    - Bacillariaceae – *Denticula, Nitzschia*
  - RHOPALODIALES
    - Rhopalodiaceae – *Epithemia, Rhopalodia*
  - SURIRELLALES
    - Surirellaceae - *Surirella*

Table 1. Freshwater diatom taxonomic placing within the phylum Bacillariophyta. Adapted from the classification system (Round et al., 1990) and updated from Algaebase (Guiry and Guiry, 2010).

Recent studies have used diatoms as a proxy for past terrestrial climatic conditions (Anderson, 2000; Bradbury, 1986; Bradshaw et al., 2000; De Batist and Fagel, 2008; Edlund and Stoermer, 2000; Hickman and Reasoner, 1998; Hillyer et al., 2009; Larocque and Bigler, 2004; Newnham et al., 2004; Rosen et al., 2001; Smol and Cumming, 2000) and inferring environmental changes in aquatic ecosystems through both qualitative and quantitative analysis. Diatoms, like many other micro-organisms, are highly complex and evolving communities within a lake and in the space of a day the diversity can change dramatically (Finlay et al., 1997). The benefits of using diatoms in such studies have been fully reviewed by Reid et al (1995) and by Cochran (2002).

The use of diatoms in palaeoclimate studies as a proxy is a globally accepted technique, based on the extensive study of modern diatoms' ecological preferences in a variety of climatic conditions (Birks and Birks, 1980). Diatoms are taxonomically distinctive and as a result diagnostic, with valves often having good preservation after death.

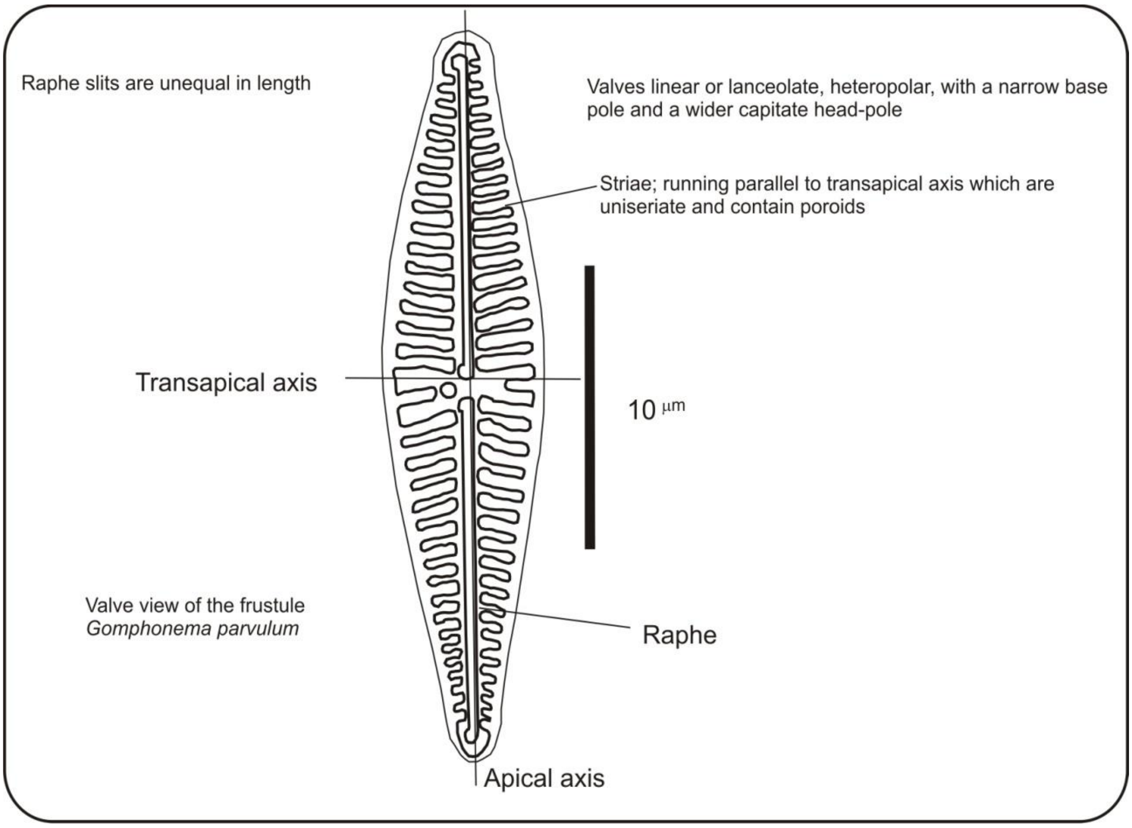


Figure 1. Sketch of *Gomphonema parvulum* highlighting points of identification on a valve. Identification points are described after Round (1990).

Growth and life habit

As algae diatoms use the process of photosynthesis for growth and, in the presence of sufficient light, nutrient availability controls their primary production (Battarbee, 2000; Round et al., 1990). Silica is taken up actively by diatoms (Round et al., 1990), making them the major repository of biogenic silica (Mann, 1999). Silicon is necessary for diatom cell wall production and it is also involved in diatom metabolic processes (Round, 1981). Diatoms have been present in the fossil record since the Mesozoic (Sims et al., 2006), where they had a scaly carbohydrate based covering over the valve.

Diatom habit is generally grouped into planktonic (open waters) and benthic (lake floor or ocean) categories. Planktonic algae can be treated as separate entities suspended in the water column; whereas benthic algae create distinct micro-environments within the sediment interface (Borchardt, 1996). Within lake benthic habitat there are sub-classes of taxa, based on the settings in which the diatoms can be found (Figure 2).

Episammic algae grow on the relatively inert substrate of sand (Figure 2) and attach themselves with stalks and mucilage (Round, 1981). Episammic algae require such attachments to survive movement by disturbance of the substrate. Epipelic algae grow on unstable inorganic or organic sediments such as clay, meaning most epipelic diatoms are large and motile (Stevenson, 1996). Epipelic diatoms are vulnerable to grazing from various macro-organisms living above them or within the sediment. They are also at risk from being buried by a disturbance or deposition of sediment, therefore being large and motile is a survival mechanism.

Epilithic diatoms encrust rocks or hard substrates that are bigger than the diatom (Round, 1981; Stevenson, 1996). Epilithic algae can attach themselves to the substrates in a similar manner to episammic algae (Round, 1981). Attachment allows the diatoms to utilise surrounding nutrients and organic matter for growth (Round, 1981). Epiphytic diatoms attached to macrophytes are aided by the potential motility of their host, allowing them access to good sources of nutrients whilst being attached to the larger algae or plant (Sayer et al., 1999; Stevenson, 1996), however epiphytic diatoms are even more exposed to grazing than epipelic diatoms (Round et al., 1990).

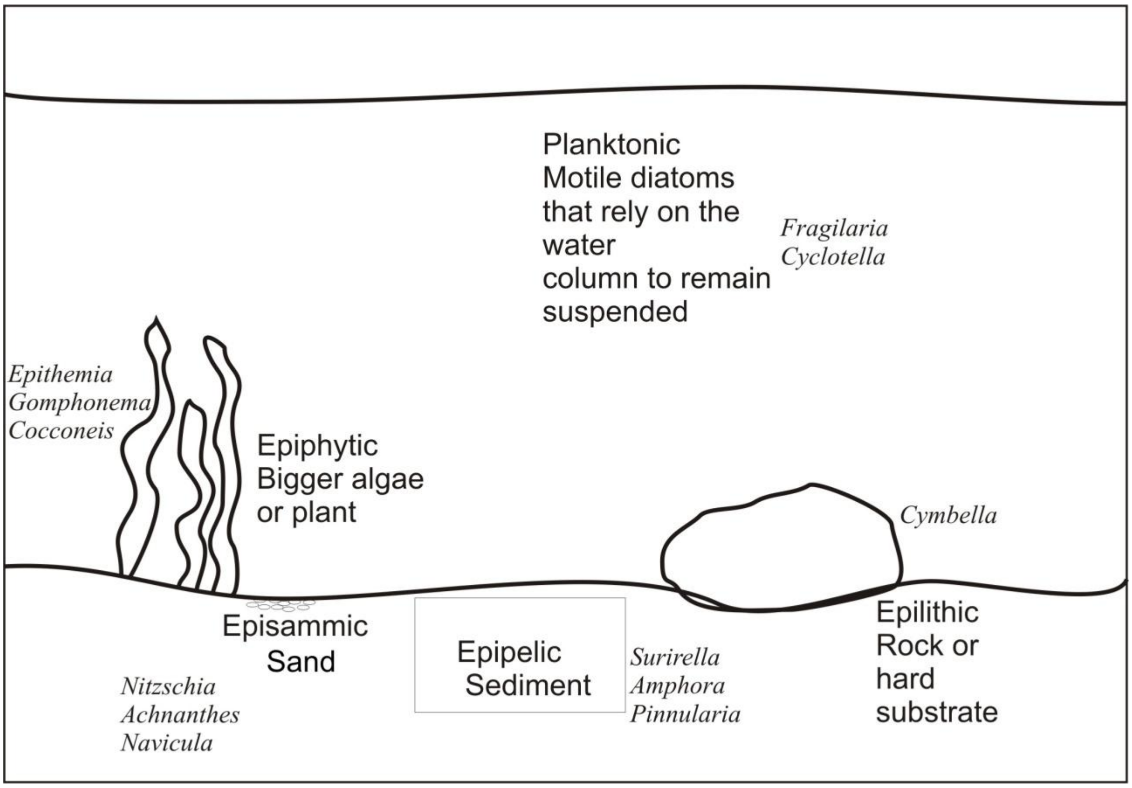


Figure 2. Settings for diatoms within a lake system. Examples of taxa that can be found in certain habitats from (Hang et al., 2008; Round, 1981).

Planktonic diatoms rely on the water column and the degree of mixing within the water column for their movement. The presence of mucilage around the diatom can determine the degree of sinking of the diatom or colony (Round et al., 1990), moving the diatom into new areas in the water column according to water movement. Some diatoms such as *Aulacoseira* form elongate chains of individuals as an adaptation to a planktonic environment (Round et al., 1990), and the chain formation allows greater mobility within the water column.

1.2 Environmental factors influencing diatom distribution

In a lacustrine environment there are many variables influencing diatoms in the water body (Figure 3), that may either limit or enhance growth (Anderson, 2000; Bigler and Hall, 2002; Borchardt, 1996). There are three external controls that influence high country lakes in New Zealand, climate, location and geology (Figure 3). These controls influence the physical, hydrological and chemical aspects that are the three main factors that affect diatom growth and productivity (Smol and Cumming, 2000). These three factors have many variables within them that impact diatom growth. All of these factors are connected, and one variable may not have complete control on diatom presence.

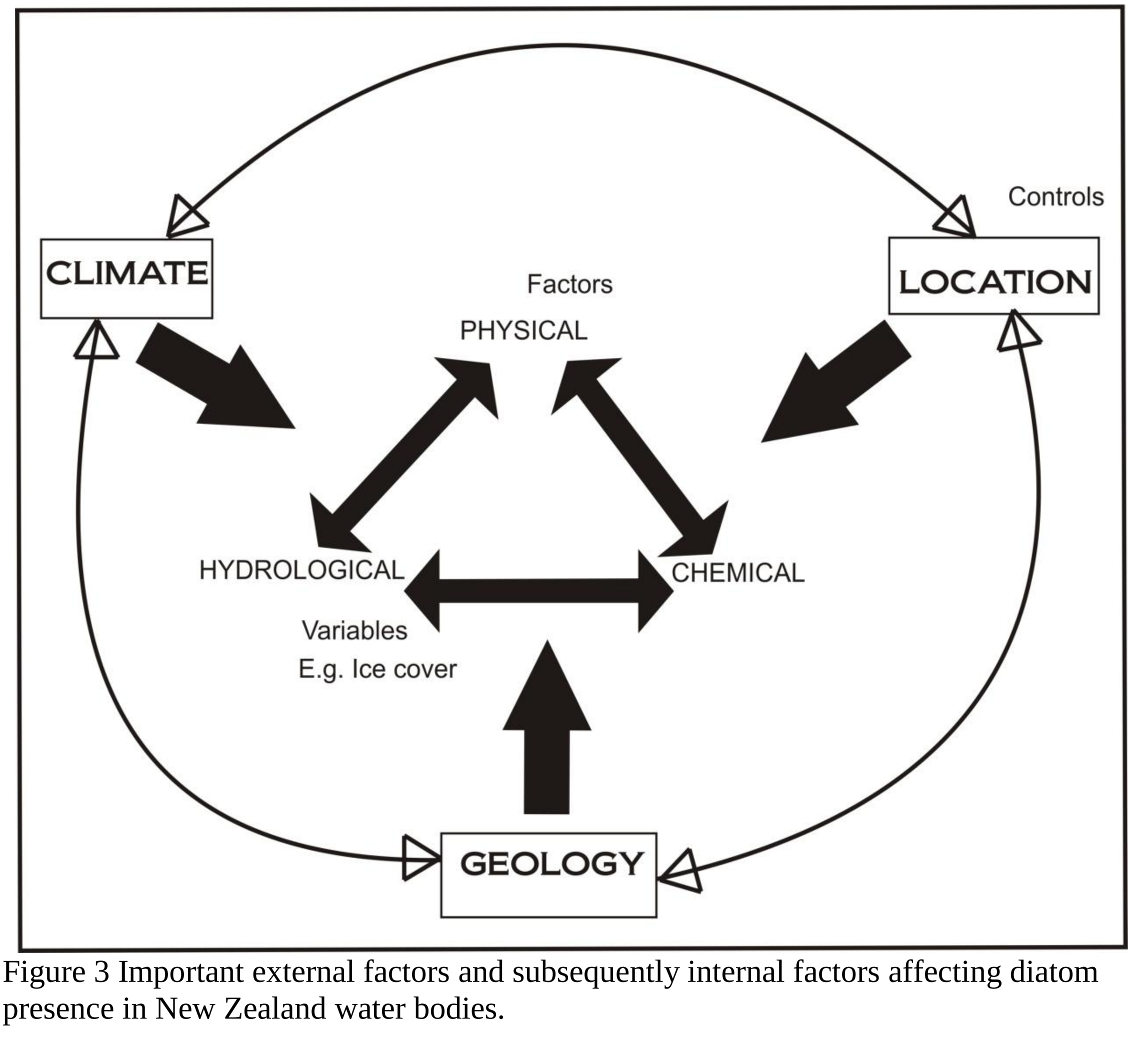


Figure 3 Important external factors and subsequently internal factors affecting diatom presence in New Zealand water bodies.

Physical factors

The main physical factor variables applicable to diatom growth and presence are temperature (Battarbee et al., 2001; Smol and Cumming, 2000), ice (Battarbee et al., 2001; Finkelstein and Gajewski, 2008; Smol and Cumming, 2000), light (Battarbee, 2000; Battarbee et al., 2001; Round, 1981; Round et al., 1990; Smol and Cumming, 2000) and wind (Anderson, 2000; Battarbee et al., 2001; McCabe and Cyr, 2006).

Temperature can directly influence diatom composition within a water body (Battarbee et al., 2001) by limiting or supporting growth of sensitive taxa. Planktonic diatoms such as *Cyclotella stelligera* have a preference for warmer open waters (Bradbury, 1986; Lotter and Bigler, 2000). Indirectly temperature can influence ice cover and chemical variables (Smol and Cumming, 2000) in a water body, controlling the duration of ice cover and the degree of chemical changes in the water body. For New Zealand, both direct and indirect temperature changes influence water bodies but in the Canterbury high country, this study will show indirect temperature changes may well have a stronger influence.

Ice cover is an important variable for high country lakes in New Zealand. Ice can directly and indirectly influence diatom assemblages (Battarbee et al., 2001; Finkelstein and Gajewski, 2008). Ice can impact the availability of light in the water body influencing planktonic diatoms by limiting their growing season (Lotter and Bigler, 2000) as well as influencing the water chemistry and nutrient supply (Keatley et al., 2008; Lowe, 1996). Ice cover is also related to water depth (Keatley et al., 2008); deep water bodies with extensive ice cover may exhibit subtle changes in diatom composition whilst shallower water bodies generally show larger changes of diatom composition (Keatley et al., 2008). Glacial advances in the high country may influence ice cover over high country lakes through increasing ice cover in an area.

Light influences the ratio of planktics to benthics within the water body. High light levels encourage planktonic diatom growth as well as benthic growth, allowing nutrient uptake for all organisms (Battarbee, 2000), increasing productivity. Lower light levels limit growth and productivity for diatoms. In New Zealand, light levels may be dependent on ice presence and cover and the depth of the water body.

Wind is another variable applicable to the New Zealand high country. Winds acting on water body can cause fluctuations in water depth and turbulence (Bradbury, 1986; McCabe and Cyr, 2006). This can result in compositional changes for benthic taxa (Battarbee et al., 2001) as well as promoting growth of some planktonic diatoms by allowing them greater motility (Round et al., 1990). Wind can also create upwelling or re-mixing of nutrients, increasing diatom productivity (Anderson, 2000). Wind strength and direction are dependent on climatic and geographical factors. A high country lake such as Lake Hawdon is strongly influenced by a variable such as wind. The Southern Alps west of the lake play an important role in the region's climate, controlling precipitation and evaporation. High winds can greatly influence that ratio between precipitation and evaporation (Battarbee, 2000) for a water body.

Chemical factors

Two chemical factor variables are of major importance to diatom growth and presence in a water body; nutrients and pH. The key nutrients for diatom growth and productivity are nitrogen, phosphorus and silica (Battarbee et al., 2001; Reid, 2005; Tibby, 2004; Tilman et al., 1982). All three elements have been described as limiting nutrients (Battarbee et al., 2001; Tilman et al., 1982). Nutrient availability is dictated by surrounding geology, vegetation cover and weather systems within the region (Bradbury, 1986). The pH is an important controlling variable on species composition in freshwater systems (Battarbee et al., 2001), as pH controls chemical and bio-chemical processes in a water body.

Nitrogen is a nutrient element that taxa will respond to positively (growth) or negatively (little growth) (Michel et al., 2006) with preferences being species specific. The majority of nitrogen is delivered to a water body through decomposition of local vegetation and regional geology through sediment influx (Bradbury, 1986; Michel et al., 2006).

Phosphorus availability creates changes within the planktonic diatom community, as well as the benthic diatoms (Battarbee et al., 2001). This change is typically seen by an increase in the ratio of planktonic to benthic diatoms in sediment cores (Battarbee et al., 2001). The ratio and presence of diatoms in cores can also be dependent on the ratio between silica and phosphorus (Tilman et al., 1982). When the ratio of silica to phosphorus is high, diatoms should dominate, and when the ratio is low, diatoms should be rare (Tilman et al., 1982). Silica regulates the size of phytoplankton crops and can also influence species composition through varying abilities of planktonic diatoms to compete for silica and phosphorus (Battarbee et al., 2001).

The pH can influence diatom community structure at local and regional scales (Anderson, 2000) as studies have shown that diatoms are particularly sensitive to high and low pH levels in a water body (Bradshaw et al., 2000). Locally pH can govern the growth of certain taxa in a water body, whilst limiting other taxa that are intolerant to certain levels of pH. Regionally pH can influence diatom community structures within a water body, e.g. endemic taxa restricted to mire pools in sub alpine conditions in the South Island of New Zealand where pH values are low (acidic) (Kilroy, 2007).

Hydrological factors

There are three main hydrological factor variables that apply to water bodies, especially in the High Country of New Zealand: lake morphology, the drainage basin (Smol and Cumming, 2000) and inflow/outflow ratios (Battarbee, 2000; Smol and Cumming, 2000). Lake morphology is dictated by the geology and surrounding geomorphic features (Bradbury, 1986), and may govern the amount of nutrient available to diatoms. A large deep lake may limit growth of some benthic taxa, by limiting nutrient supply and light for growth.

The size of the drainage basin can influence diatom composition and community structure. Large drainage basins tend to amplify changes in precipitation in closed water body systems, whilst smaller drainage basins may have little or no influence on water levels within the water body (Smol and Cumming, 2000). The size of the drainage basin will also influence the amount and source of sediment entering the water body. A large drainage basin, for instance, may travel through a limestone area, influencing the composition of nutrient elements entering the water body.

Inflow and outflow is an important variable that needs to be identified at modern water bodies if they are to be cored for analysis, as they influence chemical factors such as nutrient input and organic material (Smol and Cumming, 2000). Inflow and outflow are linked to lake morphology and drainage basin. A closed system will have little or no outflow (Smol and Cumming, 2000) which will in turn influence water depth, light availability (Smol and Cumming, 2000), nutrient supply (Battarbee, 2000) and as a result, diatom composition.

1.3 Utility of palaeolimnological studies

Palaeolimnology is the study of the physical, chemical, and biological information stored in lake deposits (Smol et al., 2001). The study of lakes allows multi-proxy analyses to be carried out, studying the chemical characteristics, isotopic variability, pollen, phytoliths and diatoms that are stored in the lake sediment. With this multi-proxy approach, one can generate detailed palaeoecological information and infer climatic changes (Battarbee, 2000). Almost any lake will have stored information (Round et al., 1990), making palaeolimnology an excellent global climatic and scientific tool.

The accumulation of sediment over time incorporates many biological communities from within the lake as well as the surrounding catchment area (Smol and Douglas, 2007), allowing insight to several indicators subject to environmental changes. The study of palaeoecology allows an important question to be posed; what causes rapid changes in species composition in space and time? (Heegaard et al., 2006) Generally a more informed, detailed and reliable answer can be generated from multi-proxy evaluation than from a single record.

The study of palaeolimnology allows the use of multiple proxies to determine the importance of various environmental controls on biological indicators (Larocque and Bigler, 2004). Palaeolimnology has become increasingly important with the requirement for a greater understanding of changing climates, as this research technique allows insight to the spatial and temporal patterns of climatic change at local, regional and global scales (Smol and Cumming, 2000). Diatoms are an effective palaeolimnological tool as they have short cell cycles and rapidly colonise new habitats, therefore, assemblage changes represent rapid response to environmental change (Cochran, 2002; Reid et al., 1995). Smol and Cumming (2000) also highlight the importance of gathering data and information qualitatively and quantitatively, as both contribute to sound palaeoecological, and hence, palaeoenvironmental interpretations. Qualitative analysis allows taxon information to be collected (Smol and Cumming, 2000), increasing knowledge of diatom taxonomy and ecological preferences whilst quantitative analysis allows statistical methods to verify the factors and variables that control diatom presence (Bigler and Hall, 2002).

1.3.1 New Zealand studies of palaeolimnology and palaeoecology

Within New Zealand historical studies have focussed on palynology (the study of plant fossils) and charcoal for determining regional environmental changes through time. New Zealand diatom studies have largely focussed on the modern day (Kilroy, 2007; Vanhoutte et al., 2006; Vyverman et al., 1998). Reid (2005) has used modern diatom assemblages from 53 lakes across New Zealand to create a transfer function for reconstructing past water conditions. A transfer function is a series of statistical tests carried out on fossil sample data against modern data in an attempt to reconstruct past conditions based on modern analogues. Reid highlighted chlorophyll α, total phosphorus and dissolved reactive phosphorus as strongly correlated with diatom species distribution. Hawes and Smith (1994) studied diatoms in Lake Taupo, focussing on the physical and chemical changes within the littoral zone. Cochran (2007) is one study that has successfully used diatoms as a palaeoenvironmental technique for detecting past seismic events in the North Island. The use of diatoms as a proxy enabled a high resolution study of individual co-seismic events in the Wellington region. Foged (1979) and Cassie (1989) have recorded New Zealand diatoms in modern samples from various water bodies around New Zealand, but there has been little work to extend their efforts.

In Auckland, anthropogenic impacts were analysed at Lake Pupuke (Augustinus et al., 2006). They were able to infer anthropogenic changes around the lake from sediment geochemistry and palaeoecological changes in the diatom community and pollen assemblages, suggesting that diatom interpretations in such studies are possible. Harper and others (1986) used diatoms to investigate the effects of water depth and tephra deposits within Lake Poukawa, Hawkes Bay. They highlighted a positive response by some taxa to the tephra deposition, especially from epipelic and planktonic diatoms. In Northland a study carried out by Newnham and others (2004) successfully carried out a multi-proxy study using a variety of developed palaeolimnological techniques. The palaeolimnological techniques allowed them to provide a reconstructed history of the lake and of the region (Newnham et al., 2004), similar to the objectives of the Lake Hawdon project. Pollen changes in the core were indicative of a cooler climate during the Last Glacial Maximum. Diatom changes were interpreted as the lake being a shallow alkaline lake for much of its history due to the strong presence of the small *Fragilaria* species (such as *Pseudostaurosira brevistriata*).

New Zealand, in particular the South Island, is a prime location for examining the global extent of climate change (Alloway et al., 2007; Vandergoes et al., 2005). Palaeoclimate studies have been a growing research area in New Zealand due to its location within the Southern Hemisphere in relation to the westerly circulation system (Alloway et al., 2007; Marra et al., 2004). The size of New Zealand and the oceanic climate (Alloway et al., 2007; Reid, 2005; Williams et al., 2005) makes the landmass a prime location for environmental change studies because it is particularly sensitive to changes in various climatic systems. This enables changes at local and regional scales to be collated to provide a greater understanding of past environmental conditions within the Southern Hemisphere. Changes in the position of the El Nino/La Nina weather patterns have been investigated (Fowler et al., 2008). Theories of changing location of weather cells (Sterken et al., 2008) have been proposed in the Quaternary in the Southern Hemisphere, which supports other papers suggesting climatic shifts resulting in stronger climate patterns over some landmasses (Bradbury, 1986; De Batist and Fagel, 2008; Fagel et al., 2008).

Palaeoclimate studies in New Zealand have shown that there is great geographical complexity (Lorrey et al., 2008) within the record and many varied inter-regional climate histories have been inferred as a result. Topography plays a significant role in climatic changes over regions within New Zealand, highlighting how complex and intricate reconstruction of broad climatic patterns can be. West Coast research suggests one set of controls such as precipitation influencing changes through time, whilst east coast sites display a range of other controls resulting in changes different to studies at similar latitudes on the West Coast. McGlone and others (2004) highlighted that in the Cass Basin during the Late Glacial tall temperate trees replaced shrubland and grasses ca. ~ 12 kyr, whilst on the West Coast, Vandergoes and others (2005) have significant tree pollen prior to the time frame in the Cass Basin.

Attempts have been made to reconstruct Last Glacial Maximum weather conditions on a country-wide scale (Drost et al., 2007). Drost and others (2007) proposed that changes in temperature and wind regimes may have been the determining factors for vegetation growth in the South Island, and more importantly, increases in seasonality would have had the greatest effect on forest growth during the Last Glacial Maximum. The effective modelling technique used in such work is important for palaeoenvironmental studies, as weather patterns or climatic changes will often impact a water body. With such a paper, climate changes can be identified and broad inferences made over what climatic controls were seen in the lake record at Lake Hawdon.

1.4 Climate systems in New Zealand

Present day climate in New Zealand is dependent on several weather patterns. El Niño Southern Oscillation (ENSO) has been described as being the most potent source of inter-annual climate variability (Tudhope et al., 2001). The presence of ENSO is determined in New Zealand by changes in the Southern Oscillation Index (SOI) associated with changes in the location and strength of the Pacific convergence zone and the inter-tropical convergence zone (Sturman and Tapper, 2006). When the SOI becomes anomalously negative, El Niño conditions can be seen in the country where stronger westerly systems impact the country; strongly positive gives La Niña weather conditions which can bring warm wet weather to eastern parts of the country (Sturman and Tapper, 2006). Sturman and Tapper (2006) noted that the SOI and the pressure gradient over New Zealand can produce anomalous south – westerly airflow if you have a negative SOI and a positive SOI can produce north-easterly airflows over the country (Figure 4).

New Zealand’s maritime climate and dramatic topography combine to create a range of limnological conditions that differ to other parts of the world (Reid, 2005). The Southern Alps in the South Island are very effective at influencing prevailing westerly airflows to create a strong west to east precipitation (Alloway et al., 2007) and temperature gradient (Vandergoes et al., 2008). Regions on the West Coast will experience high amounts of precipitation where the average rainfall can exceed 16 000 mm a year whilst parts of the east coast of the South Island can receive less than 350mm of annual precipitation (Alloway et al., 2007). This can be seen in the limnological record from Reid (2005) where Lake Moreaki on the West Coast plotted quite separately from central South Island Lake Hayes.

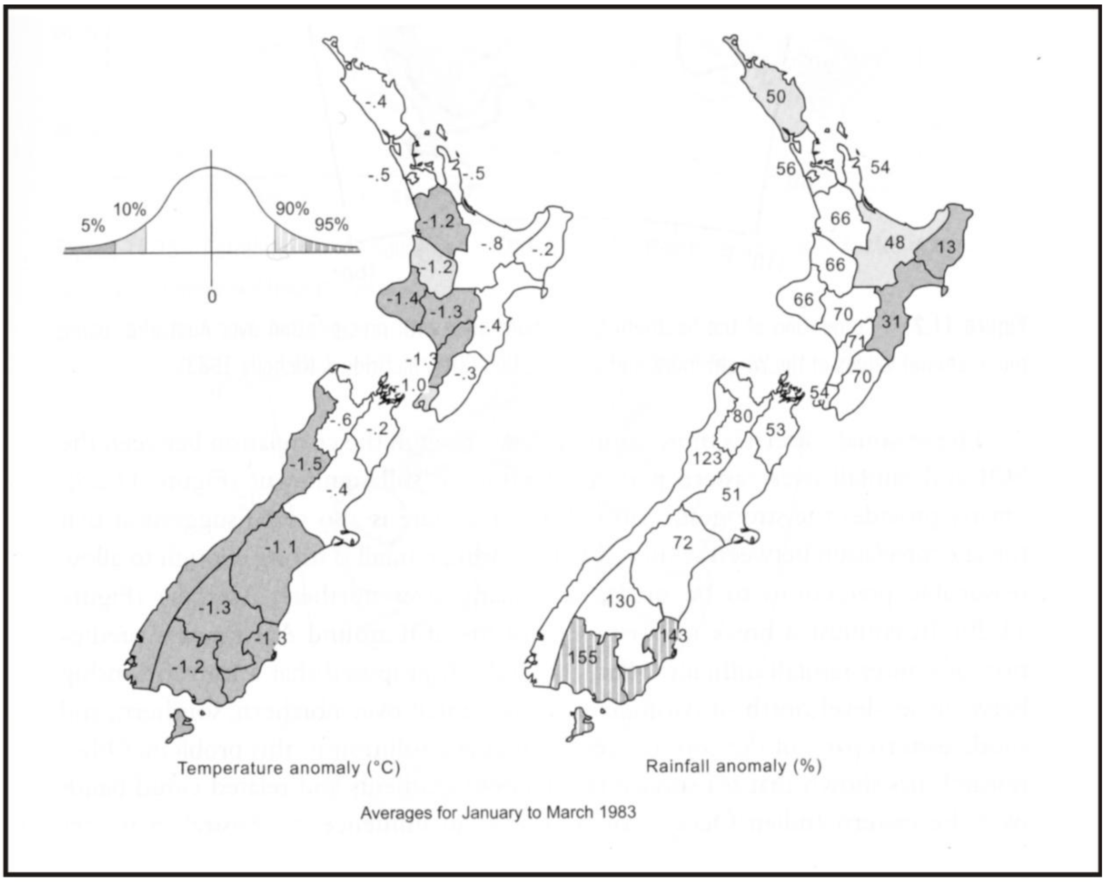


Figure 4. The relationship of the Southern Oscillation Index (SOI) in New Zealand, which influences temperature and precipitation over the country (Sturman and Tapper, 2006).

1.4.1 Late Quaternary climate systems

New Zealand climate in the Late Quaternary has been of great interest. Alloway and others involved in INTIMATE (2007) highlight the need for high resolution palaeo-climate records from southern mid-latitude sites as essential for establishing inter-hemispheric climate change (Figure 5). Southern New Zealand has been highlighted as a prime location for examining such inter-hemispheric links in climate (Vandergoes et al., 2005). Several studies (McGlone, 2005; Shulmeister et al., 2005; Vandergoes et al., 2005; Williams et al., 2005) have used various proxies and dating techniques to understand the timing and magnitude of climatic shifts seen in regions across New Zealand. Other studies have attempted to model past weather patterns across New Zealand based on the numerous proxy studies (Drost et al., 2007).

Climate change during the Last Glacial Maximum (LGM), according to Drost et al (2007), included significant changes in temperature on the east coast of the South Island. They also proposed that a shift in the precipitation band across the South Island reduced the amount of precipitation falling in the Southern Alps region, increasing rainfall on the West Coast of the South Island. This model put forward by Drost et al (2007) appears in agreement with Shulmeister et al (2004). They put forward changing circulation patterns across the Southern Hemisphere that would create three main responses; changes in the intensity of the circulation, changes in the main latitudinal track of the circulation and changes in the position of blocking highs on the dominant westerly system (Shulmeister et al., 2004).

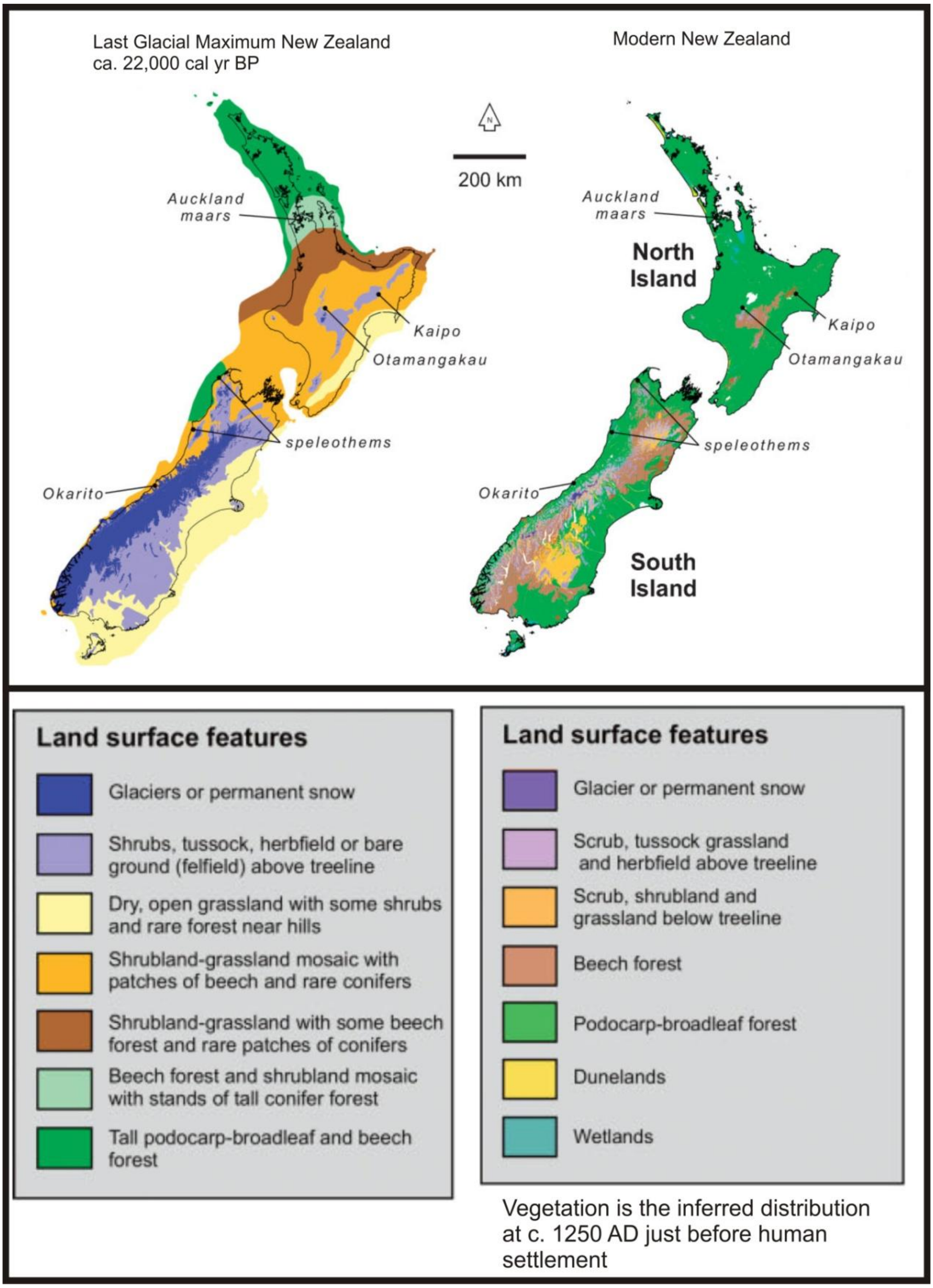


Figure 5. Topography, glaciers and vegetation zones, and location of existing and proposed high-resolution climate record sites in New Zealand. Inferred environmental changes at the Last Glacial Maximum are significantly different from modern day (Alloway et al., 2007).

A greater understanding on New Zealand's role in the global past climate debate was another point of interest for this projects research. The extent of the teleconnections between the Northern and Southern Hemispheres at the Late Glacial Interglacial Transition (LGIT) remains an extended debate within the scientific community (De Batist and Fagel, 2008; McGlone et al., 2004; Turney et al., 2003). More research from the Southern Hemisphere can only add to the knowledge and understanding of past environmental conditions. Shulmeister and others (2005) highlighted that the Southern Hemisphere signal is dominated by the Southern Ocean and Antarctic and tropical signals rather than teleconnections with the Northern Hemisphere.

With further research focussing on the LGIT, more information can be collated to compile a comprehensive and detailed understanding of regional climate and environmental changes in New Zealand, and add to the global climate change story. This research will allow a greater understanding of the response of New Zealand environmental systems to climate change, especially during the termination of the last ice age and contribute to the NZ-INTIMATE research highlighted by Alloway and others (2007).

1.5 South Island Geology

New Zealand is divided into an Eastern and Western Province (see Figure 6). The Eastern province includes the Torlesse and coeval terranes, thought to have been part of an extensive, largely Mesozoic belt deposited along the margin of Gondwana (MacKinnon, 1983). The Western Province consists of Palaeozoic sedimentary rocks and a variety of crystalline rocks of Late Precambrian to Cretaceous age, thought to have originally formed part of the Gondwana continent (MacKinnon, 1983). The presence of extensive faulting systems such as the Alpine Fault, have influenced the Eastern Province rocks to create a re-curved arc structure seen in Figure 6.

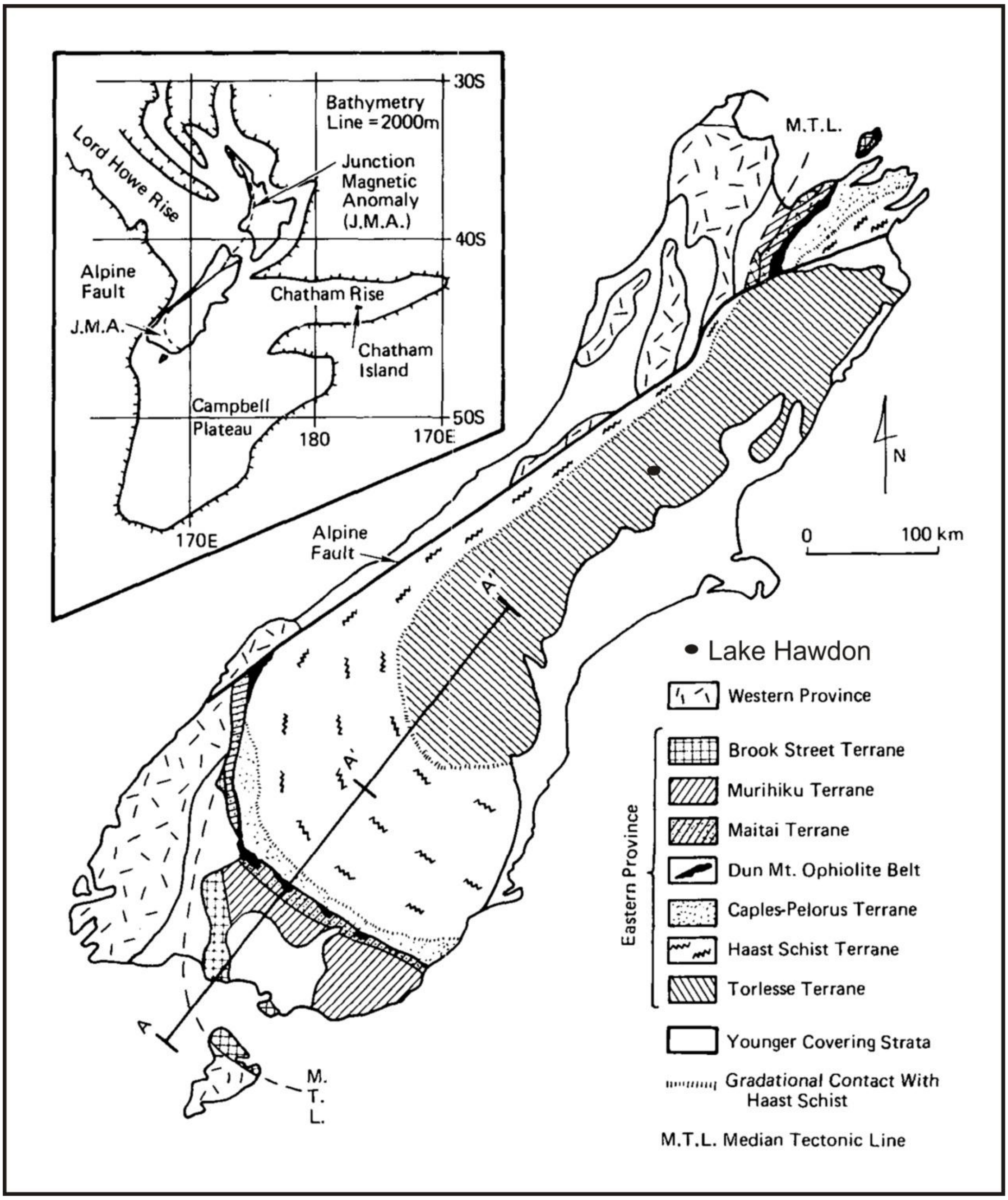


Figure 6 - A geologic map of the South Island, NZ showing the Western and Eastern Provinces and the various terranes in the Eastern Province (MacKinnon, 1983).

1.5.1 Regional geology

The Rakaia Torlesse terrane dominates the geology of the Cass Basin, commonly known as the Torlesse greywacke (Bradshaw, 1977). The Torlesse terrane is part of the Rangitata Sequence which is late Palaeozoic to Mesozoic in age (Bradshaw, 1977; MacKinnon, 1983). The Torlesse greywacke in the Cass basin area varies between marine and non-marine in origin, and sandstones, siltstones, mudstones and volcanic associated deposits can all be found in the surrounding area. The Torlesse surrounds Lake Hawdon on three sides, with the remaining valley basement geology obscured by post glacial outwash deposits (Figure 8). Local geology will affect and influence sediment deposition and influx (Bradbury et al., 2004) into Lake Hawdon, and the weathering processes of the surrounding bedrock will govern elements and nutrients entering the lake. Fine grain sizes due to weathering will influence light availability for benthic diatoms (Battarbee, 2000; Smol and Cumming, 2000) and the availability of nutrients to micro-organisms.

Faults are evident in the area, with a thrust fault running directly through Lake Hawdon (Quigley pers. comm., 2010). There has been little research into the faulting immediately surrounding the lake in terms of the timing of rupture events and the degree of movement. There is, however, present research at the University of Canterbury that may provide more insight into faulting in the area.

1.5.2 Glacial History of the Waimakariri and Cass Basin

The glacial history of the Waimakariri and Cass Basin is well recognised, although little has been published. The first New Zealand glacial sequence describing multiple events was carried out by Gage (1958), and this glacial sequence has been used as a reference for other eastern South Island locations (Suggate, 1990). There are two advances that are of importance to the area immediately around Lake Hawdon, the Poulter and Blackwater. Both are correlated to the Otira Glaciation (Gage, 1977) (Table 2). The landscape in the area contains numerous glacial and post-glacial landscape features (Figure 8), indicative of extensive ice presence within the basin (Gage, 1958).

Waimakariri glacial sequence	**Ltihostratigraphic equivalent**	**NZ correlation**	**Ages** from Fitzsimons 1997
Poulter Advance	St Bernard Formation	Otira Glaciation	9 – 12 ka BP
Blackwater Advances III	Burnham Formation	Otira Glaciation	18 ka BP
II			22 ka BP
I			29 ka BP

Table 2. Late Quaternary Early Holocene Glacial Events seen in the Lake Hawdon area. Glacial sequences and lithostratigraphic equivalent are adapted from Gage (1977), and ages are taken from Fitzsimons (1997) based on weathering rind values.

The following information on the advances is taken from Gage (1958) with additional information about Lake Speight (Figure 8), a Poulter advance lake, taken from Gage (1977).

Blackwater Advances:

- Abundant evidence of the successive glacial events occurs in the Cass region. Moraines and outwash gravels indicating two main advances separated by an important recession and possible followed by a third minor re-advance are widespread in the Waimakariri Valley.
- Evidence for a later small advance is demonstrated by a small inner moraine loop in Winding Creek and a small area of outwash near Lake Marymere, but is not compelling (Figure 8).
- Blackwater II was the final occasion when all three main distributary lobes functioned, the Waimakariri, the Poulter and the Esk (Figure 8)
- Lakes within the area (Hawdon, Marymere, Blackwater) (Figure 8) formed in glacial troughs during the recession of the Blackwater event.

Poulter Advance

- Two distinct pulses of advance occurred, separated by a minor retreat and a period of stagnation.

For a short period after the final ice retreat from the main valley glacial Lake Speight (Figure 8) extended from the end moraines near the Poulter River mouth upstream to beyond the Hawdon River. The whole system of Lake Speight shorelines are tilted slightly downstream, possibly due to isostatic response to the removal of ice or due to tectonic movement within the area. Lake Speight was first described by Gage in 1958 and is evidence to suggest a second Poulter advance. The lake would have extended behind a terminal moraine, which is shown by a series of lake benches on the northern side of the Waimakariri River in the valley (Figure 8).

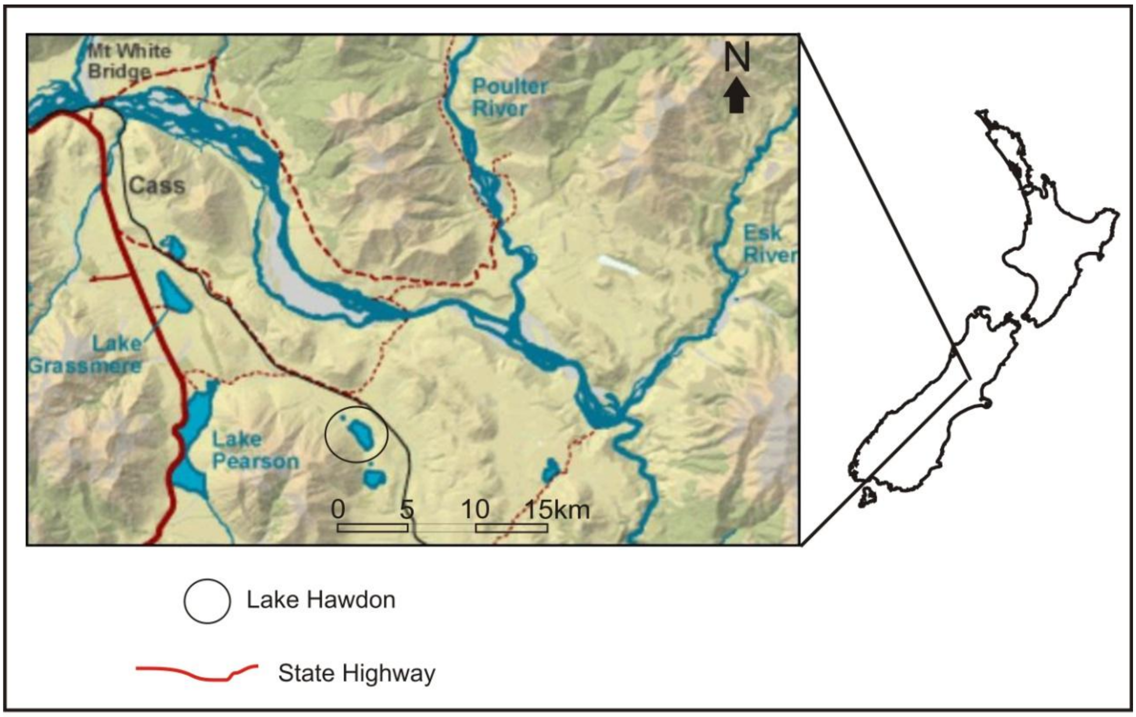


Figure 7 – The location of Lake Hawdon in the Canterbury High Country, New Zealand

1.5.3 Lake Hawdon

Lake Hawdon (43°06’11.65”S 171°50’57.58”E, 580m a.s.l), is located in the Canterbury High Country in the South Island of New Zealand (Figure 7). Lake Hawdon is part of an extensively glaciated area just east of the Southern Alps. The lake is bound by basement rock known as Torlesse greywacke (Bradshaw, 1977) and separated from Lake Marymere by an ablation moraine (Figure 8) and outwash gravels from the retreat of the second Blackwater advance (22 kyr) (Figure 8; Table 2) (Gage, 1958). At the northern end of the lake, a delta has prograded into the lake (Figure 10).

Modern temperature records from Cass have recorded the mean annual average temperature at 9°C and mean annual precipitation at 1300 mm (Greenland, 1977).

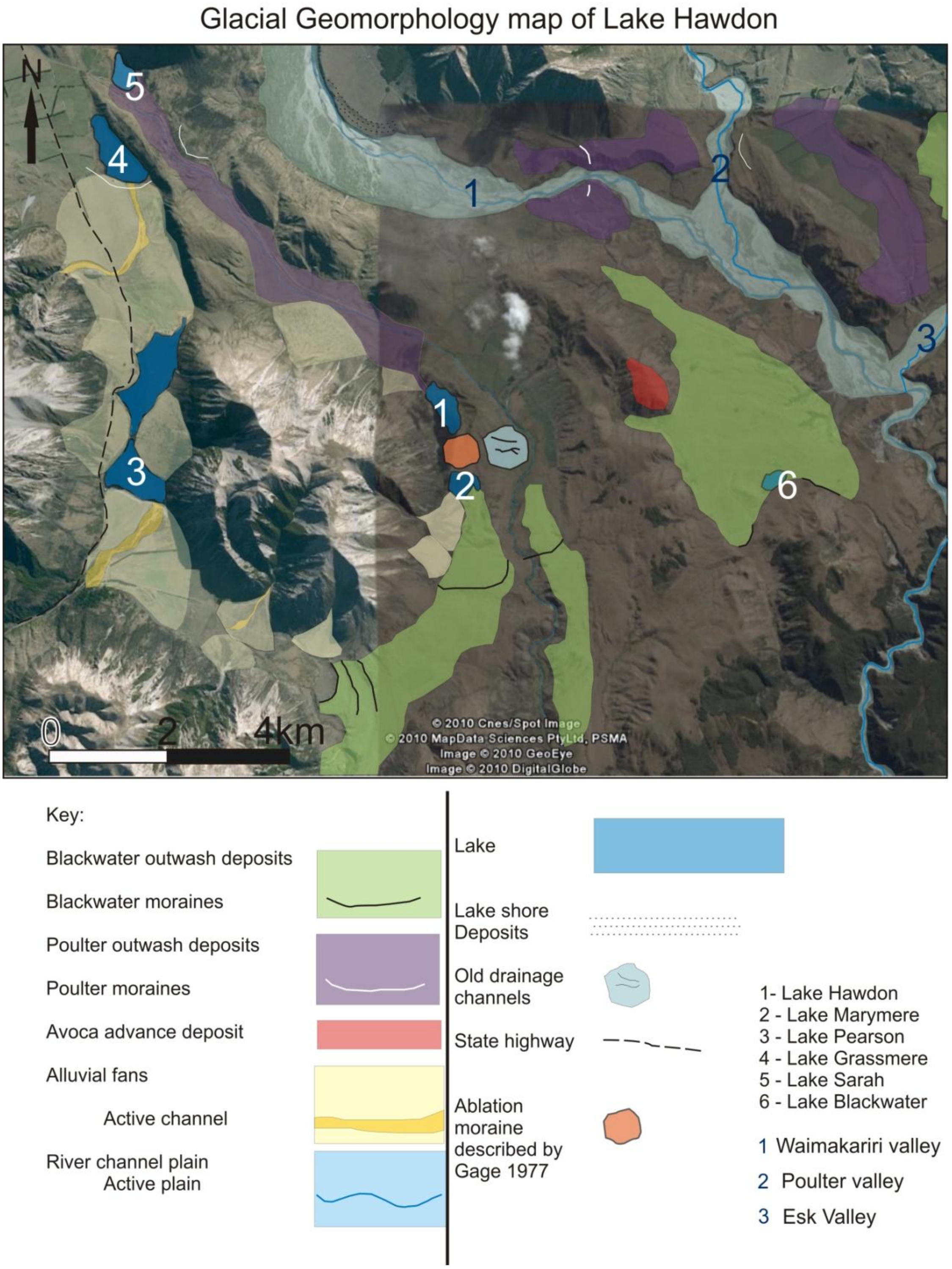


Figure 8 – Glacial geomorphological map (overlaying Google Earth image 2010) of the Lake Hawdon area. Positions of glacial advances are according to Gage (1958).

1.6 Aim of this research

The project set at Lake Hawdon was collaborative work between Queen’s University Belfast and the University of Canterbury. The project’s aim was to create a multi-proxy study for the east coast of the South Island with a focus on the Late Glacial Interglacial Transition.

The Late Glacial Interglacial Transition is of international interest because changes in the Southern Hemisphere do not appear to be in accord with changes seen in the Northern Hemisphere. Debate remains as to which hemisphere leads and the degree of their synchrony or asynchrony (De Batist and Fagel, 2008; Turney et al., 2003), or even what the linkages are.

The author’s role in this project was to study the diatoms from Lake Hawdon. The aim was to investigate the use of diatoms as a proxy in a high country lake. It is hypothesised that a high resolution study should highlight environmental changes for Lake Hawdon and potentially might enable changes to be seen that are not visible with other proxies such as pollen and chironomids. Statistical analyses were carried out to investigate quantitatively if environmental variables can be recreated from fossil diatom samples. If changes in diversity and abundance indicate environmental changes in Lake Hawdon, these changes should be seen qualitatively and quantitatively.

2 Methodology

Many components mentioned below have been carried out by the members of the Lake Hawdon project group. Core descriptions, pollen, chironomid, beetle, XRF and carbon dating were all carried out at Queen's University by Nicola Whitehouse, Craig Woodward and Jenny Watson. As a result sections of this chapter are an account recorded by those members.

2.1 Coring

10 cores were taken from Lake Hawdon in the summer of 2007 by the Queen's University Belfast team from the northern end of the lake (Figure 9). The bog immediately adjacent to the lake margin was sampled using a Russian corer for the upper sediments (LH2) 0 – 450 cm, and a Livingston corer was used to collect the deeper, clay and silt rich sediments (HZ) 430 – 520 cm. Cores HZ and LH2 were taken 40cms apart and were initially correlated using a distinctive transition between *Myriophyllum* and *Isoetes* silts and sandy organic silts. The remaining cores were taken in the immediate area to the first two, and were correlated based on the lithologic transitions and through magnetic susceptibility. Ten lithological units were identified from the cores, and samples were taken from the cores to carry out analysis of the beetle remains, chironomid identification, and pollen and diatom analysis (Figure 11). Other samples of the core were taken for geochemical analysis and radiocarbon dating, from which 36 dates have been obtained. Diatom samples were taken from cores HZ, HD and LH2/2 which were then correlated to the master core.

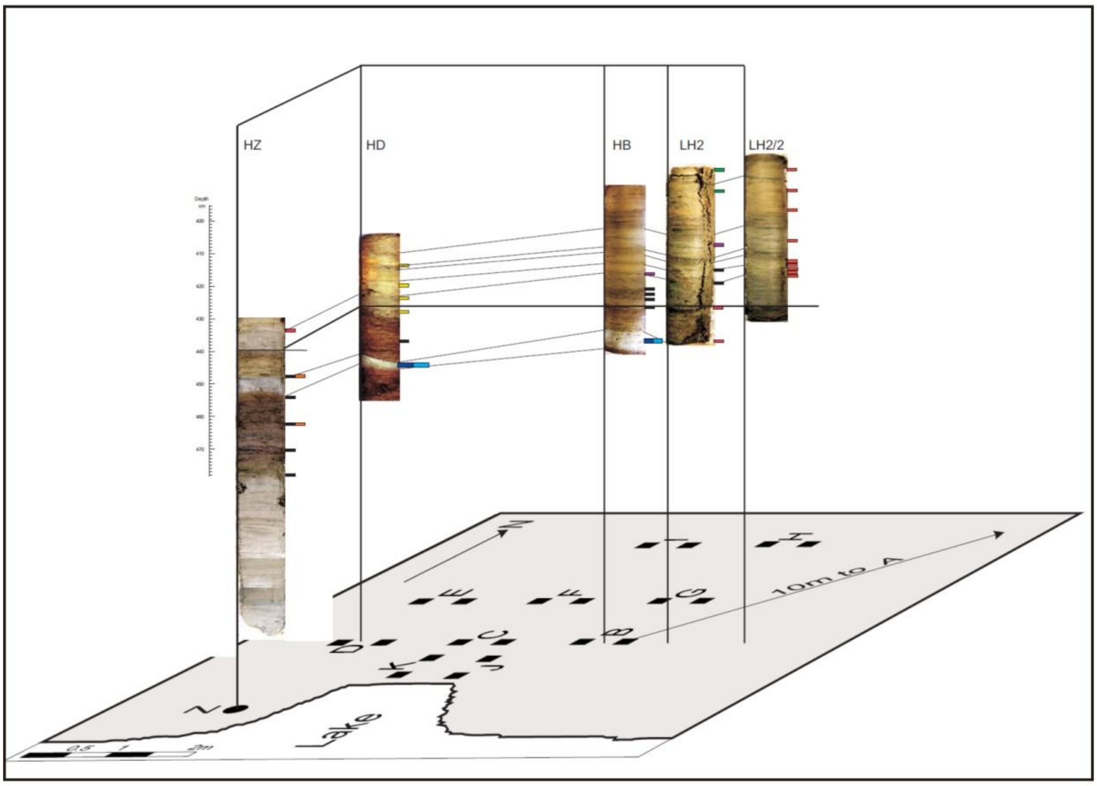


Figure 9 – Original core location in 2007. ‘Lake’ highlights the edge of Lake Hawdon. Letters represent the core locations, with diatom samples collected from HZ, HD and LH2/2. (Image courtesy of Jenny Watson, project member)

A second coring trip was made by the author in April 2009, where a core was taken to obtain surface sediment information and gather samples for a modern diatom assemblage (Figure 10). 21 samples in total were taken from the gravity core and the top 3 samples of 1cm increment, were taken for processing and counting. The 3cm of sample were taken from below the water sediment interface to allow for potential disturbance and macrophyte growth. These samples were processed in the same manner as the diatom samples from cores HZ, HD and LH2/2 described below. Recordings were made whilst out on Lake Hawdon so that water pH, conductivity, water depth and salinity measurements could be recorded at the same site as the gravity core was taken.

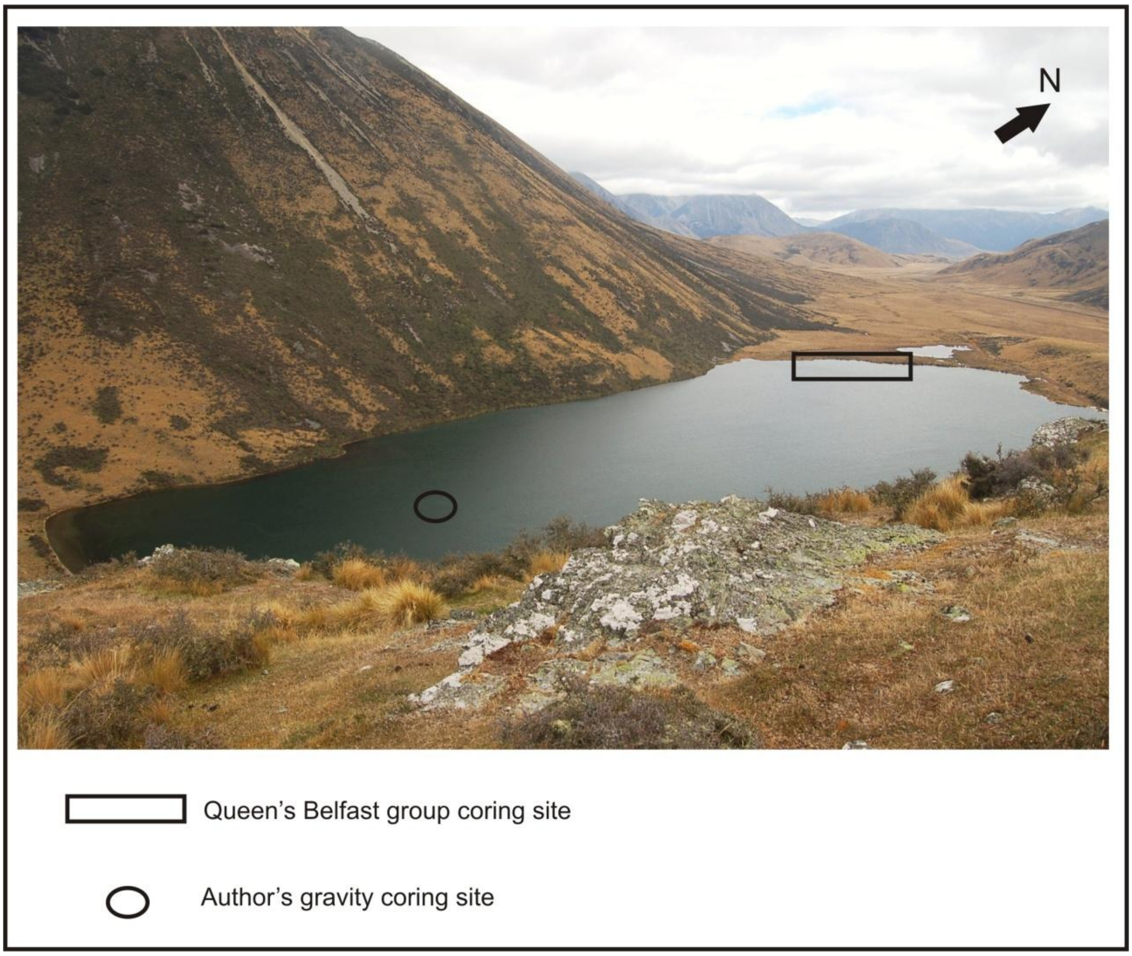


Figure 10 - Highlighting the locations of cores taken at Lake Hawdon.

2.2 Diatoms

Sediment samples for diatom analysis were sent over from Queen's University in 2008, and processing occurred during 2008 and 2009 by the author, following Cochran (Cochran). Samples were washed with potassium hydroxide and concentrated hydrochloric acid to remove carbonates and organics before being centrifuged. Samples were then shaken to remove sand particles and clay was removed with the use of Calgon ™. Samples were then mounted on glass slides with the use of Naphrax™. For in-depth processing procedure see appendix.

Individual diatoms within the sample were counted and identified using light microscopy and differential interference contrast (D.I.C.), both at the University of Canterbury and the University of Adelaide. A total of 400 valves were counted from each of 85 samples taken from HD, HZ and LH2/2 that were correlated with the master core. Valves were identified to species level where possible, or to genera where identification was not possible. Taxa were identified using standard texts i.e. (Krammer and Lange-Bertalot, 1991a; 1991b; 1999a; 1999b), and (Cassie, 1989; Foged, 1979) for the New Zealand diatoms.

Diatom stratigraphy was carried out in C2 (Juggins, 2007). Taxa that represented more than 2% of the assemblage were included in the interpretation (Figure 12). Diatom abundance was shown as percentage values after transforming the data. The data was drawn in bar format to highlight actual values through the core. Diatom taxa were assigned names recognised by Algaebase (Guiry and Guiry, 2010) to maintain current name classifications and diatom ecological preferences were identified using Van Dam (1994) and Renburg (1982) and were graphed in a similar manner to the diatom stratigraphy in C2. Ecological groupings were recorded in C2 with as much data about diatom taxa as available after extensive literature review, however some ecological data for Lake Hawdon taxa is absent.

2.3 Chronology

Other team members submitted thirty six samples to the ^{14}CHRONO Centre, Queen's University Belfast for ^{14}C AMS radiocarbon analysis. A variety of sample sizes and types of samples were analysed due to the low level of terrestrial organic material found in Lake Hawdon, producing a multi-sample comparison for possible reservoir effects from bulk dates and aquatic macrofossils. Samples were taken from <90µm fraction, >90µm, >500µm, >90µm <500µm, sedge epidermis, bulk sediment, pollen concentrate and *Phyllocladus* leaves. The raw 14C dates were adjusted for the Southern Hemisphere offset of 56 ± 24 years (McCormac et al., 2004), and calibrations were performed using the CALIB REV 5.1 Beta in conjunction with the IntCal04 calibration curve (Reimer et al., 2004).

2.4 Statistics

Statistical analyses were carried out in C2 software (Juggins, 2007), PAST (Hammer et al., 2001), CANOCO 4.5 (ter Braak and Smilauer, 1997) and the online reconstruction using the European Diatom Database (EDDI) (Juggins, 2010). Ecological groupings were based on Northern Hemisphere ecological data (Renberg and Hellberg, 1982; Van

Dam et al., 1994). Various statistical techniques were generated to create a robust quantitative analysis of the diatoms from Lake Hawdon. In C2, statistics such as Hill's No were recorded as it allows the detection of effective number of occurrences (Reid, 2005) from Lake Hawdon to be collated (appendix).

A Shannon diversity index (H') was generated to measure the diversity within the diatom community. Shannon diversity is a measure of diversity calculated using the following equation:

$$= - \sum P_i In P_i$$

Where P_i is the proportion of the ith taxon in sample (Woodward, 2006).

A Detrended Correspondence Analysis (DCA) was carried out for the Lake Hawdon diatom samples to determine the gradient length for taxa at the site and assign various methods to run against the data. According to Birks (1995; 1998) a gradient length less than 2 standard deviations suggests the use of methods based on linear models such as Principal Components Analysis (PCA) whilst gradient lengths greater than 4 standard deviations suggest the use of methods based on uni-modal modals such as Correspondence Analysis (CA) or DCA to be run. The gradient length was such that a Principal Component Analysis was performed for Lake Hawdon. Tests were performed to investigate the effect of removing rare species from the statistical analyses (Table 4). The PCAs were run for the Lake Hawdon samples with rare species removed and included respectively. The addition of rare species did not adversely affect the performance of the PCA (Table 3) so they were included in the final analysis.

PCA allows the study of multivariate correlations in diatoms (Theriot, 1992) and it allows linearly correlated variables to be studied. PCA allows the discovery of groups where species can be grouped without necessarily being identified together, and can simultaneously identify the relative contribution of size dependent and size-free variation to species discrimination (Theriot, 1992). PCA was run for the other proxies recorded at Lake Hawdon in an attempt to identify the environmental variables that influence the proxy data along axes one and two.

The next stage was to test the fossil diatom samples with modern data. Lake Hawdon samples were synchronised with modern-day training sets from Europe and run through CANOCO to test the similarity in a PCA plot. Fossil and modern data should have plotted well against each other, overlapping points on the PCA plot. The EDDI dataset and Lake Hawdon diatom samples did not overlap in a PCA plot, suggesting that the application of a transfer function would be unsuccessful. See discussion 5.4.4 for explanation for the failure of generating a transfer function.

3 Results

3.1 Sediment

Unit 1 480 – 470 cm
Golden brown organic silt. *Myriophyllum* fragments and *Isoetes* megaspores dominant.

Unit 2 470 – 464 cm
Grey-brown organic rich silty clay. Monocot fragments dominant.

Unit 3 464 – 456 cm
Grey-brown organic rich silts. *Myriophyllum* fragments dominant.

Unit 4 456 – 450 cm
Pale grey sandy clay. Monocot fragments and *Isoetes* megaspores dominant with abundant *Trichoptera* cases.

Unit 5 450 – 440 cm
Grey-brown organic silt. *Myriophyllum* fragments and sedges dominant.

Unit 6 440 – 434 cm
Grey-brown sandy gyttja. Monocot fragments dominant.

Unit 7 434 – 427.5 cm
Cream brown silty gyttja. Thin rust coloured band in middle of unit. Monocot fragments dominant.

Unit 8 427.5 – 425 cm
Brown silty gyttja. Gradational contact with unit. Monocot fragments dominant.

Unit 9 425 – 418 cm
Cream brown silty gyttja. Gradational contact with unit 10. *Myriophyllum* and monocot fragments dominant.

Unit 10 418 – 395 cm
Orange – brown gyttja, some bands of sand and woody detritus. Sedges, *Myriophyllum* and monocot fragments dominant.

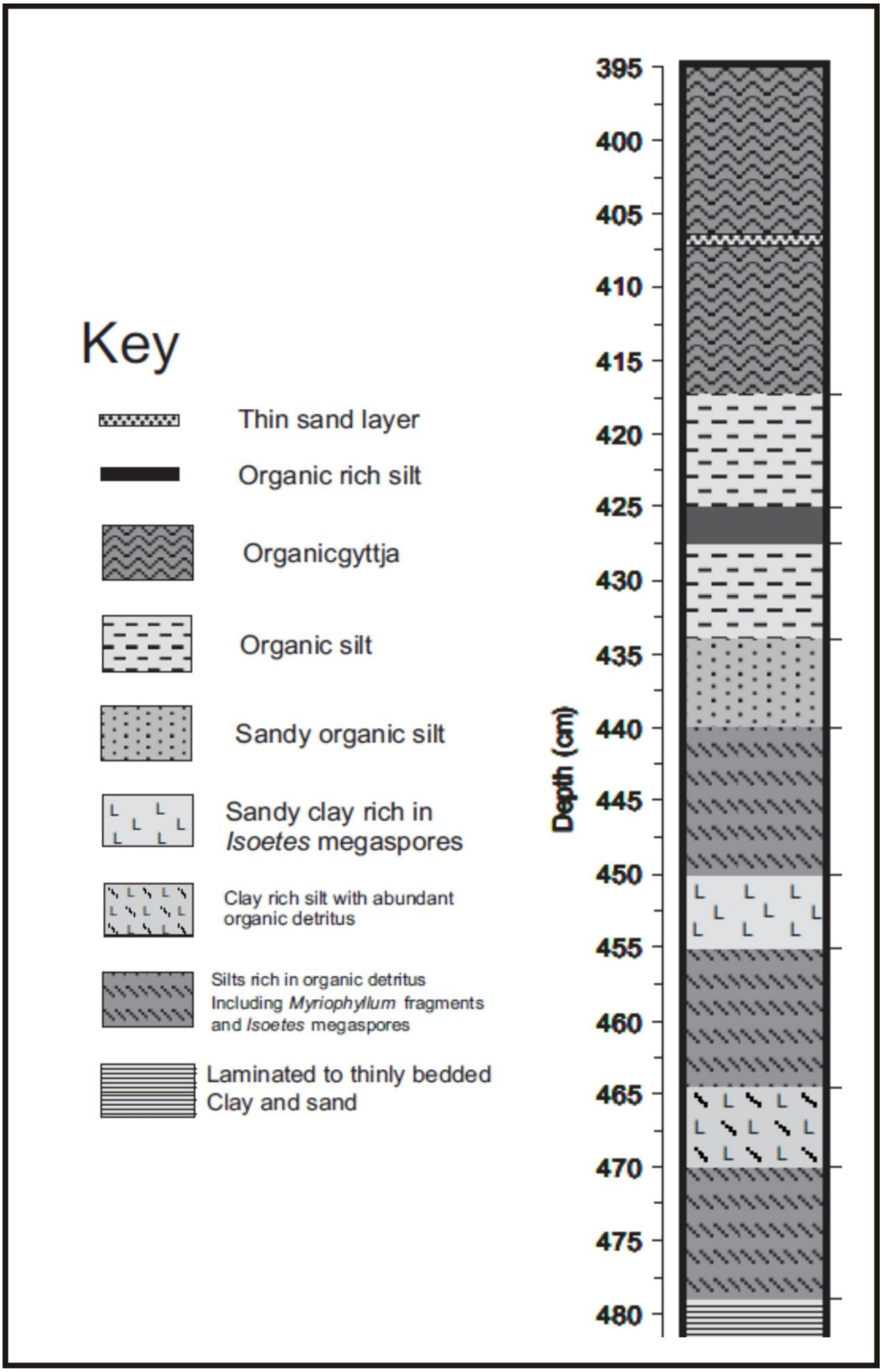


Figure 11. Stratigraphy of the master core taken from Lake Hawdon in 2007 (image courtesy of Craig Woodward, project member).

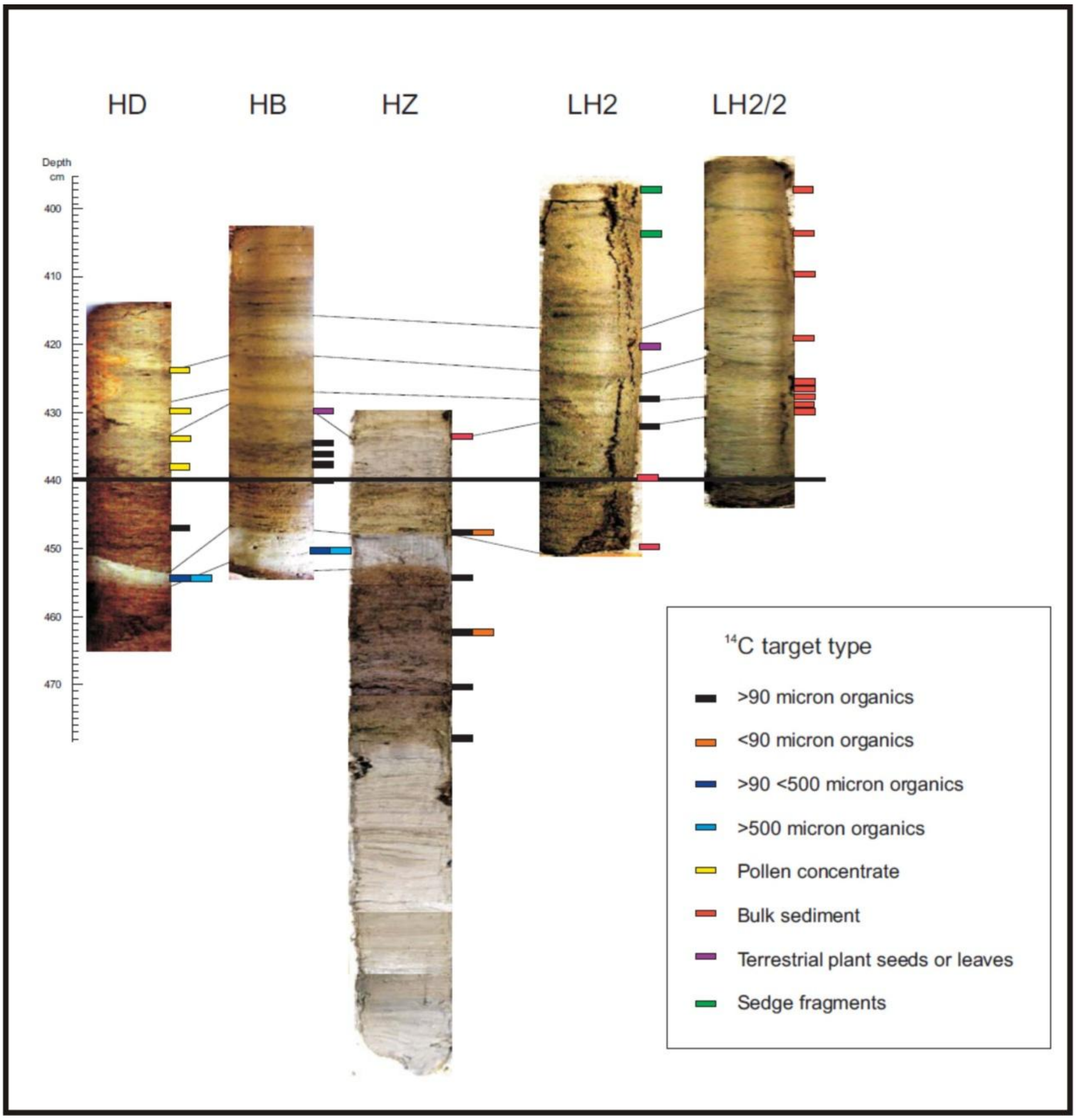


Figure 12. Correlation of the cores taken at Lake Hawdon in 2007. Diatom samples were taken from HD, HZ and LH2/2 and sample location for radiocarbon dates taken from five cores (image courtesy of Jenny Watson, project member).

3.2 Diatoms

103 diatom taxa were identified from the 85 Lake Hawdon samples. Of the 103 taxa, 47 that were present at values of more than 2% in at least one sample are displayed in the diatom stratigraphy diagram (Fig 13). Six zones have been identified.

Zone I - 478-467 cm *Pseudostaurosira brevistriata, Cocconeis placentula, Staurosirella pinnata* zone

Pseudostaurosira brevistriata peaks at 26% abundance. *Cocconeis placentula* is increasing near the top of the zone to 20% of the diatom abundance. *Staurosirella pinnata* peaks at 18% and remains constant through this zone. *Epithemia sorex* is present in low numbers, never exceeding 11%. *Gomphonema gracile* is present in low numbers at less than 7%, and *Grunowia sinuata* fluctuates but does not exceed 6%. *Cymbella cistula* is present throughout although numbers are low, and range from 0% to 4%. *Navicula cryptocephala* is represented in low abundance, never exceeding 4%. *Nitzschia amphibia* is present in low numbers and only in the lower part of the zone, and *Staurosirella lapponica* is present throughout this zone with abundance ranging from 4-7%. *Staurosira construens* fluctuate through the zone while *Staurosira construens* var *venter* fluctuates from 1 to 8%.

Zone II – 467 – 451 cm *Cocconeis placentula, Epithemia sorex, Pseudostaurosira brevistriata* zone

Cocconeis placentula continues to increase with a peak near the top of the zone at 45% abundance. *E. sorex* fluctuates before increasing to 29% abundance near the top of the zone. *G. sinuata* continues to fluctuate. *Karayevia oblongella* appears with an increase in abundance over 5% to 7%. *P. brevistriata* numbers fluctuate but and peaks at 26% abundance. *S. pinnata* fluctuates through this zone, peaking at 16% abundance, but is beginning to decrease. *Cymbella cistula* abundance is low, not exceeding 5% and *G. gracile* is present, but fluctuates between 0% and 6% abundance through this zone. *N. cryptocephala* is present in the lower half of this zone, with a peak abundance of 7%. *S. lapponica* and *S. construens* abundances are low, not exceeding 5% and 3%

respectively. *S. construens* var *venter again* fluctuates through this zone, with peak abundance at 13%.

Zone III – 451 – 437.5 cm *Pseudostaurosira brevistriata, Epithemia sorex, Cyclotella stelligera* zone

P. brevistriata significantly increases in abundance to 43% abundance near the top of this zone. *E. sorex* abundance peaks at 20% near the top of the zone. The planktonic taxon *Cyclotella stelligera* appears in low numbers, with a peak in the zone of 11%. *Karayevia oblongella* numbers fluctuate, peaking at 11% at the base of the zone whilst *Cocconeis placentula* has decreased in abundance, dropping to just 7%. *N. cryptocephala* numbers again fluctuate never exceeding 6%. *Staurosirella pinnata* numbers decrease to 5% abundance as do *S. lapponica* also decreases to 5% abundance. *Cymbella cistula* numbers remain low, never exceeding 5%, and *Achnanthidium minutissimum* appears, but has a low abundance percentage of 3%.

Zone IV – 437.5 – 434 cm *Pseudostaurosira brevistriata* zone

P. brevistriata is the dominant taxa with 85% abundance. *Cyclotella stelligera* numbers are increasing, with 20% abundance at the top of the zone. *S. pinnata* fluctuates, peaking at 12% near the base of this zone.

Zone V – 434 – 417 cm *Pseudostaurosira brevistriata, Cyclotella stelligera, Epithemia sorex* zone

P. brevistriata begins to decrease significantly, from 60% abundance at the bottom of the zone to 0.5% abundance near the middle of the zone. *C. stelligera* continues to increase through this zone, reaching 55% abundance near the top of the zone. *Epithemia sorex* also fluctuates, peaking at 22%. *C. pseudostelligera* fluctuates through this zone, but peaks at 22% abundance. *Karayevia clevei* appears in significant numbers, peaking at 14% abundance. *S. pinnata* appears in moderate numbers at the base of the zone at 14% abundance but then decreases significantly through the rest of this zone. *K. oblongella* numbers fluctuate, peaking near the top of the zone at 13%. *Encyonopsis microcephala* fluctuates, ranging from 0% to 13% abundance. *Cymbella cistula* increases in abundance through this zone, increasing to 10%. *Sellaphora bacillum* appears with two peaks, but does not exceed 7% abundance, and *Sellaphora pupula* also appears, but fluctuates, also peaking at 7% abundance. *Grunowia sinuata* is present in the lower section of this zone, peaking at 6% abundance before falling below the 2% threshold.

Zone VIa – 417 – 403 cm *Cyclotella stelligera, Epithemia sorex, Cyclotella pseudostelligera* zone

C. stelligera numbers fluctuate from 8-30% abundance. *E. sorex* peaks at 18%. *C. pseudostelligera* also fluctuates between 0% and 16%. *Navicula cryptocephala* increases in abundance, peaking at 15% abundance in the middle and near the top of the zone. *E. microcephala* fluctuates, with low numbers at the base of the zone, up to 12% abundance near the top of the zone. *K. clevei* fluctuates, peaking at 11% abundance. *Cymbella affinis* appears in moderate numbers, but fluctuates from 0% to 10% abundance. *C. cistula* fluctuates through this zone from 1% to 10% abundance. *Nitzschia frustulum* appears in moderate numbers but fluctuates between 0% and 9%. *S. bacillum* and *S. pupula* numbers remain low but present at 6% and 7% respectively. *Encyonema gracile* appears at low abundance, peaking at 7%. *K. oblongella* fluctuates through this zone with abundance remaining low.

Zone VI b – 403 – 395 cm *Epithemia sorex, Karayevia clevei, Navicula cryptocephala* zone

E. sorex numbers peak at 32% in the middle of this zone before starting to decrease near the top of the zone. *K. clevei* peaks at the top of this zone at 18% abundance. *N. cryptocephala* numbers also fluctuate, never exceeding 12% abundance. *N. frustulum* abundance increases to 12%. *C. stelligera* numbers are beginning to decrease, peaking at 12% abundance. *E. microcephala* fluctuates to 11% near the top of this zone. *K. oblongella* fluctuates from 0% to 10%. *C. affinis* fluctuates, peaking at 9% abundance. *S. bacillum* numbers peak near the top of this zone at 7% abundance. *C. cistula* numbers reduce to 5% abundance. *C. pseudostelligera* decreases to 4% abundance.

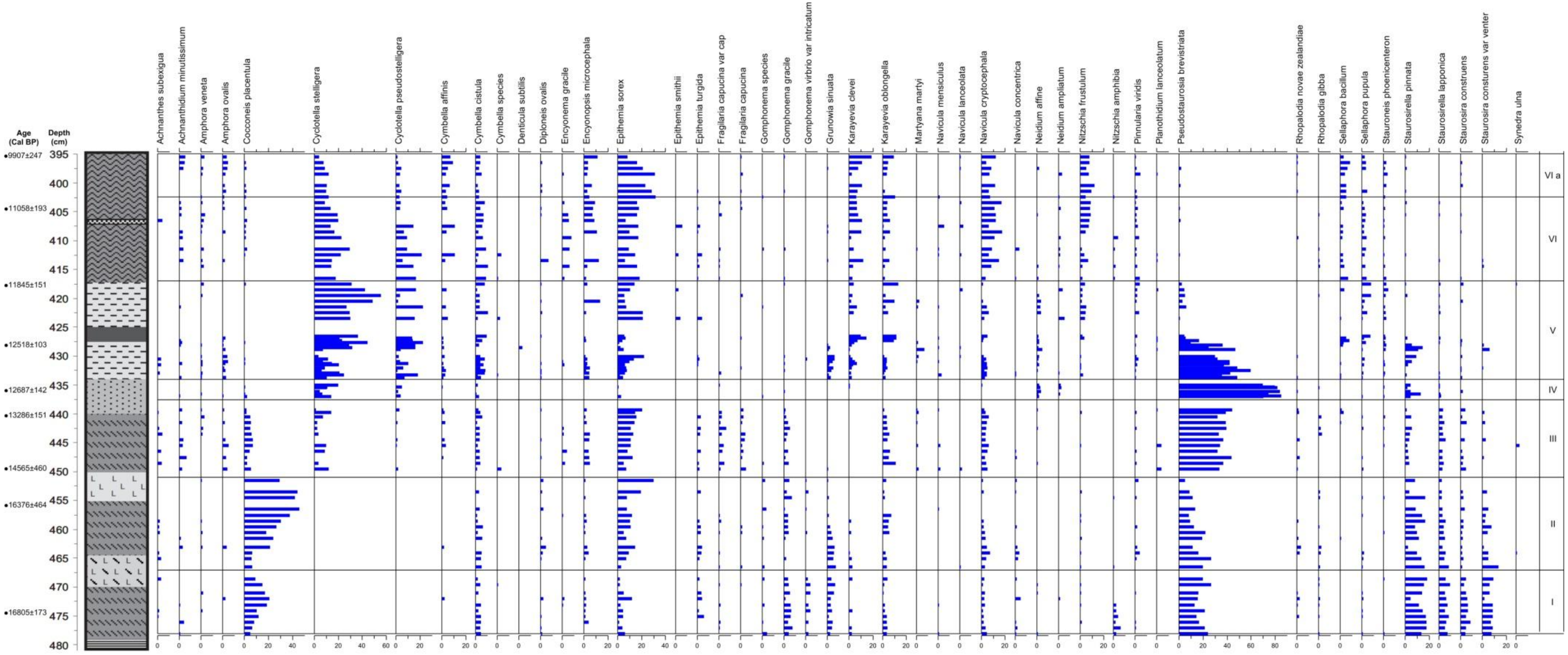


Figure 13. Lake Hawdon diatom stratigraphy for 85 samples. Taxa are represented in percentage abundance. Radiocarbon dates are taken from model 2 (Figure 22)

3.3 Ecological ranges

pH

pH values are based on ecological works by Van Dam (1994), where circumneutral taxa prefer pH levels at or around 7, whilst alkaliphilous taxa prefer conditions ≥7. Alkalibiontic taxa prefer conditions exclusively above 7. 64 taxa were found to have defined pH preferences in Van Dam (1994), and have been grouped accordingly (see appendix for ungrouped figures).

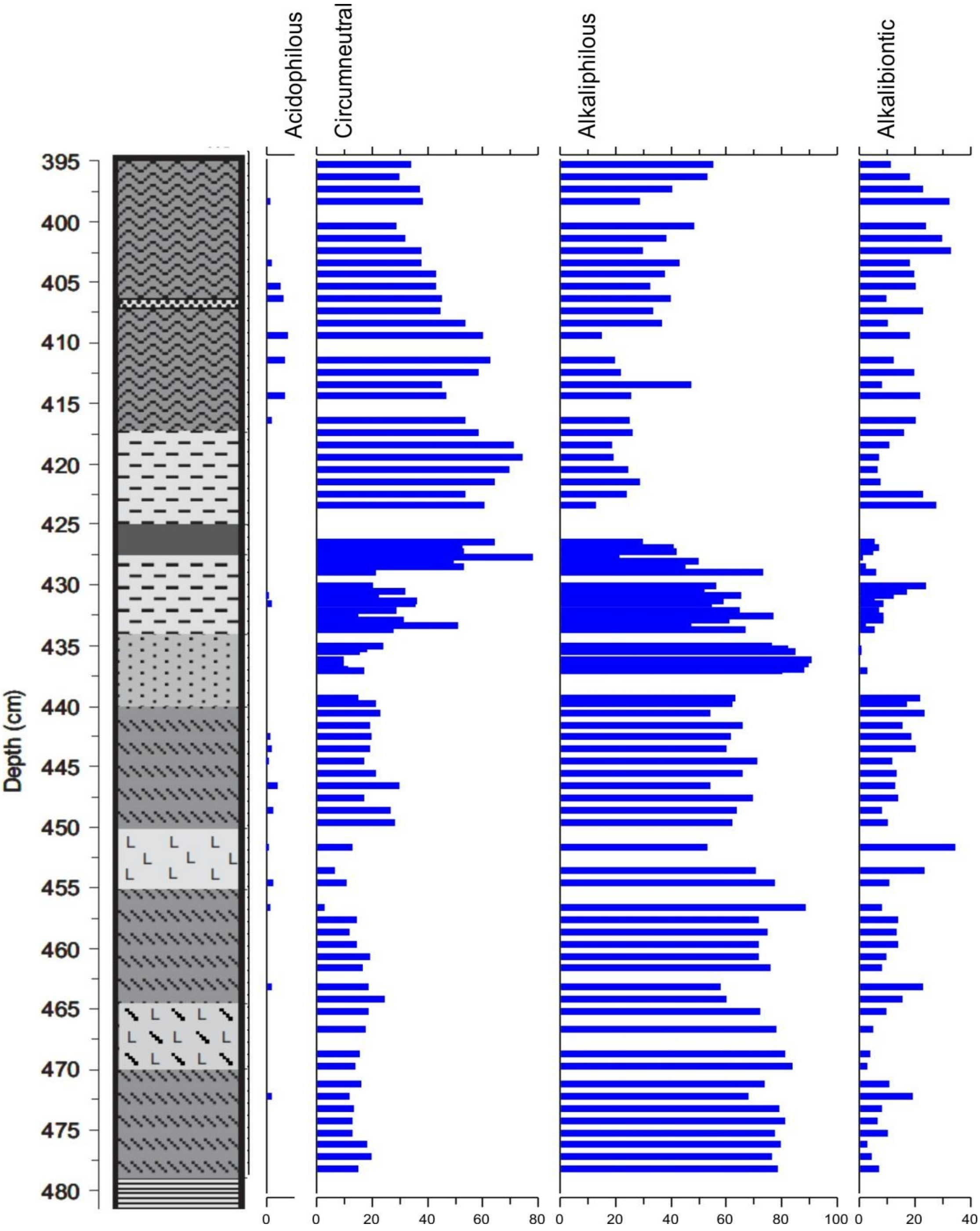


Figure 14. Grouped pH tolerant diatoms from Lake Hawdon. Taxa information according to Van Dam (1994).

Saprobity

Saprobity values are based on pollution tolerance studies carried out by Van Dam (1994) which combines the measure of organic matter and oxygen concentrations. Classification values define oligosaprobous taxa as tolerant of little or no organic matter whilst β-mesosaprobous taxa as tolerant of moderate matter. 62 taxa from Lake Hawdon were included in saprobity classifications out of the possible 103.

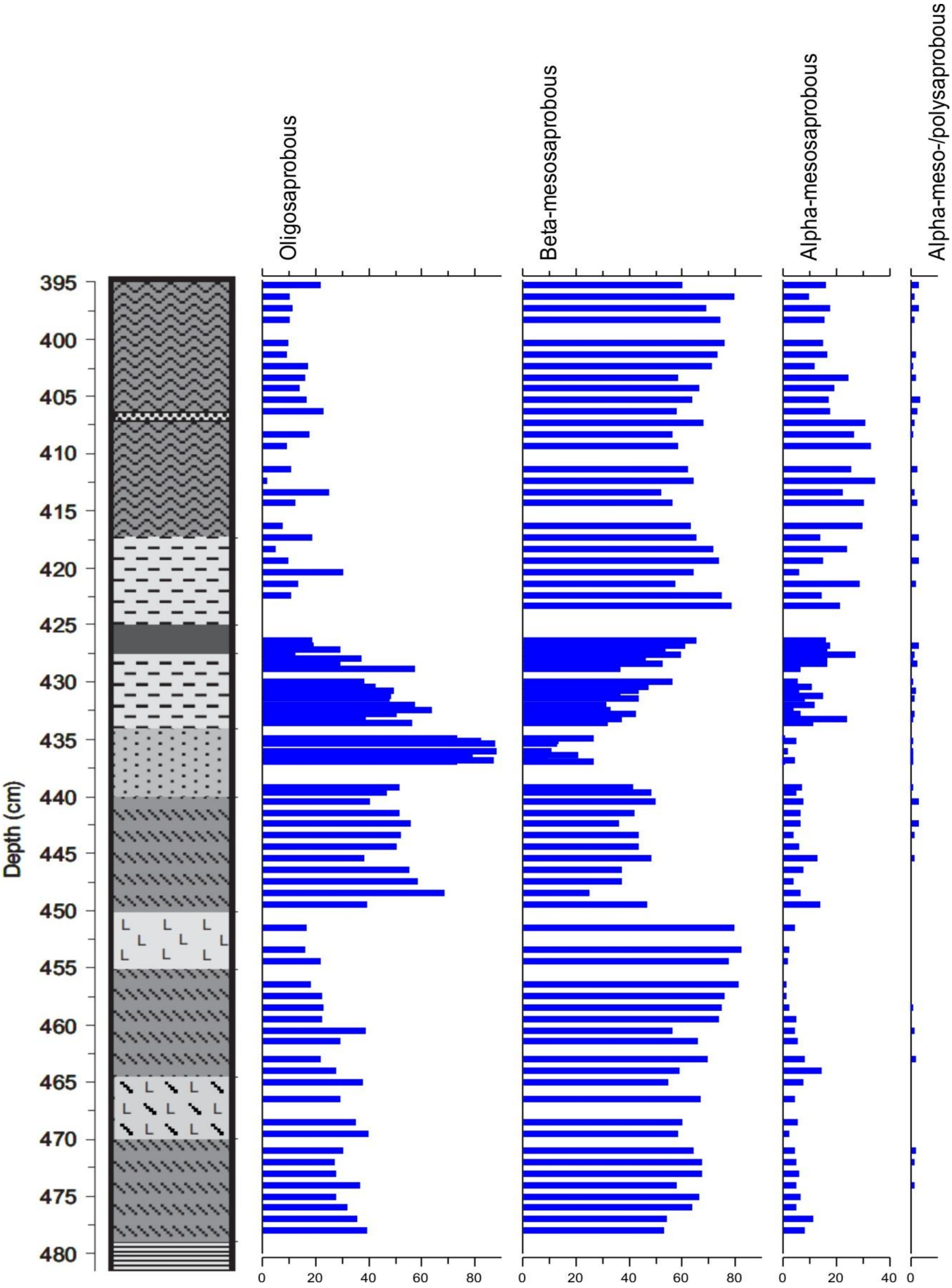


Figure 15 Grouped saprobity states from Lake Hawdon diatom samples.

Trophic state

Trophic conditions are changes in the amount of available nutrients within a system (Van Dam et al., 1994). 65 taxa from Lake Hawdon were matched with taxa from Van Dam (1994), with taxa indicating all six states of nutrient conditions. Oligotraphentic taxa indicate preferences for low nutrient conditions, whilst eutraphentic taxa indicate preferences for high nutrient conditions, and mesotraphentic taxa represent moderate nutrient conditions.

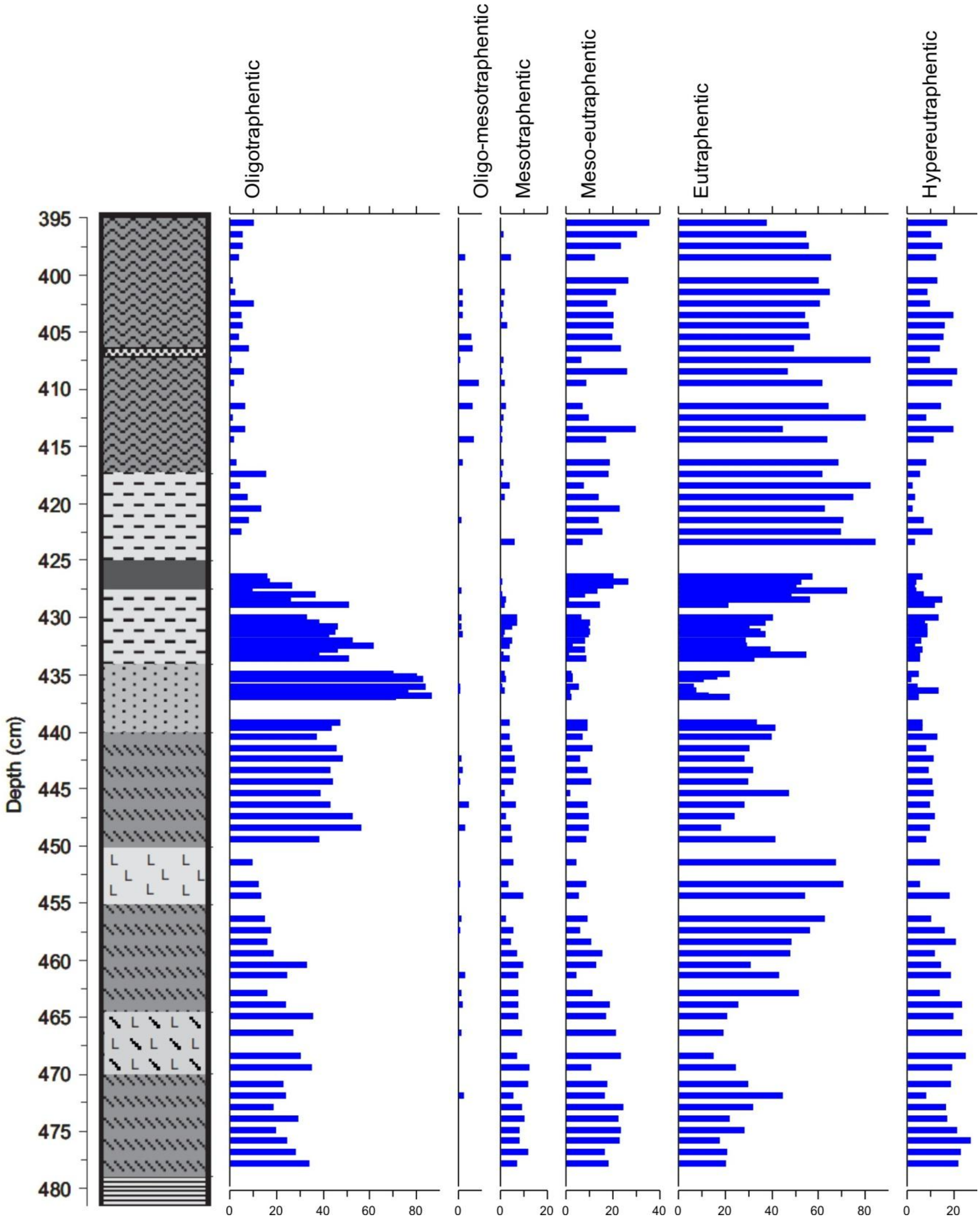


Figure 16 Grouped trophic state for Lake Hawdon diatoms, according to Van Dam (1994).

4 Statistical Analysis

4.1 Shannon diversity index

Shannon diversity index (H') is a mathematical approach to identify diversity within a community (Hammer et al., 2001). The average diversity was calculated (see appendix for data) to determine diversity changes below the average for Lake Hawdon.

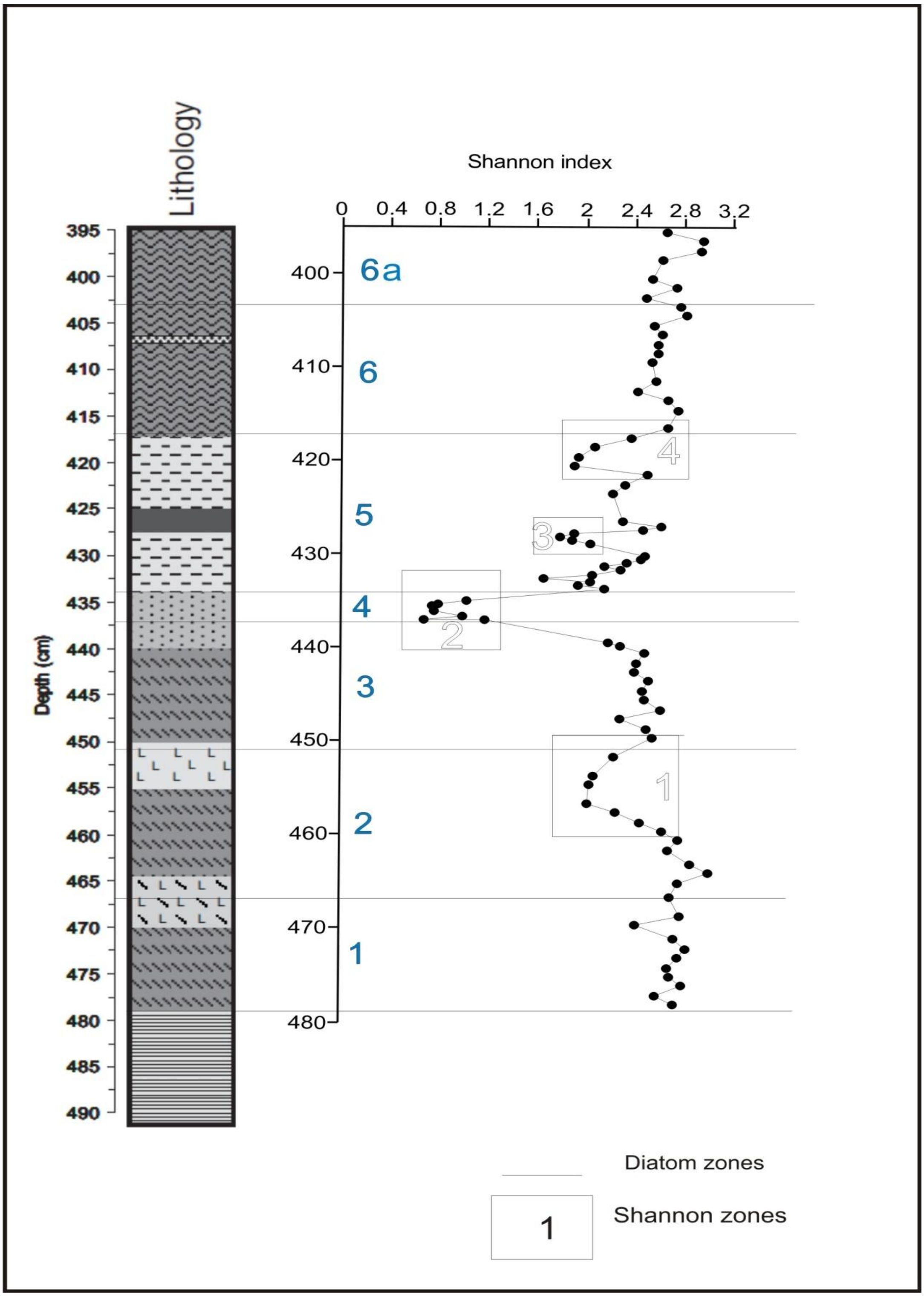
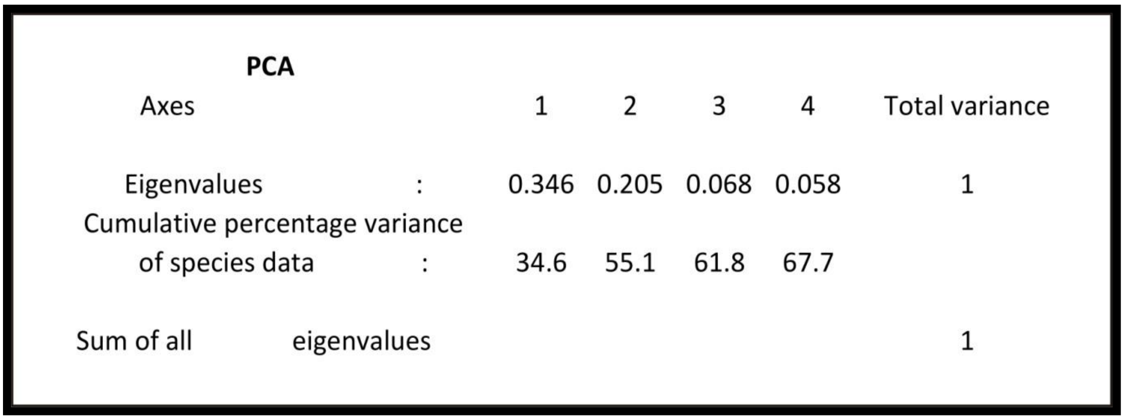


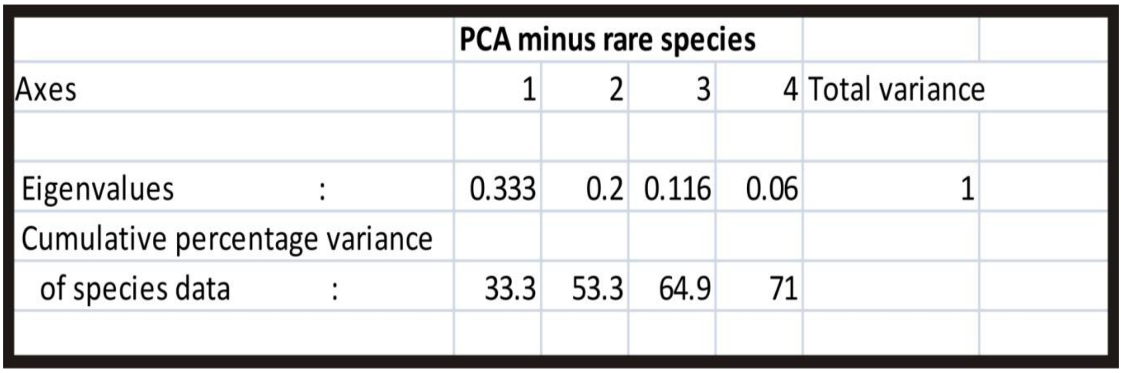
Figure 17. Shannon diversity index plot highlighting changes in diversity through the core from Lake Hawdon.

4.2 Principal Component Analysis – Diatoms



PCA					
Axes	1	2	3	4	Total variance
Eigenvalues :	0.346	0.205	0.068	0.058	1
Cumulative percentage variance of species data :	34.6	55.1	61.8	67.7	
Sum of all eigenvalues					1

Table 3. Principal Component Analysis data with all species included from Lake Hawdon.



	PCA minus rare species					
Axes	1	2	3	4	Total variance	
Eigenvalues :	0.333	0.2	0.116	0.06	1	
Cumulative percentage variance						
of species data :	33.3	53.3	64.9	71		

Table 4 Principal Component Analysis results with rare species removed from the data.

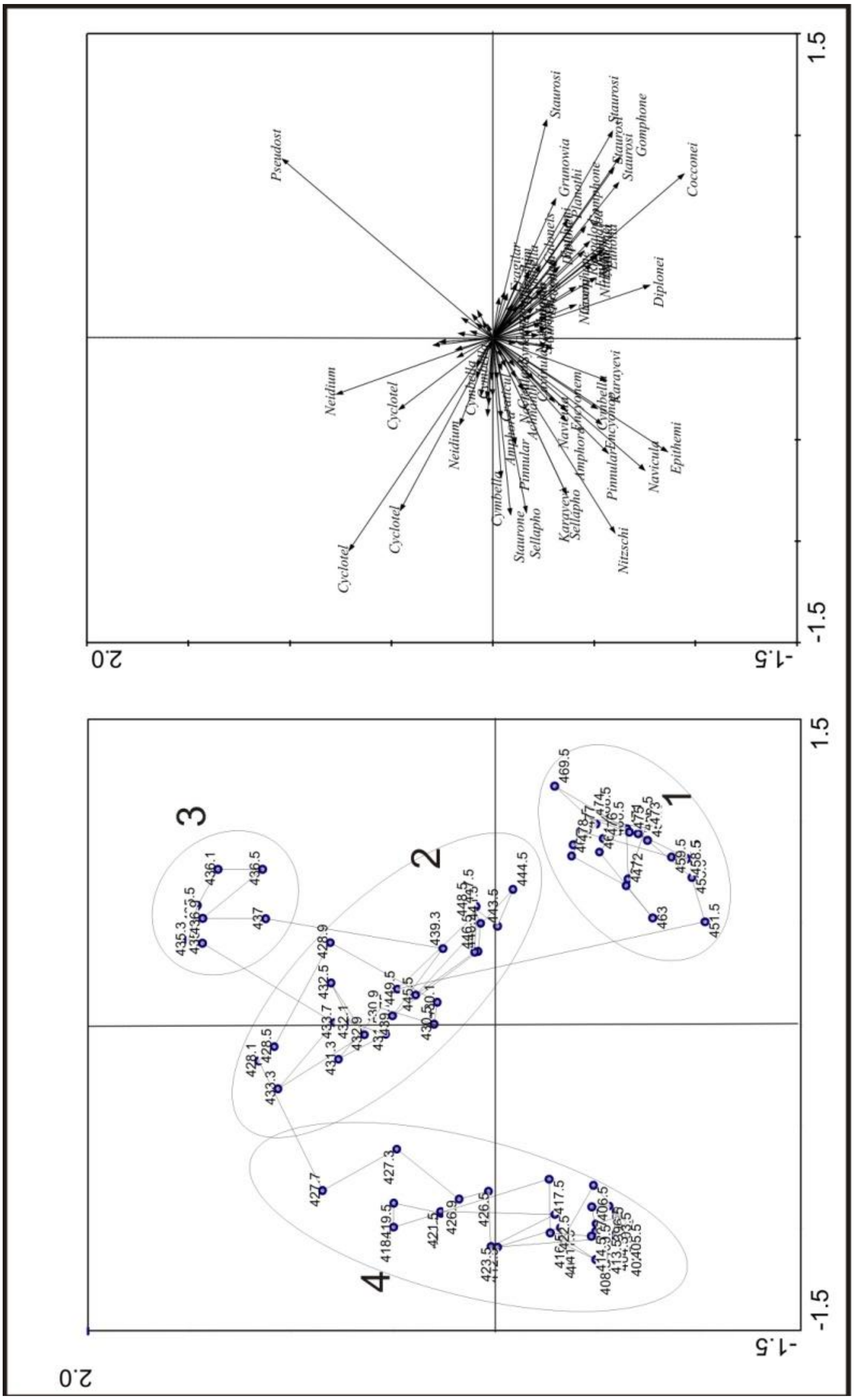


Figure 18. Time track and plot of PCA results for Lake Hawdon diatom samples. Time tracks highlight the sample depth, whilst the plot highlights the relationship between species.

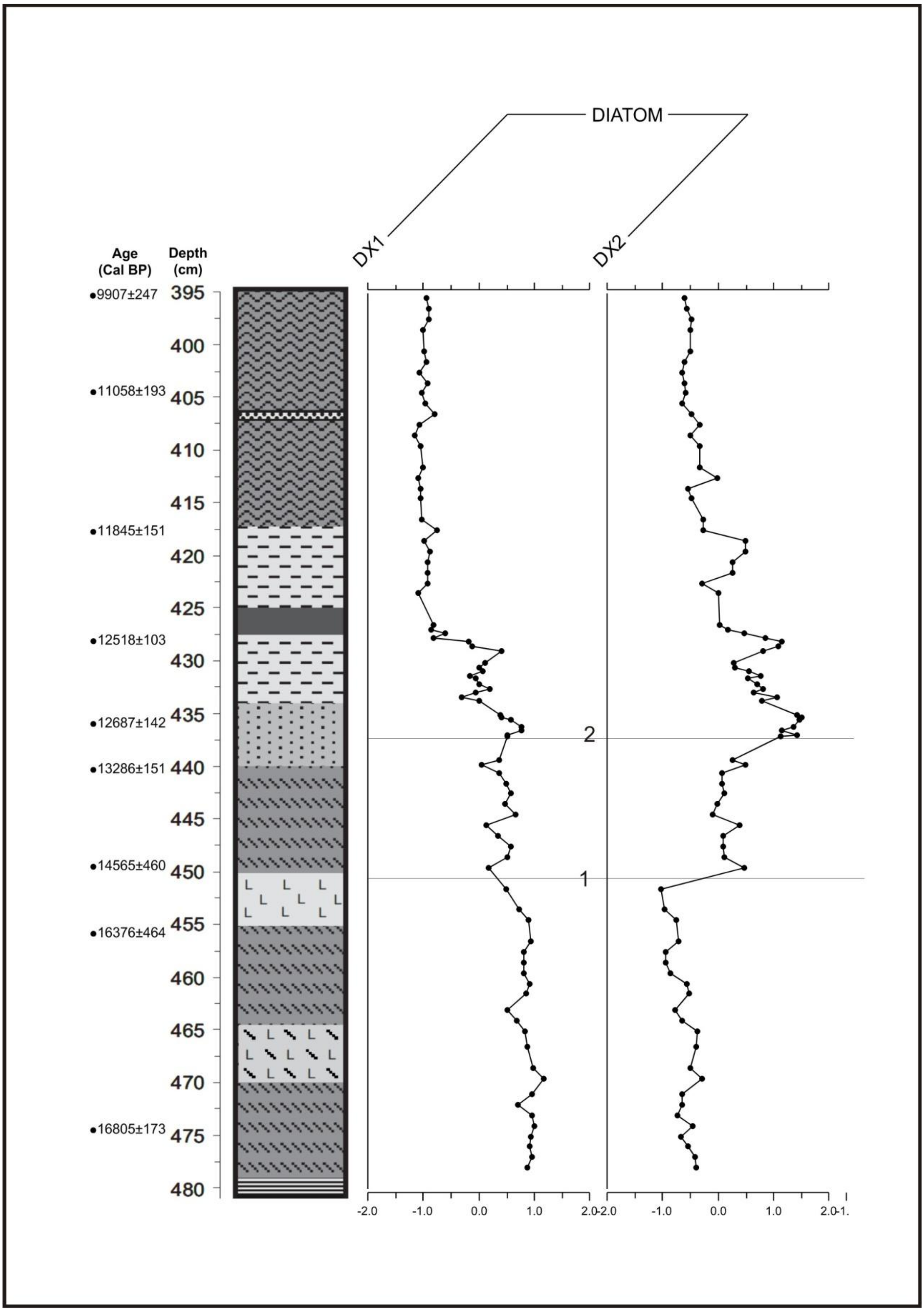


Figure 19. Principal Component Analysis plot for diatom results from Lake Hawdon. DX1 represents axis 1, whilst DX2 represents axis 2. Radiocarbon ages are taken from figure 22.

Discussion

This section will discuss the various ecological inferences from the Lake Hawdon diatom data in separate categories and then combine that discussion with statistical analyses to create an overall palaeoenvironmental reconstruction for Lake Hawdon.

5.1 Diatoms

Diatom interpretations for this study has focussed on the literature from high altitude and high latitude studies from the Northern Hemisphere were environmental changes inferred are likely to be similar to the controls for the environment at Lake Hawdon. See section 5.5 for further discussion on this issue.

Zone I 478 – 467 cm

Zone I is indicative of the development stages for Lake Hawdon, where abundance is low but diversity is moderate. Dominant taxa are representative of cool temperature conditions and an immature freshwater system due to the early stages of stabilisation in the lake.

Cocconeis placentula is the dominant taxon in zone I (Figure 13), known as a late coloniser efficient at incorporating nutrients (Gari and Corigliano, 2007). This would indicate the beginning stabilisation phase in Lake Hawdon, where periods of stabilisation are offset by stages of instability. The abundance of *P. brevistriata* does not exceed 30%, suggesting that productivity is low, reinforcing the idea that this zone is the development of Lake Hawdon. The presence of *Pseudostaurosira brevistriata* (formerly *Fragilaria brevistriata*) suggests that the lake has recently become developed, as this lacustrine benthic diatom is tolerant of many environmental conditions (Sayer et al., 1999) and is commonly found in shallow water depths (Harper et al., 1986) making it an efficient coloniser of newly formed lakes. The absence of planktonic taxa such as *Cyclotella stelligera* supports this zone representing the development of Lake Hawdon.

Some studies have suggested that *Pseudostaurosira brevistriata* is also associated with cold conditions and extensive ice cover in arctic and alpine regions (Finkelstein and

Gajewski, 2008; Smol et al., 2005). *Staurosirella pinnata* and *Staurosira construens* are also temperature sensitive taxa (Cremer et al., 2001). *S. pinnata* indicates cooler conditions (Westover et al., 2006) and suggests low productivity within lakes (Cremer et al., 2001) and in cooler conditions is more competitive than *S. construens* and *S. construens* var *venter* who have been regarded as very competitive tax in low nutrient lake conditions (Cremer et al., 2001). In addition, the high ratio of *S. construens* to *S. construens* var *venter* also suggests cool conditions at this time. These taxa have also been interpreted as indicating of shallow water environments (Bradbury et al., 2004). Macrophyte fossil fragments found in this zone agree confirm the shallow depth, due to *myriophyllum* being found to depths of 6m (Clayton et al., 1989).

Zone II 467 – 451 cm

This zone is representative of the true establishment of Lake Hawdon, with macrophyte growth allowing *C. placentula* and *E. sorex* increase in abundance through the zone and the presence of *P. brevistriata* suggesting conditions are still unfavourable for diverse diatom growth

The diversity of taxa remains the same as Zone I, but taxa such as *Cocconeis placentula* and *Epithemia sorex* increase in abundance. *Pseudostaurosira brevistriata* is the other abundant taxon in this zone and together with other taxa in this zone indicate the establishment of the lake. The increased abundance of epiphytic taxa *C. placentula* and *E. sorex* (Round, 1981) suggest that there was an increased abundance in macrophyte growth to support such taxa. The abundance of the epiphytic taxa *Epithemia sorex* during this zone provides further evidence for the recent establishment in the lake. *E. sorex* has a broad tolerance for pH levels, and can be found in a wide range of habitats (Lowe, 1996) as this epiphytic taxon relies on established macrophyte growth for their productivity.

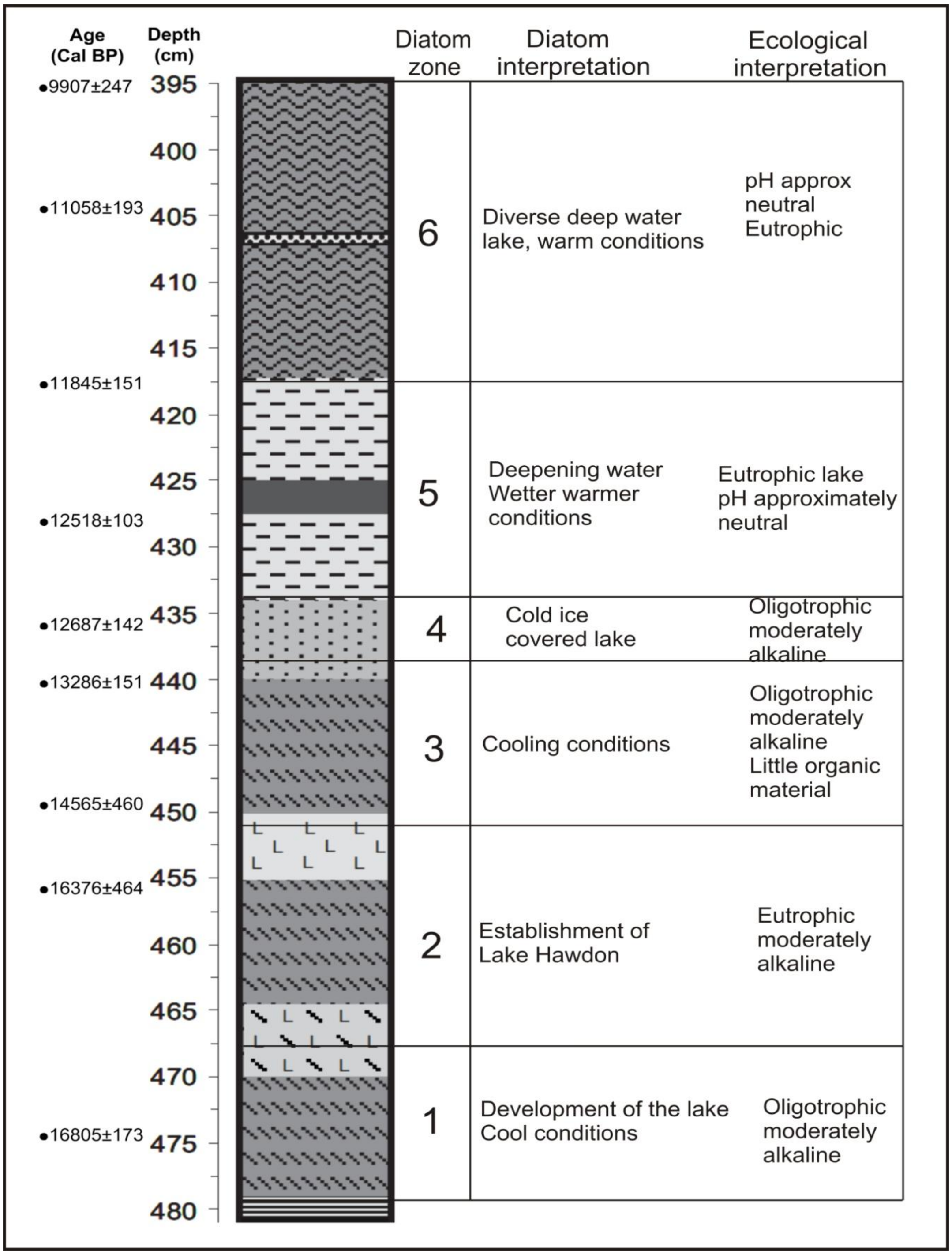


Figure 20 Summary of qualitative interpretations from Lake Hawdon fossil diatom samples.

Zone III 451 – 437.5 cm

This zone is representative of changing water depth and ecological conditions within the lake. The increase of *P. brevistriata* combined with the presence of *C. stelligera* suggests that growing conditions have shifted temporally and/or spatially.

In zone III the benthic taxa *Pseudostaurosira brevistriata* dominates. *P. brevistriata* has been described as an r – strategists by Lotter (2000); in unstable conditions, it effectively adapts to environmental changes within a lake system and become very productive. As *P. brevistriata* is indicative of cold conditions (Finkelstein and Gajewski, 2008; Smol et al., 2005) then the increase through this zone would suggest a cooling of the lake. The presence of the planktonic diatom, *Cyclotella stelligera* suggests increased water depth (Bradbury, 1986) and environmental conditions have become more favourable for plankton growth. The marked decrease in *Cocconeis placentula* suggests instability within the epiphytic diatom substrata. Macrophyte fragments from the core may suggest a disturbance in the lake, accounting for the disruption of the epiphytic community.

Zone IV 437.5 – 434 cm

This zone is representative of a cold phase with ice cover on Lake Hawdon, with partial or complete yet brief ice restricting diatom growth with the exception of the cold tolerant small benthic fragilarioid taxa.

The diatom assemblage of *Pseudostaurosira brevistriata* in this zone generally indicates a cold phase. The sharp shift to dominance of *P. brevistriata* (85% of the assemblage) suggests that this was a rapid environmental change in the lake system. *P. brevistriata* indicates an unproductive, alkaline and immature system (Bradshaw et al., 2000) typical of cold environments. *P. brevistriata* is a pioneer (Round, 1981), often being the first colonisers of waters in recently glaciated areas.

There are only two other taxa with more than 5% of relative abundance, *Cyclotella stelligera* and *Staurosirella pinnata*. This could suggest ice cover either partially over the lake, or complete but brief cover. When ice - free seasons are short, diatom assemblages are dominated by taxa associated with the complex and diverse littoral zone habitats (Finkelstein and Gajewski, 2008). More persistent ice cover over lakes can exclude planktonic diatoms from the lake, changing the diatom assemblage to be dominated by benthic and epiphytic taxa (Finkelstein and Gajewski, 2008). Ice cover can limit planktic growth by restricting nutrient input and limiting light availability for growth. The lack of benthic taxa beyond the fragilarioids *P. brevistriata* and *Staurosirella pinnata* suggests that climatic conditions were limiting other benthic diatom growth. *P. brevistriata* and *Staurosirella pinnata* were highlighted by Finkelstein and Gajewski (2008) to have optima for summer air temperatures of 5.62°C and 5.32°C respectively; (approximately 9 degrees colder than February mean air temperature (Woodward pers. comm., 2010)), meaning that partial ice cover over Lake Hawdon was quite possible.

The planktonic taxon, *Cyclotella stelligera* would generally suggest warmer and ice free conditions (Bradshaw et al., 2000; Cremer et al., 2001) as it blooms early in open water during summer (Lotter and Bigler, 2000). In cold conditions however, *C. stelligera* can indicate an increase in available nutrients or an improvement in light conditions (Bradshaw et al., 2000). Cremer and others (2001) also highlight that in some situations ice growth may only partially restrict *C. stelligera* growth, supported by low abundance in this zone. For Lake Hawdon, the co-occurrence of warm indicator taxa with cold indicator taxa suggests that seasonality at through this zone was extreme; potentially with long ice covered winters with a short summer growing season. Heightened seasons would allow strategists *P. brevistriata* to dominate the benthic lake habitat during ice covered periods, whilst limiting other taxa beyond the short summer growth period.

Zone V 434 – 417 cm

This zone is representative of an increase in productivity within the lake. Planktonic diatoms have increased in abundance and cold tolerant benthic taxa have decreased, indicative of warmer conditions.

In zone V there is a distinctive change in the ratios between benthic and planktonic diatoms, as the rapid decline in the relative abundance of *P. brevistriata* suggests that conditions are less favourable for benthic diatoms. The steady increase in the planktonic species *Cyclotella stelligera* and *C. pseudostelligera*, suggests warmer deeper waters (Bradbury, 1986). The increase in *C. stelligera* indicates a reversal of the limiting factors from the previous zone. The appearance of *Karayevia clevei* in this zone may suggest an increase in biological productivity compared to zone IV due to its preference for moderate trophic conditions (Cantonati et al., 2009). This zone is representative of the lake moving out of the cold phase.

Zone VIa and VI b 417 – 395.5 cm

This zone is representative of a diverse, productive lake that has deeper water in comparison to the commencement of the record. The presence of taxa with requirements for higher nutrients suggests that the lake is an open system with a high nutrient and sediment influx.

This zone is indicative of a further change in dynamics within the lake. The increase in the epiphytic taxon *Navicula cryptocephala* in this zone suggests an increase in nutrient concentrations in the lake. *N. cryptocephala* has a high tolerance to organic material (Austin and Deniseger, 1985) whilst preferring circumneutral pH (Van Dam et al., 1994). The sediment unit that is seen in this zone is described as an organic gyttja, which may explain why the organic tolerant taxon is represented well in this zone. *Encyonopsis microcephala* is a shallow to mid-depth tolerant diatom (Cantonati et al., 2009), indicating that water levels increased from earlier zones. The increase in abundance of *Encyonopsis microcephala* suggests that the habitat benthic taxa are colonising in the lake is dependent on the lake area; some deeper water tolerant benthic taxa are able to establish habitats where originally only shallow benthic taxa could colonise. The presence of *Cocconeis placentula* in low abundance suggests that macrophyte growth is present in the lake, but perhaps shifted towards the periphery of the lake.

5.2 Ecological information

Reference as to how these chemical changes may influence diatom distribution and productivity see section 1.1.2, with data summarised in figures 14 to 16.

pH

According to Van Dam (1994) circumneutral diatom taxa respond ‘indifferently’ to lake pH value of around 7. Alkaliphilous diatom taxa mainly occur at pH values greater than 7 while alkalibiontic taxa exclusively occur above 7 (Van Dam et al., 1994). Inferences from the diatom assemblage suggest that pH conditions in Lake Hawdon to be ≥ 7 (Figure 14). pH changes through the core are not particularly notable, but can allow inferences from the diatom taxa of past conditions within the lake.

Within the Lake Hawdon core the dominant taxa representing pH changes are *Cyclotella stelligera*, *Epithemia sorex* and *Pseudostaurosira brevistriata*. *Cyclotella stelligera* is the dominant planktonic taxa present in the Lake Hawdon samples, and its preference for circumneutral pH conditions suggests that the lake after 434 cm provided a suitable environment to generate the necessary chemical and bio-chemical processes for growth (Battarbee et al., 2001). *E. sorex* is categorised by Van Dam (1994) as alkalibiontic but Lowe (1996) suggests that this benthic taxa has a broad pH tolerance. For Lake Hawdon, the combination of *E. sorex* and *C. stelligera* suggests that conditions in the lake were only moderately alkaline. *P. brevistriata* is categorised as alkaliphilous (Van Dam et al., 1994), is abundant at stages (Figure 14), supporting the hypothesis of Lake Hawdon being a moderately alkaline lake.

The change at 425 cm from alkaliphilous taxa to circumneutral taxa coincides with an important change in lithology. Between 425 and 427 cm the core shows a pulse of organic rich silt, followed by units of organic silts and organic gyttja, both of which generally contain higher levels of organics than previous units (see figure 11). This change to organic rich units in Lake Hawdon occurs when the pollen record indicates that tree growth is present in the area (Woodward, pers. comm. 2010). According to Cutler (1977), organic layers in soils are often found in areas surrounding trees that produced acidic leaf litter. An increase in organic material influx, particularly acidic leaf litter is a likely cause for the pH shift in Lake Hawdon. This increase occurs shortly after the presence of ice over Lake Hawdon, inferred earlier in this section, suggesting the absence of ice also physically allows more organic matter to enter the lake. Engstrom (2000) highlight that chemical differences in recently de-glaciated lakes are related to the hydrological variables for lakes that are in the same catchment lithology, suggesting that ice retreat has a significant role in governing chemical processes and inputs.

Saprobity

The saprobity system combines measures of the abundance of biodegradable organic matter and oxygen concentrations (Van Dam et al., 1994). Oligosaprobous taxa are tolerant of little organic matter, but also taxa intolerant of organic matter (Van Dam et al., 1994). Organic sensitive taxa will often correspond to oligotraphentic categories (Rott et al., 1998) and the results for both categories vary for some taxa and change with seasons. In Lake Hawdon the majority of the taxa are oligosaprobous, indicative of a lake with low to moderate levels of organic material, which changes through the core.

The bottom of the core is dominated by mesosaprobous taxa (such as *Cocconeis placentula*, *Epithemia sorex*) that are tolerant of moderate organic material (Van Dam et al., 1994). This may indicate that runoff into Lake Hawdon was occurring. Glacial outwash into the area could provide a source for the organic material, but abundant macrophyte growth such as *Myriophyllum* could also contribute to the organic material. At 437 – 434 cm there is a dramatic change represented by *Pseudostaurosira brevistriata* dominating the samples (Figure 15). This change to oligosaprobous taxa may reinforce the inference of ice cover at this time. If ice cover was present over Lake Hawdon, then sources of the organic material could easily have been limited by the presence of ice, acting as a mechanism for the control of mesosaprobous taxa.

After 434 cm, moderately organically tolerant taxa such as planktonic *Cyclotella stelligera* dominate the site, suggesting that a source or sources for organic material were again able to reach Lake Hawdon. According to Rott (1998) macrophyte production and periphyton growth can alter oxygen consumption in a freshwater system. Higher diversity in Lake Hawdon may be a result of organic sediment input into the lake, increasing oxygen consumption, and increasing the organic material levels in the lake. The lithology also suggests an increase in organic material as the top unit (unit 10 – see fig 11) is described as an organic gyttja. The presence of *Navicula cryptocephala* confirms this change in organic matter as it has a high tolerance for organic material (Austin and Deniseger, 1985).

Trophic states

Trophic states in are changes in the amount of available nutrients within a system (Van Dam et al., 1994) are evident throughout the core. Oligotraphentic and eutraphentic taxa tend to dominate the site. Oligotraphentic taxa are tolerant of low levels of nutrients, whilst eutraphentic taxa are prefer high trophic levels within lake systems. The distribution of these taxa suggests two phases of trophic state within Lake Hawdon (Figure 16). The lower half of the core is dominated by oligotraphentic taxa, especially *Pseudostaurosira brevistriata* and *Karayevia clevei*. The upper part of the core is dominated by taxa tolerant of moderate to high nutrient concentrations (meso – eutraphentic), especially *Cyclotella stelligera*, *Cyclotella pseudostelligera* and *Epithemia sorex*.

Pseudostaurosira brevistriata prefers oligotrophic conditions (Bradshaw et al., 2000; Lotter and Bigler, 2000) which contribute to its previously mentioned success in cold lakes which often, due to ice cover, have low nutrient influx (Bradshaw et al., 2000). *Karayevia clevei* has been argued to be similarly oligotrophic (Van Dam et al., 1994) however, *K. clevei* has been found to prefer moderate trophic conditions (Cantonati et al., 2009). In Lake Hawdon, the combination of taxa likely represents higher trophic conditions than *P. brevistriata* normally tolerates yet conditions mean that both taxa can be present.

The upper part of the core (434 – 395 cm) from Lake Hawdon is dominated by *Cyclotella stelligera* and *C. pseudostelligera*. They prefer a high level of nutrients (Van Dam et al., 1994) which allows high productivity of planktonic taxa within a water body. Lake Hawdon must have been deep enough to allow the mixing of nutrients through the water column to have the presence of the planktonic taxa and also moderate abundance of benthic taxon *Epithemia sorex*. This may also suggest that the benthic and planktonic taxa are not directly competing for the same nutrient resource or that planktonic forms are providing nutrients through death which benthic taxa can utilise. The presence of *E. sorex* is indicative of high lake productivity and macrophyte growth in Lake Hawdon. The top of the core is dominated by high nutrient tolerant taxa indicative of a productive open water lake with a steady inflow of sediments providing nutrients and organic material.

5.3 Radio carbon dates

The radio carbon dates obtained from Lake Hawdon can be seen in figures 21 and 22. There are two models illustrated here, to highlight two theories pertaining to possible processes affecting radiocarbon dates occurring in Lake Hawdon. The first figure (Figure 21, model 1) is based on the assumption that there is no reservoir effect on the carbon found in the samples. The second (Figure 22, model 2) has been corrected for a reservoir effect. Reservoir effects result from a source of ‘old’ carbon entering the lake system, giving misleading ages through the core (Vandergoes and Prior, 2003). The author has used the dates corrected for a reservoir effect that has been applied to all the radiocarbon dates from Lake Hawdon.

The first uncorrected model (model 1, Figure 21) was discarded for a number of reasons. Radiocarbon dated samples comprise a variety of targets; bulk sediment samples, macrofossils and sieve fractions, that give ages through the core of ~19,000 – 9,000 cal. BP. The samples have all been adjusted for the Southern Hemisphere offset (McCormac et al., 2004), and have tight error constraints on the dates. Rules for selecting sample dates appear inconsistent when choosing what sample dates should be used and what are being discarded, and selection of point samples that have been corrected for reservoir effect sit alongside bulk sediments that have avoided correction. Bulk sediments are very likely to have reservoir carbon, and this may be older or younger carbon (Vandergoes and Prior, 2003), giving it an inverted age. Point samples are stronger targets for radiocarbon dating due to the carbon coming from one source such as atmospheric CO_2 (Bjorck and Wohlfarth, 2001) whereas bulk samples can contain a mixture of organics from a variety of sources. Vandergoes and Prior (2003) noted that Westland samples from New Zealand had severe contamination problems in their bulk samples. In Westland, in-washing from inorganic carbon potentially provided older ages whilst younger ages were thought to be caused by root penetration. In Lake

Hawdon older carbon contamination is likely to be more of a factor than young carbon contamination. This is due to the location of Lake Hawdon, and the interpretation from diatoms from the core, indicating the presence of ice cover near 440 cm. The presence of ice over lakes would delay the input of sediment and atmospheric carbon into the lake (Bjorck and Wohlfarth, 2001), thus influencing the radiocarbon samples at Lake Hawdon.

There is a particular zone in the model 1 plot (Figure 21) where samples give older ages than neighbouring samples. When plotted there is a considerable ‘jump’ at ~440cm in the core (Figure 21). The appearance of an unconformity could be inferred, influencing the interpretation of changes through the core. An unconformity in a sedimentary sequence is a section where a period of time is not represented by sediment. This could be due to an absence of sediment deposition during this time period (a hiatus) or subsequent re-working or removal of the sediment sequence that would represent the missing time period. Reworking of sediment within a lake may have occurred at Lake Hawdon, as there are no younger and older ages in this section that sit directly on top of each other suggesting a possible unconformity. This could explain the changes in model one if there was evidence of shallow, windy conditions, however, lacking such evidence we suspect a reservoir effect. This section may also account for a low sedimentation rate, but the lithology (Figure 11) suggests that sedimentation was active, due to the sandy sediment present.

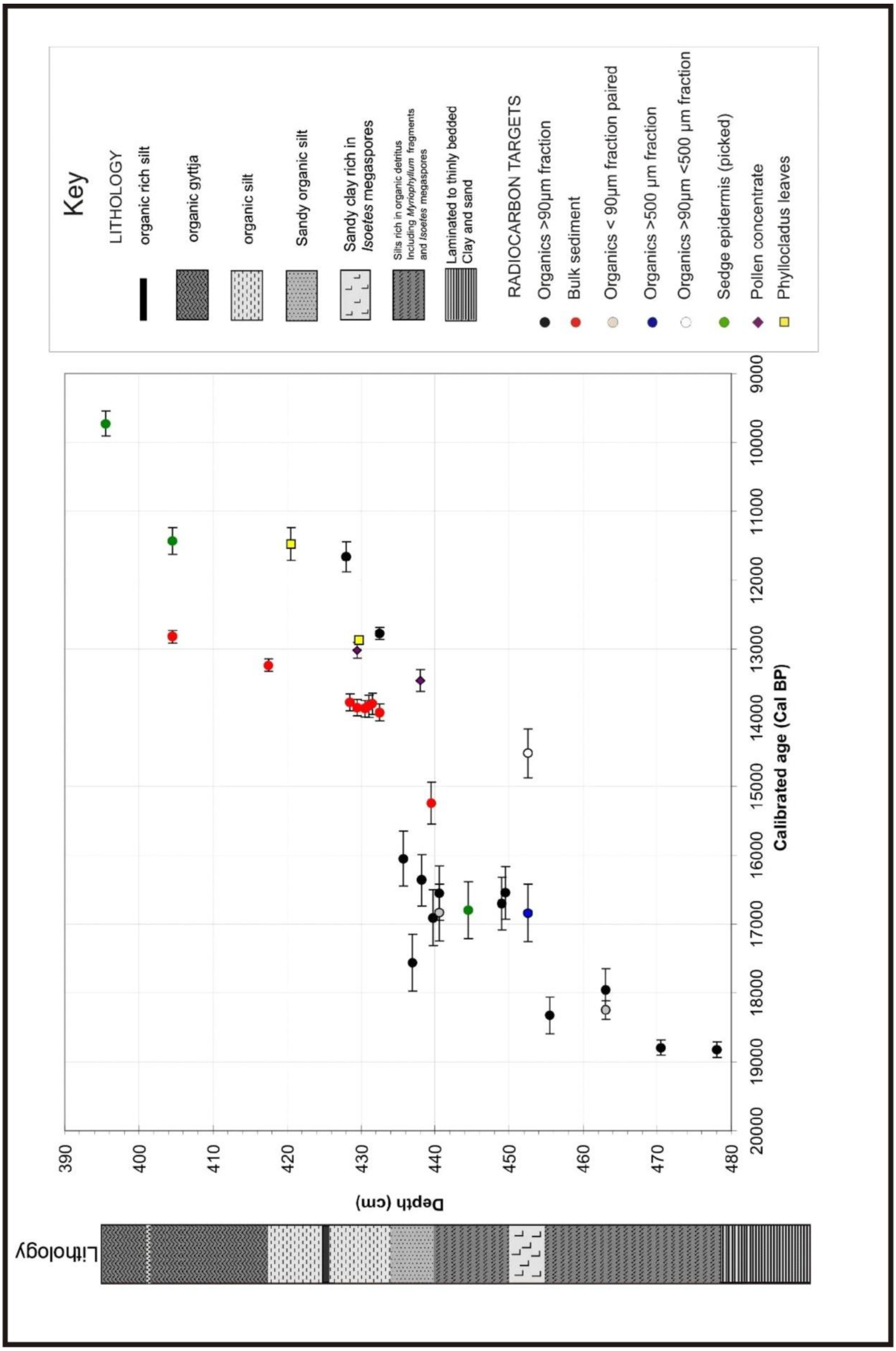


Figure 21 Radiocarbon age model theory one, accounting for no reservoir effect. (Image courtesy of Jenny Watson, project member)

Model two (Figure 22) has accounted for a reservoir effect on the bulk sediment samples from Lake Hawdon. As a result, the reservoir correction has shifted ages at the base of the core from ~19,000 cal yr BP to ~17,000 cal yr BP (refer to appendix for results). This shift is less considerable near the top of the core, where ~11,000 cal yr BP shifts to ~10,000 cal yr BP respectively. Applying a correction to the bulk sediment samples is logical given the offset between the bulk sediment dates and the dates based on material from terrestrial plants, as dates from specific targets are likely to be more reliable than bulk sediments. Therefore when attempting to quantify the reservoir effect, differences between the bulk sediments and neighbouring target-specific samples need to be highlighted.

There is a cluster of ages between 435 and 445cm in model two that do not seem to fit with the rest of the ages in the model. Studies from Antarctica mentioned by Bjorck and Wohlfarth (2001) discuss the influences of ice and glacial melt water on reservoir effects on Antarctic lakes. Glacial meltwater affected the reservoir carbon in Antarctic lakes through the input of ‘old’ carbon in the meltwater mixing with atmospheric CO_2. In Lake Hawdon, ice cover has been inferred by the diatom changes around 437 cm which can seal the lake from atmospheric inputs, and alter the amount of dissolved inorganic carbon entering the lake system (Bjorck and Wohlfarth, 2001).

Accepting age model two means that the cooling inferred from the diatom ecology in diatom zones III and IV occurs between 12,686 +/- 166 and 13,928 +/-142 calendar years BP (Figure 22). These dates fit in the range of the ACR of ~14,500 – 12,500 cal yr BP (Members, 2006), enforcing that the diatoms from Lake Hawdon are highlighting a cold phase in the Canterbury High Country and further supporting the potential for an ice cover driven reservoir effect.

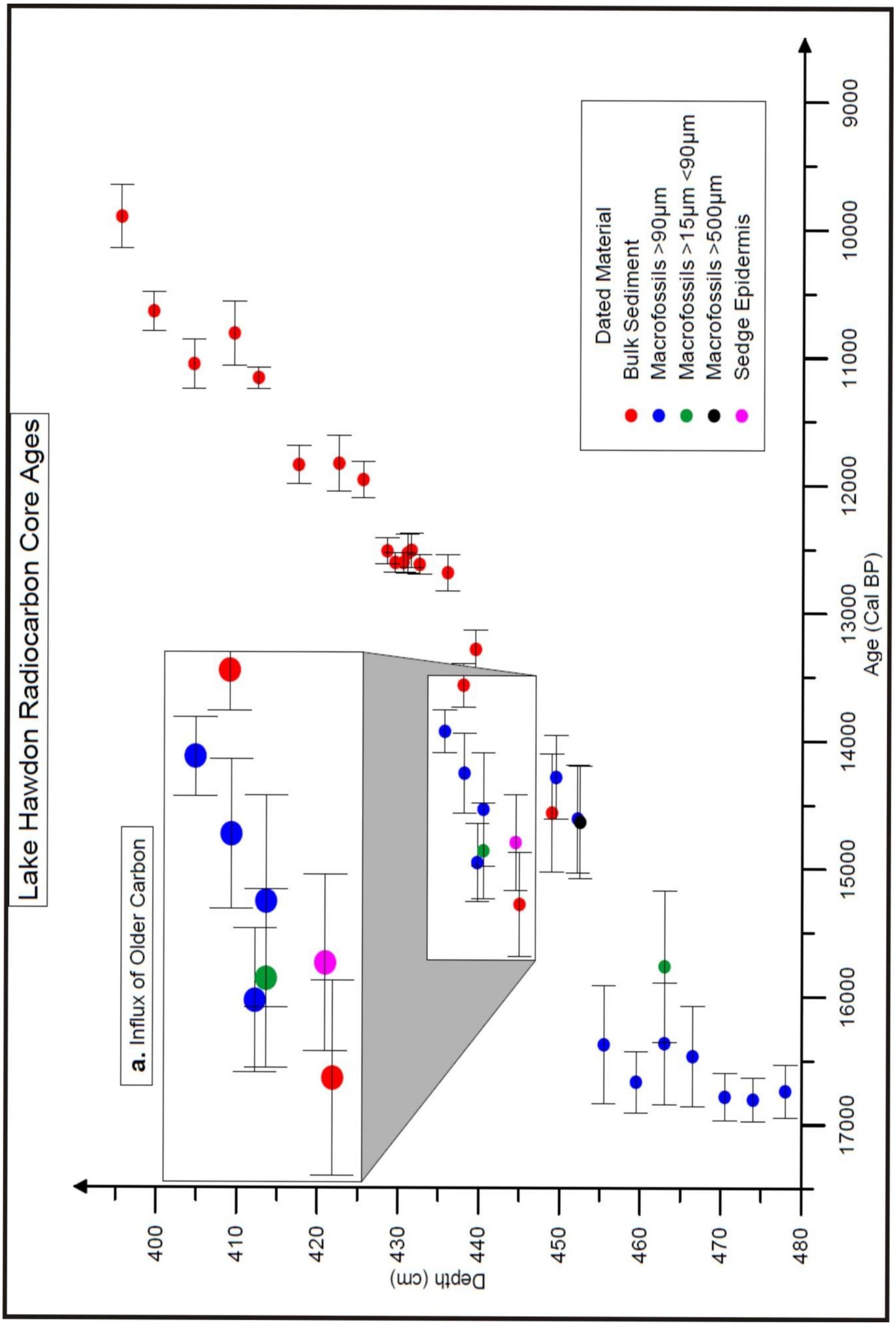


Figure 22 Radiocarbon age model from Lake Hawdon with a reservoir effect factored in for all of the samples. Samples that are macrofossils are sieved samples.

5.4 Statistical Analysis

5.4.1 Shannon diversity index

Shannon diversity index is a mathematical equation for data that highlights changes in abundance within a community. The Shannon diversity calculations based on the fossil diatom data from Lake Hawdon indicate four sections of major diversity change through the core. Values from the Shannon diversity index are expected in the range of 0 – 4 (Hammer et al., 2001). High values in H' are indicative of high diversity within a community whilst low values are poor diversity. Therefore, diversity in general from Lake Hawdon is moderate. The four sections highlighted in figure 17 are those of significant decreases in diversity. The sections highlight where more than one sample has decreased below the average H' index of 2.3.

Low diversity section 1 449.5 – 456.5 cm

Diatom taxa that represent the most change in this section are *Cocconeis placentula*, *Epithemia sorex*, *Cyclotella stelligera* and *Pseudostaurosira brevistriata*. Epiphytic taxa such as *C. placentula* and *E. sorex* were present earlier, but have decreased in abundance. The appearance of planktonic *C. stelligera* coincident with the decrease in epiphytic taxa may suggest an increase in water depth. This change may also indicate a cooling in temperature and low nutrient availability. The decrease in diversity (H') to 2.0 represents an increase in the abundance of the few taxa present. This section occurs where there are changes in the lithology. There is a lithology change from organic silt to sandy clay. This may be indicative of a meltwater pulse from a Blackwater retreat. A meltwater pulse could be inferred from the marked increase in *P. brevistriata* as this small benthic taxon is found in cold oligotrophic lakes (Bradshaw et al., 2000).

Low diversity section 2 434 – 437.5 cm

This section represents the most significant change in diversity in the Lake Hawdon diatom community. *Pseudostaurosira brevistriata* dominates the assemblage for this section, and diversity (H') 2.4 to 0.6 (Figure 17). This decrease in diversity coincides with the highest relative abundance of *P. brevistriata* and a period of climate cooler climate. The other taxa present in this section are *Staurosirella pinnata* and *Cyclotella* *stelligera*. *S. pinnata* is also indicative of cool temperatures (Finkelstein and Gajewski, 2008). *C. stelligera'*s low abundance, as mentioned earlier, may be indicative of restricted summer blooms (Lotter and Bigler, 2000) in open waters, or partial ice coverage over the lake (Cremer et al., 2001). Cold conditions will limit nutrient availability; and light available for growth which will limit diversity. According to the radiocarbon model two this significant change occurs during the Antarctic Cold Reversal (ACR) at approximately 13,000 cal yr BP.

Low diversity section 3 427.7 – 428.9 cm

This section marks another important change in the dominant diatom taxon where the diversity decreases to ~1.8 (H'). *Cyclotella stelligera* is abundant, whilst *Pseudostaurosira brevistriata* abundance decreases. Changes in these taxa have been interpretated as warmer wetter conditions, with increased lake depth and reduced ice cover. This change corresponds to ~12,000 cal yr BP based on radiocarbon model two (Figure 22). Assuming all corrections are accurate, this post dates the ACR. Conditions are interpretated as stabilising from this section onwards due to the appearance of the tall podocarp tree pollen. Warmer wetter conditions increase nutrient input, which will influence diversity after this section.

Low diversity section 4 416.5 – 421.5 cm

In this section diversity changes similar to that of section 3 are driving the decrease in diversity (Figure 17). This section represents the last point diversity decreases below (H') 2. Planktonic diatoms dominate this section, particularly *Cyclotella stelligera*. The dominance of *C. stelligera* suggests that conditions were favourable for planktonic growth, and this limited benthic growth potentially due to planktonic diatom blooms. The dominance of planktonic taxa in this section may be indicative of deeper water and as a result, shallow water benthic taxa have shifted towards the peripheral margins the lake.

A silty gyttja occurs in unit 9 (Figure 11) where the dominance of *C. stelligera* occurs. Silty deposits are indicative of low energy conditions, suggesting there was minimal sediment input, yet the high abundance of planktonic taxa suggests productivity was good. There is a unit change at the top of this section to an organic gyttja with woody fragments, suggesting that sediment influx increased and the lake energy was higher. This positive shift in diversity relates to the organic sediment influx for Lake Hawdon, which would limit oligotrophic taxa such as *Pseudostaurosira brevistriata* and *Gomphonema gracile*, but encourage growth from eutrophic taxa such as *Cyclotella stelligera* and *Epithemia sorex*.

5.4.2 PCA diatom interpretation

PCA time track plots for Lake Hawdon are depicted in figure 18. The time track plot highlights four main clusters for the 85 samples (labelled 1 – 4). Samples from the bottom of the core (cluster 1) are clustered tightly in the lower right part of the plot. There is a significant jump from this cluster to a large cluster (cluster 2) close to the junction of the two axes. There is a small cluster that represents 437-434 cm in the core, where *Pseudostaurosira brevistriata* dominates the samples (cluster 3) which matches with the diatom zone IV. The last cluster represents samples from 434 – 395.5 cm (cluster 4) is distinctly separate from the other clusters. The clusters are representative of diversity changes through the core, as a result of environmental factors influencing Lake Hawdon which cluster the diatom zone V, IVa and IVb together.

The PCA plot highlighting taxa from Lake Hawdon indicates positive or negative correlations between taxa. If the angle between two arrows is greater than 90° there is a negative correlation between taxa, with sharp angles indicative of a positive correlation (ter Braak and Smilauer, 1997). Taxa with a positive correlation tend to occur together in the fossil record (a species assemblage), while taxa with a negative correlation tend to be mutually exclusive. There is a positive correlation between *Staurosirella pinnata*, *Staurosirella elliptica*, *Staurosira construens* and *Pseudostaurosira brevistriata* (Figure 18). These fragilarioid taxa are often found in arctic, and high alpine lakes in the Northern Hemisphere (Finkelstein and Gajewski, 2008), and have been described as competitive taxa in unfavourable conditions. There is a negative correlation between the fragilarioid taxa and the planktonic taxa (*Cyclotella stelligera* and *Cyclotella pseudostelligera*). This emphasises the qualitative interpretations of environmental changes in Lake Hawdon which focus on changes from fragilarioid complexes to the planktonic *Cyclotella stelligera*.

There are several possibilities for environmental variables influencing diatom changes throughout the core, and it is sometimes not possible to disentangle these effects using the ecological data available for taxa alone The next logical step to deal with this challenge would be to create a modern New Zealand diatom dataset with species and environmental data to constrain the species environment relationships for the taxa present in this record. Such a modern dataset (a ‘training set’) can be used to numerically partition the variance in the diatom species distribution explained by various measured environmental variables. This dataset can also be used to develop inference models or ‘transfer functions’ that can be used to reconstruct values for environmental variables that have an important effect on diatom distribution and abundance.

Data available from the northern hemisphere was used in this study to develop a transfer function, but there was a poor overlap between the New Zealand fossil assemblages and the northern hemisphere modern assemblages, a no analog situation (refer to 5.4.4). Interpretations were therefore based on qualitative or species based ecology methods. The results from the PCA were used to aid in the interpretation of the ecological affinities for the large number of taxa present in the Lake Hawdon record. The PCA axis 1 and 2 (Figure 19) can be interpreted as environmental gradients based on the known environmental preferences of the main species assemblages present in the fossil record.

Diatom changes can reflect a myriad of quite specific environmental variables such as changes in pH, turbidity, salinity and temperature; these variables are generally controlled by physical factors influencing the lake. A single variable such as sediment influx can easily alter pH, turbidity and temperature throughout the water column. Consequently, the variables considered for the PCA axes are from these ‘higher order’ physical processes, potentially responsible for multiple smaller changes within the lake. Nutrient availability and sediment influx and water depth/light availability were highlighted as major variables due to the correlation between diatoms changes and the sediment units in the core. Grain size and sediment content changes within the core were present at each major diatom assemblage shift, suggesting a strong relationship between the diatoms and stratigraphy.

Axis 1 accounted for 34.6% of the variance in the Lake Hawdon samples, and is interpreted as nutrients/sediment influx (Figure 19). Nutrients are vital for the growth and productivity of diatoms within a water body. Changes in nutrients within a lake will influence organisms, depending on the type of nutrients and the mode in which they enter the lake. As mentioned earlier nitrogen, phosphorus and silica are key nutrients for diatom growth and productivity (Battarbee et al., 2001; Reid, 2005; Tibby, 2004; Tilman et al., 1982). An increase in the availability of nutrients to a lake will promote eutrophic taxa while a decrease in the availability of nutrients should mean that oligotrophic taxa will respond positively.

The mode in which nutrients are supplied to a lake influences diatom composition. Pulses of sediment containing nutrients may encourage growth of some eutrophic taxa, but may limit other taxa due to their intolerance of nutrient inputs. The volume of this pulse will influence the rate of growth; a large volume may extend completely through a small lake, disrupting benthic diatom growth (Round et al., 1990). Figure 19 highlights a change in nutrient availability in the lake with a negative response from the PCA values in axis 1. This negative response is merely a change from nutrient intolerant taxa to favourable trophic conditions and eutrophic taxa. Oligotrophic taxa such as *Pseudostaurosira brevistriata* dominates the bottom half of the core, while *Cyclotella stelligera* and *Navicula cryptocephala* dominate the top half. This can be seen at point 2 highlighted on the figure (Figure 19) after 434 cm where nutrient tolerant taxa shift away from intolerant taxa, stabilising movement in axis one. This point is where there is a dramatic shift in PCA values for Lake Hawdon due to sediment changes seen in the lithology and subsequent nutrient inputs.

Axis 2 accounted for 20.5% of the variance in Lake Hawdon record and has been interpretated as being water depth/light availability. Water depth influences the ratio of planktonic to benthic diatoms within a water body while light availability influences the growth and development of benthic taxa: little light generally means few benthic diatoms. Again, the dominant taxa are the epiphytes taxa *Cocconeis placentula* and *Epithemia sorex,* benthic *Pseudostaurosira brevistriata* and planktonic *Cyclotella* *stelligera* and *Cyclotella pseudostelligera*. Point 1 highlighted on figure 19 in axis two there is a distinct change in the PCA plot that coincides with a change in lithology. The coloniser *C. placentula* decreases in abundance here, suggesting that the macrophyte habitat in Lake Hawdon was impacted by light availability for growth and an increase in water depth, limiting growth areas. The change is reflected in an increase in abundance in the small benthic taxa of *P. brevistriata*, tolerant of harsh immature lake environments (Bradshaw et al., 2000).

Lake Hawdon is thought to be a shallow lake below 440cm, with sediment pulses entering the lake between 450 and 440 cm, encouraging the growth of planktonic taxa such as *Cyclotella stelligera*. Between 440 – 434 cm there is further change in the plot in axis 2 suggesting that only the r - strategist's *P. brevistriata* was able to be productive during this time. Ice cover for this zone has been inferred, and ice can limit growth by restricting the light availability to benthic taxa. Limiting light can affect macrophytes, restricting growth, and increased water depth influences the available light. Ice cover allows the cold tolerant *P. brevistriata* to grow productively which can bloom, limiting light availability for other benthic taxa such as *Cocconeis placentula* and *Epithemia sorex*.

An increase in water depth after ~434 cm is suggested by the increase in the abundance of *C. stelligera*. Light availability changes in the upper half of the core with depth, as seen by spikes in the PCA plot in axis two after 434 cm, influenced by the planktonic *Cyclotella stelligera*, and the benthic *Navicula cryptocephala*. Again in this axis there are direct changes aligned with changes in lithology, suggesting that water depth and limited light by initial sediment deposition influence diatom taxa composition in Lake Hawdon. Chironomid stratigraphy suggests that water depth is a stronger factor with a change ~430cm to *Tanytarsus* which is not tolerant of turbid waters (Woodward, pers. comm., 2010), suggesting that lake conditions were deep enough for planktonic growth but calm enough for the settling out of incoming sediment.

5.4.3 PCA diatom, chironomid and pollen interpretation

The Principal Component Analysis plots for three proxies from Lake Hawdon complement each other, and contribute to create a solid interpretation (Figure 23). In consultation with Craig Woodward, fellow project member, interpretations were made for the environmental variables influencing changes in the chironomids and pollen.

Axis one for the chironomids appears to correspond to lake conditions; including substrate and lake productivity, while axis two is a temperature gradient. The dominant species influencing the first zone in the core are *Chironomus* spp. and *Naonella kimihia*. *Chironomus* spp. builds tubes and prefers a muddy substrate while *Naonella kimihia* is associated with macrophytes (Woodward, 2006). The chironomids below 455cm indicate a predominantly cooler climate and a shallow, mesotrophic lake. Major changes occurring below 455cm correspond to changes in substrate and temperature.

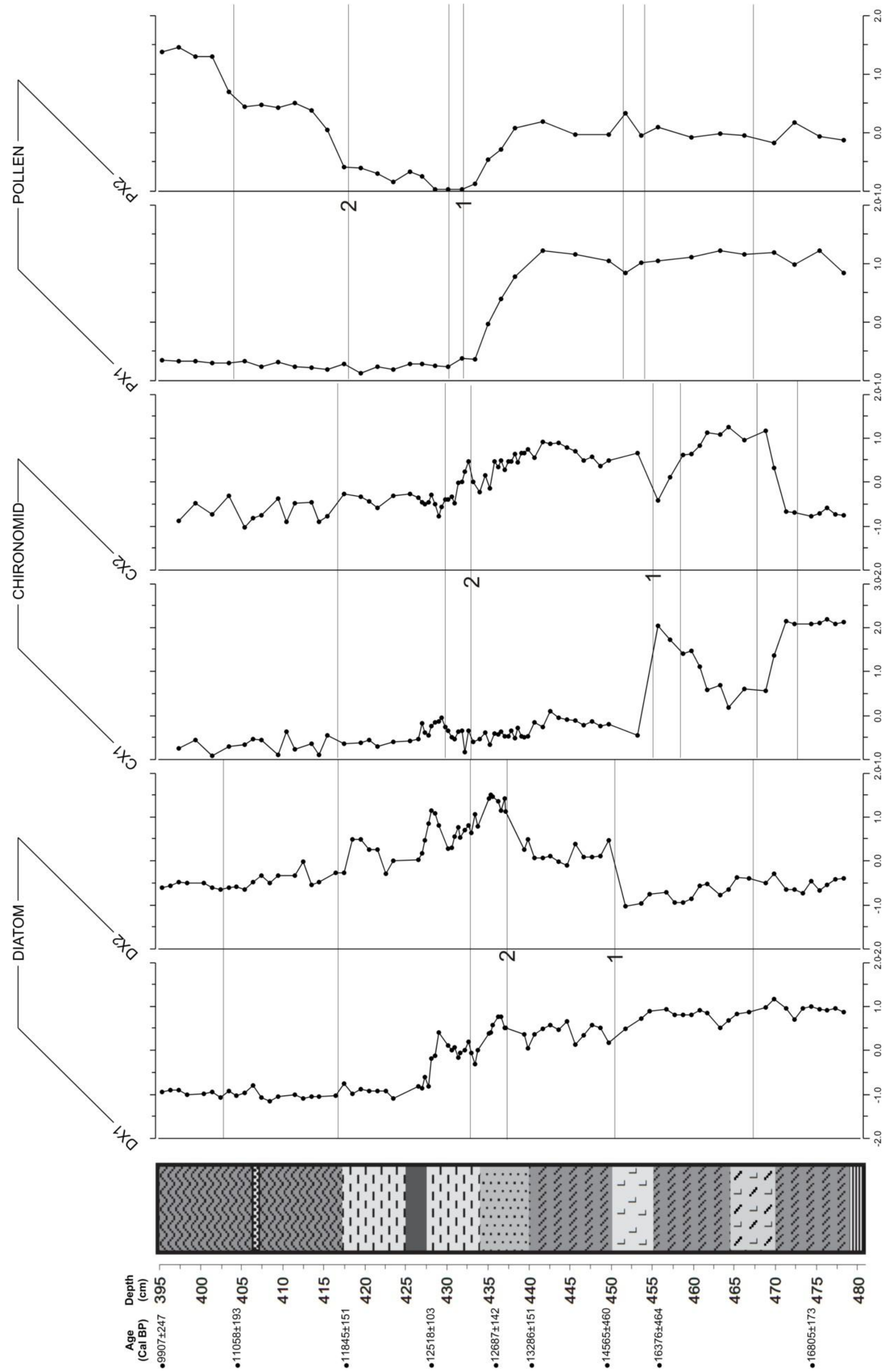


Figure 23 Combined PCA plots for diatoms, chironomids and pollen from Lake Hawdon. Additional data for statistical analysis from Craig Woodward, project member. Lines across axes represent proxy zone, with numbers indicating major changes in taxa.

The marked change in chironomid species occurs at point 1 where it is interpreted that conditions improved for chironomid growth after 450 cm. Temperature has been inferred to control changes in axis 2. Temperature has been documented in other studies to influence chironomid growth and presence (Dieffenbacher-Krall et al., 2007; Larocque and Bigler, 2004; Lotter and Bigler, 2000; Rosen et al., 2003; Woodward, 2006). The generation of a PCA was based on the diatom results conforming to a linear model, whilst chironomid results should be conforming to uni-modal methods (Woodward pers. comm., 2010). This would have an effect on the environmental controls for axis one and two. If a Canonical Correspondence Analysis (CCA) was carried out for the chironomids from Lake Hawdon the controls for each axis would likely be reversed, due to temperature being recognised as a significant control on chironomid assemblages in New Zealand (Woodward, 2006).

Pollen PCA axis one separates vegetation types typical open landscapes to the right (e.g. *Poaceae*) from vegetation types typical of shrubland and forest to the left (Figure 23). Pollen PCA axis two separates conifer shrubland (*Phyllocladus* and *Halocarpus*) to the bottom from podocarp forest vegetation types (e.g. *Prumnopitys taxifolia* and *Dacrydium cupressinum*) to the top. Temperature is likely to influence transitions between vegetation types on both pollen PCA axes, but landscape stability and forest succession could also be very important.

The lower half of the core is dominated by grasses and low shrubs such as *Coprosma* with tall trees absent from the record. The dryland pollen concentrations are also very low, implying a very sparse vegetation cover. There is then a transition towards conifer shrubland (*Phyllocladus* and *Halocarpus*) at about 435cm depth, indicated by the ‘1’ in Figure 23. This transition could be stimulated by a temperature increase and increased landscape stability. The chironomid temperature reconstructions indicate summer temperatures are highly variable below 435cm and the frequent pulses of inorganic sediment suggest instability in the lake catchment. From 435cm to the top of the core there is a transition from *Phyllocladus*/*Halocarpus* shrubland to podocarp forest. Temperature, soil development and hydrosere succession in the Lake Hawdon Valley are factors that could control this succession. *Phyllocladus* and *Halocarpus* are tolerant of cooler conditions, where *Phyllocladus* is tolerant of up to -18°C frosts (Sakai et al., 1981).

Together the PCA plots for diatoms, chironomids and pollen enable a robust multi-proxy interpretation to be made. The diatoms and chironomids infer changes within Lake Hawdon, whilst the pollen enables inferences for the area surrounding Lake Hawdon. The zones highlighted by each proxy in figure 23 show broad agreements between the proxies, with some interesting divergences. Zones below 440 cm appear separate from each other, whilst after 440 cm correlations amongst the proxies are generally close. Diatoms are the first to signal a change in the Lake Hawdon environment at 437.5-434 cm (Figure 23), which overlaps with an important zonal change in the pollen, closely followed by the chironomids. Here the concept of 'lead' and 'lag' can be applied, where high resolution sampling for a proxy can indicate a greater magnitude of change within a confined area. In the order of food chains, diatoms are likely to be affected or changed first, and you might expect a delay for fauna higher in the food chain. This concept depends on the external changes affecting Lake Hawdon (section 1.2); some controls (e.g. temperature) will directly influence organisms at all levels of the lake system while others (e.g. nutrient availability) will affect lower organisms like diatoms directly and affect larger organisms indirectly. The fact that a small pollen zone falls here can allow inferences towards the magnitude of change in the Lake Hawdon area. Pollen changes reflect shrubland environment where the previous pollen zone represented a shrubland grass environment in the catchment area. Response to environmental changes in the area will be fast and dramatic for some proxies (such as diatoms) and slower for others, as a result of how direct such a change may influence that proxy. Since all three proxies indicate changes in this area, it suggests that the impact of environmental change applied to the entire catchment area, not just Lake Hawdon.

5.4.4 Transfer function

Attempts were made to generate a transfer function using the European diatom database (EDDI) (Juggins, 2007) to determine the environmental variables influencing Lake Hawdon diatoms and the magnitude of changes in those variables. The result was unsuccessful, and resulted in the Lake Hawdon diatom samples plotting quite separately from the European training set. This posed a potential problem for carrying out further quantitative analysis.

All diatom identification was carried out with the recognised texts Krammer and Lange-Bertalot (1991-1999) and ecological information for modern diatoms was collated in the Northern Hemisphere (Van Dam et al., 1994). So why did the transfer function fail? The issue of ubiquity and endemism is raised here as well as morphological differences. Diatoms have generally been considered cosmopolitan, present in almost any water body (Charles and Smol, 1988; Cochran, 2002; Reid et al., 1995), but there have been a few publications recently arguing against such claims (Finlay, 2002; Kilroy, 2007; Vanormelingen et al., 2008). In the case of Lake Hawdon, the diatoms might be morphologically similar, but genetically different. Convergent evolution provides another theory that could explain why taxa from Lake Hawdon failed to function when analysed with data generated from a European training set. This concept suggests that similar organisms can evolve and adapt in quite separate environments (Moore and Willmer, 1997). The location of freshwater systems in New Zealand in the past and the environmental controls that impact on those systems are likely to be quite different from the environmental controls seen on modern freshwater systems in the Northern Hemisphere. Genetic studies of diatoms have been limited to common species. Lewis and others (1997) genetically tested *Fragilaria capucina* in North America along a latitudinal gradient. There was a large genetic variation amongst seven populations across North America, and different genetic patterns were seen within the populations (Lewis et al., 1997). If a large continental landmass can show significant genetic variation then it is highly likely that New Zealand taxa isolated since the break-up of Gondwana (McGlone, 2005) will also show genetic variability. Lake Hawdon diatoms were all identified using northern hemisphere texts, but genetic differences may mean adjusted environmental preferences that do not work with the European training set.

Conventional literature suggests that diatom taxa do not exhibit endemism due to the large population removing dispersal as a constraint (Finlay et al., 2002). Vanormelingen (2008) highlights geographic dispersal as a potential factor favouring endemic taxa in remote locations. Vanormelingen (2008) suggests that the geographic distribution of diatoms in fact ranges from global to narrow endemic. This geographic dispersal theory is similar to that of fauna, where dispersal can be limited by landmass or restricted by oceans. Research carried out by Kilroy (2007) focussed on mire pools in the South Island of New Zealand. These systems are limited by closed basins, often being isolated from other water bodies. The degree of endemism shown in these studies is high, reflecting and confirming the idea of geographic dispersal. In the case of Lake Hawdon, geographic dispersal might have been an issue for the fossil diatoms, but due to the lack of diatom studies within the region, similarities with the other water bodies cannot be confirmed or disproved. Under-sampling of suitable freshwater systems and the under – representation of rare diatom taxa can influence the knowledge of the geographic distribution (Vanormelingen et al., 2008). Increase study sites and record all taxa found at the site, and more understanding of diatom taxa distribution might be known.

The ecological work carried out in Europe was done in modern lake systems. Many modern day lakes in Europe have had significant impact from anthropogenic activities surrounding the lakes. By changing the surrounding landscape, nutrient and sediment influxes into the lakes will have changed since human arrival influencing the diatom taxa present. Human activities can also cause what has been termed ‘human-mediated introductions’ (Vanormelingen et al., 2008). Human movement encouraged diatom dispersal into new areas that they were otherwise excluded from. The fossil diatoms from Lake Hawdon are indicative of an environment devoid of anthropogenic impact or activity as the earliest human arrivals were around the thirteenth century CE (Wilmshurst and Higham, 2004) after the latest date in the core. Natural dispersal means would have been the major contributing factor in Lake Hawdon, such as water currents, wind and animals (Vanormelingen et al., 2008).

Further work needs to be carried out on New Zealand diatom taxa, especially in regard to genetic investigations, but also with geographic dispersal. If modern diatom taxa are limited by geographic barriers, then it would have considerable consequences for fossil diatom studies, especially where ecological and environmental variables were inferred.

Genetic investigations for modern diatom taxa should also be carried out, to explore the degree, if any, of variation within species in different locations.

There is however, modern data from New Zealand which would enable the generation of a transfer function for Lake Hawdon but it is not as freely available as the EDDI database. In 2005 Reid carried out a widespread study of New Zealand lakes, measuring the water quality of 53 lakes and taking diatom samples; the creation of a transfer function from Reid's (2005) New Zealand water quality data set was in preparation to be carried out. Whilst access to the raw data has been granted, for reasons beyond the control of this author, the data have yet to be provided. Upon arrival of the raw data from Reid (2005), the generation of a transfer function will be carried out for publication of the Lake Hawdon project work.

5.4.5 Diatoms in the broader palaeoenvironmental context

The diatom record from Lake Hawdon can be separated into three main phases of environmental change (Figure 20). The first phase is the cool water temperature, establishment phase for Lake Hawdon where diatom growth was present but not abundant. The second phase is a short cold phase where ice cover is inferred over Lake Hawdon. The third is a warmer wetter phase where water depth increased and sediment influx increased promoting higher productivity from a broader range of taxa.

The first phase according to the presence of the fragilarioid species *Staurosirella pinnata*, *Staurosira construens* and *Pseudostaurosira brevistriata* the diatom record represents an immature system with cool to cold temperature conditions. The dominance of these cold tolerant taxa relates well to the chironomid data and the pollen record from the site. The chironomid data in this phase is dominated by the cold summer air temperature *Chironomus spp*. which also prefer muddy substrate conditions consistent with a disturbed newly formed, shallow lake. Temperature reconstructions from chironomid data suggest that at the beginning of this phase summer air temperatures were up to 4°C cooler than modern February air temperatures (Figure 24). Pollen interpretations from Lake Hawdon suggest a grass and shrub dominated environment, similar to McGlone and others (2004) characteristic of colder alpine conditions findings at nearby Kettlehole Bog.

Towards the end of this first phase of diatom growth the appearance of epiphytic diatom taxa such as *Cocconeis placentula* and *Epithemia sorex* is indicative of an established lake. The increase in abundance of epiphytic taxa suggests that landscape stability had improved, allowing permanent macrophyte growth to occur in the lake. The pollen record changes near the end of this phase to the presence of grasses and shrubs such as *Coprosma*, suggesting pockets of more substantial vegetation growth in the surrounding area was present. The chironomids reflect cool summer air temperatures between 10 - 12°C, suggesting that environmental conditions were not yet stable (figure 24).

The second phase is interpreted as a cold ice - covered phase at Lake Hawdon. The high abundance of benthic diatom *Pseudostaurosira brevistriata's* in this phase has led interpretations towards an ice cover stage due to its well established preference for cold, harsh conditions (Bradshaw et al., 2000; Round et al., 1990). The diatom interpretation is in disagreement with the chironomid temperature reconstruction (Figure 24) in regards to the timing of such an event. The sampling resolution for the diatoms, however, is much finer than that of the chironomids and they may well be detecting finer changes within the core.

The timing of this cold phase has age constraints of 13,928 ± 142 cal yr BP to 12,686 ± 166 cal yr BP (Figure 22). The timing coincides with the Antarctic Cold Reversal (ACR), which extended from ~14,500 – 12,500 cal yr BP (Members, 2006). The Antarctic Cold Reversal has been widely discussed in publications in respect to its timing and synchronicity with the Northern Hemisphere Younger Dryas (Members, 2006; Singer et al., 1998; Turney et al., 2003). Theories as to the see-saw effect on the mechanism of where cooling occurred first (Northern or Southern Hemisphere) relate to the connections between oceanic and atmospheric conditions in both hemispheres in relation to Milankovitch forcing (Members, 2006).

Evidence of the ACR in New Zealand proxy studies has varied from ACR type events (McGlone et al., 2004; Turney et al., 2003) where a climate signal has been inferred but the shift is not great enough, to an event that has a climate signal similar to the ACR (Williams et al., 2005).The Lake Hawdon project inferences are similar to the interpretations made by McGlone (2004) where proxy changes suggest a cold phase during the ACR with a warming soon after; limiting the theory of a Younger Dryas event in the Canterbury high country. The diatoms suggest a dramatic cooling at this time, and the chironomids temperature reconstruction confirms a cool phase (Figure 24). Pollen from Lake Hawdon mimics McGlone's (2004) interpretations confirming an ACR type event occurred in the area. Further work with a transfer function may shed light on this connection by quantifying the degree of temperature change in New Zealand; the change was approximately 3°C (Jouzel et al., 1995), and could contribute towards the debate for the Southern Hemisphere leading changes during this time. Lake level changes in this phase could also represent changes in precipitation in the area which would contribute towards the concept of changing weather pattern positions over the country. Shulmeister (2004) suggest that shifts in the dominant westerly system over the South Island will impact proxy interpretations from study sites through the Last Glacial.

Having drawn these conclusions, it is appropriate to mention that the range of literature for diatom studies is vast. For this thesis, the literature collected has focussed on high altitude and high latitude studies primarily from the Northern Hemisphere where environmental controls are likely to be similar to the controls for the alpine environment of Lake Hawdon. Interpretations of the diatom stratigraphy have been based on the evidence from the Northern Hemisphere studies, with the acknowledgement that there are many studies that lead to different interpretations for the abundant taxa seen in Lake Hawdon. This is a disadvantage when interpreting cosmopolitan taxa that are geographically widespread and found in a broad range of ecological conditions. This limitation is discussed here because a prime example is *Pseudostaurosira brevistriata* which is crucial to the cooling interpreted within Lake Hawdon; the interpretation is based on similar situations and studies from the Northern Hemisphere (Bradshaw et al., 2000; Finkelstein and Gajewski, 2008; Smol et al., 2005). In multiple United Kingdom locations and in warm lowland lakes in Australia however, the same taxon has been interpreted to be indicative of disturbance and turbidity (Bennion et al., 2001; Sayer, 2001; Tibby et al., 2007). These studies have primarily focussed on modern samples and therefore non-glacial environments, which is a potential limitation of their application to a glacial environment. Conversely, other Northern Hemisphere studies

(Smol, 2005; Bradshaw; 2000; Finkelstein and Gajewski, 2008) are based within glacial environments and timeframes.

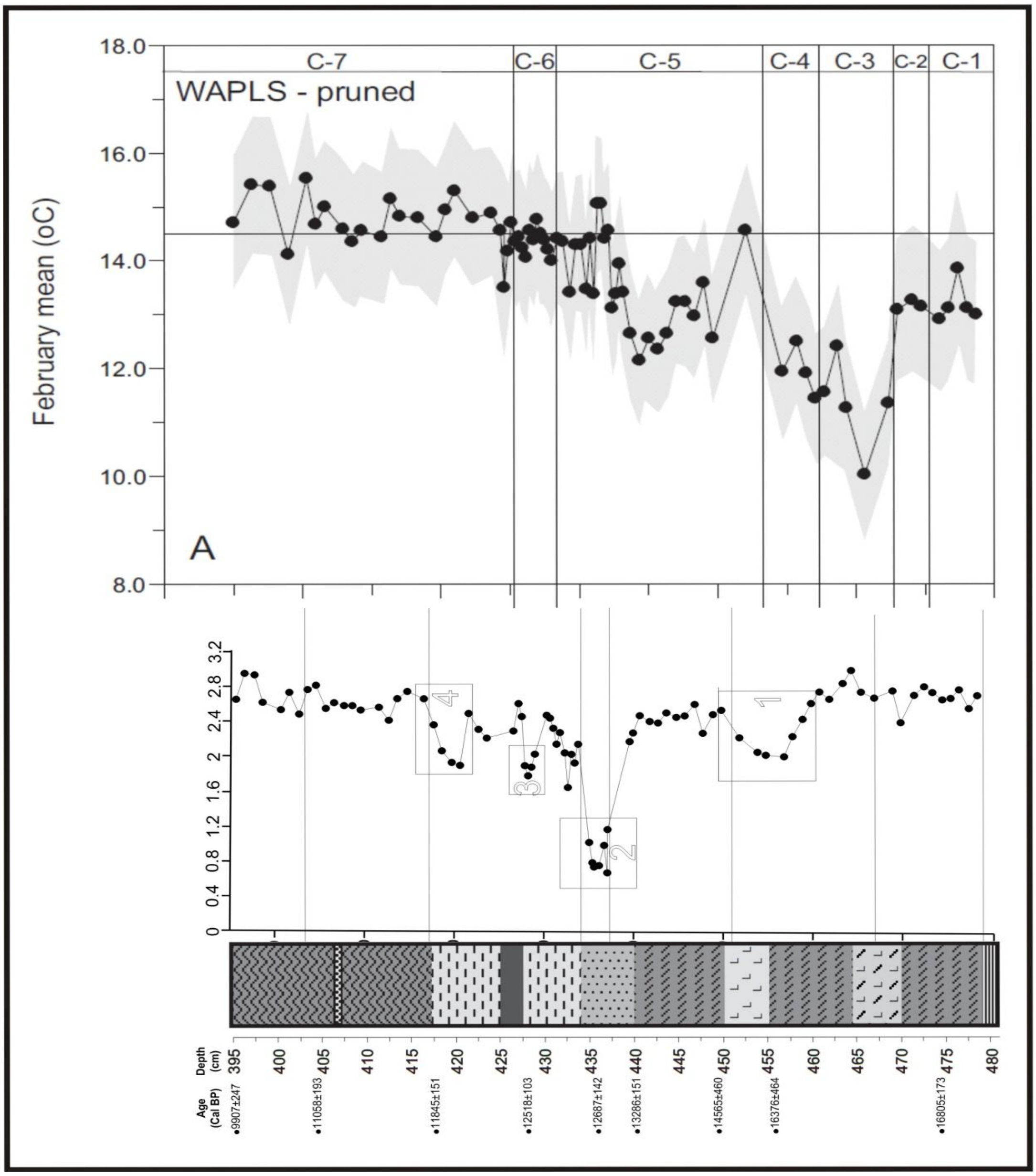


Figure 24 Diatom Shannon diversity index plot plotted next to chironomid temperature reconstruction (courtesy of Craig Woodward, project member), highlighting how the diatoms correspond to the chironomid data from Lake Hawdon.

In Lake Hawdon, *P. brevistriata* could represent disturbance, providing a false cooling signal. The best way to test this would be through comparative studies of other high country lakes. The increase in study locations could distinguish the regional cooling interpretation from an unrelated, localised disturbance signal particular to Lake

Hawdon. Multi-proxy studies allow ‘cross referencing’ of proxy records limiting the potential for a ‘false’ signal from a single proxy. The chironomids clearly support the diatom interpretation of a cooling phase, whilst the pollen does not strongly agree with such interpretation.

The emergence of the planktonic taxa *Cyclotella stelligera* after 434 cm (12, 686 cal yr BP) suggests a warming after the ACR. This could be evidence that the Poulter advance did not directly affect Lake Hawdon, as one would expect the dominance of *Pseudostaurosira brevistriata*, a pioneer of recently glaciated areas (Round et al., 1990) to continue had the lake been glaciated during the advance which occurred ~12 kyr BP (Fitzsimons, 1997). Rather than a continuance or strengthening of *P. brevistriata’s* dominance, instead it gives way to the warm, deep water *Cyclotella stelligera*. Chironomid data from Lake Hawdon also shows a warming after 434 cm, supporting the diatom interpretation in this phase. Unfortunately there has been little geomorphological research in the area since the pioneering investigations of Gage (1958), so there is currently no published physical evidence to support or contradict this hypothesis. One could argue that if there is no Poulter advance, then there is also no Younger Dryas signal in Lake Hawdon. The Younger Dryas has been well documented in the Northern Hemisphere, but there has been little conclusive evidence for such an event in the Southern Hemisphere (McGlone, 1995). Younger Dryas glacial evidence in New Zealand is seen at Waiho Loop moraine in Westland (Denton and Hendy, 1994) and in the Arthurs Pass moraine complex (Ivy-Ochs et al., 1999) but there are strong debates as to the age and environmental controls causing such moraines, especially the Waiho Loop. If these moraines are to be Younger Dryas events then pollen records from Kettlehole Bog (McGlone et al., 2004) and indeed for all proxy records at Lake Hawdon do not agree with the glacial evidence. There have been few proxy studies that have shown a significant degree of change through the Younger Dryas (YD) (Singer et al., 1998). The pollen record from Lake Hawdon conforms to other pollen studies in Westland (Alloway et al., 2007) and the Cobb Valley (Singer et al., 1998) around the time of the YD where a dominance of grasses and herbs gives way to the dominance of montane *Halocarpus* taxa, suggesting a generally warmer environment.

The third major phase in the diatom record is indicative of a warm, wetter period where diatom diversity was high, as was abundance, particularly in the planktonic taxa

Cyclotella stelligera. The presence of *C. stelligera* suggests the lake was deep enough for planktonic diatom growth. Nutrient and sediment influx also seem to have risen, encouraging growth from nutrient favouring taxa such as *Navicula cryptocephala* and *Epithemia sorex*. Stable isotope evidence from Kettlehole Bog (McGlone et al., 2004) also suggests an increase in atmospheric humidity, complementing diatom interpretations of a wetter period during this phase. A shift in the intensity and position of the westerly system (Shulmeister et al., 2004) may alter precipitation levels east of the Main Divide, causing an increase in the ratio between precipitation and evaporation over Lake Hawdon. Chironomid interpretations in this phase suggest that summer air temperatures increased to above the present day average of 14.5°C (Woodward pers. comm., 2010). Chironomid diversity increases through this phase, indicating that Lake Hawdon was evolving into a productive lake system. Lake Hawdon interpretations agree with other New Zealand studies showing a similar warming in Westland (Alloway et al., 2007), Cobb Valley in North West Nelson (Singer et al., 1998) and Kettlehole bog (McGlone et al., 2004).The pollen record also complements the interpretation of a warming phase with the presence of tree pollen in Lake Hawdon signalling an increase in temperatures. Pollen records suggest that the surrounding landscape had become stable enough that larger, long-lived trees such as podocarp species could establish themselves in the area. The warming into the Holocene agrees with the general trend established by other proxy studies including pollen, chironomids and isotopes in New Zealand (Alloway et al. 2007, Turney et al. 2003, Vandergoes et al. 2008, Williams et al. 2005), contributing to the palaeoenvironmental knowledge of New Zealand during the Late Quaternary.

6 Conclusions

Diatoms have been used as a biological proxy for environmental changes in Lake Hawdon, New Zealand, retrieved from a set of 10 sediment cores, covering ~8,000 years. 85 diatom samples were taken from the cores to create a high resolution (1cm) study through the Late Pleistocene to early Holocene. For each sample, 400 valves were identified and counted and qualitative and quantitative (statistical) analyses were carried out to evaluate whether environmental changes were reflected in the diatom record and if so, which environmental variables were dominant.

6.1 Qualitative Analysis

The diatom diagram (Figure 13) from Lake Hawdon highlighted three main phases of change from ~17,000 - ~10,000 yr BP. The first phase is indicative of the development and establishment of the lake, where conditions have been interpreted as being cool, with shallow water and limited habitat for productive diatom growth. As the lake became established, macrophyte growth allowed epiphytic taxa such as *Cocconeis placentula* to dominate the shallow lake. The diatoms include a broad range of nutrient tolerant taxa, suggesting Lake Hawdon’s trophic state fluctuated; productive at times, whilst unstable during other periods.

A significant change at 437.5 cm (zone IV) ~13,000 yr BP delineates the beginning of the second phase: a cold period during which Lake Hawdon was covered in ice that limited productivity and growth for most taxa except for *Pseudostaurosira brevistriata*. This cold tolerant, oligotrophic taxon peaks at 85% in this phase abundance, with other taxa present limited to benthic *Staurosirella pinnata* and planktonic *Cyclotella stelligera*. The presence of *C. stelligera* suggests that the lake depth increased for Lake Hawdon near the beginning of this phase. This second phase corresponds to the time frame of the Antarctic Cold Reversal (ACR), and the diatoms clearly reflect environmental changes related to this cooling event. The ACR is a major cooling event that has Southern Hemispheric climate implications, and the detection in Lake Hawdon via diatoms identifies a suitable proxy for isolating such an event in New Zealand where other proxies have been unable to do so.

The third phase has been interpreted as a warming phase around 12,500 yr BP, suggesting that Lake Hawdon was not subject to another period of cooling such as the Younger Dryas. Diversity increased through this phase, and planktonic taxon such as *Cyclotella stelligera* and benthic taxon such as *Navicula cryptocephala* suggest that the pH conditions in Lake Hawdon were becoming more neutral, reflected also in the change of eutrophic tolerant taxa indicating higher levels of nutrient availability. This may reflect the general increase in landscape productivity due to warmer conditions.

6.2 Quantitative Analyses

Along with qualitative analysis of the diatoms, statistical methods were used to quantify changes detected in the diatoms. Shannon diversity index results highlighted four sections through the core where diatom diversity shifted below the 2.3 (H’) average, including the diatom zone IV where *Pseudostaurosira brevistriata* dominates the samples. These sections relate to the qualitative interpretations, where diatom zones were representing the changes in dominant taxa through the core.

Principal Component Analysis carried out on the diatom data suggest that the primary and secondary axes influencing diatoms in Lake Hawdon should be interpreted as nutrients/sediment influx and water depth/light availability. These relate well to the qualitative interpretations due to the ecological and habit evidence from the dominant taxa seen in the core. There were many potential variables that influenced Lake Hawdon diatoms and the next stage for testing such variables would be to create a transfer function with the New Zealand dataset from Michael Reid.

6.3 Multi-proxy

Diatom responses to changes in Lake Hawdon have complemented the interpretations from the chironomid and pollen records generated as part of a multi – proxy study on the lake. Both the pollen and chironomid data highlight a cool phase where the diatoms have also suggested a cool phase at 478- 440 cm in the core. The high resolution sampling of diatoms allows changes to be identified from Lake Hawdon that the chironomid and pollen data failed to detect. The primary example is in zone IV (437.5 –

434 cm) where a significant cooling phase with potential ice cover suggested by the diatom taxon change was not reflected in the chironomid record. If diatoms were excluded from the study at Lake Hawdon, the ‘warming’ phase would have appeared to begin earlier in the core, leading interpretations away from the potential of an ACR climate signal.

6.4 Future work

Diatoms in combination with chironomids and pollen highlight how a high resolution, multi-proxy study can provide detailed interpretations and contribute to palaeolimnological studies in New Zealand. Further work using diatoms as a proxy for palaeolimnological studies in New Zealand, especially in regard to studies related to the Late Quaternary, would provide an increased understanding of past environmental conditions in New Zealand. Diatoms respond to environmental conditions within the lake, whilst pollen represents the catchment area for the study site. The relationship and nature hierarchy of diatoms to chironomids strengthen the inclusion of diatoms into multi-proxy studies. The complementary interpretations of multiple proxies allow a comprehensive interpretation of localised and regional environmental changes which could refine the currently limited interpretations of significant events such as the ACR.

Genetic studies of New Zealand modern diatoms could also be addressed to assess and contribute to the global debate surrounding the nature of diatoms; do New Zealand diatoms provide evidence for endemism based on geographic dispersal or genetic variability? Genetic studies would increase the knowledge of diatoms in freshwater and marine systems, significantly enhancing the accuracy of interpretations when using diatoms as a tool for investigating environmental changes, whilst potentially refining taxonomic classifications for diatoms. The expansion of the Southern Hemisphere diatom dataset is crucial to the quality of palaeolimnological studies inferring palaeolimnological changes from fossil diatom assemblages.

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Appendices

Table identifying taxa names, the number of occurrences (N), the effective number of occurrences (Hill's N2), the maximum, mean and standard deviation for Lake Hawdon diatoms

Full name	N	Hill's N2	Max.	Mean	SD
Achnanthes exigua Grunow	3	2.81	5	0.129	0.699
Achnanthes levanderi Hustedt	6	4.53	7	0.318	1.334
Achnanthes linearis (W. Smith) Grunow	6	5.16	3	0.165	0.648
Achnanthes species Bory	3	2.67	2	0.047	0.261
Achnanthes subexigua Hustedt	18	13.44	17	1.694	3.908
Achnanthidium minutissimum (Kutzing) Czarnecki	36	23.31	25	3.282	5.339
Amphora coffeaeformis (C. Agardh) Kutzing	1	1	1	0.012	0.108
Amphora ovalis (Kutzing) Kutzing	32	24.00	19	3.294	5.251
Amphora species Ehrenberg	14	10.99	9	0.818	2.106
Amphora veneta Kutzing	48	31.88	12	2.2	2.840
Caloneis bacillum (Grunow) Cleve	15	11.17	5	0.423	1.089
Cavinula cocconeiformis (Gregory ex Greville) Mann & Stickle	30	20.37	8	0.906	1.613
Cocconeis placentula Ehrenberg	70	21.68	190	26.941	46.036
Cocconeis species Ehrenberg	2	1.8	2	0.035	0.240
Craticula accommoda (Hustedt) Mann	2	1.97	9	0.188	1.222
Craticula cuspidata (Kutzing) Mann	23	17.23	6	0.623	1.234
Craticula halophila (Grunow) Mann	6	3.97	8	0.259	1.170
Cyclotella meneghiniana Kutzing	17	10.65	9	0.647	1.70
Cyclotella pseudostelligera Hustedt	44	24.42	99	16.271	25.626
Cyclotella stelligera (Cleve & Grunow in Cleve) Van Heurck	60	38.83	232	48.694	53.095
Cymbella affinis Kutzing	36	21.35	49	5.718	9.871
Cymbella aspera (Ehrenberg) Cleve	1	1	1	0.012	0.108
Cymbella cistula Kirchner	78	55.38	44	14.341	10.489
Cymbella cuspidata Kutzing	1	1	3	0.035	0.323
Cymbella helvtica Kutzing	1	1	1	0.012	0.108
Cymbella incerta Grunow	2	2	2	0.047	0.303
Cymbella lineolatea Patrick	1	1	1	0.012	0.108
Cymbella naviculiformis (Auerswald) Cleve	2	2	2	0.047	0.303
Cymbella species Agardh	8	4.02	16	0.553	2.481

Denticula species Ehrenberg	3	1.68	6	0.094	0.662
Denticula subtilis Grunow	1	1	11	0.129	1.186
Denticula tenuis Kutzing	4	3.57	2	0.059	0.281
Diatomella balfouriana var *constricta* Krasske ex Hustedt	13	8.31	9	0.423	1.287
Diploneis marginestriata Hustedt	5	4.55	3	0.118	0.495
Diploneis ovalis (Hilse) Cleve	48	17.14	30	2	3.979
Encyonema gracile Ehrenberg	22	11.46	29	2.318	5.872
Encyonema javanicum (Hustedt) Mann	1	1	6	0.071	0.647
Encyonema minutum (Bleisch in Rabenhorst) Mann	2	2	1	0.024	0.152
Encyonema silesiacum (Bleisch in Rabenhorst) Mann	2	2	3	0.071	0.455
Encyonopsis microcephala (Grunow) Krammer	57	30.65	60	9.471	12.611
Epithemia adnata (Kutzing) Brebisson	11	4.22	20	0.541	2.369
Epithemia smithii Carruth	5	3.70	24	0.706	3.311
Epithemia sorex Kutzing	82	54.15	132	41.612	31.409
Epithemia turgida (Ehrenberg) Kutzing	38	23.80	22	3.212	5.150
Eunotia pectinalis (Kutzing) Rabenhorst	10	5.95	8	0.294	1.072
Eunotia species Ehrenberg	1	1	1	0.012	0.108
Fragilaria cap var *gracilis* (Oectrup) Hustedt	2	1.6	3	0.047	0.339
Fragilaria capucina Desmazieres	32	16.84	19	1.765	3.550
Fragilaria cap var *capucina* Desmazieres	34	16.11	24	2.024	4.184
Fragilaria species Lyngbye	21	12.86	13	1.082	2.563
Fragilariforma species Williams and Round	2	2	1	0.024	0.152
Fragilariforma virescens (Ralfs) Williams & Round	1	1	1	0.012	0.108
Gomphonema gracile Ehrenberg	47	25.70	30	5.082	7.720
Gomphonema parvulum (Kutzing) Kutzing	6	4.76	3	0.106	0.434
Gomphonema pseudoaugur Lange-Bertalot	1	1	1	0.012	0.108
Gomphonema species Ehrenberg	20	11.08	16	1.047	2.705
Gomphonema vibrio var *intricatum* Agardh	14	9.49	17	1.223	3.452
Grunowia sinuata (Thwaites) Rabenhorst	42	25.73	27	5.165	7.840
Gyrosigma spenceri (Smith) Griff & Henfey	1	1	1	0.012	0.108
Karayevia clevei Grunow in Cleve & Grunow	59	29.39	73	11.141	15.326

Karayevai oblongella Ostr.	66	41.30	53	12.741	13.107
Lemnicola hungarica (Grunow) Round & Basson	2	1.38	5	0.071	0.548
Martyana martyi (Heribaud) Round	15	6.31	28	1	3.531
Navicula concentrica Carter & Bailey-Watts	24	11.79	19	1.329	3.312
Navicula cryptocephala Lund	75	44.46	76	16.894	16.131
Navicula helvetica Brun	3	2.67	2	0.047	0.261
Navicula lanceolata Ehrenberg	13	7.44	11	0.553	1.786
Navicula mensiculus Schumann	22	8.03	22	0.929	2.877
Navicula rhyncocephala Kutzing	19	14.95	4	0.494	1.07
Navicula viridula (Kutzing) Ehrenberg	1	1	1	0.012	0.108
Neidium affine (Ehrenberg) Pfizer	43	23.66	18	2.471	3.978
Neidium ampliatum (Ehrenberg) Krammer	19	10.95	20	1.247	3.243
Neidium iridis (Ehrenberg) Cleve	1	1	1	0.012	0.108
Nitzschia amphibia Grunow	20	10.28	25	1.459	3.933
Nitzschia frustulum (Kutzing) Grunow	56	25.46	43	7.482	11.44
Nitzschia gracilis Hantzsch	1	1	2	0.0023	0.216
Nitzschia palea (Kutzing) Smith	12	10.31	3	0.223	0.601
Nitzschia species Hassall	7	5.56	3	0.118	0.445
Nitzschia tubicola Grunow	1	1	2	0.023	0.216
Pinnularia silvatica Petersen	25	16.9	9	0.918	1.842
Pinnularia species Ehrenberg	6	3.70	7	0.235	1.102
Pinnularia viridis (Nitzsch) Ehrenberg	55	32.58	19	3.447	4.372
Planothidium frequentissimum Lange-Bertalot	23	16.56	7	0.576	1.172
Planothidium lanceolatum (Brebisson ex Kutzing) Lange-Bertalot	11	3.81	18	0.541	2.500
Pseudostaurosira brevistriata (Grunow) Williams & Round	77	42.93	348	95.353	94.387
Rhopalodia gibba (Ehrenberg) Muller	44	26.48	12	1.494	2.221
Rhopalodia novae zealandiae Hustedt	31	18.24	13	1.353	2.588
Sellaphora bacillum (Ehrenberg) Mann	35	20.21	33	4.235	7.583
Sellaphora pupula (Kutzing) Mereschkowsky	56	26.73	30	4.624	6.827
Stauroneis anceps Ehrenberg	7	5.76	3	0.129	0.480
Stauroneis phoenicenteron (Nizsch) Ehrenberg	46	27.88	15	2.224	3.182
Staurosira construens Ehrenberg	56	30.85	32	5.365	7.107
Staurosira construens var *venter*	30	19.73	52	6.694	12.171

(Ehrenberg) Hustedt					
Staurosirella lapponica (Grunow) Williams & Round	56	30.85	36	7.788	9.757
Staurosirella leptostauron Williams & Round	6	3.02	12	0.271	1.409
Staurosirella pinnata (Ehrenberg) Williams & Round	70	34.03	75	19.718	24.129
Surirella angusta Kutzing	3	2.27	3	0.058	0.355
Surirella linearis Grunow	5	3	6	0.141	0.738
Synedra acus Turpin	17	11.54	5	0.353	0.890
Synedra species Ehrenberg	15	8.51	13	0.717	2.151
Synedra ulna (Nitzsch) Ehrenberg	5	2.21	11	0.2	1.225
Tabellaria species (ex Kutzing) Ehrenberg	2	1.6	3	0.047	0.340

Processing Procedure for Diatom Samples

SAFETY
Steps 2, 3 and 6 are carried out under a fume hood with rubber gloves and safety glasses on. This is to avoid contact with hydrogen peroxide, hydrochloric acid, and toluene (the solvent used in Naphrax) which is carcinogenic.

CLEANLINESS
It is important that all glassware, stirrers, centrifuge tubes, and pipette tips are thoroughly clean before use. Care must be taken throughout the procedure to avoid contamination between samples.

1. SAMPLE PREPARATION

A cube of sediment with a wet weight of approximately 1 g is taken from the core and placed in a weighed 250 ml beaker. The sample are oven-dried for a period of 24 hours at 50°c, removed and left to reach room temperature, then weighed. The initial beaker weight is subtracted to provide the dry sample weight. Samples are processed in batches of eight to match the capacity of the centrifuge.

2. REMOVAL OF ORGANIC MATTER

20 ml of 27 % hydrogen peroxide is slowly added to each sample. If a sample reacts vigorously it is placed in a cold water bath and a stirring rod is used to break up the foam. Reactive samples should be left to digest for about 8 hours at room temperature.

Samples are then heated on a hot plate to about 80°C and left to warm for 1-2 hours. To avoid contamination between samples (by splattering) and damage to diatom valves, the samples are not boiled. When reactions are slowing add some drops of hydrogen peroxide to determine whether the samples need further digestion. Most visible organic material should be digested.

3. REMOVAL OF CARBONATE

10 ml of 32 % hydrochloric acid is slowly added to the warm samples on top of the hydrogen peroxide. The samples are left to sit until visible reactions cease. They are then heated gently on a hot plate for about 10 minutes. For calcareous samples more HCl is added and the samples are heated for a longer period. Reactions may need to be controlled using a cold water bath and stirring rod as above.

Once cool, each sample is washed into a centrifuge tube using filtered water. They are centrifuged at 3000 rpm for 5 minutes, the liquid is poured off and replaced with filtered water. This is repeated four times to remove the chemicals from the sample.

4. REMOVAL OF SAND

A lid is screwed onto the centrifuge tube; each sample is shaken for 15 seconds and left to stand for 45 seconds. The suspension is poured into a clean tube and retained, sand remains behind and is discarded. This process is repeated and each sample is returned to its original container. The timing of this process means that it is best carried out in batches of four samples. For very sandy samples it is wise to re-suspend the sand in distilled water and repeat the process above to get as much of the fines out of the sand fraction before it is discarded.

5. REMOVAL OF CLAY

The sample is made up to the centrifuge tube limit with filtered water, and then six drops of calgon (sodium hexa-metaphosphate) are added. This mixture is shaken well and then centrifuged at 1800 rpm for 3 minutes. Cloudy liquid is gently poured off and the process repeated about 5 times until liquid is clear. The sample is rinsed with filtered water and centrifuged at 3000 rpm for 5 minutes.

6. SLIDE PREPARATION

Pipette Method

For each sample a labelled microscope slide and two coverslips are warmed on a hotplate. The sample is re-suspended in about 10 ml of filtered water and shaken vigorously for 30 seconds. A 0.02 ml aliquot is taken from the sample with a micro-pipette and dropped onto a coverslip. This is diluted with drops of filtered water until the coverslip is covered with a large droplet of solution. The same is done for the second coverslip but with twice the concentration of suspension. The slips are heated gently until all the water has evaporated. Two drops of Naphrax are added to the microscope slide and warmed. The slips are lifted with the help of a toothpick and inverted onto the Naphrax drops. The slides are left to bubble gently for a few minutes to allow the toluene to evaporate out of the Naphrax. The slides are removed from the hotplate and the slips are tapped gently with a toothpick to remove air bubbles. Excess Naphrax can be removed with a scalpel once it has cooled and hardened.

7. STORAGE OF SAMPLES

The sample residue is rinsed into a 5 ml storage phial with filtered water and 2 drops of dilute formalin solution is added.

Raw diatom counts from Lake Hawdon

DEPTH	Sample name	K oblongella	A minutissimum	K clevei	P lanceolatum
395.5	LH2/2 400.5	37	18	73	0
396.5	LH2/2 1.5	18	18	45	0
397.5	LH2/2 2.5	15	13	31	0
398.5	LH2/2 3.5	13	0	9	1
400.5	LH2/2 5.5	0	0	39	0
401.5	LH2/2 6.5	7	2	28	0
402.5	LH2/2 7.5	41	0	24	0
403.5	LH2/2 8.5	16	4	25	0
404.5	LH2/2 9.5	14	7	27	0
405.5	LH2/2 10.5	15	6	31	0
406.5	LH2/2 411.5	26	0	44	0
407.5	LH2/2 12.5	1	0	0	0
408.5	LH2/2 13.5	26	12	43	0
409.5	LH2/2 14.5	6	11	6	0
411.5	LH2/2 16.5	9	12	15	0
412.5	LH2/2 17.5	0	0	0	1
413.5	LH2/2 18.5	26	14	53	1
414.5	LH2/2 19.5	7	0	12	0
416.5	LH2/2 21.5	9	0	12	0
417.5	LH2/2 422.5	53	0	14	0
418.5	LH2/2 23.5	0	0	0	5
419.5	LH2/2 24.5	10	0	11	0
420.5	LH2/2 25.5	45	0	7	0
421.5	LH2/2 26.5	8	5	25	0
422.5	LH2/2 27.5	18	0	17	0
423.5	LH2/2 28.5	0	0	0	0
426.5	HD 44	50	0	41	0
426.9	HD 43	45	0	58	1
427.3	HD 42	37	5	27	1
427.7	HD 41	0	9	18	0
428.1	HD 40	0	5	8	0
428.5	HD 39	0	0	0	0
428.9	HD 38	3	0	1	1
430.1	HD 35	5	2	4	0
430.5	HD 34	14	0	11	0
430.9	HD 33	13	2	20	0
431.3	HD 32	10	9	26	0
431.5	HD 31	12	0	12	0
432.1	HD 30	15	2	8	0
432.5	HD 29	8	0	3	0
432.9	HD 28	5	0	6	0

DEPTH	Sample name	K oblongella	A minutissimum	K clevei	P lanceolatum
433.3	HD 27	0	0	0	0
433.7	HD 26	8	6	8	0
435	HD 23	0	0	1	0
435.3	HD 22	0	0	1	0
435.5	HD 21	2	0	0	0
436.1	HD 20	0	0	0	0
436.5	HD 19	3	0	2	0
436.9	HD 18	0	1	0	0
437	HD 17	2	0	0	0
439.3	HD12	4	8	0	1
439.75	HD 11	0	2	2	0
440.5	HD 10	13	0	0	0
441.5	HD 9	13	8	0	0
442.5	HD 8	15	0	2	0
443.5	HD 7	25	0	3	0
444.5	HD 6	17	13	0	0
445.5	HD 5	0	10	0	14
446.5	HD 4	25	0	0	0
447.5	HD 3	21	25	0	0
448.5	HD 2	48	0	0	0
449.5	HD1	0	10	0	18
451.5	HZ 23.5	10	3	0	0
453.5	HZ 25.5	4	0	0	0
454.5	HZ 26.5	8	0	0	0
456.5	HZ 28.5	0	0	0	0
457.5	HZ 29.5	37	0	0	0
458.5	HZ 30.5	21	0	7	0
459.5	HZ 31.5	20	0	3	0
460.5	HZ 32.5	22	0	6	0
461.5	HZ 33.5	0	5	0	0
463	HZ 35	0	10	2	0
464	HZ 36	9	0	1	0
465	HZ 37	14	0	9	0
466.5	HZ 38.5	14	2	10	0
468.5	HZ 40.5	16	0	11	0
469.5	HZ 41.5	4	2	0	0
471	HZ 43	1	0	3	0
472	HZ 44	0	0	3	0
473	HZ 45	7	1	2	0
474	HZ 46	7	0	13	0
475	HZ 47	13	0	3	0
476	HZ 48	13	16	2	0
477	HZ 49	17	0	10	0

478	HZ 50	13	1	9	2

DEPTH	**A exigua**	**A levanderi**	**L hungarica**	**A linearis**	**A veneta**
395.5	0	0	0	0	10
396.5	0	0	0	0	2
397.5	3	0	0	0	7
398.5	0	0	0	0	4
400.5	0	0	0	0	2
401.5	0	0	0	0	2
402.5	0	0	0	0	1
403.5	0	0	0	0	4
404.5	0	7	0	0	3
405.5	0	0	0	0	12
406.5	0	0	0	0	9
407.5	0	0	0	0	4
408.5	0	0	0	0	1
409.5	0	0	0	0	0
411.5	0	0	0	0	8
412.5	0	0	0	0	0
413.5	0	0	0	0	4
414.5	0	0	0	0	8
416.5	0	0	0	0	0
417.5	0	0	0	0	8
418.5	0	0	0	0	0
419.5	0	0	0	1	5
420.5	0	0	0	0	0
421.5	0	0	0	0	0
422.5	0	0	0	0	2
423.5	0	0	0	0	0
426.5	0	0	0	0	0
426.9	0	0	0	0	2
427.3	0	0	0	0	3
427.7	0	0	0	0	0
428.1	0	0	0	0	1
428.5	0	0	0	0	0
428.9	0	0	0	0	0
430.1	0	0	0	0	1
430.5	0	0	0	0	0
430.9	0	0	0	0	5
431.3	0	0	0	0	3
431.5	0	0	0	0	4
432.1	0	1	0	0	0
432.5	0	0	0	0	0
432.9	0	0	0	0	5
433.3	0	0	0	0	1

433.7	0	0	0	0	1
435	0	0	0	0	0
435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	1
436.9	0	0	0	0	0
DEPTH	**A exigua**	**A levanderi**	**L hungarica**	**A linearis**	**A veneta**
437	0	0	0	1	0
439.3	0	0	0	0	1
439.75	0	0	0	0	0
440.5	0	0	0	3	10
441.5	0	1	0	0	0
442.5	0	0	0	0	7
443.5	0	0	0	0	5
444.5	0	0	1	0	3
445.5	0	0	5	0	3
446.5	0	0	0	3	2
447.5	0	0	0	0	2
448.5	0	0	0	0	2
449.5	0	0	0	3	2
451.5	0	0	0	0	1
453.5	0	0	0	0	0
454.5	0	0	0	0	0
456.5	0	0	0	0	0
457.5	0	0	0	3	3
458.5	0	0	0	0	1
459.5	0	0	0	0	0
460.5	0	0	0	0	4
461.5	0	7	0	0	0
463	0	6	0	0	5
464	0	0	0	0	0
465	0	0	0	0	0
466.5	0	0	0	0	0
468.5	0	0	0	0	0
469.5	0	0	0	0	0
471	0	0	0	0	6
472	0	5	0	0	3
473	0	0	0	0	0
474	0	0	0	0	4
475	0	0	0	0	0
476	5	0	0	0	0
477	0	0	0	0	0
478	3	0	0	0	0

DEPTH	A ovalis	A coffeaeformis	C placentula	C stelligera	C pseudostelligera
395.5	12	0	0	15	5
396.5	18	0	5	31	7
397.5	16	0	7	34	18
398.5	9	0	2	51	13
400.5	6	0	3	37	9
401.5	10	0	7	38	16
402.5	4	0	4	47	11
403.5	5	0	3	34	15
404.5	6	0	6	55	14
405.5	0	0	3	78	0
406.5	0	0	9	84	0
407.5	0	0	5	58	63
408.5	9	0	5	72	28
409.5	0	0	4	90	36
411.5	0	0	8	118	37
412.5	0	0	1	102	99
413.5	8	0	3	67	25
414.5	0	0	3	56	57
416.5	0	0	3	85	79
417.5	0	0	4	125	0
418.5	0	0	3	167	66
419.5	0	0	0	232	13
420.5	0	0	0	223	7
421.5	2	0	2	109	90
422.5	0	0	0	130	0
423.5	0	0	3	121	62
426.5	0	0	2	157	0
426.9	9	0	0	84	53
427.3	1	0	3	92	56
427.7	2	0	1	182	92
428.1	1	0	0	118	66
428.5	0	0	0	130	65
428.9	8	0	2	28	16
430.1	15	0	0	14	8
430.5	0	0	1	47	0
430.9	16	0	0	27	12
431.3	8	0	1	58	42
431.5	0	0	2	83	0
432.1	5	0	0	34	23
432.5	9	0	0	23	4
432.9	0	0	2	95	0
433.3	0	0	0	103	75
433.7	11	0	0	41	27

435	0	0	0	84	0
435.3	0	0	1	44	19
435.5	0	0	0	41	0
436.1	0	0	2	16	6
436.5	0	0	1	27	0
436.9	1	0	1	27	16

DEPTH	**A ovalis**	**A coffeaeformis**	**C placentula**	**C stelligera**	**C pseudostelligera**
437	0	0	10	58	0
439.3	5	0	7	5	12
439.75	0	0	7	57	0
440.5	0	0	20	28	0
441.5	6	0	22	8	5
442.5	0	0	20	9	0
443.5	0	0	27	15	0
444.5	8	0	29	0	5
445.5	19	0	28	38	1
446.5	0	0	18	36	0
447.5	11	0	10	0	3
448.5	0	0	10	15	0
449.5	18	0	26	56	7
451.5	0	0	119	0	0
453.5	0	0	188	0	0
454.5	0	0	179	0	0
456.5	0	0	181	0	0
457.5	0	0	190	0	0
458.5	0	0	131	0	0
459.5	0	0	126	0	0
460.5	0	0	73	0	0
461.5	0	0	96	0	0
463	12	0	85	0	0
464	0	0	28	0	0
465	0	0	24	0	0
466.5	0	1	26	0	0
468.5	0	0	36	0	0
469.5	0	0	59	0	0
471	0	0	68	0	0
472	10	0	86	0	0
473	0	0	74	0	0
474	0	0	46	0	0
475	0	0	50	0	0
476	0	0	32	0	0
477	0	0	26	0	0
478	0	0	21	0	0

DEPTH	C meneghiniana	C affinis	C cistula	C incerta	C helvtica
395.5	0	27	15	0	0
396.5	2	38	16	0	0
397.5	0	19	11	0	0
398.5	0	13	20	0	0
400.5	0	24	5	0	0
401.5	4	13	11	0	0
402.5	0	17	10	0	0
403.5	2	11	30	0	0
404.5	0	17	16	0	0
405.5	0	0	26	0	0
406.5	0	0	28	0	0
407.5	0	47	24	0	0
408.5	0	17	10	0	0
409.5	0	0	23	0	0
411.5	0	0	33	0	0
412.5	0	49	9	2	0
413.5	0	12	5	0	0
414.5	0	0	40	0	0
416.5	0	0	40	0	0
417.5	3	0	30	0	0
418.5	0	14	5	0	0
419.5	5	0	14	0	0
420.5	0	0	14	0	0
421.5	6	12	12	0	0
422.5	0	0	44	0	0
423.5	0	19	6	0	1
426.5	2	0	40	0	0
426.9	8	4	4	0	0
427.3	0	0	21	0	0
427.7	5	5	0	0	0
428.1	0	0	11	0	0
428.5	9	6	0	0	0
428.9	0	3	0	0	0
430.1	0	8	16	0	0
430.5	0	0	30	0	0
430.9	1	0	14	0	0
431.3	0	5	4	0	0
431.5	0	0	27	0	0
432.1	0	7	16	0	0
432.5	0	13	32	0	0
432.9	0	0	34	0	0
433.3	0	12	6	0	0
433.7	2	5	17	0	0
435	2	0	6	0	0

435.3	1	1	0	0	0
435.5	0	0	2	0	0
436.1	1	0	0	0	0
436.5	0	0	1	0	0
436.9	1	2	0	0	0

DEPTH	**C meneghiniana**	**C affinis**	**C cistula**	**C incerta**	**C helvtica**
437	1	0	11	0	0
439.3	0	5	10	0	0
439.75	0	9	16	0	0
440.5	0	0	21	0	0
441.5	0	12	4	0	0
442.5	0	0	14	2	0
443.5	0	0	15	0	0
444.5	0	9	13	0	0
445.5	0	12	6	0	0
446.5	0	0	13	0	0
447.5	0	4	15	0	0
448.5	0	0	17	0	0
449.5	0	0	5	0	0
451.5	0	0	3	0	0
453.5	0	0	11	0	0
454.5	0	0	3	0	0
456.5	0	0	13	0	0
457.5	0	0	6	0	0
458.5	0	0	6	0	0
459.5	0	0	27	0	0
460.5	0	0	7	0	0
461.5	0	0	22	0	0
463	0	7	2	0	0
464	0	0	21	0	0
465	0	0	16	0	0
466.5	0	0	18	0	0
468.5	0	0	7	0	0
469.5	0	0	15	0	0
471	0	0	9	0	0
472	0	8	0	0	0
473	0	0	17	0	0
474	0	0	9	0	0
475	0	0	19	0	0
476	0	0	17	0	0
477	0	0	15	0	0
478	0	0	18	0	0

DEPTH	E microcephala	C aspera	C naviculiformis	C cuspidata	D tenuis
395.5	44	0	0	0	0
396.5	14	0	0	0	0
397.5	14	0	0	0	0
398.5	11	0	0	0	0
400.5	23	0	0	0	0
401.5	11	0	0	0	0
402.5	17	0	0	0	0
403.5	37	0	0	0	0
404.5	31	0	0	0	0
405.5	28	0	0	0	0
406.5	35	0	0	0	0
407.5	0	0	0	0	1
408.5	45	0	0	0	0
409.5	0	0	0	0	0
411.5	0	0	0	0	0
412.5	0	0	0	0	1
413.5	56	0	0	0	0
414.5	11	0	0	0	0
416.5	7	0	0	0	0
417.5	11	0	0	0	0
418.5	0	0	0	0	0
419.5	3	0	0	0	0
420.5	60	0	0	0	0
421.5	3	0	0	0	0
422.5	6	0	0	0	0
423.5	0	0	0	0	0
426.5	3	0	0	0	0
426.9	4	0	0	0	0
427.3	6	0	0	0	0
427.7	0	0	0	0	0
428.1	0	0	0	0	0
428.5	0	0	0	0	0
428.9	3	0	0	0	0
430.1	4	0	0	0	2
430.5	10	0	0	0	0
430.9	5	0	0	0	0
431.3	11	0	0	0	0
431.5	8	0	0	0	0
432.1	20	0	0	0	0
432.5	6	0	0	0	0
432.9	18	0	0	0	0
433.3	0	0	0	0	0
433.7	17	0	0	0	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**E microcephala**	**C aspera**	**C naviculiformis**	**C cuspidata**	**D tenuis**
437	0	0	0	0	0
439.3	8	0	0	0	0
439.75	0	0	0	0	0
440.5	4	0	0	0	0
441.5	9	0	0	0	0
442.5	0	0	0	0	0
443.5	21	0	0	0	0
444.5	17	0	0	0	0
445.5	0	0	0	0	0
446.5	16	0	0	0	0
447.5	19	0	0	0	0
448.5	20	0	0	0	0
449.5	0	0	0	0	0
451.5	5	0	0	0	0
453.5	0	0	0	0	0
454.5	4	0	0	0	0
456.5	0	0	0	0	0
457.5	7	0	0	0	0
458.5	10	0	0	0	0
459.5	1	0	0	0	0
460.5	5	0	0	0	0
461.5	0	0	0	0	1
463	11	0	0	0	0
464	15	0	0	0	0
465	5	0	0	0	0
466.5	0	1	2	0	0
468.5	5	0	0	0	0
469.5	0	0	2	0	0
471	5	0	0	3	0
472	6	0	0	0	0
473	6	0	0	0	0
474	6	0	0	0	0
475	4	0	0	0	0
476	14	0	0	0	0
477	0	0	0	0	0
478	0	0	0	0	0

DEPTH	D subtilis	D marginestriata	D ovalis	E gracile	E sorex	E turgida
395.5	0	0	2	0	33	0
396.5	0	0	4	0	69	0
397.5	0	0	2	0	85	0
398.5	0	0	3	5	132	0
400.5	0	0	3	0	84	0
401.5	0	0	4	3	114	1
402.5	0	0	0	2	129	0
403.5	0	0	0	6	66	0
404.5	0	0	1	0	74	1
405.5	0	0	1	19	65	0
406.5	0	0	0	22	27	0
407.5	0	0	0	0	74	9
408.5	0	0	0	0	42	1
409.5	0	0	0	29	68	0
411.5	0	0	0	23	36	0
412.5	0	0	0	0	68	17
413.5	0	0	30	0	28	1
414.5	0	0	0	24	64	7
416.5	0	0	2	8	88	1
417.5	0	0	1	0	56	0
418.5	0	0	0	0	41	0
419.5	0	0	0	0	22	0
420.5	0	0	1	0	28	0
421.5	0	0	0	0	29	0
422.5	0	0	4	0	93	0
423.5	0	0	0	0	86	15
426.5	0	0	1	2	23	0
426.9	0	0	0	0	26	0
427.3	0	0	0	0	16	0
427.7	0	0	0	0	4	0
428.1	0	0	0	0	2	0
428.5	11	0	0	0	8	0
428.9	0	0	0	0	20	0
430.1	0	0	3	0	91	1
430.5	0	0	3	0	57	7
430.9	0	0	0	1	39	1
431.3	0	0	1	0	16	0
431.5	0	0	2	6	25	1
432.1	0	0	0	0	28	0
432.5	0	0	1	0	31	0
432.9	0	0	1	0	27	2
433.3	0	0	0	0	7	0
433.7	0	0	1	0	18	0
435	0	0	0	0	0	0

435.3	0	0	0	0	1	0
435.5	0	0	0	0	0	0
436.1	0	0	0	0	0	0
436.5	0	0	2	0	2	0
436.9	0	0	0	0	3	0
DEPTH	**D subtilis**	**D marginestriata**	**D ovalis**	**E gracile**	**E sorex**	**E turgida**
437	0	0	0	0	12	0
439.3	0	0	1	0	87	3
439.75	0	0	0	0	60	3
440.5	0	0	0	0	61	11
441.5	0	0	0	0	58	0
442.5	0	0	0	4	46	10
443.5	0	0	0	6	58	10
444.5	0	0	1	0	45	0
445.5	0	0	2	0	43	2
446.5	0	0	0	15	35	11
447.5	0	0	1	0	54	0
448.5	0	0	2	9	20	5
449.5	0	0	0	0	32	8
451.5	0	0	9	0	122	0
453.5	0	0	5	0	83	12
454.5	0	0	3	0	33	0
456.5	0	0	8	0	30	0
457.5	0	0	3	1	61	0
458.5	0	0	3	2	45	6
459.5	0	2	2	0	50	12
460.5	0	0	2	0	20	10
461.5	0	0	4	0	28	2
463	0	0	16	2	58	15
464	0	3	6	0	40	14
465	0	1	1	0	28	6
466.5	0	0	3	0	11	0
468.5	0	0	2	0	7	6
469.5	0	0	2	0	6	0
471	0	0	2	0	20	13
472	0	0	10	7	50	16
473	0	0	3	1	8	0
474	0	0	0	0	19	5
475	0	2	1	0	18	22
476	0	0	0	0	5	3
477	0	2	1	0	15	0
478	0	0	4	0	24	3

DEPTH	E adnata	E pectinalis	F capucina	G gracile	G virbrio var. intricatum
395.5	0	0	1	1	0
396.5	0	0	2	0	0
397.5	0	0	2	0	0
398.5	0	0	6	0	0
400.5	0	0	1	1	0
401.5	0	0	1	1	0
402.5	0	0	3	0	0
403.5	0	0	1	0	0
404.5	0	0	5	0	0
405.5	0	0	0	0	0
406.5	0	0	0	2	0
407.5	0	0	0	0	0
408.5	0	0	0	0	0
409.5	0	0	0	0	0
411.5	0	0	0	4	3
412.5	0	0	0	0	0
413.5	1	0	0	0	0
414.5	0	0	0	0	0
416.5	0	0	0	1	0
417.5	0	0	0	1	0
418.5	0	0	0	0	0
419.5	0	0	6	0	0
420.5	0	0	0	0	0
421.5	0	0	0	2	0
422.5	0	0	0	0	0
423.5	0	0	0	0	0
426.5	0	0	0	0	0
426.9	0	0	1	0	0
427.3	0	0	0	0	0
427.7	0	0	0	0	0
428.1	0	0	0	0	0
428.5	0	0	0	0	0
428.9	1	0	0	2	0
430.1	0	0	0	1	0
430.5	0	0	2	0	4
430.9	0	0	0	2	0
431.3	1	0	0	1	0
431.5	0	0	0	0	0
432.1	0	0	1	0	0
432.5	0	0	0	1	0
432.9	0	0	0	0	0
433.3	0	0	0	0	0
433.7	0	0	2	2	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	1	0
436.5	0	0	0	3	0
436.9	0	0	0	0	0

DEPTH	E adnata	E pectinalis	F capucina	G gracile	G virbrio var. intricatum
437	0	0	0	0	0
439.3	0	0	10	4	0
439.75	0	0	0	1	0
440.5	0	0	8	6	0
441.5	2	0	5	14	0
442.5	0	0	0	21	0
443.5	0	0	16	11	0
444.5	0	1	13	6	0
445.5	0	0	5	0	0
446.5	0	0	10	14	0
447.5	1	0	4	4	0
448.5	0	0	0	16	0
449.5	0	0	19	0	0
451.5	6	1	0	17	1
453.5	0	2	3	9	10
454.5	6	8	0	27	0
456.5	0	4	0	1	1
457.5	0	1	0	17	0
458.5	0	0	0	14	0
459.5	0	2	5	15	0
460.5	0	0	5	16	5
461.5	0	1	0	5	2
463	0	3	0	0	0
464	0	2	2	2	0
465	0	0	2	6	0
466.5	3	0	4	0	0
468.5	0	0	0	12	6
469.5	3	0	1	16	15
471	0	0	0	20	15
472	0	0	0	4	0
473	20	0	0	21	8
474	0	0	0	26	17
475	0	0	2	23	0
476	2	0	0	12	8
477	0	0	2	30	0
478	0	0	0	16	9

DEPTH	G parvulum	G pseudoaugur	C bacillum	N lanceolata	N cryptocephala
395.5	0	0	0	1	47
396.5	0	0	0	0	16
397.5	3	0	2	1	34
398.5	0	0	0	0	28
400.5	0	0	0	0	42
401.5	0	0	0	0	25
402.5	0	0	0	0	28
403.5	0	0	0	5	68
404.5	0	0	0	0	46
405.5	0	0	0	0	48
406.5	0	0	0	0	51
407.5	0	0	0	11	27
408.5	0	0	0	0	76
409.5	0	0	0	0	44
411.5	0	0	0	0	35
412.5	0	0	0	4	28
413.5	0	0	0	0	68
414.5	0	0	0	0	33
416.5	0	0	0	0	16
417.5	0	1	0	0	5
418.5	0	0	0	8	2
419.5	0	0	0	0	0
420.5	0	0	0	0	5
421.5	0	0	0	0	17
422.5	0	0	0	0	27
423.5	0	0	0	0	9
426.5	0	0	0	0	20
426.9	0	0	3	0	7
427.3	0	0	0	0	4
427.7	0	0	0	0	3
428.1	0	0	0	0	0
428.5	0	0	0	1	0
428.9	0	0	0	0	2
430.1	0	0	0	1	7
430.5	0	0	0	0	15
430.9	0	0	2	0	9
431.3	0	0	0	0	18
431.5	0	0	0	0	17
432.1	0	0	1	0	19
432.5	0	0	0	0	9
432.9	0	0	0	0	20
433.3	0	0	0	2	17
433.7	0	0	0	0	12
435	0	0	0	0	1

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	1	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**G parvulum**	**G pseudoaugur**	**C bacillum**	**N lanceolata**	**N cryptocephala**
437	0	0	0	0	0
439.3	0	0	0	0	9
439.75	1	0	0	0	14
440.5	0	0	0	0	23
441.5	0	0	1	0	18
442.5	2	0	0	0	15
443.5	0	0	0	0	15
444.5	0	0	0	0	14
445.5	0	0	0	3	23
446.5	0	0	0	0	22
447.5	1	0	1	0	12
448.5	0	0	0	0	16
449.5	0	0	0	7	22
451.5	0	0	0	0	5
453.5	0	0	0	0	7
454.5	0	0	0	0	0
456.5	0	0	0	0	3
457.5	0	0	1	0	2
458.5	0	0	0	0	7
459.5	0	0	4	0	7
460.5	0	0	1	0	11
461.5	0	0	4	2	14
463	0	0	0	0	18
464	0	0	5	0	30
465	0	0	4	0	15
466.5	0	0	0	1	11
468.5	0	0	0	0	10
469.5	0	0	0	0	4
471	0	0	0	0	11
472	1	0	0	0	10
473	0	0	0	0	11
474	1	0	2	0	5
475	0	0	4	0	8
476	0	0	0	0	7
477	0	0	0	0	14
478	0	0	0	0	18

DEPTH	**N concentrica**	**N rhyncocephala**	**N viridula**	**C cocconeiformis**	**C cuspidata**
395.5	0	0	0	0	0
396.5	0	1	0	0	0
397.5	0	1	0	2	1
398.5	0	4	0	6	0
400.5	0	2	0	1	1
401.5	0	0	0	4	2
402.5	0	3	0	5	0
403.5	0	0	0	0	2
404.5	0	2	0	3	0
405.5	0	0	0	1	0
406.5	0	0	0	0	2
407.5	0	0	0	1	0
408.5	0	0	0	2	0
409.5	0	4	0	0	0
411.5	13	4	0	0	0
412.5	2	0	0	0	0
413.5	0	0	0	2	4
414.5	0	2	1	0	0
416.5	1	2	0	0	0
417.5	0	0	0	0	4
418.5	0	0	0	0	0
419.5	0	0	0	0	4
420.5	0	0	0	0	0
421.5	0	0	0	4	0
422.5	0	0	0	0	0
423.5	0	0	0	0	0
426.5	0	0	0	1	6
426.9	0	0	0	3	0
427.3	0	0	0	0	0
427.7	0	0	0	5	0
428.1	0	0	0	0	0
428.5	0	0	0	0	0
428.9	0	0	0	1	3
430.1	0	0	0	4	0
430.5	0	0	0	0	1
430.9	0	0	0	3	0
431.3	0	0	0	0	0
431.5	2	0	0	0	1
432.1	0	0	0	0	3
432.5	0	0	0	0	1
432.9	1	2	0	0	0
433.3	1	0	0	0	0
433.7	0	0	0	0	4

435	0	1	0	0	0
435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	1	0
436.5	0	0	0	1	0
436.9	0	0	0	0	0

DEPTH	**N concentrica**	**N rhyncocephala**	**N viridula**	**C cocconeiformis**	**C cuspidata**
437	0	1	0	0	0
439.3	0	0	0	3	1
439.75	0	0	0	0	0
440.5	0	3	0	0	0
441.5	0	0	0	1	0
442.5	0	0	0	0	0
443.5	0	3	0	0	0
444.5	0	0	0	1	2
445.5	0	0	0	0	0
446.5	1	0	0	0	0
447.5	4	0	0	2	0
448.5	2	0	0	1	0
449.5	0	0	0	0	0
451.5	5	0	0	0	0
453.5	1	0	0	1	0
454.5	0	0	0	0	0
456.5	0	0	0	4	0
457.5	4	0	0	0	0
458.5	3	0	0	0	0
459.5	5	0	0	0	2
460.5	2	0	0	0	2
461.5	0	0	0	8	0
463	7	4	0	1	1
464	15	1	0	0	0
465	10	0	0	0	1
466.5	0	0	0	3	0
468.5	5	0	0	0	0
469.5	0	0	0	0	0
471	2	0	0	0	0
472	19	1	0	0	2
473	0	1	0	0	0
474	0	0	0	0	3
475	0	0	0	0	0
476	1	0	0	2	0
477	6	0	0	0	0
478	1	0	0	0	0

DEPTH	C halophila	N affine	N iridis	N ampliatum	N gracilis
395.5	0	0	0	0	0
396.5	0	3	0	0	0
397.5	0	6	0	0	0
398.5	0	0	0	11	0
400.5	0	3	0	0	0
401.5	0	3	0	2	0
402.5	0	2	0	1	0
403.5	0	2	0	0	0
404.5	2	0	0	6	0
405.5	0	1	0	0	0
406.5	0	0	0	0	0
407.5	0	0	0	3	0
408.5	0	2	0	0	0
409.5	0	0	0	7	0
411.5	0	0	0	5	0
412.5	0	0	0	4	0
413.5	0	0	0	0	0
414.5	0	4	0	1	0
416.5	0	4	0	3	0
417.5	0	0	0	0	0
418.5	0	0	0	14	0
419.5	8	6	0	0	0
420.5	0	16	0	0	0
421.5	0	12	0	0	0
422.5	0	15	0	0	0
423.5	0	0	0	20	0
426.5	4	4	0	0	0
426.9	0	1	0	0	0
427.3	0	6	0	0	0
427.7	0	6	0	0	0
428.1	0	3	0	0	0
428.5	0	4	1	0	0
428.9	0	18	0	0	0
430.1	0	8	0	0	0
430.5	6	4	0	0	0
430.9	0	2	0	0	0
431.3	0	1	0	0	0
431.5	0	7	0	0	0
432.1	0	0	0	0	0
432.5	0	1	0	0	0
432.9	0	0	0	1	0
433.3	0	0	0	0	0
433.7	0	2	0	0	0

435	0	8	0	7	0
435.3	0	9	0	0	0
435.5	0	11	0	8	0
436.1	0	13	0	0	0
436.5	0	4	0	4	0
436.9	0	2	0	0	0

DEPTH	**C halophila**	**N affine**	**N iridis**	**N ampliatum**	**N gracilis**
437	0	7	0	3	0
439.3	0	1	0	2	0
439.75	0	0	0	0	0
440.5	1	2	0	0	0
441.5	0	0	0	0	0
442.5	0	1	0	0	0
443.5	0	0	0	0	0
444.5	0	0	0	0	0
445.5	0	0	0	0	0
446.5	0	0	0	0	0
447.5	0	0	0	0	0
448.5	1	1	0	0	0
449.5	0	0	0	0	0
451.5	0	0	0	0	0
453.5	0	0	0	0	0
454.5	0	0	0	0	0
456.5	0	0	0	0	0
457.5	0	0	0	0	0
458.5	0	0	0	0	0
459.5	0	0	0	0	0
460.5	0	0	0	0	0
461.5	0	0	0	0	2
463	0	0	0	0	0
464	0	0	0	0	0
465	0	2	0	0	0
466.5	0	0	0	0	0
468.5	0	0	0	0	0
469.5	0	1	0	0	0
471	0	1	0	0	0
472	0	0	0	4	0
473	0	0	0	0	0
474	0	0	0	0	0
475	0	0	0	0	0
476	0	0	0	0	0
477	0	0	0	0	0
478	0	1	0	0	0

DEPTH	N palea	N frustulum	N amphibia	P viridis	R gibba
395.5	0	31	0	1	0
396.5	1	32	0	3	2
397.5	0	21	0	4	0
398.5	1	31	0	19	0
400.5	2	43	0	1	0
401.5	0	37	0	4	0
402.5	0	17	1	7	0
403.5	0	36	0	1	0
404.5	0	33	0	8	2
405.5	0	35	0	5	1
406.5	0	33	0	4	2
407.5	0	31	0	10	0
408.5	0	18	0	2	0
409.5	0	0	15	13	0
411.5	0	5	5	5	1
412.5	0	14	0	5	0
413.5	0	30	0	0	1
414.5	0	7	6	7	4
416.5	0	8	5	17	2
417.5	0	15	0	14	0
418.5	0	6	0	7	0
419.5	0	7	0	7	1
420.5	0	5	0	4	0
421.5	0	19	0	3	0
422.5	0	20	0	15	2
423.5	0	16	0	3	0
426.5	0	6	2	6	0
426.9	0	13	0	0	0
427.3	0	3	0	0	0
427.7	2	0	0	0	0
428.1	0	0	0	1	0
428.5	0	0	0	0	0
428.9	0	0	0	0	0
430.1	0	1	0	5	0
430.5	0	2	0	11	3
430.9	0	2	0	1	3
431.3	0	3	0	0	2
431.5	0	1	0	7	3
432.1	0	1	0	0	0
432.5	0	2	0	1	2
432.9	0	3	0	3	2
433.3	0	8	0	0	0
433.7	0	0	0	1	3
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	1
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**N palea**	**N frustulum**	**N amphibia**	**P viridis**	**R gibba**
437	0	0	0	0	0
439.3	0	0	0	3	2
439.75	0	4	0	4	0
440.5	0	0	0	2	9
441.5	0	0	0	2	2
442.5	0	0	0	5	7
443.5	0	0	0	0	12
444.5	0	0	0	0	0
445.5	0	1	0	0	0
446.5	0	0	0	4	2
447.5	0	0	0	0	0
448.5	0	0	0	5	3
449.5	0	0	0	0	0
451.5	0	2	0	10	2
453.5	0	4	0	2	4
454.5	0	3	1	4	5
456.5	0	2	0	0	0
457.5	0	1	0	3	2
458.5	2	1	0	2	3
459.5	0	3	2	7	1
460.5	2	2	0	2	2
461.5	0	4	0	0	0
463	2	0	2	7	8
464	1	1	0	16	7
465	0	2	3	4	2
466.5	1	1	1	0	4
468.5	0	0	2	3	1
469.5	0	1	3	0	1
471	1	1	2	1	2
472	3	0	0	0	4
473	0	1	9	0	1
474	1	0	10	0	0
475	0	3	15	0	1
476	0	4	7	1	0
477	0	0	25	1	2
478	0	0	8	0	1

DEPTH	S phoenicenteron	S anceps	S linearis	S angusta	G sinuata
395.5	3	0	0	0	0
396.5	8	0	0	0	2
397.5	4	0	0	0	1
398.5	13	0	0	0	0
400.5	7	0	0	1	0
401.5	3	0	0	0	3
402.5	5	0	0	0	0
403.5	3	0	1	0	0
404.5	4	0	0	0	0
405.5	2	0	0	0	0
406.5	1	0	0	0	0
407.5	1	0	0	0	1
408.5	3	0	0	0	1
409.5	5	0	3	0	0
411.5	0	0	0	0	0
412.5	1	1	0	0	0
413.5	0	0	0	0	1
414.5	4	0	0	0	0
416.5	11	1	0	0	0
417.5	8	0	0	0	0
418.5	15	0	0	0	0
419.5	6	0	0	0	0
420.5	0	0	0	0	0
421.5	4	0	0	0	0
422.5	7	0	0	0	0
423.5	8	0	0	0	0
426.5	4	2	0	0	0
426.9	7	0	0	0	0
427.3	3	0	0	0	0
427.7	4	0	0	0	0
428.1	9	0	0	0	1
428.5	0	0	0	0	8
428.9	6	0	0	0	4
430.1	0	0	0	0	24
430.5	0	0	0	0	25
430.9	1	0	0	0	16
431.3	1	0	0	0	6
431.5	4	0	0	0	4
432.1	0	0	0	0	19
432.5	0	0	0	0	13
432.9	4	0	0	0	2
433.3	1	0	0	0	4
433.7	0	0	0	0	10
435	0	0	0	0	0

435.3	1	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**S phoenicenteron**	**S anceps**	**S linearis**	**S angusta**	**G sinuata**
437	1	0	0	0	0
439.3	0	0	0	0	0
439.75	0	0	0	0	0
440.5	4	0	0	0	0
441.5	0	0	1	0	0
442.5	1	0	0	0	0
443.5	0	0	0	0	0
444.5	0	0	0	0	0
445.5	1	0	0	0	0
446.5	0	0	0	0	0
447.5	0	0	0	0	0
448.5	0	0	0	0	0
449.5	0	0	0	0	1
451.5	2	0	0	0	1
453.5	0	0	0	0	0
454.5	1	0	0	0	5
456.5	0	0	0	0	2
457.5	0	1	0	0	6
458.5	0	0	0	0	2
459.5	0	1	0	0	9
460.5	1	0	0	0	13
461.5	0	0	1	0	17
463	3	0	0	3	23
464	0	2	6	0	22
465	0	3	0	0	19
466.5	0	0	0	0	27
468.5	1	0	0	0	13
469.5	0	0	0	1	26
471	0	0	0	0	22
472	2	0	0	0	12
473	0	0	0	0	11
474	0	0	0	0	17
475	0	0	0	0	5
476	0	0	0	0	18
477	0	0	0	0	15
478	1	0	0	0	8

DEPTH	P brevistriata	S pinnata	S lapponica	S elliptica	S construens
395.5	2	1	0	0	0
396.5	3	2	0	0	5
397.5	6	4	0	0	0
398.5	3	0	0	0	1
400.5	3	0	0	0	5
401.5	2	1	3	0	0
402.5	0	0	0	0	2
403.5	2	4	1	0	2
404.5	1	2	0	0	0
405.5	0	1	1	0	1
406.5	5	0	2	0	0
407.5	0	0	0	0	0
408.5	0	0	0	0	1
409.5	0	0	0	0	0
411.5	0	0	0	0	0
412.5	1	1	0	0	0
413.5	0	0	1	1	0
414.5	0	0	0	4	0
416.5	2	2	0	0	1
417.5	8	1	5	0	8
418.5	17	0	0	0	0
419.5	20	7	1	0	0
420.5	13	0	0	0	8
421.5	23	3	1	0	3
422.5	2	2	4	0	2
423.5	1	0	0	0	0
426.5	18	0	0	0	2
426.9	22	7	5	0	3
427.3	65	3	0	0	4
427.7	39	3	1	0	1
428.1	150	22	0	4	1
428.5	101	58	3	0	0
428.9	190	42	0	23	0
430.1	122	36	0	0	5
430.5	133	3	2	0	0
430.9	168	21	0	0	3
431.3	172	7	0	0	0
431.5	152	8	2	0	0
432.1	198	3	0	1	1
432.5	239	2	0	0	1
432.9	193	2	1	0	0
433.3	149	4	0	0	0
433.7	196	3	1	0	4
435	292	17	1	0	0

435.3	325	4	1	0	0
435.5	336	7	2	0	0
436.1	332	17	0	0	6
436.5	321	55	5	0	0
436.9	348	1	7	0	0
DEPTH	**P brevistriata**	**S pinnata**	**S lapponica**	**S elliptica**	**S construens**
437	297	19	1	0	0
439.3	190	5	14	3	15
439.75	161	3	0	6	0
440.5	127	20	10	0	4
441.5	161	3	18	9	20
442.5	164	22	10	0	3
443.5	152	18	15	0	2
444.5	153	13	21	10	13
445.5	137	7	2	0	0
446.5	137	10	11	0	5
447.5	193	11	11	5	10
448.5	161	15	16	0	8
449.5	158	0	12	0	19
451.5	19	33	9	0	3
453.5	36	13	9	15	7
454.5	48	70	10	0	9
456.5	53	34	11	20	13
457.5	40	70	14	14	2
458.5	38	70	22	9	9
459.5	58	38	18	34	10
460.5	89	39	16	18	5
461.5	77	46	20	0	6
463	44	9	11	5	4
464	68	42	22	21	5
465	106	53	16	19	9
466.5	78	64	32	52	5
468.5	81	75	22	38	17
469.5	107	62	36	23	11
471	64	55	20	24	17
472	64	18	25	6	23
473	50	44	28	33	23
474	99	66	23	40	27
475	62	72	34	36	17
476	68	70	23	28	32
477	90	75	20	36	17
478	100	56	30	32	16

DEPTH	S leptostauron	S bacillum	S pupula	N helvetica	G spencer‍i
395.5	1	10	8	0	0
396.5	0	33	14	0	0
397.5	0	24	13	0	0
398.5	0	16	2	0	0
400.5	0	17	0	2	0
401.5	0	19	18	0	0
402.5	0	19	0	0	0
403.5	0	5	4	0	0
404.5	0	12	8	0	0
405.5	0	0	13	0	0
406.5	0	0	12	0	0
407.5	0	9	6	0	0
408.5	0	9	7	0	0
409.5	0	6	15	0	0
411.5	0	0	12	0	0
412.5	2	11	10	0	0
413.5	0	10	3	0	0
414.5	0	13	11	0	0
416.5	0	29	17	0	0
417.5	0	0	30	0	0
418.5	0	13	0	0	0
419.5	0	0	30	0	0
420.5	0	0	10	0	0
421.5	0	3	4	0	0
422.5	0	0	18	0	0
423.5	0	1	1	0	0
426.5	0	0	30	0	0
426.9	0	20	6	0	0
427.3	0	29	3	0	0
427.7	0	11	13	0	0
428.1	0	8	0	0	0
428.5	0	0	0	0	0
428.9	0	0	1	0	0
430.1	0	2	0	0	0
430.5	0	0	8	0	0
430.9	0	3	0	0	0
431.3	0	1	0	0	0
431.5	0	0	6	0	0
432.1	0	0	2	0	0
432.5	0	0	0	0	0
432.9	0	0	4	0	0
433.3	3	1	0	0	0
433.7	0	1	1	0	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**S leptostauron**	**S bacillum**	**S pupula**	**N helvetica**	**G spenceri**
437	0	0	1	0	0
439.3	0	4	3	0	0
439.75	12	11	0	0	0
440.5	0	0	1	0	0
441.5	0	1	0	0	0
442.5	0	0	4	0	0
443.5	0	0	0	0	0
444.5	0	0	0	0	0
445.5	0	3	0	0	0
446.5	0	0	2	0	0
447.5	0	3	1	0	0
448.5	0	0	2	0	0
449.5	4	0	4	0	0
451.5	0	0	0	0	0
453.5	0	0	0	0	0
454.5	0	0	1	0	0
456.5	0	0	0	0	0
457.5	0	0	1	0	0
458.5	0	0	0	0	0
459.5	0	0	2	0	0
460.5	0	0	0	0	0
461.5	0	1	2	1	1
463	0	0	0	0	0
464	0	0	7	0	0
465	0	0	4	0	0
466.5	0	0	1	1	0
468.5	1	0	3	0	0
469.5	0	0	0	0	0
471	0	0	1	0	0
472	0	0	5	0	0
473	0	0	0	0	0
474	0	0	1	0	0
475	0	0	1	0	0
476	0	0	2	0	0
477	0	0	3	0	0
478	0	2	1	0	0

DEPTH	N mensiculus	N tubicola	N species	P silvatica	P species
395.5	0	0	1	2	0
396.5	0	0	0	7	0
397.5	0	0	2	4	0
398.5	0	0	0	0	0
400.5	0	0	0	1	0
401.5	0	0	0	4	0
402.5	4	0	0	3	0
403.5	0	0	0	8	0
404.5	2	0	0	0	0
405.5	0	0	0	0	0
406.5	0	0	0	0	0
407.5	22	0	0	0	0
408.5	0	0	0	1	0
409.5	0	0	0	0	0
411.5	1	0	0	0	0
412.5	1	0	0	0	0
413.5	2	0	0	2	0
414.5	3	0	1	0	0
416.5	3	0	1	0	7
417.5	0	0	0	0	0
418.5	0	0	0	4	0
419.5	0	0	0	2	0
420.5	0	0	0	0	0
421.5	1	0	0	2	0
422.5	0	0	0	0	7
423.5	0	0	0	4	0
426.5	0	0	0	0	0
426.9	1	0	0	2	0
427.3	0	0	0	3	0
427.7	0	0	0	1	0
428.1	0	0	0	3	0
428.5	1	0	0	0	0
428.9	0	0	0	0	0
430.1	3	0	0	5	0
430.5	0	0	0	0	0
430.9	1	0	0	4	0
431.3	0	0	0	1	0
431.5	0	0	0	0	0
432.1	0	0	0	0	0
432.5	0	0	0	0	0
432.9	0	0	0	0	0
433.3	11	0	0	0	0
433.7	0	0	0	2	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	N mensiculus	N tubicola	N species	P silvatica	P species
437	0	0	0	0	0
439.3	1	0	0	0	0
439.75	3	0	0	0	0
440.5	0	0	0	0	0
441.5	0	0	0	0	0
442.5	0	0	0	0	0
443.5	0	0	0	0	0
444.5	0	0	0	0	0
445.5	7	0	0	1	0
446.5	0	0	0	0	0
447.5	0	0	0	0	0
448.5	0	0	0	0	0
449.5	7	0	0	0	0
451.5	0	0	0	9	0
453.5	0	0	0	0	2
454.5	0	0	0	1	0
456.5	1	0	1	0	0
457.5	0	0	0	0	0
458.5	0	0	0	0	0
459.5	0	0	0	0	0
460.5	0	0	0	0	0
461.5	0	2	0	2	1
463	0	0	0	0	0
464	0	0	0	0	0
465	0	0	0	0	0
466.5	2	0	0	0	0
468.5	0	0	0	0	0
469.5	0	0	0	0	0
471	0	0	0	0	0
472	0	0	0	0	0
473	1	0	0	0	1
474	0	0	0	0	0
475	0	0	0	0	0
476	0	0	0	0	0
477	0	0	1	0	0
478	1	0	3	0	2

DEPTH	P frequentissimum	R novae zealandiae	S linearis	S acus	S ulna
395.5	0	1	0	0	0
396.5	0	1	0	0	0
397.5	0	0	0	0	0
398.5	0	1	0	0	0
400.5	0	0	0	0	0
401.5	0	1	0	0	0
402.5	0	0	0	0	0
403.5	0	2	0	0	0
404.5	0	0	0	0	0
405.5	0	0	0	0	0
406.5	0	0	0	0	0
407.5	0	0	0	0	0
408.5	0	0	0	3	0
409.5	0	5	0	0	0
411.5	1	0	0	0	0
412.5	0	0	0	0	0
413.5	0	0	0	1	0
414.5	0	0	0	0	0
416.5	0	0	0	0	0
417.5	0	0	0	0	1
418.5	0	0	0	0	0
419.5	0	0	0	0	0
420.5	0	0	0	0	0
421.5	0	0	0	0	0
422.5	0	0	0	0	0
423.5	0	0	0	0	0
426.5	0	0	0	0	0
426.9	0	0	0	1	0
427.3	2	0	0	0	0
427.7	1	0	0	0	0
428.1	0	0	0	1	0
428.5	0	0	0	0	0
428.9	0	0	0	1	0
430.1	2	1	0	0	0
430.5	0	0	0	0	0
430.9	0	0	0	0	0
431.3	0	0	0	1	0
431.5	0	0	0	0	0
432.1	1	3	0	0	0
432.5	0	0	0	0	0
432.9	0	0	0	0	0
433.3	0	0	0	0	0
433.7	0	1	0	1	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	1	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**P frequentissimum**	**R novae zealandiae**	**S linearis**	**S acus**	**S ulna**
437	0	0	0	0	0
439.3	0	4	0	0	0
439.75	0	6	0	0	2
440.5	0	0	0	0	0
441.5	2	3	0	2	0
442.5	0	0	0	1	0
443.5	0	0	0	0	0
444.5	0	8	0	4	0
445.5	0	0	0	0	11
446.5	2	0	0	0	0
447.5	1	10	0	5	0
448.5	1	0	0	1	0
449.5	0	1	0	1	2
451.5	1	0	0	0	0
453.5	0	2	0	1	0
454.5	0	0	0	1	0
456.5	0	0	0	2	0
457.5	3	3	0	0	0
458.5	0	5	0	0	0
459.5	0	3	0	0	0
460.5	7	0	0	0	0
461.5	3	4	0	3	0
463	0	13	0	0	0
464	0	9	0	0	1
465	2	3	0	0	0
466.5	3	0	0	0	0
468.5	3	2	0	0	0
469.5	1	0	0	0	0
471	0	1	0	0	0
472	1	8	0	0	0
473	3	1	0	0	0
474	3	2	0	0	0
475	3	7	0	0	0
476	0	3	0	0	0
477	1	0	0	0	0
478	2	0	1	0	0

DEPTH	**Synedra species**	**Tabellaria species**	**M martyi**	**A subexigua**	**Achnanthes sp**
395.5	0	0	0	0	0
396.5	0	0	0	0	1
397.5	0	0	0	0	0
398.5	0	0	0	0	0
400.5	0	0	0	0	0
401.5	0	0	0	0	0
402.5	0	0	0	0	0
403.5	0	0	0	0	0
404.5	0	0	0	0	0
405.5	8	0	0	0	0
406.5	13	0	0	15	0
407.5	0	0	0	0	0
408.5	0	0	0	0	0
409.5	0	0	0	0	0
411.5	0	0	1	0	0
412.5	0	0	0	0	0
413.5	0	0	0	0	0
414.5	0	0	0	0	1
416.5	0	0	0	0	0
417.5	0	0	0	0	0
418.5	0	0	0	0	0
419.5	0	0	0	0	0
420.5	0	0	10	0	0
421.5	0	0	4	0	0
422.5	1	0	0	0	0
423.5	0	0	0	0	0
426.5	5	0	0	2	0
426.9	0	0	2	0	0
427.3	0	0	0	0	0
427.7	0	0	4	0	0
428.1	0	0	0	0	0
428.5	0	0	0	0	0
428.9	0	0	28	0	0
430.1	0	0	8	0	0
430.5	9	0	0	11	0
430.9	0	0	1	0	0
431.3	0	0	0	0	0
431.5	4	0	0	10	0
432.1	0	0	0	0	0
432.5	0	0	0	0	0
432.9	0	0	0	6	0
433.3	4	3	0	0	0
433.7	0	0	0	0	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**Synedra species**	**Tabellaria species**	**M martyi**	**A subexigua**	**Achnanthes sp**
437	0	0	0	0	0
439.3	0	0	1	0	0
439.75	0	0	8	1	0
440.5	1	0	0	0	0
441.5	0	0	1	0	0
442.5	0	0	0	4	0
443.5	7	0	0	17	0
444.5	0	0	0	0	0
445.5	0	0	4	0	0
446.5	0	0	0	11	0
447.5	0	0	0	0	0
448.5	0	0	0	15	0
449.5	0	0	8	0	2
451.5	0	0	0	0	0
453.5	0	0	0	0	0
454.5	0	0	0	0	0
456.5	2	0	0	0	0
457.5	0	0	0	0	0
458.5	0	0	0	7	0
459.5	0	0	0	6	0
460.5	0	0	0	6	0
461.5	1	1	0	0	0
463	0	0	0	0	0
464	1	0	0	5	0
465	2	0	0	11	0
466.5	1	0	0	0	0
468.5	2	0	0	10	0
469.5	0	0	0	0	0
471	0	0	0	0	0
472	0	0	3	0	0
473	0	0	0	0	0
474	0	0	0	6	0
475	0	0	2	1	0
476	0	0	0	0	0
477	0	0	0	0	0
478	0	0	0	0	0

DEPTH	Amphora species	Cocconeis species	C lineolata	E javanica	Cymbella species
395.5	0	0	0	0	0
396.5	0	0	0	0	0
397.5	0	0	0	0	0
398.5	0	0	0	0	0
400.5	0	0	0	0	0
401.5	0	0	0	0	0
402.5	0	0	0	0	0
403.5	0	0	0	0	0
404.5	0	0	0	0	0
405.5	0	0	0	0	0
406.5	0	0	0	0	0
407.5	6	0	0	0	0
408.5	0	0	0	0	0
409.5	8	0	0	0	0
411.5	0	0	0	0	0
412.5	9	2	0	0	14
413.5	0	0	0	0	0
414.5	0	0	0	0	0
416.5	8	0	0	0	1
417.5	0	0	0	0	0
418.5	5	0	0	0	0
419.5	0	0	0	0	0
420.5	3	0	0	0	0
421.5	0	0	0	0	0
422.5	6	0	0	0	0
423.5	8	1	0	0	9
426.5	0	0	0	0	0
426.9	0	0	0	0	0
427.3	0	0	0	0	0
427.7	0	0	0	0	0
428.1	0	0	0	0	0
428.5	0	0	1	0	0
428.9	0	0	0	0	0
430.1	0	0	0	0	0
430.5	0	0	0	0	0
430.9	0	0	0	0	0
431.3	0	0	0	0	0
431.5	0	0	0	0	0
432.1	0	0	0	0	0
432.5	0	0	0	0	0
432.9	0	0	0	0	0
433.3	1	0	0	0	1
433.7	0	0	0	0	0
435	0	0	0	0	0

435.3	0	0	0	0	0
435.5	0	0	0	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**Amphora species**	**Cocconeis species**	**C lineolata**	**E javanica**	**Cymbella species**
437	0	0	0	0	0
439.3	0	0	0	0	0
439.75	4	0	0	0	0
440.5	0	0	0	0	0
441.5	0	0	0	0	0
442.5	4	0	0	0	0
443.5	0	0	0	0	0
444.5	0	0	0	0	0
445.5	0	0	0	0	2
446.5	1	0	0	0	0
447.5	0	0	0	0	0
448.5	0	0	0	0	0
449.5	0	0	0	0	16
451.5	0	0	0	0	0
453.5	0	0	0	0	0
454.5	0	0	0	0	0
456.5	0	0	0	0	0
457.5	0	0	0	0	0
458.5	0	0	0	0	0
459.5	0	0	0	0	0
460.5	2	0	0	0	0
461.5	0	0	0	0	0
463	0	0	0	0	0
464	0	0	0	0	0
465	0	0	0	0	0
466.5	0	0	0	6	3
468.5	0	0	0	0	0
469.5	0	0	0	0	1
471	4	0	0	0	0
472	0	0	0	0	0
473	0	0	0	0	0
474	0	0	0	0	0
475	0	0	0	0	0
476	0	0	0	0	0
477	0	0	0	0	0
478	0	0	0	0	0

DEPTH	D balfouriana var. constricta	Denticula species	E minutum	E silesiacum
395.5	0	0	0	0
396.5	0	0	0	0
397.5	0	0	0	0
398.5	0	0	0	0
400.5	0	0	0	0
401.5	0	0	0	0
402.5	0	0	0	0
403.5	0	0	0	0
404.5	0	0	0	0
405.5	0	0	0	0
406.5	0	0	0	0
407.5	0	0	0	0
408.5	0	0	0	0
409.5	0	0	0	0
411.5	0	0	0	0
412.5	0	0	0	0
413.5	0	0	0	0
414.5	0	0	0	0
416.5	0	0	0	0
417.5	0	0	0	0
418.5	0	0	0	0
419.5	0	0	0	0
420.5	1	0	0	0
421.5	0	0	0	0
422.5	0	0	0	0
423.5	0	0	0	0
426.5	0	0	0	0
426.9	0	0	0	0
427.3	0	0	0	0
427.7	0	0	0	0
428.1	0	0	0	0
428.5	0	6	1	0
428.9	0	0	0	0
430.1	2	0	0	0
430.5	1	0	0	0
430.9	0	0	0	0
431.3	0	0	0	0
431.5	0	0	0	0
432.1	0	0	0	0
432.5	0	0	0	0
432.9	0	0	0	0
433.3	0	0	0	0
433.7	0	0	0	0
435	0	0	0	0

435.3	0	0	0	0
435.5	0	0	0	0
436.1	0	0	0	0
436.5	0	0	0	0
436.9	0	0	0	0

DEPTH	**D balfouriana var. constricta**	**Denticula species**	**E minutum**	**E silesiacum**
437	0	0	0	0
439.3	0	0	0	0
439.75	0	0	0	0
440.5	0	0	0	0
441.5	0	0	0	0
442.5	0	0	0	0
443.5	0	0	0	0
444.5	0	0	0	0
445.5	0	0	0	0
446.5	0	0	0	0
447.5	0	0	0	0
448.5	0	0	0	0
449.5	0	0	0	0
451.5	2	0	0	0
453.5	0	0	0	0
454.5	0	0	0	0
456.5	0	0	0	0
457.5	9	0	0	3
458.5	2	0	0	0
459.5	2	0	0	0
460.5	2	1	0	0
461.5	4	0	0	0
463	2	0	0	0
464	4	0	0	0
465	0	0	0	0
466.5	1	0	0	0
468.5	0	0	1	3
469.5	0	0	0	0
471	0	0	0	0
472	4	0	0	0
473	0	0	0	0
474	0	0	0	0
475	0	0	0	0
476	0	0	0	0
477	0	1	0	0
478	0	0	0	0

DEPTH	E smithii	Eunotia species	Fragilaria species	F capucina var. cap	G species
395.5	0	0	0	0	0
396.5	0	0	0	0	0
397.5	0	0	0	0	0
398.5	0	0	0	0	0
400.5	0	0	0	0	0
401.5	0	0	0	0	0
402.5	0	0	0	0	1
403.5	0	0	0	4	0
404.5	0	0	0	0	2
405.5	0	0	0	9	0
406.5	0	0	0	2	0
407.5	24	0	0	0	0
408.5	0	0	0	0	0
409.5	0	0	1	0	3
411.5	0	0	0	4	5
412.5	10	0	0	0	0
413.5	0	0	0	1	0
414.5	0	0	6	1	3
416.5	0	0	2	1	0
417.5	0	0	0	0	0
418.5	8	0	0	0	0
419.5	0	0	0	0	0
420.5	0	0	0	0	0
421.5	0	0	0	0	1
422.5	0	0	0	0	0
423.5	15	0	0	0	0
426.5	0	0	0	0	2
426.9	0	0	0	0	0
427.3	0	0	0	2	0
427.7	0	0	0	0	0
428.1	0	0	0	0	0
428.5	0	0	0	0	0
428.9	0	0	0	0	0
430.1	0	0	0	2	0
430.5	0	0	0	0	0
430.9	0	0	0	3	0
431.3	0	0	0	2	0
431.5	0	0	0	3	0
432.1	0	0	0	0	0
432.5	0	0	0	0	0
432.9	0	0	9	8	0
433.3	0	0	2	0	2
433.7	0	0	0	0	0
435	0	0	1	1	0

435.3	0	0	0	0	0
435.5	0	0	1	0	0
436.1	0	0	0	0	0
436.5	0	0	0	0	0
436.9	0	0	0	0	0

DEPTH	**E smithii**	**Eunotia species**	**Fragilaria species**	**F capucina var. cap**	**G species**
437	0	0	0	0	1
439.3	0	0	0	0	0
439.75	3	0	6	8	0
440.5	0	0	0	9	0
441.5	0	0	0	5	0
442.5	0	0	4	24	0
443.5	0	0	0	9	0
444.5	0	0	0	0	0
445.5	0	0	0	14	0
446.5	0	1	13	11	0
447.5	0	0	0	0	0
448.5	0	0	4	19	4
449.5	0	0	0	4	0
451.5	0	0	0	0	8
453.5	0	0	1	0	0
454.5	0	0	0	0	0
456.5	0	0	1	0	13
457.5	0	0	1	1	0
458.5	0	0	0	6	0
459.5	0	0	0	0	1
460.5	0	0	8	1	0
461.5	0	0	0	2	5
463	0	0	0	0	0
464	0	0	0	1	0
465	0	0	0	0	0
466.5	0	0	0	1	6
468.5	0	0	4	2	7
469.5	0	0	0	1	2
471	0	0	10	0	0
472	0	0	1	0	0
473	0	0	3	5	6
474	0	0	6	0	0
475	0	0	0	0	0
476	0	0	8	5	1
477	0	0	0	1	0
478	0	0	0	0	16

DEPTH	F cap var gracilis	F virescens	Fragilariforma species	C accommoda
395.5	0	0	0	0
396.5	0	0	0	9
397.5	0	0	0	0
398.5	0	0	0	0
400.5	0	0	0	0
401.5	0	0	0	0
402.5	0	0	0	0
403.5	0	0	0	0
404.5	0	0	0	0
405.5	0	0	0	0
406.5	0	0	0	0
407.5	0	0	0	0
408.5	0	0	0	0
409.5	0	0	0	0
411.5	0	0	0	0
412.5	0	0	0	0
413.5	0	0	0	0
414.5	0	0	0	0
416.5	0	0	0	0
417.5	0	0	0	0
418.5	0	0	0	0
419.5	0	0	0	0
420.5	0	0	0	0
421.5	0	0	0	0
422.5	0	0	0	0
423.5	0	0	0	0
426.5	0	0	0	0
426.9	0	0	0	0
427.3	0	0	0	7
427.7	0	0	0	0
428.1	0	0	0	0
428.5	0	0	0	0
428.9	0	0	0	0
430.1	0	0	0	0
430.5	0	0	0	0
430.9	0	0	0	0
431.3	0	0	0	0
431.5	0	0	0	0
432.1	0	0	0	0
432.5	0	0	0	0
432.9	0	0	0	0
433.3	0	0	0	0
433.7	0	0	0	0
435	0	0	0	0

435.3	0	0	0	0
435.5	0	0	0	0
436.1	0	0	0	0
436.5	0	0	0	0
436.9	0	0	0	0

DEPTH	**F cap var gracilis**	**F virescens**	**Fragilariforma species**	**C accommoda**
437	0	0	0	0
439.3	0	0	0	0
439.75	3	0	0	0
440.5	0	0	0	0
441.5	0	0	0	0
442.5	0	0	0	0
443.5	0	0	0	0
444.5	0	0	0	0
445.5	0	0	0	0
446.5	0	0	0	0
447.5	0	0	0	0
448.5	0	0	0	0
449.5	0	0	0	0
451.5	0	0	0	0
453.5	0	0	0	0
454.5	0	0	1	0
456.5	0	0	1	0
457.5	0	0	0	0
458.5	0	0	0	0
459.5	0	0	0	0
460.5	0	0	0	0
461.5	1	0	0	0
463	0	0	0	0
464	0	0	0	0
465	0	0	0	0
466.5	0	0	0	0
468.5	0	0	0	0
469.5	0	1	0	0
471	0	0	0	0
472	0	0	0	0
473	0	0	0	0
474	0	0	0	0
475	0	0	0	0
476	0	0	0	0
477	0	0	0	0
478	0	0	0	0

Shannon diversity and evenness results

Depth	***Shannon***	***Evenness***	***Sp richness***	***Depth***	***Shannon***	***Evenness***	***Sp richness***
395.5	2.647271	0.803217	27	**435**	1.020458	0.397847	**13**
396.5	2.928106	0.837437	33	**435.3**	0.796777	0.320647	12
397.5	2.914955	0.833676	33	**435.5**	0.744631	0.323389	10
398.5	2.599514	0.780118	28	**436.1**	0.754559	0.303657	12
400.5	2.530612	0.759441	28	**436.5**	0.994556	0.367259	15
401.5	2.720801	0.771561	34	**436.9**	0.675657	0.271904	12
402.5	2.481996	0.75307	27	**437**	1.171778	0.42263	16
403.5	2.752149	0.794102	32	**439.3**	2.181399	0.623879	33
404.5	2.811615	0.818761	31	**439.75**	2.273093	0.682159	28
405.5	2.539333	0.799021	24	**440.5**	2.468111	0.766762	25
406.5	2.606089	0.84311	22	**441.5**	2.40605	0.700658	31
407.5	2.567804	0.818947	23	**442.5**	2.396298	0.727068	27
408.5	2.568269	0.797878	25	**443.5**	2.501454	0.809259	22
409.5	2.527706	0.817752	22	**444.5**	2.45064	0.761334	25
411.5	2.563934	0.786942	26	**445.5**	2.4778	0.743592	28
412.5	2.405803	0.721985	28	**446.5**	2.607656	0.791197	27
413.5	2.6554	0.780725	30	**447.5**	2.27208	0.674749	29
414.5	2.743964	0.806764	30	**448.5**	2.48935	0.739273	29
416.5	2.648459	0.744923	35	**449.5**	2.537599	0.761538	28
417.5	2.357658	0.751926	23	**451.5**	2.22049	0.673726	27
418.5	2.06268	0.713638	18	**453.5**	2.055174	0.638476	25
419.5	1.934881	0.61709	23	**454.5**	2.028935	0.647086	23
420.5	1.901706	0.657945	18	**456.5**	2.01347	0.642154	23
421.5	2.493462	0.740494	29	**457.5**	2.242289	0.652969	31
422.5	2.313158	0.748342	22	**458.5**	2.443975	0.741534	27
423.5	2.208294	0.725333	21	**459.5**	2.629869	0.75882	32
426.5	2.289926	0.702842	26	**460.5**	2.759243	0.782462	34
426.9	2.608028	0.774517	29	**461.5**	2.664072	0.727181	39
427.3	2.460625	0.764436	25	**463**	2.849027	0.814821	33
427.7	1.898627	0.605527	23	**464**	2.994774	0.842329	35
428.1	1.787195	0.606973	19	**465**	2.748079	0.792928	32
428.5	1.882116	0.664304	17	**466.5**	2.686245	0.75555	35
428.9	2.030403	0.638883	24	**468.5**	2.77167	0.792697	33
430.1	2.469731	0.706342	33	**469.5**	2.401342	0.720647	28
430.5	2.445068	0.750459	26	**471**	2.720955	0.799999	30
430.9	2.327627	0.677821	31	**472**	2.81557	0.805252	33
431.3	2.144877	0.650784	27	**473**	2.757298	0.810684	30
431.5	2.277651	0.691069	27	**474**	2.67821	0.812604	27
432.1	2.040099	0.641933	24	**475**	2.690041	0.816194	27
432.5	1.655723	0.543837	21	**476**	2.789885	0.828524	29
432.9	2.023483	0.621063	26	**477**	2.577201	0.800653	25
433.3	1.921772	0.612909	23	**478**	2.729724	0.787632	32
433.7	2.138683	0.628803	30				

Radiocarbon results

Lab no.	14C Age	±	δ13C	%Modern	±	SH adjusted dates	adjusted errors	theta
UBA-9727	9815	49	-28.6	29.467	0.18	9759	55	48
UBA-10036	10482	64	-26.3	27.12	0.22	10426	68	47
UBA-7732	10847	60	-21.6	25.914	0.19	10791	65	45
UBA-9728	10635	50	-25.6	26.609	0.17	10579	55	43
UBA-10035	10953	51	-18.3	25.57	0.16	10897	56	42
UBA-7731	11422	37	-23	24.124	0.11	11366	44	41
UBA-10034	11493	52	-20.4	23.91	0.16	11437	57	39
UBA-10033	11606	34	-19.3	23.58	0.1	11550	42	37
UBA-7763	11966	45	-23.7	22.545	0.13	11910	51	35
UBA-7764	12050	45	-23.5	22.31	0.13	11994	51	34
UBA-7765	12063	45	-20.1	22.275	0.13	12007	51	31
UBA-7707	12023	72	-16.2	17.62	0.2	11967	76	30
UBA-7767	11987	64	-17.7	22.486	0.18	11931	68	29
UBA-7768	12128	43	-16.6	21.773	0.15	12072	49	28
UBA-8286	13553	64	-18.8	18.504	0.15	13497	68	25
UBA-10032	12227	75	-20.1	21.82	0.2	12171	79	24
UBA-10031	13218	58	-19	19.29	0.14	13162	63	22
UBA-8284	13791	48	-26.5	17.963	0.11	13735	54	20
WK-18074	12957	77	-20.4	19.9	0.2	12901	81	19
UBA-8283	14230	50	-28.3	17.007	0.11	14174	55	18
UBA-7706	13946	71	-14.7	17.62	0.16	13890	75	17
UBA-	14174	63	-18	17.127	0.13	14118	67	16

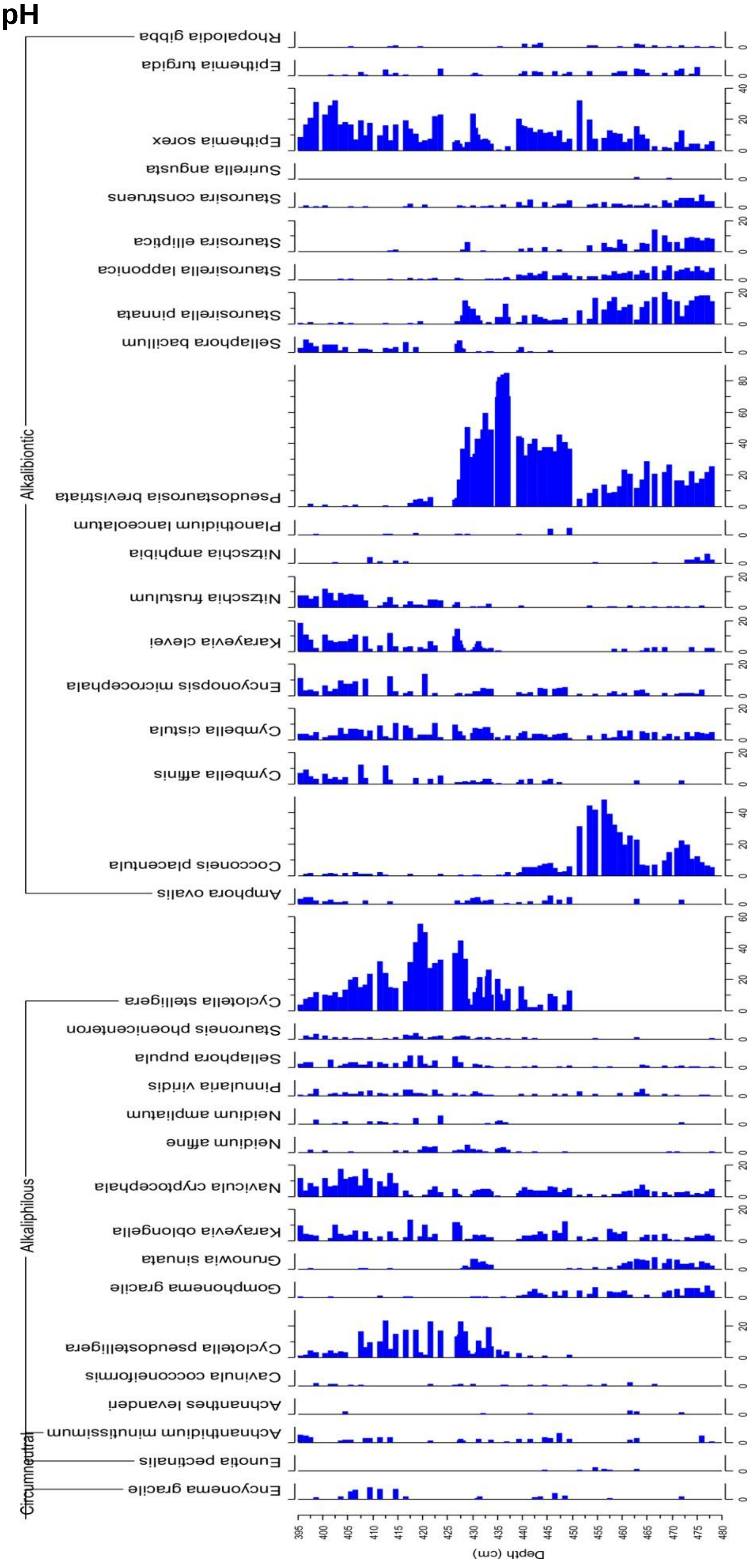
7762								
UBA-9050	14163	65	-13.2	17.15	0.14	14107	69	15
UBA-10030	14440	49	-17.2	16.57	0.1	14384	55	14
WK-18073	14070	86	-18.6	17.4	0.2	14014	89	13
UBA-7705	13942	54	-15.7	17.629	0.12	13886	59	12
UBA-10029	14157	44	-16.4			14101	50	10
UBA-9049	14186	66	-7.6	17.1	0.14	14130	70	9
UBA-7704	15079	57	-13.9	15.301	0.11	15023	62	8
UBA-10028	15296	64	-10.8	14.89	0.12	15240	68	7
UBA-7761	14838	53	-19.1	15.769	0.1	14782	58	6
UBA-7703	15159	56	-15.6	15.151	0.11	15103	61	5
UBA-10026	15247	50	-14.2	14	0.09	15191	55	4
UBA-7702	15526	49	-11.2	14.474	0.09	15470	55	3
UBA-10025	15591	44	-12.7			15535	50	2
UBA-7701	15577	58	-14.2	14.383	0.1	15521	63	1

Reservoir effect correction process

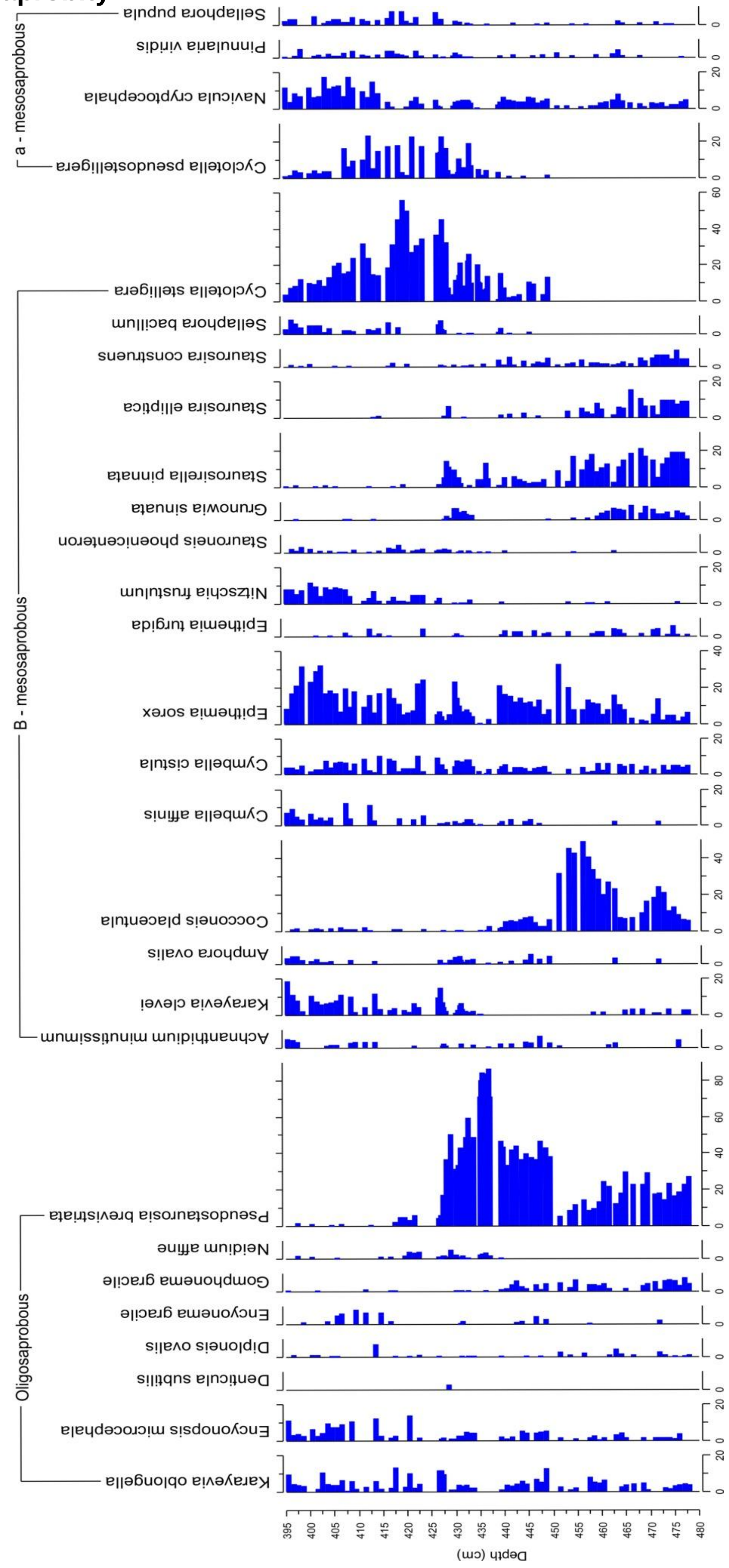
				Adjusted 14C	error	Calibrated 2 sigma			
depth	R	R+100	R-100			lower	upper	mid	error
395.5	955	1105	805	8804	49	9660	10153	9906.5	246.5
399.5	1002	1152	852	9424	64	10494	10799	10646.5	152.5
404.5	1061	1211	911	9730	60	10865	11251	11058	193
409.5	1120	1270	970	9459	50	10567	11067	10817	250
412.5	1155	1305	1005	9742	51	11082	11248	11165	83
417.5	1214	1364	1064	10152	37	11694	11995	11844.5	150.5
422.5	1273	1423	1123	10164	52	11613	12054	11833.5	220.5
425.5	1308	1458	1158	10242	34	11822	12099	11960.5	138.5
428.5	1343	1493	1193	10567	45	12415	12620	12517.5	102.5
429.5	1355	1505	1205	10639	45	12529	12687	12608	79
430.5	1367	1517	1217	10640	45	12529	12687	12608	79
431	1373	1523	1223	10594	72	12384	12688	12536	152
431.5	1378	1528	1228	10553	64	12377	12648	12512.5	135.5
432.5	1390	1540	1240	10682	43	12549	12696	12622.5	73.5
435.7	1428	1578	1278	12069	64	13762	14094	13928	166
436	1431	1581	1281	10740	75	12545	12828	12686.5	141.5
438	1455	1605	1305	11707	58	13396	13736	13566	170
438.14	1456	1606	1306	12279	48	13941	14568	14254.5	313.5
439.5	1472	1622	1322	11429	77	13135	13437	13286	151
439.75	1475	1625	1325	12699	50	14650	15258	14954	304
440.5	1484	1634	1334	12406	71	14093	14981	14537	444
440.5	1484	1634	1334	12634	63	14485	15238	14861.5	376.5
444.5	1531	1681	1381	12576	65	14424	15168	14796	372
445	1537	1687	1387	12847	49	14871	15689	15280	409
449	1584	1734	1434	12430	86	14105	15024	14564.5	459.5
449.5	1590	1740	1440	12296	54	13959	14612	14285.5	326.5
452.2	1622	1772	1472	12479	44	14189	15031	14610	421
452.5	1625	1775	1475	12505	66	14196	15076	14636	440
455.5	1660	1810	1510	13363	57	15912	16839	16375.5	463.5
459.5	1707	1857	1557	13533	64	16428	16907	16667.5	239.5
463	1749	1899	1599	13033	53	15170	16357	15763.5	593.5
463	1749	1899	1599	13354	56	15888	16842	16365	477
466.5	1790	1940	1640	13401	50	16072	16860	16466	394
470.5	1837	1987	1687	13633	49	16599	16967	16783	184
474	1878	2028	1728	13657	44	16632	16977	16804.5	172.5
478	1925	2075	1775	13596	58	16528	16947	16737.5	209.5

Ungrouped Ecological Diatom Diagram

pH



Saprobity


a - mesosaprobous
Sellaphora pupula
Pinnularia viridis
Navicula cryptocephala
Cyclotella pseudostelligera
B - mesosaprobous
Cyclotella stelligera
Sellaphora bacilium
Staurosira construens
Staurosira elliptica
Staurosirella pinnata
Grunowia sinuata
Stauroneis phoenicenteron
Nitzschia frustulum
Epithemia turgida
Epithemia sorex
Cymbella cistula
Cymbella affinis
Cocconeis placentula
Amphora ovalis
Karayevia clevei
Achnanthidium minutissimum
Oligosaprobous
Pseudostaurosia brevistriata
Neidium affine
Gomphonema gracile
Encyonema gracile
Diploneis ovalis
Denticula subtilis
Encyonopsis microcephala
Karayevia oblongella
0
20
40
60
80
395
400
405
410
415
420
425
430
435
440
445
450
455
460
465
470
475
480
Depth (cm)

Trophic State