The Environmental History of Te Waihora – Lake Ellesmere

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Abstract

Te Waihora – Lake Ellesmere is an expansive, shallow, turbid, brackish, hyper-eutrophic, lowland lake located on the east coast of New Zealand's South Island. The catchment and lake are in a highly modified state, with much of the catchment used for intensive agriculture and the lake's level artificially controlled by cutting a channel through the barrier separating the lake from the sea. Although it is known that Waihora is highly modified, it is difficult to determine the factors contributing to the current lake state and what constitutes a natural state for this lake. In order to plan management strategies, it is important to have this information. This study aims to provide insight into these matters using paleoecological techniques, in particular, analysis of sediment characteristics, palynology and diatom analysis, on cores obtained from the lake bed.

The results of these analyses show that Waihora has had a diverse history, beginning as a freshwater lake, low in nutrients, not long before c. 7500 years ago, following the fusion of Kaitorete 'Spit' with Bank Peninsula. This freshwater state was interrupted by the discharge of a large river into the basin, causing a permanent barrier opening and tidal, brackish conditions to prevail. A second brackish state formed after this, caused either by a shift in the discharge point through the barrier or, more likely, a second avulsion event of the Waimakariri River to a discharge point into Waihora. Upon the avulsion of this river to a discharge point north of Banks Peninsula, a freshwater, nutrient rich lake formed. Subsequently, human influenced lake changes became evident, with a hypereutrophic, shallow, brackish lake forming. This research provides evidence that modern lake management has led to decreased lake levels and increasing salinity within Waihora. Intensive agriculture, particularly since the 1970's has led to an increase in nutrients within the lake and its current hypereutrophic state. A combination of lake level management and the 'Wahine Storm' (1968) has led to the lake's current turbid, phytoplankton dominated state. Therefore, sediment characteristics, palynological and diatom data suggest that a natural condition for the lake is one with lower nutrient levels, lower salinity with greater depth and area than the current lake, with a large distribution of freshwater riparian vegetation and little halophytic vegetation.

If restoration of the lake is a target then (1) the lake should be opened to the sea less frequently, allowing a decrease in lake salinity and conditions conducive to the prevalence of freshwater riparian vegetation to prevail, and (2) a transition from a phytoplankton dominated state to a macrophyte dominated state should be targeted, by maintaining the lake at greater depths, the use of riparian planting practices and decreasing nutrient input. However, the latter will be costly and involve questionable trade-offs between lake values and stakeholders. Regardless of whether or not restoration of Waihora to something resembling a natural state is, or will be, a management aim, a decrease in nutrient input catchment wide and riparian planting in the area surrounding the lake should be a priority and may present a more realistic, short term management objective.

Acknowledgments

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Thesis format

In Chapter 1 (Introduction), the study area and catchment are introduced, followed by the factors influencing the current state of the lake and a summary of the Waihora's values. The latter two are revisited in the discussion chapter (Chapter 7) in the context of results. The history of Waihora according to previous research and an introduction to paleoecology is then presented.

This thesis is formatted in a way that best presents the large amount of information and results gathered. Several techniques, each with their respective introductory material, methods and results are presented in this study. In order to streamline the presentation of these, each technique has been treated as a separate chapter which includes an introduction to the technique, methods and results. These chapters are as follows:

Chapter 2: Sediment cores used in this study
Chapter 3: Dating
Chapter 4: Core descriptions
Chapter 5: Palynology
Chapter 6: Diatom analysis

The results of all these analyses are then collaborated and interpreted in detail in the discussion chapter (Chapter 7). Here the factors influencing the current state of the lake and values of the lake (presented in the introduction, chapter 1) are revisited in the context of results from chapters 3, 4, 5, and 6.

Finally, some implications and management suggestions are presented in the discussion based on information in previous literature and findings from this study.

Chapter 1 Introduction

In this chapter the study area and the wider catchment are introduced, factors influencing the current state of the lake are presented, the values of Waihora are summarised, the history of Waihora according to previous research is described and an introduction to paleoecology is given. The factors influencing the current state of Waihora and identified values of the lake are discussed in the context of results in the discussion chapter (Chapter 7).

1.1 Introduction to the study area

Te Waihora – Lake Ellesmere is a large, shallow brackish water body separated from the sea by a narrow mixed sand and gravel barrier (Kaitorete barrier). The lake occupies an interfan depression between the Rakaia and the Waimakariri River fans and is bordered to the east by the volcanic complex of Banks Peninsula (Hemmingsen 1997). The terrain surrounding the lake is flat, low-lying farmland, while the lake bed consists of mud and silt derived mainly from the Selwyn and Halswell Rivers, other streams as well as old estuarine deposits and beach gravels on the barrier margin (Burrows 1969).

Waihora is New Zealand's fourth largest lake by area, ranging from 16,600 to 23,900 hectares (ha) throughout the lakes artificial opening and closure cycles (Hemmingsen 1997). Although immense in area, the lake is very shallow, with an average depth of 1.4 m. Salinity within the lake is typically between 5 and 8 parts per thousand (‰) (Leipe 2009). However, salinity near Taumutu (adjacent to the lake outlet), during artificial opening, can reach 31.9 parts per thousand (‰), approaching that of sea water (Wood 2008). The lake is highly turbid, with a secchi depth of around 7 to 18 cm and temperature within the lake varies seasonally from 16ºC to 23.5ºC, although it is nearly isothermal, with less than 1ºC difference between the surface and the bottom water (Leipe 2009).

Coastal lakes, at the base of lowland plains, often display signs of human modification, particularly eutrophication and sedimentation. Waihora is a good example of such modification and is currently in a shallow, turbid, brackish and hypereutrophic state. Recently concerns have been raised over how the current modified lake state is influencing the lakes values, including its ecological, cultural, commercial and recreational value (Kelly and Jellyman 2007; Taylor 1996; Te Waihora Joint Management Plan 2005; Wood 2008).

Waihora is located on the east coast of the South Island, New Zealand, approximately 40 km south of Christchurch (Wood 2008), between 172º21'E - 172º40'E and 43º42'S - 43º50'S, on the Canterbury Plains (Leipe 2009) (*Figure 1*).

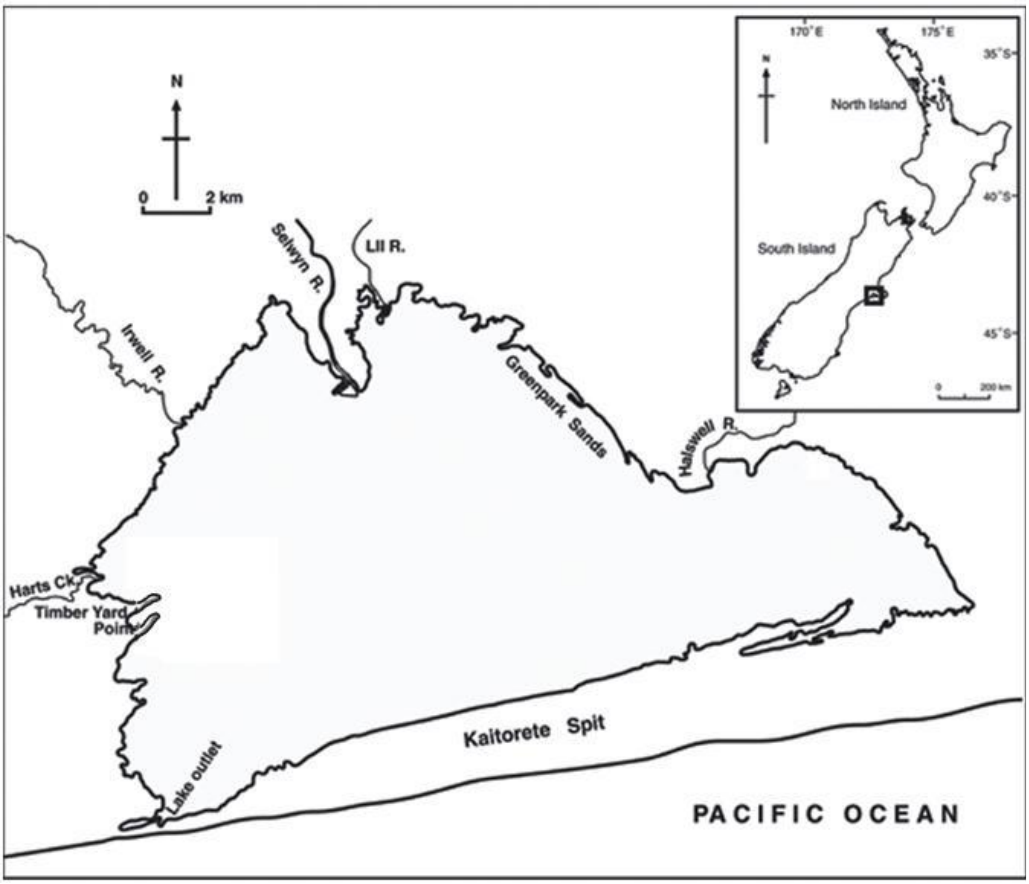

Figure 1: The location of Te Waihora – Lake Ellesmere, South Island, New Zealand. Modified from: Kelly and Jellyman (2007).

1.2 Water body classification

Kirk and Lauder (2000) propose the use of the term 'Waituna-type lagoon' to define the water body type that Waihora belongs to. This term refers to a lagoon "that is exceedingly 'choked' with respect to exchanges of water with the ocean via an outlet or inlets. The water body is typically fresh or brackish, and the lagoon is more usually closed from the sea than open to it" (Kirk and Lauder 2000, p. 15). Waihora is one of the best examples of such a water body, as well as Waituna lagoon in Southland, New Zealand. See Kirk and Lauder (2000, p. 16) for a list of characteristics displayed by this type of water body.

1.3 Catchment information

According to Hemmingsen (1997), Waihora contains water drained from a catchment of 777 square kilometres of hills and 1,295 square kilometres of plains. The lake occupies 7% of this catchment area (Leipe 2009) and is charged mainly by surface runoff from five main rivers and thirty two drains. The main rivers are the Selwyn River with a mean annual flow of 3435 litres per second (l/s^{-1}), the LII River with a mean annual flow of 2334 l/s^{-1}, the Halswell River with a mean annual flow of 1085 l/s^{-1}, the Irwell River with a mean annual flow of 1019 l/s^{-1} and the Kaituna River with a mean annual flow of 622 l/s^{-1} (Hemmingsen 1997). However, this accounts for only a small proportion of freshwater moving through the catchment each year (around 271,395,360 m^3/year), compared to that of groundwater flow, of which around 840 million m^3/year moves from the foothills to the coast in a south-easterly direction (Leipe 2009).

A proportion of this groundwater reaches the lake through groundwater percolation, artesian springs and spring-fed streams. However, groundwater is first contained and transported in underground aquifers, which consist of sequential laminations of sediment of high and low permeability. The highly permeable material consists of course grained gravels that have been produced during glacial periods, then reworked and dispersed as river fans during interglacial periods. The material of low permeability consists of fine grained material transported towards the coast during warm periods. So a lamination of course – fine – course – fine material exists underground. The Canterbury Plains gravels can reach a thickness of around 600 m below Te Waihora. These gravels produce water accumulation conditions that have become essential to Canterbury for domestic and industrial water supply and agricultural irrigation (Leipe 2009).

The water in these aquifer systems comes from groundwater inflow from the Rakaia River (157 million m^3/year), the Selwyn River and tributaries (139 million m^3/year), rainfall surplus (452 million m^3/year) and an unknown but presumably significant volume from the Waimakariri River groundwater inflow. The flow of aquifer water from the foothills of the Southern Alps to Waihora seems to follow the previous paths of the large braided rivers. Therefore, it is reasonable to assume that a proportion of the groundwater supply into the catchment comes from the Waimakariri River catchment and follows its paleo-river beds to Waihora, where it has discharged in the past. Seawater percolation and seawater intrusion

during lake openings also contribute to the water within Waihora (Hemmingsen 1997). For further catchment and lake statistics refer to *Table 1*.

Table 1: Lake and catchment information. From: Hemmingsen (1997).

Map reference (260 series)	M36 654 130
Lake area @ 0.3 m (above MSL)	16,000 ha
Lake area @ 0.6 m (above MSL)	17,700 ha
Lake area @ 0.8 m (above MSL)	18,900 ha
Lake area @ 1.0 m (above MSL)	20,300 ha
Lake area @ 1.5 m (above MSL)	24,200 ha
Lake length	24 km east to west
Lake width	11 km north to south
Catchment area	256,000 ha
Mean lake depth	2.1 m
Maximum lake depth	2.7 m
Main inflow	Selwyn River
Main outflow	Sea via artificial outlet

1.4 Factors influencing the current state of Te Waihora

1.4.1 Hysteresis

The lake has gone through cycles of macrophyte (primarily *Ruppia megacarpa* and *Potamogeton pectinatus*) abundance and scarcity since records began in 1870. According to Hughes et al. (1974) there have been periodic disappearances of macrophyte beds since 1904 and there was a large decrease in macrophyte abundance observed in the 1940's. However, in the 1930's macrophyte beds are reported to have been thick and dense, with one in particular reported to be 8 km long stretching from Taumutu to the mouth of the Selwyn River. In the 1960's large areas of macrophyte beds occurred between the mouths of the Halswell and Selwyn Rivers (*Figure 2*). Yet, prior to 1946 this area was reported to have had no such macrophyte beds. It is clear from these records that fluctuations in macrophyte abundance occurred even before the near total destruction of macrophyte beds due to the 1968 Wahine storm (Hughes et al. 1974; Wood 2008). Hughes et al. (1974) reports that the mechanism of macrophyte disappearance prior to this date is likely to be the development of anaerobic conditions following vigorous growth, stagnation and decomposition of plant material. These anaerobic conditions lead to the further decomposition of living plants at the roots.

Although the extent of macrophyte abundance was known to fluctuate prior to 1968, there is no evidence that complete switches from a macrophyte-dominated lake state to a phytoplankton-dominated lake state occurred. A switch in lake state from clear water and macrophyte-dominated, to turbid water and phytoplankton-dominated, is a phenomenon that has been observed in many lakes and is referred to as 'hysteresis'. In Waihora, this switch in lake state reportedly occurred following the Wahine storm of 1968. Wave action and turbulence during the storm 'ripped out' macrophyte beds and dispersed fine sediment from the lake bed into suspension. This resulted in the occurrence of highly turbid lake water, preventing light to penetrate into the water column and prohibiting photosynthesising activity to be carried out by the remaining macrophytes. Thus, the macrophytes perished and have not re-established since. Primary production is now carried out predominantly by phytoplankton. This phytoplankton dominant state is maintained by the action of wind, resuspending nutrient rich bottom sediments, which facilitates phytoplankton growth, while inhibiting the re-establishment of macrophyte beds due to lake bed instability (Wood 2008).

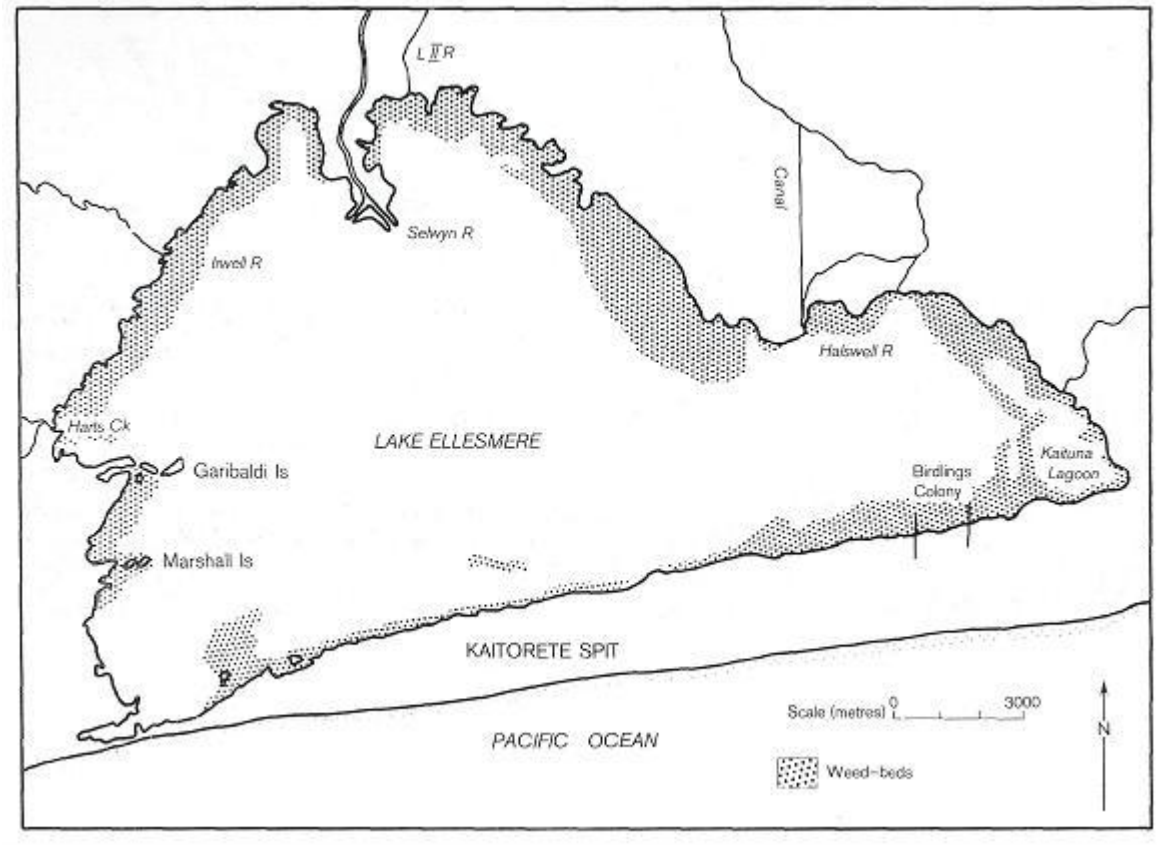

Figure 2: The distribution of macrophyte beds within Waihora in 1960. From: Hughes et al. (1974).

1.4.2 Deforestation and loss of riparian vegetation:

From around the 1860's felling of the extensive forest covering Banks Peninsula began. In 1864 William Coop established a sawmill at Little River. Timber (primarily *Podocarpus totara*) was punted along Wairewa – Lake Forsyth, taken by tramline to Birdlings Point or Stony Point and carried by shallow draught paddle steamers across Waihora to either Taumutu, the Selwyn River mouth or the mouth of Harts Creek (Timer Yard Point) (Palmer 1982). By 1920 much of the forest cover on Banks Peninsula had been lost due to continued deforestation (*Figure 3*). As a result of deforestation and subsequent grazing of Banks Peninsula, slope stability was decreased and the peninsula became subject to tunnel gullying and soil slip erosion, in particular, as well as wind, sheet, gully and rill erosion (Taylor 1996). Sediment transported down valley on the north-western face of Banks Peninsula is expected to end up in Waihora via fluvial transport.

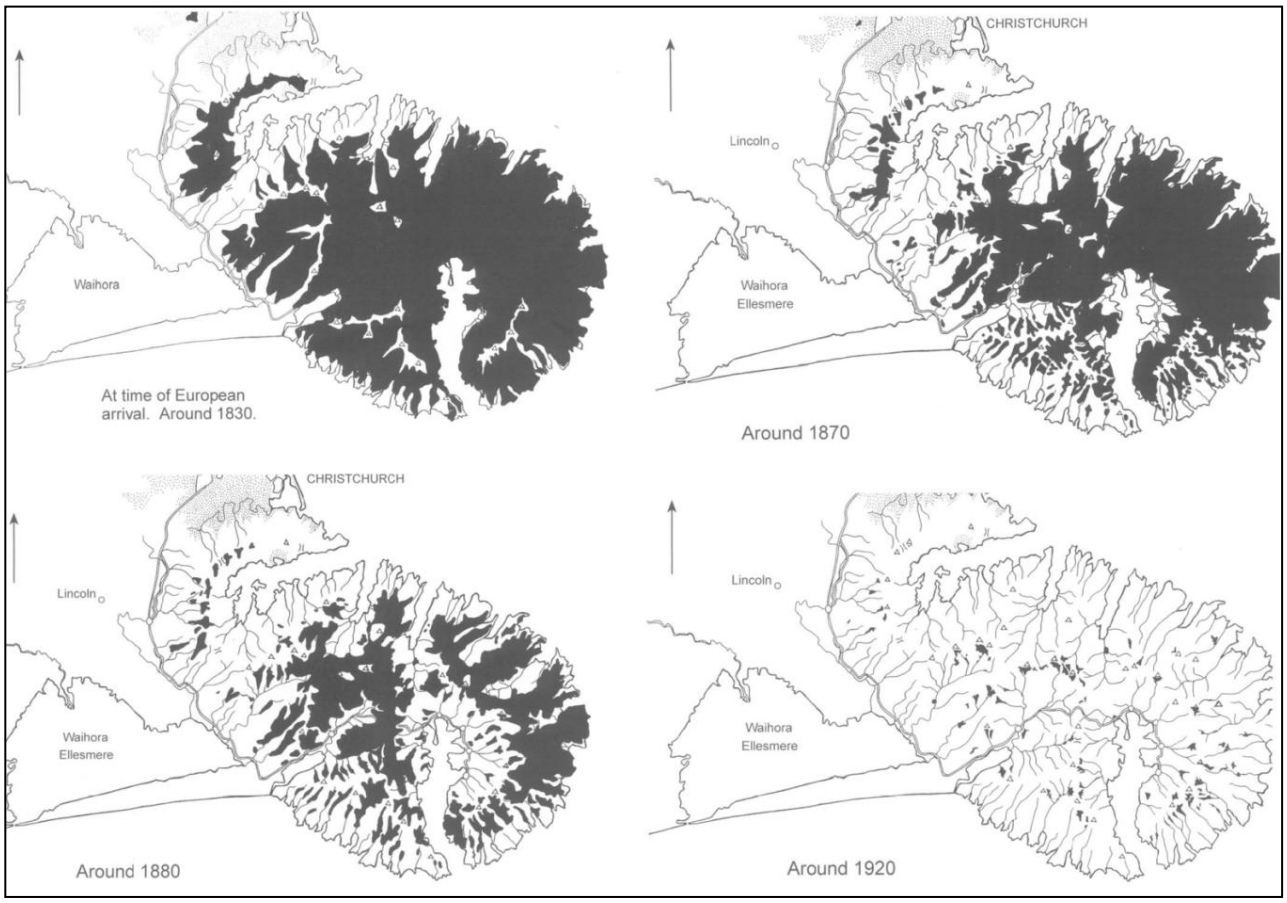

Figure 3: Forest cover on Banks Peninsula from around 1830 to 1920. From: Petrie (1963), cited in Bank Peninsula Landscape Study (2007).

The reduction of riparian vegetation probably coincides with the beginning of agriculture and land reclamation around Waihora. The swamp and tussock that surrounded the lake were converted to large farming runs. Lake rushes were cut to facilitate the growth and cropping of browntop grass seed (Palmer 1982). Agriculture and the degradation of the vast riparian wetland areas surrounding the lake began in the 1850's (Palmer 1982) and intensified after 1880, when the construction of water races in order to reclaim wetland areas for farming boomed (Bowden et al. 1983). Stop banks and pumps were also put in place in order to reclaim this wetland area. Stop banking in areas such as the Halswell River (completed by 1890) and lower Selwyn River (completed in 1940s), facilitate the direct transport of sediments and nutrients to the lake. Whereas, prior to this, floodwaters spread out across the wetland area (Palmer 1982). The removal of riparian wetland vegetation surrounding the lake decreases the ability of this riparian zone to act as a buffer (sediment and nutrient trap) between the lake and the rest of the catchment. Additionally, the removal of riparian vegetation has led to an increase in shoreline erosion around the lake. This erosion is greatest on the northwest and northeast shorelines due to prevailing wind and is attributed to both the loss of sheltering macrophyte beds as well as riparian species (Taylor 1996).

1.4.3 Agriculture:

The Canterbury Association was established in 1848, in order to guide the settlement of the Canterbury area which had been recently obtained from the New Zealand Company. Initially, this area was intended to be used for crop farming. However, Robert Godly, the associations agent realised that Canterbury's immediate future lay in pastoralism and lowered the price of potential freehold land. This led to a rush to purchase land and by the end of 1852 applications for land covering much of Canterbury had been made. By 1853 around 100 sheep farms consisting of over 100,000 sheep occupied the Canterbury plains. Between 1875 and 1895 there was a reduction in pastoralism and increase in cropping due to a drop in wool prices. However, the economic return associated with pastoralism again became more attractive, particularly upon the advent of refrigeration in 1882, leading to a change from wool to meat production (Bowden et al. 1983).

Settlers soon realised that the low-lying swampland area surrounding Waihora contained soils that were lighter and more fertile than those of the higher central plains. This led the rapid reclamation of Waihora's wetlands (from around 1880) and by 1894 there were around 41

drains in the area. Other major drainage schemes included the construction of the 5 km long Halswell canal in 1889 (later increased by an additional 3 km in 1937) the construction of a more direct outlet between the Selwyn River and Waihora in 1947 and the dredging and clearing of willows from the LII River between 1946 and 1947 (Bowden et al. 1983).

In 1979-80 there were approximately 2200 farms in the central plains region. 1.4 million sheep, 23, 000 dairy cattle, 32000 beef cattle, 31000 pigs (Bowden et al. 1983). From 1990 to 2003 dairy stock numbers increased 390%, beef cattle number increased 73%, deer numbers increased 178%, while sheep numbers decreased 24% (Tait and Cullen 2010).

1.4.4 Abstraction:

Ground and surface water is essential for the regions agriculture/horticulture industry (responsible for 91% of abstracted groundwater), aquaculture and public water supply. The abstraction of groundwater on the Canterbury Plains has markedly increased since the 1970's (*Figure 4*). This increase is due to drought conditions in the 1960's - 1970's, improvement in drilling technology and the increased awareness of this extensive resource (Bowden et al. 1983). Abstraction has two main effects on Waihora; (1) reduced flow of lowland rivers and streams and (2) increased nutrient levels in shallow groundwater through surface irrigation (Canterbury Groundwater study 2005).

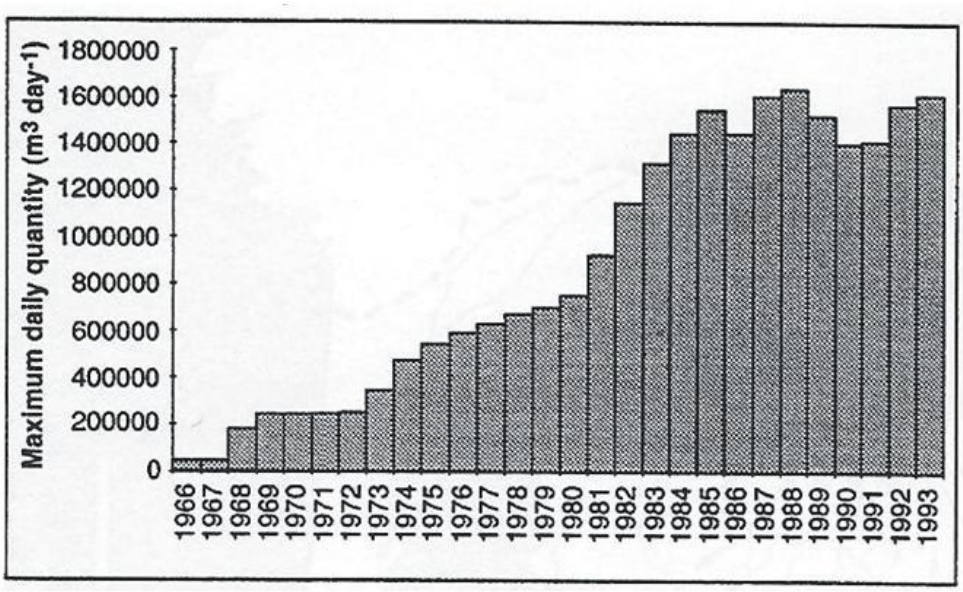

Figure 4: Maximum daily abstraction limits allocated by permits from 1966 to 1993. From: Taylor (1996).

The rivers and streams surrounding Waihora (such as the lower Selwyn, LII, Halswell Rivers and Harts Creek) are hydraulically connected to shallow groundwater, and surface flows are generally reduced with increased groundwater abstraction (Canterbury Groundwater Study 2005). According to simulations, described in the Canterbury Groundwater Study (2005), the smaller streams and drains flowing into Waihora between the Selwyn and Rakaia Rivers are most affected by irrigation development inland. The same study estimated flows in the Selwyn River under various abstraction pressures and found that under a 'no abstraction' scenario flow would be around 820 *l*/s, 'status quo' scenario flow is around 631 *l*/s and with abstraction in the Dunsandel-Te Pirita area fully developed flow would be around 590 *l*/s. *Figure 5* displays the relationship between groundwater level and flows within the Selwyn River.

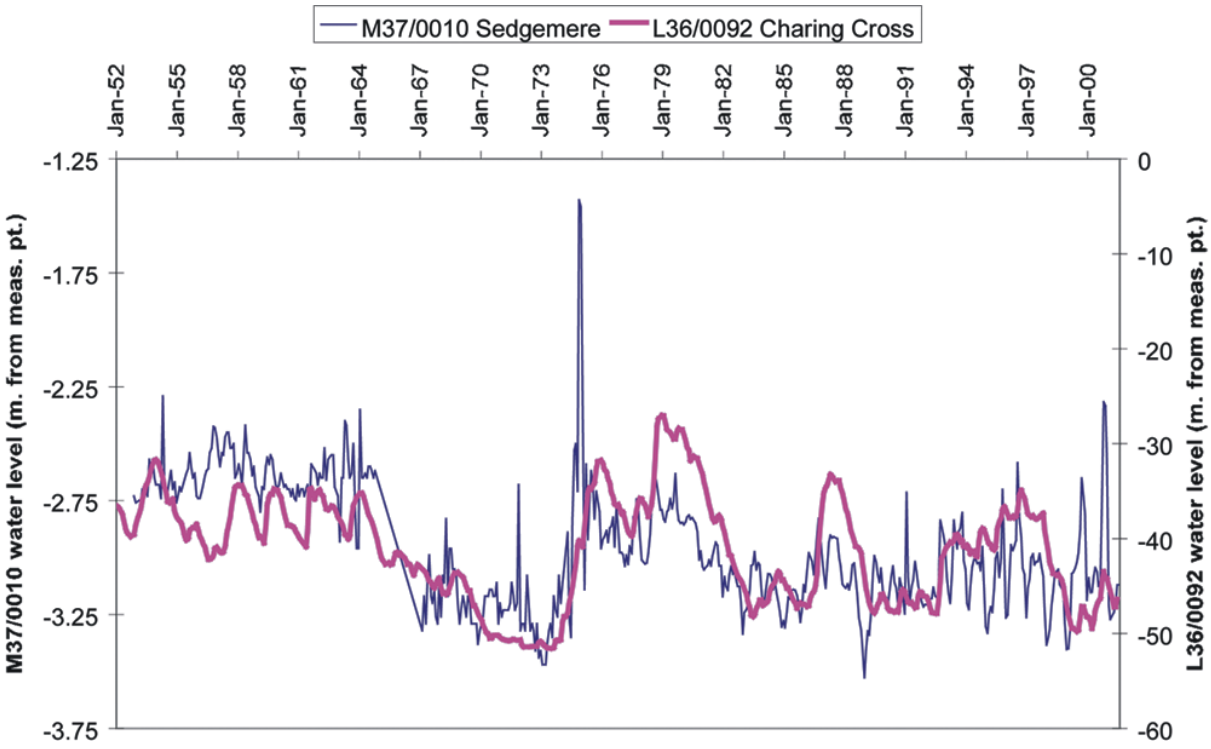

Figure 5: Long-term Selwyn River water level and groundwater level trend. From: Smith (2003).

Groundwater is abstracted and used to irrigate pasture on the plains in order to facilitate pasture growth. The soils of these irrigated areas are often high in nitrates, which are soluble in water, and upon irrigation are transported either directly to surface waters (rivers and

streams) through runoff, or percolate into shallow groundwater before entering surface waters. Thus, irrigation of agricultural land leads to an increase in nitrates in lowland waterways. Phosphates are also transported to waterways via particulate runoff. However, they are not as soluble and not transported with water as readily as nitrates (Canterbury Groundwater Study 2005). The use of groundwater is controlled with the allocation of permits, with a maximum daily water allocation (Canterbury Groundwater Study 2005).

The same relationships, as described above, are associated with abstraction of surface water (rivers and streams) rather than groundwater. Currently, more water is allocated for extraction from surface waters than from groundwater (Bidwell et al. 2009). Abstraction of surface water directly lowers the flow of waterways and nutrient enriched water re-enters the waterways in the same manner as irrigated groundwater.

1.4.5 Nutrients:

Waihora is currently regarded as being in a hypereutrophic state. This is often attributed to increased nutrient runoff due to the development of agriculture and the lake's current shallow, wind mixed state. Wind mixing re-suspends sediments and nutrients which leads to high phytoplankton productivity with cyanobacteria and Chlorophyta dominating. Waihora is considered light limited due to the high concentrations of suspended sediment (Kelly and Jellyman 2007) and Hughes et al. (1974) consider that it may also be slightly Phosphorus limited.

The current hypereutrophic state of the lake is well known (Lineham 1983). However, no evidence exists to suggest that the current trophic state of the lake is any different to earlier times. This is due to the paucity of monitoring data available until around 1965 and lack of regular yearly monitoring until 1983. Total Phosphorus and Nitrate concentrations per year were obtained from Hughes et al. (1974) for the years 1965, 1969, 1970 and 1972 and from Environment Canterbury (pers. comm.) for the years 1983 to 2010. There does not appear to be any trend in Nitrate concentrations from 1965 to 2010, though there may be an increase in Phosphorus concentrations from the 1970's to 1983. However, this increase may reflect inconsistencies in sampling between Hughes et al. (1974) and Environment Canterbury, such as sampling location and sampling time. Therefore, this data is not displayed here.

1.4.6 Kaitorete Barrier and barrier openings:

1.4.6.1 About the barrier

Perhaps the most important feature of Waihora is the barrier that separates the water body from the sea. The barrier is partly responsible for salinity gradients within the lake, with exchange of water between the lake and the sea occurring (as well as artificial openings). Indeed, it is the barrier that determines the very system type that occurs in Waihora basin today. Without a barrier Waihora would more likely resemble a bay, or with an incomplete barrier (spit) in place the water body would more resemble an estuary. A description of barrier size, components, formation, and barrier openings to control lake level follows.

Waihora is separated from the sea by a mixed sand and gravel barrier. The barrier is referred to as 'Kaitorete spit' on maps and in most literature. However, it is correctly referred to as a 'barrier' as it completely encloses the lake, separating it from the sea for most of the year (Kirk and Lauder 2000). Currently, the barrier extends from Taumutu, near the mouth of the Rakaia River in the west, to Banks Peninsula in the east. The widest point of the barrier spans over 2 km and the barrier as a whole contains over 700 million m^3 of sediment (mainly gravel). This sediment is up to 15 m thick and the highest point on the barrier is 11 m above sea level (Soons et al. 1997).

The barrier is almost entirely constructed of greywacke gravel. This is a testament to the origin of the barrier material, with river derived sediment and coastal cliffs to the south-west consisting almost entirely of greywacke, while Banks Peninsula sediment consists mainly of volcanic rocks, such as basalts and andesites. Within the dominant greywacke sediment of the barrier there are occasional deposits of siliceous rock, which are likely to have come from the amygdaloids occurring in the andesites of the Rakaia Gorge, Client Hills and Gawler Downs. Additionally, there are occasional deposits of volcanic rock and limestone which must have come from the foothills of the Southern Alps. Therefore, the origin of barrier sediment is the river derived sediment and coastal cliffs to the south-west (Speight 1930).

As the rivers on the Canterbury Plains flow eastwards from the Southern Alps to the sea they carry with them large quantities of greywacke gravels, especially during the rapid and energetic flood events that occur in these catchments during north-westerly rainstorms. The

large quantities of sediment transported through these systems is primarily due to the large accumulation of greywacke uplifted in the Southern Alps, combined with the energetic and voluminous flows of these rivers (Hemmingsen 1997; Kirk 1991; Speight 1930). According to Kirk (1991) the Ashburton River has a mean daily discharge of 11.6 cubic meters per second (cumecs) and a maximum discharge of 360 cumecs, while the larger Rakaia River has a mean daily discharge of around 320 cumecs and a maximum discharge of around 2690 cumecs.

The formation of the barrier from these sediments is described by Haast (1864, p.22). He wrote that the "…the action of waves very soon began to disintegrate the Pleistocene accumulations. The sand and shingle derived from that destruction, travelling northwards, were augmented considerably by the material of the same nature being brought down by the rivers, and assisted by the two prevailing winds, finally formed a dam from the mouth of the Rakaia River to Banks Peninsula, becoming every year more considerable."

The rivers to the south-west, notably the Rakaia and the Ashburton Rivers, as well as the continued erosion of the coastline to the south-west, continue to provide significant quantities of sediment to the barrier. According to Hemmingsen (1997), the rate of sediment supply to the barrier is almost equivalent to the rate of erosion. As such, the Barrier is currently maintained in quasi-equilibrium. However, this is not the case further to the south-west. Here the eroding coast, that acts as a sediment source for the barrier, is eroding faster than deposition is occurring. According to Hemmingsen (1997) and Kirk (1994) the rate of erosion is around 1 to 3 m per year on average. This variation in erosion rates has caused the orientation of the coast to swivel on a hinge point (discussed in more detail on pp. 33-34).

1.4.6.2 Barrier openings

There is no permanent opening between Te Waihora and the sea. Under natural conditions, without the influence of humans, the lake level would rise to around 4 m (Armon 1974a) or 5.5 m above MSL (Hemmingsen 1997) before the barrier would be breached and a temporary outfall to the sea created. An alternate theory is that the natural increase in lake level may have led to a link between Waihora and the Rakaia lagoon via the previously existing Little Rakaia River (Armon, 1974a). It is estimated that a lake level of 4 m above sea level may have induced this. Either way, prior to human modification, the lake level would have been

significantly greater before discharge occurred. Indeed, historical reports indicate that Waihora reached levels significantly higher than today even after lake level management began (Hemmingsen 1997; Kirk 1994). Norton (1980) mentions a report by Bray (1875) which describes the lake as reaching the 9 foot (2.7432 m) contour in 1856.

A high lake level condition may have also been present during Mäori occupation of the area from around 700 years ago (McGlone and Wilmshurst 1999), although it has been suggested that the lake was occasionally opened by Mäori. Indeed, Mäori are known to have opened the lake on seven occasions between 1852 and 1867, before Europeans began artificial openings in 1868. A lake level of approximately 2.7 m above sea level would warrant a lake opening by Mäori as it is at this height that the settlement at Taumutu would have been threatened by inundation (Hemmingsen 1997).

The reason for these artificial openings, following European arrival, is to protect reclaimed farmland from inundation during high lake levels. Around 14,000 hectares of farmland is protected due to these artificial openings. Consequently, the modern Waihora is considerably shallower than the natural lake, pre-human modification. Europeans began opening the lake in 1868 and from then until 1901 the lake was opened annually. From 1901 to 1947 the lake was opened 70 times (Hemmingsen 1997) and from 1947 onwards the lake has been opened an average of 3.5 times per year (Waihora Ellesmere Trust 2009) (*Figure 6*). An agreement was reached in January, 1947 between the Ellesmere Land Drainage Board and the North Canterbury Catchment Board, for the North Canterbury Catchment Board to open the lake when the level reached 1.05 m above mean sea level (above MSL) during summer months from August to March inclusive, and 1.13 m above MSL in winter from April to July. This policy of lake openings remains today (Norton 1980; Dwyer 1980). Data from Norton (1980) shows that from 1930 to 1947 there were fewer openings per year and they remained open longer. Conversely, from 1947 to 1980 there were more openings per year and they remained open for less time than from 1930 to 1947. This trend is displayed in *Figure 6* (below) based, on data obtained from Dwyer (1980) and Horrell pers. comm. (2010).

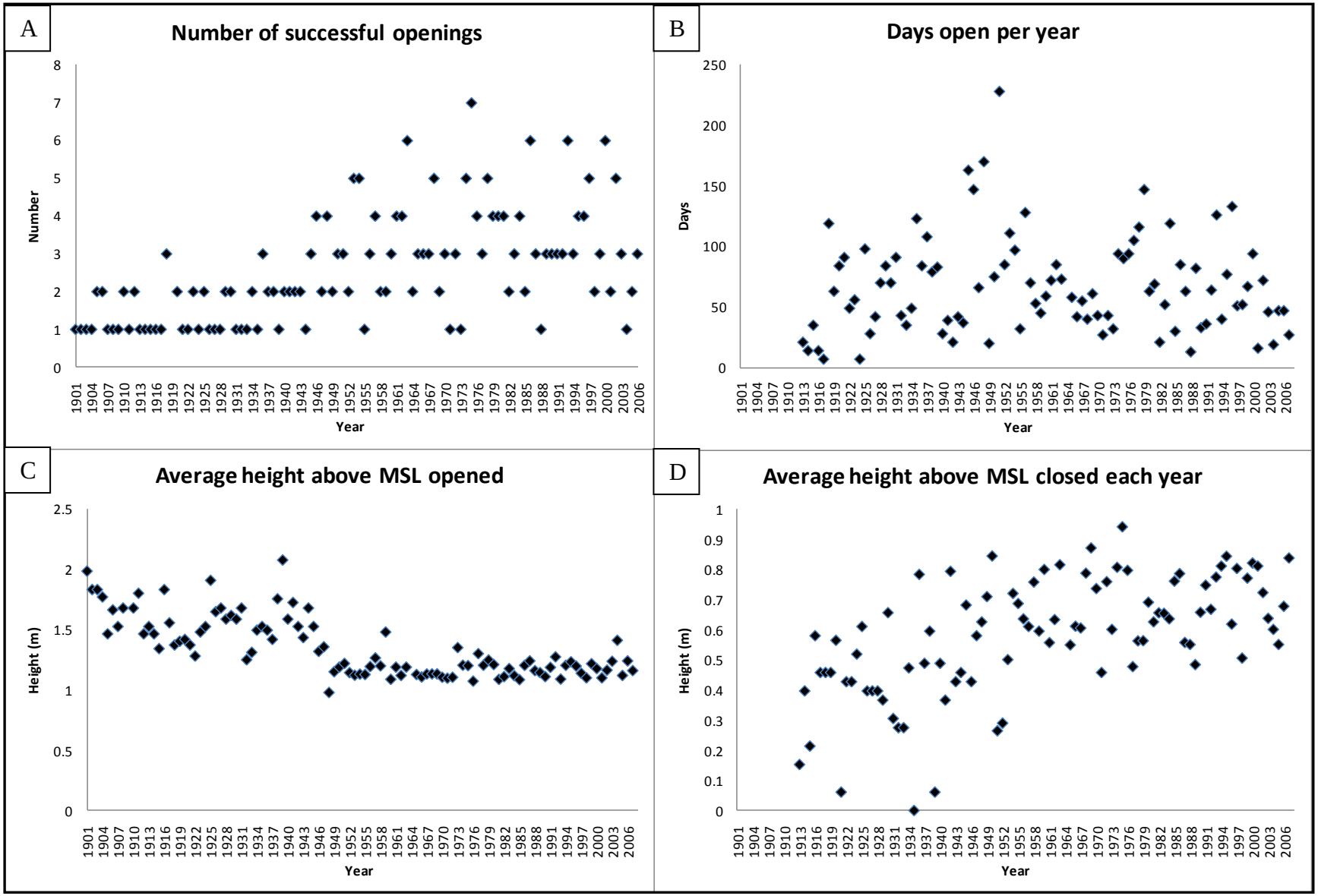

Figure 6: Information on (A) number of barrier openings, (B) days barrier open per year, (C) average height opened (per year) and (D) average height closed (per year). Graphs plotted from data in Dwyer (1980) (for the years 1901–1980) and obtained from Horrell pers. comm. (2010) (1980-2007).

The earthmoving procedure involved in opening the lake currently requires the use of bulldozers and an excavator and can take up to four days. However, a horse drawn scoop was used when cuttings were first made from 1868. An opening for a minimum of four days is required for it to be considered successful. This can pose a problem, as it is not uncommon for a southerly to produce rough seas and close the opening before this has been achieved. Similarly, it is not uncommon for the lake to be open for considerably longer than 4 days. The longest recorded opening lasted for 123 days from 18 September, 1935 to 19 January, 1937 (Hemmingsen 1997).

Closure of the cut through the barrier is governed entirely by natural forces. The considerable movement of sediment due to longshore drift naturally closes the artificial opening. Therefore, the duration of the opening is dependent on variables such as wind seiche effects (a strong wind can increase lake level by +0.6 m on the downwind side of the lake and -0.6 m on the upwind side), sea forecasts (cut is made only when appropriate conditions are thought to prevail), wave action, swell orientation, swell size (effects the duration of the cut because these determine to the amount and rate of north-easterly longshore sediment transport) and tidal levels (determines the amount of hydraulic gradient between the lake and the sea) (Hemmingsen 1997; Leipe 2009; Waihora Ellesmere Trust 2009).

Under the current program of artificial openings the frequency of lake openings to the sea is greatly increased compared to the natural, unmodified cycle. The average salinity within the lake is around one sixth the salinity of seawater. However, the salinity can rise to around 17 ‰ evenly throughout the lake when it is open to the sea, and around that of seawater close to the cut (Leipe 2009). The lake has been opened to the sea an average of 3.5 times per year since 1945 (*Figure 6*). The exact timing and duration of these openings is completely irregular and is determined by the lake depth. Under the resource consents CRC042860 and CRC012186, the lake is opened when it reaches a level of 1.05 m above mean sea level during summer (August – March inclusive) and 1.13 m above mean sea level during winter (April – July inclusive). Consequently, the exact timing that the opening occurs varies from year to year (Waihora Ellesmere Trust 2009).

1.5 Values of Te Waihora

1.5.1 Ecological values

Waihora, largely due to its shallow nature, displays high biological productivity. Additionally, due to the varied salinity gradients, Waihora supports are large variety of habitats, leading to a high biological diversity (Palmer 1982). The base of the food web within Waihora consists primarily of photosynthesising organisms. These include lake margin plants that are periodically submerged, macrophytes (large aquatic plants), and micro-algae including benthic, epiphytic and planktonic forms. In addition to these plants, cyanobacteria also contribute to primary production. These are not plants, but photosynthesising bacteria (Taylor 1996).

Of the macrophyte community within the lake, nine species of vascular plants and three species of macrophytic algae have been recorded. The most common species of vascular macrophytes within the lake are *Ruppia megacarpa* and *Potamogeton pectinatus*. However, the distribution of these species is now very restricted compared to historical times. According to Palmer (1982), there has been little recovery of the macrophyte beds since their destruction caused by the Wahine storm in 1968. The micro-algae community consists of (in order of abundance) Chromophyta (including diatoms and dinoflagellates), Chlorophyta (including chlorococcales and ulotrichales) and cyanobacteria (Taylor 1996).

Micro-algae provide food for zooplankton and other invertebrates. The zooplankton community within Waihora consists of large numbers of brackish water preferring calanoid copepods (two species) and two species of freshwater mysids. Macroinvertebrates, such as amphipods, isopods, ostracods, snails and the larvae/nymphs of insects such as Coleoptera, Lepidoptera, Odonata and Diptera (mainly chironomids) have been observed in Waihora. These invertebrates feed on micro-algae and/or zooplankton and/or other macroinvertebrates (Taylor 1996; Wood 2008).

Macroinvertebrates are consumed by the variety of fish species that live in the lake. Twenty six fish species have been recorded, including foraging fish such as smelt, common and giant bullies, inanga, flounder, mullet, brown trout and goldfish. These feed on a variety of materials depending on their life stage, including plant material, microalgae, zooplankton or

invertebrates. Piscivorous (fish eating) species within the lake include eels, kahawai, perch and brown trout. However, some (such as eels) may depend on other food sources at juvenile life stages, especially macroinvertebrates such as *Potamopyrgus antipodarum*, Oligochaetes and chironomids, which are abundant in the lake (Kelly and Jellyman 2007). The final step in the aquatic food web consists of the decomposing activity of fungi, bacteria and protozoa. These organisms are responsible for the breakdown of organic material into nutrient forms assimilable by plants (Taylor 1996).

Terrestrial organisms surrounding the lake consist of four main groups of plants; agricultural species, halophytes, freshwater wetland species and submergent species. The distribution of these is determined primarily by salinity, sediment type and elevation. Plant species related to agriculture, such as *Agrostis stolonifera* (creeping bent), occur in areas around the lake subjected to agriculture (Taylor 2006). Halophytic plants grown in areas around the lake margins that are subjected to periodic flooding. Water here goes through cycles of pond formation followed by evaporation. This causes the salinity of the sediment to increase, in which halophytic plants, such as glasswort (*Sarcocornia*) can grow (Evans 1953). Freshwater and wetland species, such as raupo (*Typha orientalis*) and willow, grow in areas around the lake margins, but unlike halophytic plants, only grow in areas where water and sediments are low in salinity (such as near inflowing streams). Submergent species, such as native musk (*Mimulus repens*), grow in areas were water levels fluctuate readily, and can be submerged for extended periods (Clark and Partridge 1984; Evans 1953; Taylor 1996).

Vegetation surrounding Waihora is consumed by livestock, insects, feral herbivores (rabbits and hares), and plant eating birds. 161 bird species have been recorded using Waihora (Taylor 1996). This is considered to be the area in the country that contains the most diverse array of bird species. As such, in 1974 it was nominated by the Department of Internal Affairs, as well as ten other locations in NZ, as a wetland with ‘international importance’. Birds occupying Waihora can be divided into three main groups; plant eating waterfowl, insectivorous waders/swamp birds and carnivorous birds (Blair and Mugford 1980).

Waterfowl such as ducks, geese and swans, feed mainly on aquatic plants in the shallow margins of the lake. They are also commonly observed feeding on adjacent farmland pasture. Black swans have been present in Waihora in large numbers since at least 1867. In 1915, the North Canterbury Acclimatisation Society began controlling the swan population by

collecting eggs, in order to limit the number of hatchlings to 20,000 per year. However, Hughes et al. (1974) report that the population remained high, with an estimated population of 80,000 swans in 1960 and Blair & Mugford (1980) also report that numbers were in excess of 60,000 before the Wahine storm of 1968. As of 1980 the numbers had dropped to around 12,000 probably due to decreased food supply following the weed bed destruction associated with the Wahine storm (Hughes et al. 1974). Waders and swamp birds, such as wrybill plover, banded dotteral, herons, stilts and gulls, primarily feed on macroinvertebrates in damp areas around the lake margin. Carnivorous birds, such as gulls, harriers, shags and herons feed mainly on fish, birds, feral animals, as wells as scavenging dead animal material (Taylor 1996).

Palmer (1982) points out that the lake is used by a high proportion of native (non-migrant) and migrant (especially trans-equatorial) bird species compared to introduced species. Additionally, many of these species are observed frequenting habitat types other than open lake water (*Figure 7*). For these reasons, attention should be given to protecting/enhancing these important lake edge habitats.

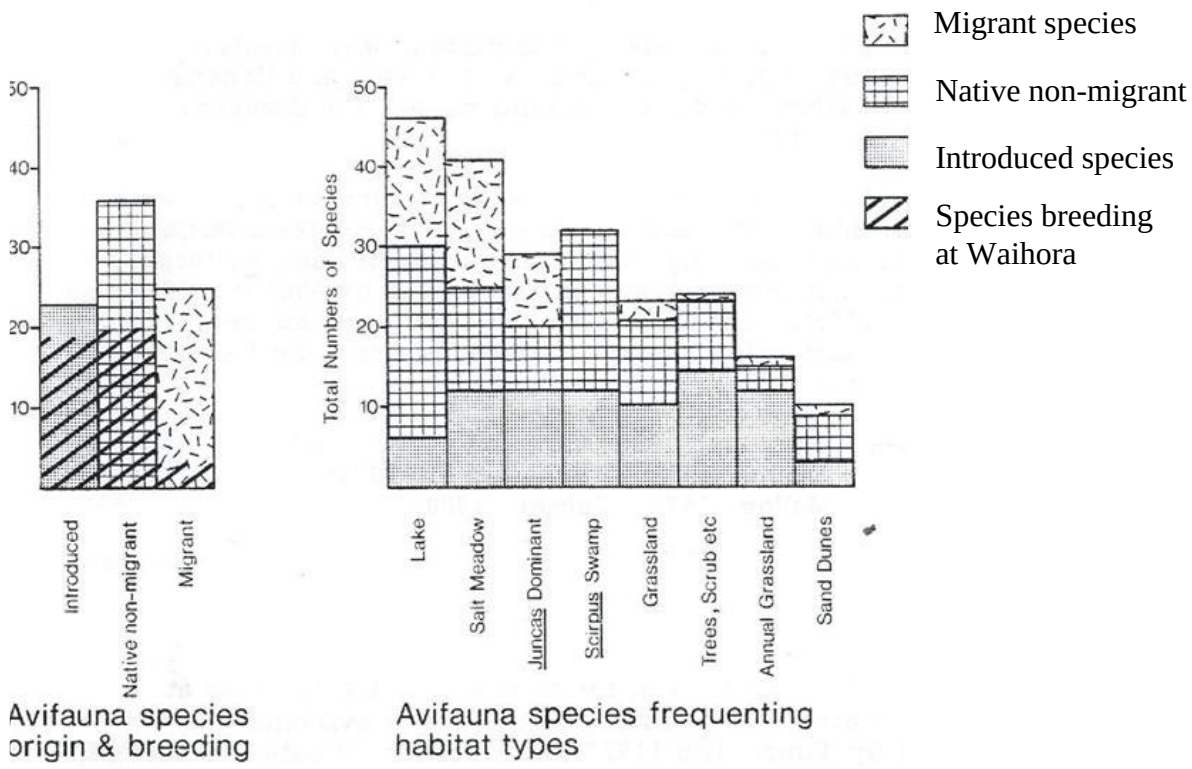

Figure 7: Origin and frequented habitat of Waihora avifauna. From: Palmer (1982).

1.5.2 Cultural values

The first people to arrive in the Waihora area were the Waitaha people led by Te Rakihouia, who had been given instructions by his father Räkaihautü to locate resources in the area. Te Rakihouia discovered Te Waihora and led his father back to Waihora, with its plentiful resources. Räkaihautü proclaimed that the lake be called Te Kete Ika a Räkaihautü (the fish basket of Räkaihautü) (Te Waihora Joint Management Plan 2005). The Waitaha people were later succeeded by the settlement of Ngäti Mamoe following their migration from Te Ika a Mäui (the North Island), due to population and resource pressure in Te Ika a Mäui. These same pressures, as well as some sibling rivalry led to the migration of Ngäti Kurï/Ngäi Tahu to Te Wai Pounamu. Defeat of Ngäti Mamoe during physical confrontations, as well as strategic marriages, led to the succession of Ngäti Mamoe by Ngäti Kurï/Ngäi Tahu (Taylor 1996).

Natural resources around and within Waihora have been, and continue to be, held in high regard by Ngäi Tahu. These resources are not considered simply as consumables, but are a statement of authority, identity and mana. Abundant resources in the area allowed for trading between tribes and intra-tribally amongst Ngäi Tahu hapu. The abundant resources and ability to trade are regarded by tängata whenua as equivalent to wealth. Gift giving between tribes and hapu demonstrated peace and hospitality, as well as demonstrating wealth and willingness to defend it. The giving of gifts not only enhanced social cohesion but demonstrated a community's dominion over a particular area (Taylor 1996). Thus, the resources of an area have a huge social value and they are essential for the interaction between communities. The Waihora area, with its abundant mahinga kai, including tuna (eels), patiki (flounder), aua (yellow-eyed mullet) and inaka (whitebait) was, and is, considered a hugely valuable resource. (Taylor 1944).

Other species of particular importance include harakeke (flax), and pikao or pingao (sand sedge). Bird species were also an important food resource. Pateke (brown teal), kukupangao (whistling duck), pukeko (swamp hen) and juvenile putakitaki (paradise duck) were taken for food. However, by far the most important resource within Waihora was/is the tuna (eel) population. Waihora contains both longfin and shortfin eels, which were trapped, tickled, netted, hooked and speared depending on season. Other methods demonstrated the intimate relationship between tangata whenua and the environment. At certain times of year,

especially when eels were migrating, channels would be dug through the barrier (Taylor 1996). Eels would run through these channels towards the sea before they were blocked off, and the eels trapped and collected. It was recognised that each hapu had their own specific area to fish and these areas were handed down generation after generation (Taylor 1996; Taylor 1944; Te Waihora Joint Management Plan 2005).

Ngäi Tahu believed that the signing of the Treaty of Waitangi (1840) would ensure that these resources and values would be protected. Additionally, with the signing of Kemp's deed (also known as the Canterbury purchase in 1848) it was believed that the rights to these resources by Ngäi Tahu would be maintained. In both cases inconsistencies in the fulfilment of obligations occurred (Taylor 1996). Despite the protests of tangata whenua since the 1860's (Palmer 1982), the land around Waihora and the water body itself has been drastically altered since European settlement. Upon European settlement the main focus was to utilize as much land for farming as possible. In order to utilize more land and to maintain this land once reclaimed, drainage of the lake was commissioned. It is the view of Ngäi Tahu that drainage and intensive agriculture has led to the destruction and alteration of many habitats in and around Waihora. In particular, Ngäi Tahu have expressed concern over the deterioration of eel stocks within Waihora. While, it is not clear what is causing this reduction in eel stocks, it is likely that the combination of habitat destruction and over-fishing are contributing (Kelly and Jellyman 2007; Taylor 1996; Todd 1980).

The grievances of Ngäi Tahu at the loss of this valuable resource were presented to the Waitangi Tribunal in a case referred to as 'Wai 27', after years of protesting. In 1991 the tribunal found that as Waihora was part of the land sold under the Kemp purchase, the crown failed to make reserves to protect Ngäi Tahu's mahinga kai, food resources and ability to participate in economic development. This was deemed in breach of article two of the Treaty of Waitangi and the terms of Kemp's purchase. In light of this finding the tribunal recommended the crown return Waihora to Ngäi Tahu and implement a plan for joint management, or return ownership of Waihora to Ngäi Tahu and remain on the title as a trustee. In addition, the tribunal recommended that financial, scientific and technical resources be made available by the crown in order to improve fisheries and water quality. These recommendations were repeated by the tribunal in 1992 and additional recommendations that eel fishing licences not be renewed, and that Waihora be returned to Ngäi Tahu as an eel fishery were also made (Taylor 1996).

In the Ngäi Tahu Claims Settlement Act (1998, p. 43) the crown acknowledged that it "…acted unconscionably and in repeated breach of the principles of the Treaty of Waitangi in its dealings with Ngäi Tahu in the purchases of Ngäi Tahu land. The Crown further acknowledges that in relation to the deeds of purchase it has failed in most material respects to honour its obligations to Ngäi Tahu as its Treaty partner, while it also failed to set aside adequate lands for Ngäi Tahu's use, and to provide adequate economic and social resources for Ngäi Tahu… The Crown acknowledges that, in breach of Article Two of the Treaty, it failed to preserve and protect Ngäi Tahu's use and ownership of such of their land and valued possessions as they wished to retain". With this act, the bed of Waihora was vested to Ngäi Tahu and the preparation of a joint management plan between Ngäi Tahu and the department of conservation was to be prepared and implemented (Taylor 1996).

Despite the recognition of Waihora as being of great value to Ngäi Tahu, the vesting of the lake bed and the establishment of a joint management plan, Waihora remains in a highly degraded state. Ecological changes that have occurred in Waihora continue to have a huge impact on the availability of food resources, as well as detrimental social implications for tangata whenua. Therefore, restoration of resources in the area is a goal for tangata whenua, to provide important food resources and to re-establish social cohesion between communities (Taylor 1996). For a more comprehensive understanding of the cultural value of Waihora, this author suggests that the reader contact those who are mana whenua of the area, although some initial insight to this effect can be gained by reading Te Waihora Joint Management Plan (2005).

1.5.3 Recreational values

Fishing:

A range of recreational fishing options exist in Waihora and its tributaries, including eeling, floundering, whitebaiting and trout fishing, with brown trout (*Salmo trutta*) fishing being by far the most popular. Brown trout were first introduced into the Waihora and its catchment around 1868. Fishing usually occurs around river mouths, slow moving water in the lower reaches of the tributaries and in the pool and riffle sequences in upstream reaches of these tributaries (Palmer 1982).

In the past Waihora and its tributaries have been regarded as one of the top brown trout fisheries in the country (Hughey and Taylor 2009; Taylor 1996). A report by Tierney et al. (1987) evaluated data collected by the North Canterbury Acclimatisation Society (now Fish and Game). They reported that in the 1978/1979 fishing season anglers made around 54,000 visits, with 29,000 of these visits being to the Selwyn River. Tierney et al. (1987) also identified the Irwell and LII Rivers as being held in high regard by trout fishers. The popularity of Waihora and its tributaries among fishermen began to decline following this 1978-79 season, reflecting the decrease in fish numbers within the system (*Figure 8*). There were around 12,920 visits, 3,780 visits and 2,770 visits in the seasons 1994-95, 2001-02 and 2007-08 respectively (Hughey and Taylor 2009).

The trout population has been measured in the past with a count of fish caught in a fish trap installed most winters in an area of the Selwyn River, above Coes Ford and below the road bridge. This has recording fish spawning activities since the 1940's. These records show that there has been a drop in fish capture rate at this trap from 1971 (*Figure 8*) (Hughey and Taylor 2009). This decline in fish numbers has been attributed to a number of factors, including; over-fishing by commercial fisherman (trout as a by-catch in the flounder fishery), weed bed destruction, loss of spawning habitat and the lake opening regime (Taylor 1996).

Mortality of adult fish within the lake may contribute to this decline. There has been some recognition that bi-catch of trout during commercial flounder netting may have impacted the trout fishery, although the extent to which this by-catch occurs remains unreported (Taylor 1996).

The loss of weed beds following the Wahine storm of 1968 is likely to have decreased recruitment due to the loss of macrophytes which provide protection and shelter for juveniles. Alternatively/additionally, a loss of spawning habitat may be responsible for declined recruitment. A report by Taylor and Good (2006) found that there has been around a 95% loss in spawning habitat in the Selwyn and LII rivers since the 1980's, largely caused by siltation of spawning gravels.

The opening regime exercised in the lake each year is likely to have an effect on the fishery. It is recognised that large numbers of sea-run trout (brown trout that spend a period of their adult life at sea) enter the lake when a cut through the barrier is made. The number of fish entering when the lake is opened to the sea is probably dependent on timing of the cut, although further research is needed in order to fully understand this relationship (Taylor et al. 1996; Hughey and Taylor 2009).

It is unlikely that any one of these factors alone would have caused the decline in trout numbers. A more reasonable suggestion is that a combination of these factors is responsible. The decline in the fishery has reduced the systems status from one of national importance to one of regional importance. The decrease in water quality and trout numbers have led to a huge decrease in popularity of this fishery (Taylor 1996).

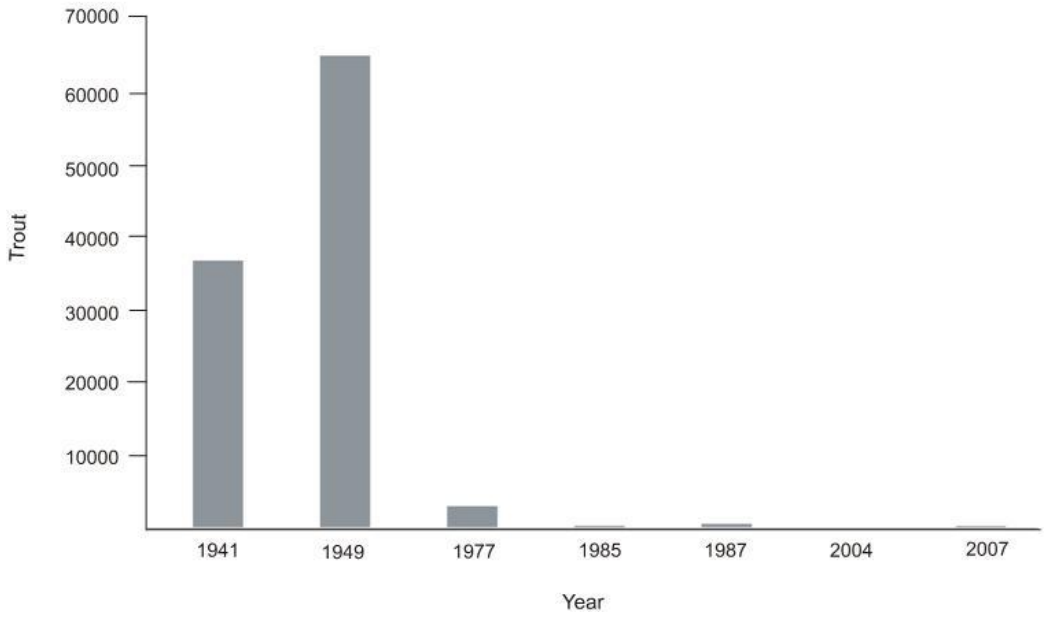

Figure 8: Estimates of brown trout numbers spawning in the Selwyn River from census trap data. From: Hughey and Taylor (2009).

Shooting:

According to Palmer (1982) Waihora is the most important game bird shooting area in the Canterbury region. Waihora regularly supports over 30,000 waterfowl (Te Waihora Joint Management Plan 2004). Game birds that inhabit the lake include the New Zealand shoveler duck (*Anas rhynchotis*), mallard (*A. platyrhynchos*), grey duck (*A. superciliosa*), paradise duck (*Tadorna variegata*), pukeko (*Porphyrio porphyrio*), black swan (*Cygnus atratus*) and Canada goose (*Branta canadensis*), with the mallard being the most commonly targeted (Palmer 1982; Hughes et al. 1974).

Water based activities:

Sailing regattas have been run on the lake in the past, as well as water skiing championships and powerboat racing (Palmer 1982). The lake is also used for these sports non-competitively as well as other water sports such as windsurfing, kitesurfing, kayaking and canoeing (Te Waihora Joint Management Plan 2004; Palmer 1982). However, recently the lake has been used considerably less than was in the past. This is primarily due to the risk of equipment damage in the lakes current shallow state (Palmer 1982), as well as the increased availability of alternative water bodies (Te Waihora Joint Management Plan 2004).

1.5.4 Commercial fishing

Six fish species within the lake are of commercial value, including yellow eyed mullet, three species of flounder and two species of eel.

Yellow eyed mullet:

The yellow eyed mullet (*Aldrichetta forsteri*) fishery is the smallest of the fisheries within Waihora. Only 14.15 tonnes were caught in 14 years between 1945 and 1959. This rose to 20.8 tonnes in 1960 and fluctuated between 20 and 40 tonnes between 1962 and 1987 (Taylor 1996). However, Todd (1980) reports that catches were only 4 tonnes in 1978. It is clear that annual catches of this species are extremely variable and have never been very large. This fishery usually only provides additional income to eel fishers in their winter off season (Todd 1980).

Flounder:

The flounder fishery is the oldest commercial fishery within Waihora, dating back to the 1800's. The principle fishing method is to use set nets to catch three species that live in the lake, common (or white) flounder (*Rhombosolea plebeia*), yellow belly flounder (*Rhombosolea leporine*) and the black flounder (*Rhombosolea retiaria*). In 1979 catches reached 272 tonnes, 15% of New Zealand's total flounder catch. Before this catches were much smaller with less than 1 tonne caught in 1970. Fishing effort dropped from 1979 to 2008, with the number of fishers decreasing from 55 to 8 in those years respectively. Despite this, annual catch rates of flounder within Waihora remain quite high, with around 150 tonnes being landed in 2005 (*Figure 9*) (Hughey and Taylor 2008).

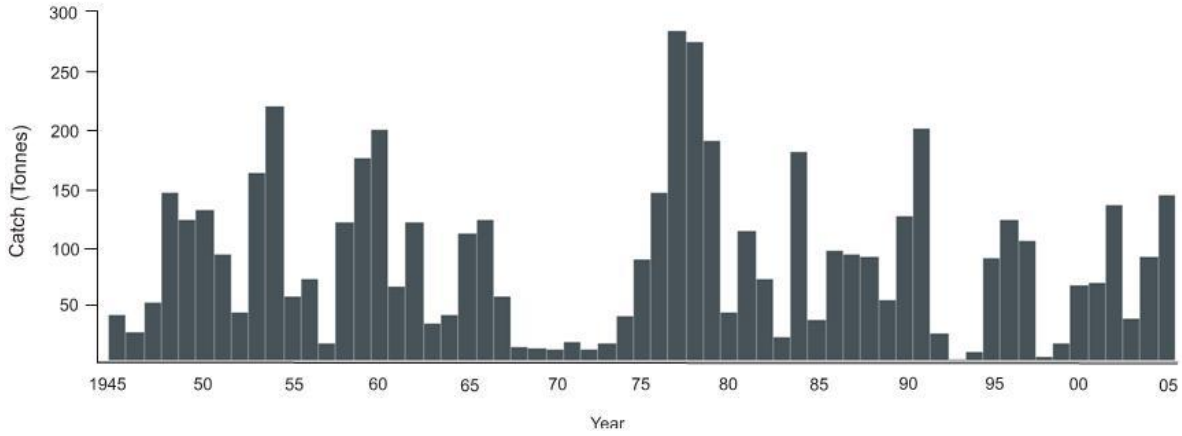

Figure 9: Commercial flounder catches within Waihora from 1945 to 2005. From: Hughey and Taylor (2008).

The catch rate displays a high rate of annual variability (*Figure 9*), probably due to the timing of lake openings from year to year. Flounder catches are highly influenced by the timing of the lake opening, with juveniles entering the lake when a cut is made in October-November (Todd 1980). Additionally, the proportions of each species caught fluctuate between years, with any one of the three species being predominant in any particular year. This is probably caused by the timing of lake openings in relation to each species migration patterns, and/or the juvenile survival rate of each species while at sea (Todd 1980; Hughey and Taylor 2008).

Eels:

The eel fishery is the most valuable fishery within Waihora. Two eel species live in Waihora and its tributaries, the shortfin eel (*Anguilla australis*) and the longfin eel (*Anguilla dieffenbachia*), with the fishery being focused almost entirely on the former. The fishery began to develop in the late 1960's to early 1970's. Catches began to rise quickly from 1972 and peaked in the 1975/1976 season. This followed the trend throughout New Zealand of increased eel fisheries and exports, with eels becoming the most valuable fin fish export in 1975 and Waihora contributing 30% to this catch. However, in the years to follow the catch declined despite increased fishing effort. Catches during the 1979/1980 season were 348 tonnes, compared to 646 tonnes landed in 1975/1976 (*Figure 10*). Due to this fishing pressure and declining catch rates, a 300 tonne annual quota was set from around 1980, to be divided between 17 fishermen (Todd 1980). From 1980 to 1986 periodic reductions in the allowable catch occurred, resulting in a total allowable catch (TAC) of 136.5 tonnes (Jellyman et al. 2003).

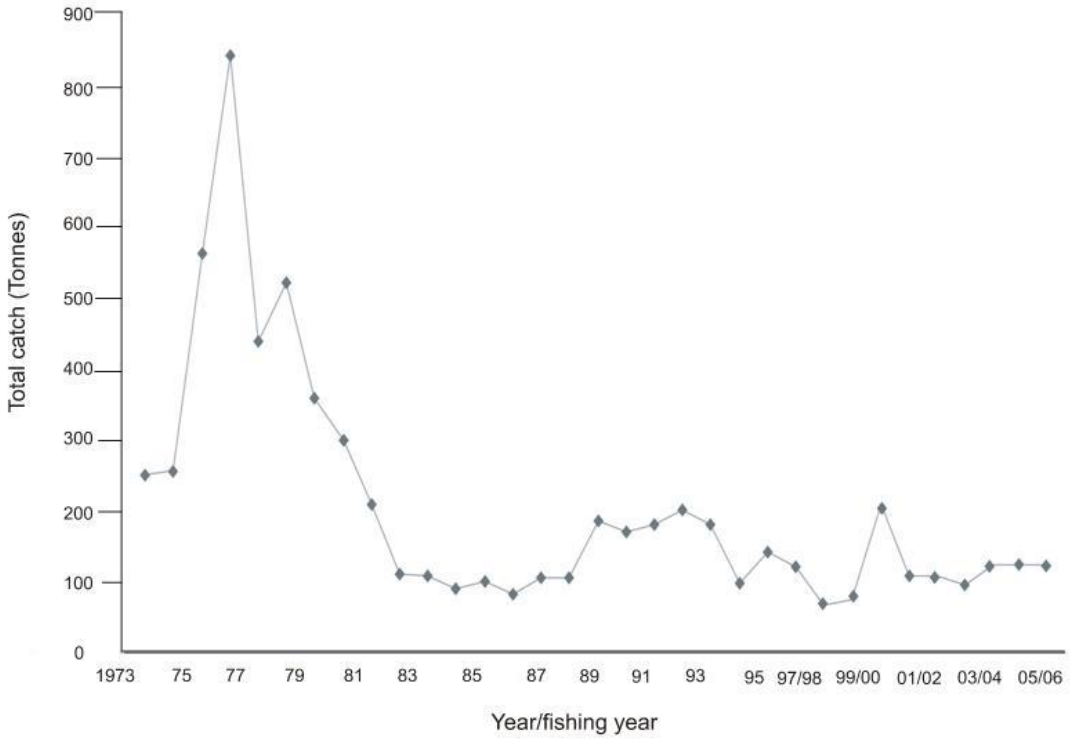

Figure 10: Total eel catches from Waihora between 1973 and 2006. From: Hughey and Taylor (2008).

The commercial catch allowance dropped sometime between 1980 and 2000 to 132 tonnes. From October 1, 2000 the Waihora eel fishery (ANG13) was introduced into the Quota Management System (QMS). Under this new system the TAC was set at 156.32 tonnes, including a customary allowance of 31.26 tonnes, and a recreational allowance of 3.13 tonnes. The recruitment of Juvenile eels (glass eels) from the sea into Waihora occurs between August and December. According to Todd (1980) an opening occurs within this period nearly every year. Therefore, the timing regime of lake openings should not be having a negative impact on the fishery.

1.6 The history of Te Waihora according to previous research

In this section the current knowledge on the developmental history of Te Waihora, based on previous research, is described. Locations of sampling carried out by the authors whose work is described in this section are displayed in *Figure 13*, p. 35, at the end of this section.

20,000 years ago the last glacial period of the Pleistocene (Otira glaciation) was approaching an end (Kirk 1994; Leipe 2009). The glaciers within the valleys of the Southern Alps advanced and from these glaciers, powerful rivers coursed, carrying vast amounts of sediment to be deposited over the Canterbury plains. The plains during this time were much more extensive than the current plains, reaching up to 50 kilometres east of the coasts present position, due to lower sea levels (150 m lower than present). Banks Peninsula existed at this time, not as a volcanic peninsula jutting from the coast that we see today, but as a lone volcanic mass located inland of the paleo-coastline. In the area of modern Waihora these plains were built up from glacial outwash deposits, primarily from the Rakaia and Waimakariri Rivers, but also from the Selwyn River in times of glacial advances in the Rakaia valley (Leipe 2009).

Following this glacial period, after 20,000 B.P., sea levels around the world began to rapidly increase. The coastline of the Canterbury plains moved westwards as the continental shelf was inundated. During this coastline migration Waihora existed as a depression in the Canterbury Plains, between the Waimakariri and the Rakaia River fans. The Selwyn River probably meandered all the way to the coast within this depression, uninhibited (Kirk 1994).

By around 13,000 B.P. the sea would have been nearing the eastern end of Banks Peninsula, now a volcanic mass at the very edge of the plains. By 11,000 B.P. the sea would have drowned some of the plains inland of the volcanic mass. Thus, a peninsula dividing the Canterbury Bight from Pegasus Bay formed. Some of the valleys of the volcanic mass were drowned and the eastern bays and what is now known as Akaroa harbour were formed. However, the coast remained east of its present position and the interfan depression remained un-submerged (Kirk 1994).

A core record taken from around halfway long the Kaitorete barrier revealed shells of estuarine bivalves at -36 and -18 m above mean sea level. These yielded ages ranging from

about 9500 to 8000 ^{14}C years B.P. (Brown, unpubl. Data 1991, cited in Soons et al. 1997). This indicates that some sort of spit may have existed before sea level rise slowed, 8000 years ago (Soons et al. 1997).

BAY:

Around 7000 B.P. the rate of sea level rise began to decrease and between 7500 and 5000 B.P. the interfan depression currently occupied by Te Waihora was flooded by the sea. Thus, Waihora was a bay on the plains during this time. Ives (1973) suggests that Banks Peninsula became an island for a short period during a time of lower alluvial deposition that existed between 7500 and 6000 B.P. Land once again met Banks Peninsula when sea levels stabilised around its current level and a period of rapid alluvial deposition occurred, developing the plains eastward. However, according to Kirk (1994), Banks Peninsula was not an island during any time considered here, but much earlier.

BAY/ESTUARY:

Sea levels stabilised to their present level by about 5000 B.P. according to Armon (1974a), Kirk (1994) and Suggate (1968) or around 6000 B.P. according to Gibb (1986). These stable sea levels, the continual transport of large quantities of sediment from the braided rivers to the south (Rakaia and Ashburton Rivers primarily), the erosion of plains sediment at the coast and the prevailing northward longshore drift led to sediment being driven across the entrance to this bay (Kirk 1994).

ESTUARY:

By around 4000 B.P. a true spit was formed across the bay that was continually growing north-eastward under these stable sea level conditions, creating an estuary (Kirk 1994; Hemmingsen 1997). An Alternative hypothesis is presented by Armon (1974a) who claims the spit began to form before stable sea levels were met. Armon (1974a) claims that the hooked ridges now seen on the barrier (*Figure 11*) were formed when sea levels were lower than at present. This is due to ridge height being between 0 and 1.5 m above present mean sea level. Armon (1974a) suggested that for these ridges to be formed, the sea level would have to have been at least 5 m lower than the ridge tops. Thus, sea level would have been at least

3.5 m below present sea level for these ridge heights to form. Based on this assumption and comparing this height with known land-sea relationships of the past in Canterbury, he dates the formation of these ridges and thus the spit between 6000 and 7000 B.P. However this hypothesis is disputed by Soons et al. (1997) who propose that the low ridge heights (0 to +1.5 m above MSL) could be formed at a modern sea level, given that the orientation of the spit tips would facilitate the dissipation of wave energy. The spit tips curve in north-easterly direction, thus, the wave approach would be oblique and wave run up would be reduced. Therefore, it is expected that ridge heights would be lower on these hooked ridges than ridges on the swash aligned shore, at modern sea levels (Soons et al. 1997).

Figure 11: Aerial photograph of the eastern end of Waihora displaying hooked ridges. From Hemmingsen (1997).

LAKE:

The spit continued to grow until it made landfall against the south-western shoreline of Banks Peninsula. According to Armon (1974a) and Suggate (1968), this would have occurred around 6000 B.P., following the formation of the spit at lower than present sea levels. However, according to Harvey (1996), Hemmingsen (1997) and Soons et al. (1997), this would have occurred between 4000 and 3000 B.P. Kirk (1994) suggested that it took around 2000 years after the formation of a true spit (5000 B.P.) for the spit to join with Banks Peninsula about 3000 B.P.

ESTUARY:

Soons et al. (1997) observed a change in the diatom assemblage of their core from Gebbies Valley from a freshwater assemblage to a mixed (brackish) assemblage. This is below a layer of sediment derived from a freshwater lake that was deposited around at least 1500 years ago (See below). Soons et al. (1997) suggest that this brackish period would have occurred around the mid-Holocene and indicates permanent or semi-permanent barrier opening at this time.

LAKE:

Soons et al. (1997) observed freshwater diatom species below a dated paleo-lake beach ridge at McQueens Valley. The elevation of this sample and historic beaches in McQueens and Gebbies Valleys, suggest that the lake surface would have been 4 m above sea level about 1500 years ago (Soons et al. 1997).

ESTUARY:

A range of radiocarbon dates have been produced describing the conditions of Waihora following this freshwater lake period. The dates produced by Soons et al. (1997), Johnston (1958) and Hemmingsen (2001) give evidence for the occurrence of estuarine conditions in Waihora following the creation of the large freshwater lake mentioned above.

According to Soons et al. (1997) shell evidence found at the spit tip area and at Birdlings Valley suggest estuarine conditions were present around 1000 yr B.P. In addition, a radiocarbon age of 937 ± 38 yr B.P. was produced from wood material within lacustrine/estuarine deposits under shell hash layer from Birdlings barrier core. This indicates estuarine conditions were present due to a breach in Kaitorete barrier. Shells identified as the estuarine bivalve *Paphies australis* were also dated from Jones Pit revealing a radiocarbon age of 775 ± 58 yr B.P. Soons et al. (1997) suggest that there must have been a breach in the barrier around 775 ^{14}C years B.P., leading to the establishment of estuarine conditions.

Further evidence exists to support the theory that estuarine conditions prevailed around the date produced by of Soons et al. (1997) on the shell from Jones Pit. It is well documented that the Waimakariri River has followed a course to the south of Banks Peninsula in the past. Evidence in the form of paleo-channels exists and buried *Podocarpus totara* logs within one of these channels have been dated and reported by Johnston (1958). These logs buried under 3.3 – 3.5 m of river gravel produced dates of 1190 ± 50 AD and 1265 ± 65 AD. It is probable that the discharge of the Waimakariri River into Waihora would cause the formation of a permanent lake opening and estuarine conditions to prevail (Johnston 1958; Soons et al. 1997).

Hemmingsen (2001) reports a radiocarbon age of 670 ± 67 B.P. from a shell sample of the estuarine bivalve species *Mactra ovata*. A shell hash layer dominated by this species was found at a site in Lakelands, 5.36 m above MSL and 1.2 km landward of the present shore of Waihora. Given that the shells were *in situ* and unburned, it is unlikely that the shells were from a midden (Hemmingsen 2001). The elevation above sea level of the sample suggests that the shells were reworked and deposited under a deep freshwater lake situation. Nonetheless, the age of 670 ± 67 B.P. (calibrated to 1480-1718 AD, 95% confidence interval), on remains of this estuarine species, gives an indication that estuarine conditions occurred in Waihora around this time.

Harvey (1996) presents qualitative paleo-environmental evidence to suggest that the Waimakariri River discharged into Waihora around 700 years ago, creating a permanent lake barrier opening and estuarine conditions to prevail. This is based on the synchronicity of pollen inferred Mäori arrival in the area with increased salinity conditions based on diatom evidence. Thus, the date of the beginning of estuarine conditions is given as 700 years ago, as

this is around the time when Mäori are believed to have first inhabited the area (Harvey 1996).

Soons et al. (1997) present a radiocarbon age of 561 ± 57 yr B.P. from shell material within a shell hash bed at Birdlings Valley, almost solely comprised of *Paphies australis*. This is an estuarine species that prefers shallow tidal races. Thus, tidal conditions existed within Birdlings Valley around 561 ^{14}C years B.P., indicating a breach in the barrier was present, only to be closed relatively recently (< 550 years ago). The discharge of the Waimakariri River into Waihora is believed responsible for this barrier breach (Soons et al. 1997).

LAKE:

Sometime around 500 ^{14}C years B.P. the spit rejoined Banks Peninsula and a freshwater lake formed. This is derived from data produced by Soons et al. (1997) based on the disappearance of the shell hash layer that was dated at 561 ± 57 ^{14}C yr B.P. According to examinations of beach ridges by Armon (1974a) it is likely that the lake was much larger than the modern lake at this time (up to 4 m above MSL before a natural breach occurred).

REVERSAL OF BARRIER SHAPE:

Since the closure of Waihora from the sea, Wairewa - Lake Forsyth (an adjacent lake sharing the same barrier complex) has been impounded by thickening at the north eastern end. Historical documentary material indicates that whalers frequently travelled by boat from the sea to Little River, located near the head of Wairewa. This information, as well as aerial photos and maps give conclusive evidence that the barrier at the eastern end has been through a period of progradation (Soons et al. 1997).

Evidence of coastal retreat at the south-western end of the barrier exists in old maps, ground surveys and aerial photographs. These suggest that the coast south of Taumutu is eroding faster than deposition is occurring. Speight (1950) wrote of the occurrence of a stream (Little Rakaia Stream) that once discharged into the northern end of the Rakaia River mouth. This stream was significant enough to warrant road bridges being built across it. By 1950 the author observed that the river bed was dry and almost completely in filled by coastal sediment due to coastal retreat. By 1967 the landward toe of the beach was located on the

former western bank of Little Rakaia Stream, and by 1883 the old stream channel had completely disappeared, replaced by beach sediment. This process is also affecting land at Taumutu at the south-western end of Te Waihora, where the coastline is increasingly encroaching on farmland adjacent to the coast (Hemmingsen 1997).

Additional evidence from the 'Black Map' Survey Canterbury in the 1860's, suggests that Little Rakaia River may have formed a link between the Rakaia River mouth and Coopers Lagoon and an additional stream connected Coopers Lagoon to Waihora near Taumutu (Hemmingsen 1997). Additionally, Kirk (1991) carried out a study of profile records from culvert sites between the Rakaia River mouth and Taumutu that revealed erosion rates along this coast of up to three feet (1 m) per year. There is also some evidence to suggest that erosion rates could be higher in years with high numbers of storm events (Hemmingsen 1997).

This progradation in the north-east of the barrier and coastal retreat in the south-western end of the barrier has caused a reversal in the barrier shape. The barrier northeast has prograded, turning in an orientation towards the prevailing southerly swells, while the barrier and coastline southwest of Taumutu is retreating. The coast is, in effect, swivelling on a hinge point slightly northeast of Taumutu (*Figure 12*) (Kirk and Lauder 2000). According to Kirk (1994) there has been no change in barrier position or shape since the 1960's.

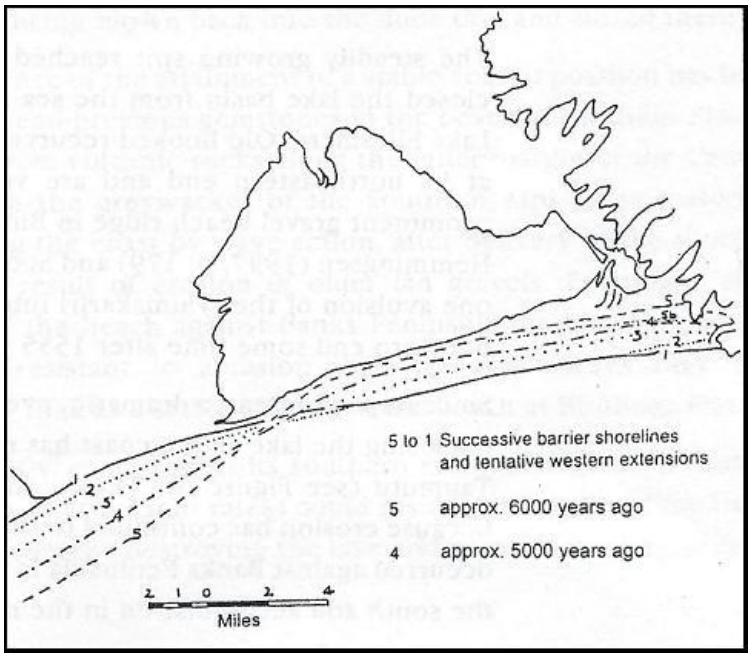

Figure 12: The clockwise rotation of the coast following enclosure, from a 'hinge point' near Taumutu. From: Kirk and Lauder (2000).

Figure 13: Satellite image of Waihora and surrounding landscape. Locations of sampling sites from the research described above are displayed. Produced in Google Earth (2010).

1.7 Aims and objectives

Previous literature such as that of Armon (1974a, 1974b), Gibb (1986), Harvey (1996), Hemmingsen (2001, 1997), Johnston (1958), Kirk (1994, 1991), Kirk and Lauder (2000), Leipe (2009), Soons et al. (1997), Speight (1950) and Suggate (1968), present valuable information towards elucidating the environmental history of Te Waihora. However, gaps in this information remain. This research involves the use of paleoecological techniques to reconstruct the natural and recent human induced changes in Waihora and aims to fill gaps in the current knowledge. Thus this study aims to determine and discuss:

- The timing of initial lake formation and conditions within/around the lake following this.
- The timing and effects of known Waimakariri River discharge events into Waihora
- Changes in the vegetation surrounding Waihora and conditions within Waihora through time
- Whether the current lake state is attributed to natural or anthropogenic forces
- What constitutes a natural state for Waihora
- The effects of lake changes on lake values
- Management suggestions based on information presented

Physical sediment description, pollen analysis and diatom analysis will be carried out on sediment cores obtained from Te Waihora, in order to provide this information. To my knowledge this is the first study on sediment cores obtained from the current lake bed.

1.8 Introduction to the paleoecology

The methods used in this study are based on the principles of paleoecology. Paleoecologists use physical and biological proxies within sedimentary material. These physical and biological proxies are related to known environmental conditions based on studies conducted in recent times. The characteristics/composition of these proxies within sedimentary material, can be used to determine conditions of the past, based on the assumption that environmental conditions, in which they are known to currently occur, reflects the environmental conditions in which they occurred in the past (Birks and Birks 1980). A summary of the seven principles of paleoecology outlined by Birks and Birks (1980) and summarised by Cochran (2002, p. 25) is given below.

1. *Paleoecology is a descriptive, historical science, it depends on inductive inferences and reasoning - one observation leads to another and extrapolations are made in an attempt to present generalisations about nature.*
2. *The method of multiple working hypotheses is applicable - one must consider as many reasonable explanations as possible, this will encourage seeking of new evidence, and lead to rejection of (hopefully) all but one working hypothesis.*
3. *Simplicity - let the simplest explanation suffice until more evidence is available that requires a more complex explanation.*
4. *A sound taxonomy and appreciation of evolutionary processes is essential.*
5. *The language of paleoecology is primarily that of biology and geology.*
6. *The data of paleoecology is often multivariate requiring multivariate mathematical methods to simplify and synthesise it prior to interpretation.*
7. *Uniformitarianism - the present is the key to the past.*

Paleoecological evidence collected and presented in this study consists of sediment physical characteristics as well as the characteristics and ecological preferences of organism remains preserved within the sedimentary sequences analysed. The fossils examined in this study are palynomorphs and diatoms. The sedimentary sequences analysed are sediment core samples collected from Te Waihora with permission from Te Rūnanga o Ngāi Tahu, the owners of the lake bed. This study is based wholly on the analysis of these core samples. Changes in sediment and fossil characteristics are related to a chronology produced with ^{14}C, ^{137}Cs, ^{210}Pb.

What follows is a description of core samples analysed in this study and methods used in sampling these cores (**Chapter 2**), background, methods and results of dating techniques (**Chapter 3)**, and introduction, methods and results of; sediment characteristics analysis (**Chapter 4**), palynological analysis (**Chapter 5**) and diatom analysis (**Chapter 6**).

Chapter 2 Sediment cores used in this study

2.1 Sediment cores analysed

Four cores have been analysed in this study. These have been named WA09, WA1, WA2 and Te Koru, the first of which was retrieved at the beginning of this study, while the other three were existing cores retrieved prior to the beginning of this study. WA1, WA2 were retrieved from 43°47'31.87"S 172°32'25.59"E, Te Koru was retrieved from 43°51'24.6"S 172°22'03.8"E and the location of WA09 core retrieval is given in the following section (section 2.2). Pollen analysis has been carried out on the WA09, WA2 and Te Koru cores, with counting of non-pollen palynomorphs being carried out on the WA09 core only, due to time constraints. Diatom analysis has been carried out on the WA09, WA1 and Te Koru cores. For diatom analysis the WA1 core was used in place of its counterpart WA2, as very little sediment was available from the WA2 core following pollen analysis, due to the use of this core for a previous pilot study. Because of the degraded nature of the WA2 core, this core is given very little attention in this study and only pollen analysis was conducted on this core. WA1 and WA2 are both gravity cores of the same length retrieved from the same location. The Te Koru core was also retrieved using a gravity corer, while the WA09 core was retrieved using a 'Livingston piston corer' (Wright 1967). As the WA1, WA2 and Te Koru cores were retrieved prior to the beginning of this research, only the coring methods used to retrieve the WA09 core are described below. However, sub sampling of all four cores is outlined following this.

2.2 WA09 core retrieval

Coring took place on 10/02/2009 near the centre of Te Waihora (Waihora basin) (*Figure 14*) at 43°47'30.67"S 172°32'26.79"E at a depth of 2.2 m. This coring location is within the deepest area of the lake and was chosen because sediment transported to, or created within the lake is transported here at a greater volume than other parts of the lake, due to sediment focusing (Blais & Kalff 1995). Thus, this area should provide the most accurate representation of pollen and diatom inferred changes throughout Waihora. Coring was conducted using a Livingston piston corer (Wright 1967) mounted on a raft platform. The coring methods used are described by Myrbo and Wright (2008) and Deevey et al. (1965). Two 2 m cores were retrieved from Waihora basin, one of which was used (WA09), while the other was archived. Cores were capped onsite and stored in a walk-in chiller until needed.

Figure 14: Bathymetry of Waihora with sampling locations displayed. Modified from: Irwin and Del Main (1989).

2.3 WA09 Core sampling

Following the collection of the WA09 core from the lake basin, core sampling was conducted in a laboratory. The PVC core pipe was scoured from top to bottom on either side with a circular bench saw. The pipe was then cut right through with a craft knife, so that the pipe was halved length-wise. Before separating the pipe halves, a craft knife blade was inserted into the tube opening and cut through the sediment all the way down the pipe. Thus, the sediment core was cut in half length-wise. The two halves of the pipe and sediment core were opened and photographs of the core were immediately taken with a digital camera mounted underneath a tripod. Sediment colours were also noted using a Munsell colour chart (Munsell 1912) (more on this in Chapter 4).

Table 2 displays the depths at which samples were taken from this core. At each sample interval approximately 4 cm^3 of sediment was removed. This sediment was homogenised and further divided into four 1 cm^3 samples. These were placed in separate zip-lock bags for sediment texture analysis, palynological analysis, diatom analysis, and the remaining 1 cm^3 stored as spare sediment.

Table 2: Depth (cm) at which 1cm^3 samples were obtained from the four cores.

WA09	WA1	WA2	Te Koru
0-1	0-1	0	0-1
10-11	4-5	5.43	6-7
20-21	9-10	10.86	12-13
30-31	14-15	16.29	18-19
40-41	19-20	21.27	24-25
50-51	24-25	27.15	30-31
60-61	29-30	32.58	36-37
70-71	34-35	38	42-43
80-81	39-40		
90-91			
100-101			
110-111			
120-121			
130-131			
140-141			
150-151			
160-161			
170-171			
180-181			
190-191			
200-201			
210-211			

2.4 WA1, WA2 and Te Koru Core sampling

4 cm^3 of sediment was obtained from evenly spaced intervals through the cores (*Table 2*) and each divided into four 1 cm^3 samples. These were stored in separate bags for sediment texture analysis, palynological analysis and diatom analysis (the remaining 1 cm^3 was stored as spare sediment). Care was taken to ensure that these sample intervals included all zones of lithologic variability in each core.

Chapter 3 Dating

3.1 Radiocarbon dating

3.1.1 Radiocarbon background

The method of dating materials using radiocarbon (^{14}C) was developed in the 1940's, primarily through the research of Willard Libby and his colleagues. Early notable publications towards the use of radiocarbon as a dating tool include Arnold and Libby (1946, 1949) and Libby (1955). The principles underlying radiocarbon dating are as follows: Carbon has three naturally occurring isotopes, ^{12}C, ^{13}C and ^{14}C, with the latter being the least commonly occurring isotope (around 1 ppm of modern carbon is ^{14}C). Unlike the former two isotopes, ^{14}C is radioactive (weakly). Radiocarbon is constantly being formed as a cosmogenic nucleotide in the upper atmosphere, through the interaction of neutrons (caused by cosmic rays) with nitrogen atoms. Upon the formation of ^{14}C the atoms readily combine with oxygen forming carbon dioxide. The carbon dioxide containing ^{14}C enters the biosphere via photosynthesis and is distributed throughout food webs. In theory there is a constant equilibrium between the ^{14}C in the atmosphere and the ^{14}C within organisms and it is only when the organism dies that carbon exchange with the atmosphere ceases. As the ^{14}C within the remains of the dead organism is radioactive, the amount of ^{14}C therein begins to decrease. This radioactive decay occurs at a known rate (^{14}C has a half life of around 5730, with a half life of 5568 being used during calculations for historical reasons). Therefore, by measuring the amount of ^{14}C atoms relative to other carbon isotopes (^{13}C and ^{12}C), one can calculate the age of a carbon containing material (Bowman 1990). The principles behind radiocarbon dating outlined above have remained largely unchanged since the method began in the 1940's. However, recent developments have greatly increased the accuracy of dates obtained through this method. These include the use of accelerator mass spectrometry (AMS) and calibration data sets (for details on these see Reimer et al. (2004)).

3.1.2 Radiocarbon methods

Four samples from the WA09 core were sent to the Rafter Radiocarbon Laboratory at GNS in Wellington, New Zealand for radiocarbon analysis. These samples were taken from the core at 51-52, 95-96, 171-172 and 207 cm depth. At 207 cm depth, sieving at 180 μm revealed

many fragments of plant material within the sediment. Around 20g of this material was sent for ^{14}C dating from this depth. Significant quantities of datable macrofossil material were not found from other depths of the core, therefore, bulk sediment samples (around 60g dry weight) were extracted form the core at the 3 other depths mentioned above. Care was taken to avoid the outer core sediment due to the risk of contamination through surface smearing during coring. These samples were dried in an oven at 60°C overnight, wrapped in tinfoil and sent to the Rafter Radiocarbon Laboratory.

3.1.3 Results

Table 3: Radiocarbon ages (conventional and calibrated) for samples from four depths of the WA09 core (present in B.P. = 1950).

Sample depth	**Sample name**	**Sample material**	**13C/12C (δ13C)**	**Conventional radiocarbon age B.P.**	**Calibrated radiocarbon age B.P.** (95% confidence interval or largest contribution to this confidence interval displayed if multiple peaks occur in calibration curve)
51-52 cm	NZA 33971	Plant material float from sediment at sp.gr. 1.30	-22.8 ‰	7839 ± 80	**8778 to 8399 B.P.** (91.5% of area)
51-52 cm	NZA 33952	Plant material precipitate from sediment at sp.gr. 1.30	-24.6 ‰	11533 ± 45	No calibration obtained
95-96 cm	NZA 33970	Plant material float from sediment at sp.gr. 1.30	-26 ‰	10257 ± 55	**12217 to 11760 B.P.** (92.2% of area)
171-172 cm	NZA 33912	Plant material float from sediment at sp.gr. 1.5	-26.8 ‰	10189 ± 50	**12072 to 11702 B.P.** (93.9% of area)
207 cm	NZA 33828	Plant material	-27.7 ‰	6760 ± 40	**7657 to 7491 B.P.** (94.8% of area)

Radiocarbon results are displayed in *Table 3* above (further details of radiocarbon measurements are displayed in Appendix IX). It is clear that there are some anomalies in the radiocarbon dates obtained. First the expected sequence of young sediments over old is not observed. The youngest date received comes from the deepest sample from this core. Additionally, the three samples from 51-52, 95-96 and 171-172 cm display very similar ages,

although all of these are much older than expected. Non-pollen palynomorph and diatom data obtained in this study (Chapters 5 & 6) suggest that a lacustrine environment occurred during the deposition period represented by the bottom zone of this core. Evidence presented by earlier authors such as (Armon 1974a; Hemmingsen 1996; Kirk 1994; Soons et al. 1997; Suggate 1968) suggests that Waihora was not a lacustrine environment until after 7000 years ago. Therefore, it is likely that deviation from the true age has occurred through either a reservoir effect or contamination.

The reservoir effect occurs because carbon in seawater appears older than atmospheric carbon. It is possible that some marine or estuarine materials were deposited in the basin during the time sedimentation occurred at these sample levels. Diatom evidence suggests that a permanent barrier opening existed during the time sediment from these three samples was deposited. Seawater exchange would have facilitated the deposition of some marine/estuarine materials. However, given the large discrepancy in ages it is more likely that these samples have been contaminated with old carbon.

If old carbon (containing considerably less ^{14}C than the autochthonous carbon within the lake at a particular time) is transported to the lake and deposited with younger carbon, an older than expected radiocarbon age can be produced. This is probably the cause of the unreasonably old dates produced here. Indeed, McGlone and Wilmshurst (1999) note that silty lake sediments appear to be particularly vulnerable to this contamination effect. It is likely that sample NZA 33828 from 207 cm core depth produced a radiocarbon age closer to the true age of sedimentation, as this was not a bulk sample, but a sample of woody macrofossil material.

3.2 ^{137}Cs and ^{210}Pb analysis

3.2.1 ^{137}Cs background

The potential of using ^{137}Cs in dating sediment core samples has been recognised since the beginning of the 1970's (Pennington et al. 1973). ^{137}Cs is an artificial radionuclide produced during nuclear weapons testing. The deposition rate of this radionuclide has been determined at various locations around the world. In New Zealand, deposition of ^{137}Cs began in 1952 with the beginning of nuclear testing in the Southern Hemisphere and ended in 1974. There is

also a considerable peak in the deposition of ^{137}Cs in 1965 through stratospheric transfer from testing in the Northern Hemisphere (Reiser pers. comm.), while Hewitt (1996) reports a peak in deposition in the Dunedin area around 1956. By measuring the amount of ^{137}Cs through various depths of a sediment core, a profile of ^{137}Cs concentration is produced which can be useful in determining the timing of deposition and deposition rates of sediment within a lake (Hewitt 1996).

3.2.2 ^{210}Pb background

^{210}Pb is a radioactive isotope in the ^{238}U series that has been used for more than two decades as a method of dating lake sediments (Benoit and Rozan 2001). ^{210}Pb bonds to aerosol particles in the atmosphere and is deposited on the Earth's surface via precipitation. Here it attaches to silicate particles and is transported to areas such as lakes (Goff et al. 1998). The method of ^{210}Pb dating relies on measuring the radioactivity produced from unsupported ^{210}Pb in the sediments (the half-life of which is 22.26 years) following this 'rain-out'. Assuming a constant input of unsupported ^{210}Pb and constant residence time within a lake, the age of sediment and deposition rates can be estimated (Appleby 1978).

3.2.3 ^{137}Cs and ^{210}Pb methods

10 samples (10 gram of dry sediment each) were taken from the WA1 core, and 11 samples were taken from the WA09 core at various depths (*Figures 15 & 16* display depths, on the y-axis, at which samples were obtained). These samples were sent to Victoria University, School of Geography, Environment and Earth Sciences for ^{210}Pb and ^{137}Cs analysis using γ spectroscopy. For ^{210}Pb, only the unsupported component was measured. This is the ^{210}Pb created through ^{222}Rn decay in the atmosphere only, not the ^{226}Ra decay in the sediment. The results of these tests are described below.

3.2.4 ^{137}Cs and ^{210}Pb results:

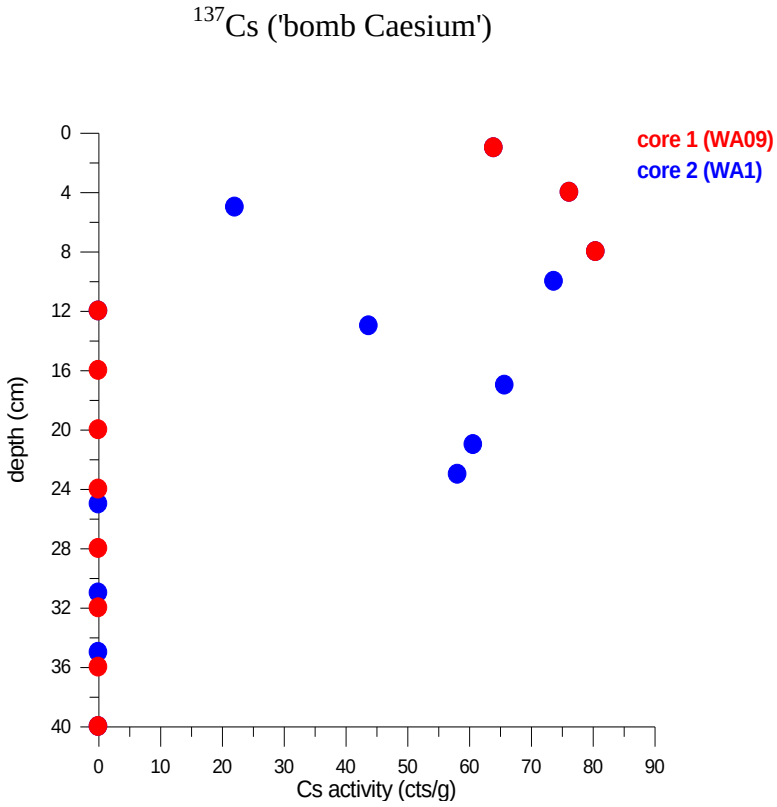

Figure 15: ^{137}Cs activity within samples from the WA09 and WA1 cores.

In both the WA09 and WA1 cores there is a clear cut off point of ^{137}Cs activity, between 8 and 10 cm in the WA09 core and between the 21-22 and 25-26 cm depth samples in the WA1 core (*Figure 15*). This indicates that sediment below these cut off points were deposited pre-1952. However, there is no clear bomb peak (1965) that is observed in many profiles. This is likely an indicator of sediment mixing somewhere above 12 cm depth in the WA09 core and above 22 cm depth in the WA1 core. Shell hash layers at 10 cm core depth in WA09 and 19-20 cm core depth in the WA1 core suggest a catastrophic event occurred here. ^{137}Cs analysis suggests that these layers are the base of the Wahine storm (1968) affected material. Above these depths there has been some mixing from this storm disturbance which has obscured bomb peaks in the profiles. However, pollen and diatom counts above these shell hash layers suggest that this mixing has been incomplete as changes in the biostratigraphy are still observed.

^{210}Pb profile ('unsupported ^{210}Pb', i.e. atmospheric input)

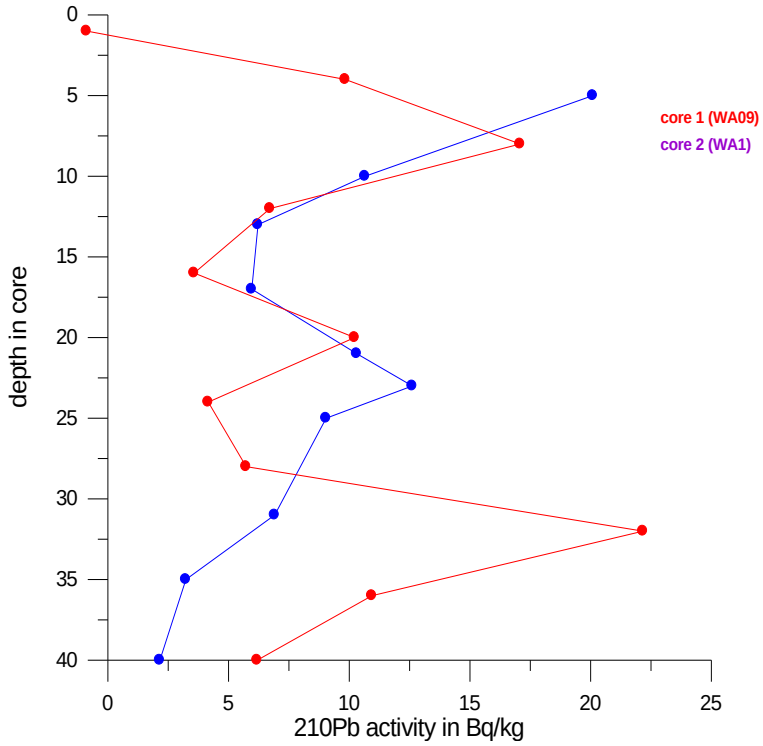

Figure 16: ^{210}Pb activity within samples from the WA09 and WA1 cores.

At first glance the ^{210}Pb profiles for the WA09 and WA1 cores suggest some mixing of sediment has occurred throughout the WA09 core profile and in the WA1 core above 22 cm depth (*Figure 16*). However, variation in pollen and diatom counts through these areas of these two cores (see chapters 5 & 6) suggests mixing has not been major factor here. Therefore, it is more likely that these dips in the ^{210}Pb activity are due to an increase in sedimentation of older sediment, containing less, or no ^{210}Pb activity. Indeed, spikes in fern spores within these areas of the WA09 core (*Figure 26 & 27*) and the WA2 core (counterpart of the WA1 core) (*Figure 29 & 30*), suggests sedimentation rates within Waihora basin are higher during these periods of decreased ^{210}Pb activity (between 8 and 32 cm depth in the WA09 core and between 9-10 and 21-22 cm depth in the WA1 core) (*Figure 16*). The decrease in ^{210}Pb activity in the WA1 core, below 22 cm depth (*Figure 16*) may indicate that sediment here were deposited in around 2.5 half-life's of ^{210}Pb (~55yrs ago) (Reiser pers. comm.).

Chapter 4 Core descriptions

4.1 Introduction to core description

The usefulness of and rationale behind analysis of sediment colour, components, texture and loss on ignition (LOI) is described in this section. Changes in sediment colour can provide clues towards changes in sediment composition and chemistry. Analysis of macroscopic sediment components, such as plant and animal matter, yields important clues towards establishing the sediment source and conditions of the depositional environment. Sediment texture is an important parameter, particularly as an indication of energy of past depositional environments. Finally, loss on ignition (LOI) gives an indication of water, organic and carbonate content of sediments, which is useful to infer productivity and mineral flux. Sediment texture analysis and LOI are the primary factors examined for core description in this study and are introduced in detail below.

4.1.1 Sediment texture

The study of textural parameters within lake sediments can yield important clues towards the source of the sediment, the mechanisms of sediment transport, environmental conditions at the site of deposition, and paleohydrological conditions of the catchment (Last 2001). A relationship between sediment particle size (median size), energy level and water depth has been proposed, while other parameters of particle texture, such as sorting, skewness and kurtosis have also been used to infer past depositional environments. These parameters can give an indication of the environmental conditions at the time of sediment deposition. According to the literature summarised in section 1.6, pp. 28-35, Waihora has had a diverse history, possibly with coastal (embayment), estuarine and lacustrine conditions occurring during its evolution. Therefore, sediment textural analysis may be useful in identifying any such depositional conditions if they occurred during the deposition period of cores analysed.

Median:

This statistic gives an indication of energetics within a water-body. In general, the larger the particle size the higher the energy involved in its transportation to the site of deposition

(Krinsley and Kaldi 1979). The median value represents the grain size corresponding to 50% of the cumulative frequency in microns.

Sorting:

Sorting measures the spread of the central portion of the distribution curve. Material that is well sorted contains a small range of particle sizes and has a low standard deviation. Mechanical sorting occurs in environments such as rivers, marine currents, beaches and lacustrine environments that have a range of speeds, transporting then depositing particles of a certain size. Still water environments can be variable in their sorting, while well sorted grains may be evidence that the velocity of the current at the time and site of deposition was within a narrow range (Hsu 1989). In a quiet water environment such as Waihora, a narrow range of sediment size in a sample may be indicative of the deposition of sediment that has been deposited previously in a well sorted environment, then reworked and deposited in the lake. Alternatively, well sorted sediments may be indicative of higher energy inputs into the basin, and longitudinal gradation occurring across the lake/lagoon from the energy source. For example, with a high energy river discharge into a still-water system, the coarser particle will be deposited close to the outlet, with a fining trend towards the lake centre. At any one point along this trend, grains may be well sorted (Hsu 1989; Hatch and Rastell 1965). According to Hatch and Rastall (1965) beach deposits are typically well sorted and river deposits are typically less so.

Skewness:

Skewness indicates the spread of the tails of the distribution curve. A negative skew value indicates grains are coarsely skewed, while a positive value indicated grains are fine skewed. According to Krinsley and Kaldi (1979) skewness of beach sands is typically negative (i.e. more coarse grains than fine). Valia and Cameron (1977) report that skewness may be an indicator of energy conditions in the depositional environment. Negative skewness may occur in an environment where high energy flows lead to fine sediment being removed through a winnowing action. Conversely, sediments accumulated in calm water conditions are often positively skewed. Negative skewness may also be an indication of the duration or frequency of fluctuation towards high energy regimes. Thus, in an environment subjected to high

energies for a long period, or on a regular basis, sediments may become negatively skewed (Valia and Cameron 1977).

Kurtosis:

Kurtosis is a measure of how peaked a distribution of grain sizes is, within a sample. If sample size distribution is excessively peaked it is referred to as 'leptokurtic', if it is flattened it is referred to as 'platykurtic'. Beach sediments are typically leptokurtic (Sly et al. 1982; Martins 1965) or display near normal kurtosis (Krinsley and Kaldi 1979). According to Sly et al. (1982) low energy deposited, silty lake sediments are expected to be platykurtic and according to (Sly et al. 1982; Martins 1965) river sediments tend to be leptokurtic.

Table 4: Summary of texture parameter interpretation as described above.

	Lacustrine	**Lagoon**	**Tidal flat**	**Fluvial**	**Barrier beach**
Sediment size	Clay to silt or sand	Clay to silt	Clay to silt	Clay to gravel	Sand (very fine to coarse)
Sorting	Variable (well sorted near centre)	Poorly sorted	Variable	Variable	Well sorted
Skewness	Fine skewed/variable	Variable	Variable	Coarse skewed	Coarse skewed
Kurtosis	Very platykurtic in silty lake sediments	Variable	Variable	Leptokurtic	Mesokurtic or leptokurtic

2.1.2 Loss on ignition:

Sequential loss on ignition (LOI) was used to estimate proportions of water, organic content and carbonate content of sediment from the cores. These estimates provide useful information on sediment source, deposition rates and productivity within lakes. This is a widely used and useful physical proxy, while also being relatively simple (Heiri et al. 2001).

LOI at 550°C (LOI550) is used to estimate organic content within sediments. A proportion of organics to other material is produced. LOI550 can be used as an indication of biological productivity within lake systems through differing nutrient input regimes (i.e. a measure of autochthonous organics), or an indication of organic levels influenced from allochthonous

sources. Indeed, it has been demonstrated that organic material within lakes often has a catchment origin (Pace et al. 2004). When considering the ecosystem effects of organic input to a lake system, it should be considered that exogenous carbon (from allochthonous inputs) is difficult for organisms to assimilate, compared to endogenously produced carbon (Pace et al. 2004). Additionally, it must be considered that changing LOI550 may be due to an increase or decrease of mineral/carbonate material rather than organics, as LOI is presented as a percentage. Thus, LOI550 can be used as an indication of mineral flux, or biogenic mineral production in certain situations (Birks and Birks 2006).

Similarly, LOI at 950°C (LOI950) is used as an estimate of carbonate content within sediments. A proportion of carbonates can be used to determine the dominance of minerogenic input versus organic input and/or production. An increase in the proportion of carbonates may be indicative of minerogenic input into a system, abundance of carbonate organism remains (such as gastropods and bivalves), or may be a function of the production and input of other sediment components, such as organics (Heiri et al. 2001; Bengtsson and Enell 1986).

4.2 Sediment colour, components and texture methods

Analysis of sediment colour, components and texture has been carried out on the WA09, WA1 and Te Koru cores. The methods for these analyses are described below.

4.2.1 Sediment colour methods

Sediment colour was immediately determined upon opening the WA09 core, and determined later for the WA1 and Te Koru cores from bagged samples. Sediment colour was measured using a Munsell colour chart (Munsell 1912). Results of this analysis are displayed under ‘Core descriptions summary’, (*Figures 20, 21 & 22*, pp. 60-62)

4.2.2 Sediment components methods

Sediment samples were sieved (180 µm aperture) in order to determine the macrofossil components of samples from various depths. These components were allocated to a Troels-Smith category (Troels-Smith 1955) if appropriate, while components not summarised by

Troels-Smith classification, such as shelly material, were simply noted as such. Results of this analysis are displayed under 'Core descriptions summary', (*Figures 20, 21 & 22*, pp. 60-62. Sediment components are interpreted in the discussion chapter (Chapter 7).

4.2.3 Sediment texture methods

Particle size was measured using a 'Micromeritics® Saturn Digisizer 5200'. This machine can produce particle size data from relatively small samples. Sediment preparation for sizing of samples from the three cores is described below. These methods have been used by authors such as Parris et al. (2010) and Harvey (1996).

(1) 1 cm^3 sediment samples placed in appropriately labelled 10 ml centrifuged tubes.
(2) 10 ml of 27% hydrogen peroxide (H_2O_2) added to each tube and left in a fume cupboard overnight to digest organics.
(3) Tubes centrifuged and decanted to clean. 10 ml 32% HCl added to each tube and left overnight in a fume cupboard to digest carbonates.
(4) Tubes centrifuged and decanted 3 times to clean. Tubes filled with distilled water and three micropipette drops of sodium hexametaphosphate (Calgon) added to each to deflocculate samples.
(5) The sizer cannot measure particles larger than 1 mm (1000 µm) in diameter. Therefore, samples were passed through a 1 mm aperture sieve and rinsed into 10 ml centrifuge tubes with distilled water. Tubes topped up with distilled water.
(6) Samples run separately through the digisizer.

Geometric scales such as the Udden-Wentworth scale have been adopted by geologists, as linear scales are usually inappropriate given the large range of sediment sizes often observed in sediment studies (Royse 1970). Therefore, sediment size has been expressed as the exponent "Phi" (Φ), for ease of plotting and due to the exponent's popular use in literature (calculated by: $\Phi = -\log_2$ (diameter in mm)). However, Udden-Wentworth size classes and the Phi exponent have only been used for calculation of the basic statistics and for *Figures 20, 21 and 22*. Troels-Smith size classes have been used in the pollen and diatom diagrams in later chapters (Chapters 5 & 6) due to the compatibility of Troels-Smith categories with the graphical and statistical program 'Psimpoll'. See section 4.4.1 for background to the basic statistic calculated (median, sorting, skewness, kurtosis) and Appendix I p. 174, for the

equations used to calculate these statistics. Formulas for these statistics were obtained from Fernandes and Tett (2001), Harvey (1996), and Royse (1970).

The calculated parameters (median, sorting, skewness, kurtosis) can be used to produce binary plots. These are scatter plots of one statistic against another. These are compared with plots of sediment texture data taken from known deposition environments. Boundaries of particular depositional environments are displayed on many of these plots produced from known environments and then depositional environments of unknown data can be inferred from plots produced. Accordingly, sediment data from this study has been superimposed on axes with these predetermined boundaries in order to infer deposition environments within the three Waihora cores (*Figure 17, 18 and 19*). Binary plots were produced of median grain size versus sorting from the delineated environmental boundaries used in Thoms and Williams (2006). CM pattern plots were also produced for the three cores following Passega (1957). However, the sample size displayed on the CM plots was too small for any patterns to be determined. Indeed, Passega (1964) proposes that approximately 30 samples from all textures available are required to produce the patterns from known environments. Therefore, CM plots are not displayed.

4.3 Sediment texture results

This section summarises the results of sediment texture and their interpretation in the form of tables with WA09 results in *Table 5*, WA1 in *Table 6* and Te Koru in *Table 7*. Here sediment statistics have been used to determine texture categories for each sample (see Appendix 1, p. 175 for the determination of texture categories based on sediment statistics). Texture categories of these samples have been used to infer depositional environment conditions (see *Tables 5, 6 & 7*), based on the interpretation rationale presented in section 4.1, pp. 48-50. Sediment texture analysis suggests that there has been little change in the depositional environment over the period represented by the WA09, WA1 and Te Koru cores. Although, there is a zone of sediment at the bottom of the WA09 core with texture parameters characteristic of a fluvial or beach influenced depositional environment (*Table 5*). Additionally, zones of sediment through the WA09 and WA1 cores indicate periods of higher energy influence on the lake basin (*Tables 5 & 6*). Binary plots are also displayed, which summarising the depositional environment, inferred from median grain size and sorting parameters (*Figures 17, 18, 19*). Further sediment texture data can be viewed in Appendix I.

4.3.1 Sediment texture tables

Table 5: WA09 core: Summary of sediment texture parameters and depositional environments inferred from these parameters.

Sample depth (cm)	Troells-Smith size class summary	Φ_{50} Udden-Wentworth grade	Sorting	Skewness	Kurtosis	Depositional environment inferred from sediment texture
0 to 1	Ag 4	Fine silt	Very poorly sorted	Fine skewed	Very platykurtic	LAKE / LAGOON
10 to 11	Ag 4	Medium silt	Poorly sorted	Fine skewed	Very platykurtic	
20 to 21	Ag 4	Fine silt	Poorly sorted	Fine skewed	Very platykurtic	
30 to 31	Ag 4	Medium silt	Poorly sorted	Symmetrical	Very platykurtic	
40 to 41	Ag 4	Medium silt	Poorly sorted	Fine skewed	Very platykurtic	
50 to 51	Ag 2, Ga 2	Medium silt	Very poorly sorted	Coarse skewed	Very platykurtic	LAKE / LAGOON WITH SOME FLUVIAL OR BEACH INFLUENCE
60 to 61	Ag 4	Medium silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	LAKE / LAGOON
70 to 71	Ag 4	Medium silt	Poorly sorted	Fine skewed	Very platykurtic	
80 to 81	Ag 4	Medium silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
90 to 91	Ag 2, Ga 2	Medium silt	Very poorly sorted	Fine skewed	Very platykurtic	LAKE / LAGOON. SOME COARSER SEDIMENT INDICATING HIGHER ENERGY IFLUENCE
100 to 101	Ag 2, Ga 2	Medium silt	Very poorly sorted	Fine skewed	Very platykurtic	
110 to 111	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	LAKE / LAGOON
120 to 121	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
130 to 131	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
140 to 141	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
150 to 151	Ag 4	Fine silt	Very poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
160 to 161	Ag 4	Fine silt	Very poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
170 to 171	Ga 4	Fine sand	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	LAKE / LAGOON SEDIMENTS WITH FLUVIAL / BEACH INFLUENCE. INCREASED FLUVIAL / BEACH INFLUENCE AT 180 AND 190 CM
180 to 181	Ga 4	Very fine sand	Poorly sorted	Coarse skewed	Very platykurtic	
190 to 191	Ag 1, Ga 3	Fine sand	Well sorted	Symmetrical	Very platykurtic	
200 to 201	Ga 4	Fine sand	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
210 to 211	Ag 2, Ga 2	Coarse silt	Very poorly sorted	Strongly skewed towards fine particles	Very platykurtic	LAKE / LAGOON. SOME COARSER SEDIMENT INDICATING HIGHER ENERGY IFLUENCE

Table 6: WA1 core: Summary of sediment texture parameters and depositional environments inferred from these parameters.

Sample depth (cm)	Troells-Smith size class summary	Φ_{50} Udden-Wentworth grade	Sorting	Skewness	Kurtosis	Depositional environment inferred from sediment texture
0 to 1	Ag 4	Medium silt	Poorly sorted	Fine skewed	Very platykurtic	LAKE / LAGOON
4 to 5	Ag 3, Ga 1	Medium silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
9 to 10	Ag 3, Ga 1	Medium silt	Poorly sorted	Coarse skewed	Very platykurtic	LAKE / LAGOON. PERHAPS SOME HIGHER ENERGY INPUT
14 to 15	Ag 3, Ga 1	Medium silt	Very poorly sorted	Strongly skewed towards coarse particles	Very platykurtic	
19 to 20	Ag 3, Ga 1	Medium silt	Very poorly sorted	Strongly skewed towards coarse particles	Very platykurtic	
24 to 25	Ag 4	Fine silt	Poorly sorted	Symmetrical	Very platykurtic	LAKE / LAGOON
29 to 30	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	
34 to 35	Ag 4	Fine silt	Very poorly sorted	Symmetrical	Very platykurtic	
39 to 40	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Very platykurtic	

Table 7: Te Koru core: Summary of sediment texture parameters and depositional environments inferred from these parameters.

Sample depth (cm)	Troells-Smith size class summary	Φ_{50} Udden-Wentworth grade	Sorting	Skewness	Kurtosis	Depositional environment inferred from sediment texture
0 to 1	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Platykurtic	LAKE / LAGOON
6 to 7	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Mesokurtic	
12 to 13	Ag 4	Fine silt	Poorly sorted	Strongly skewed towards fine particles	Mesokurtic	
18 to 19	Ag 4	Fine silt	Poorly sorted	Symmetrical	Very platykurtic	
24 to 25	Ag 4	Fine silt	Poorly sorted	Fine skewed	Very platykurtic	
30 to 31	Ag 4	Fine silt	Poorly sorted	Fine skewed	Very platykurtic	
36 to 37	Ag 4	Fine silt	Poorly sorted	Fine skewed	Very platykurtic	
42 to 43	Ag 4	Fine silt	Poorly sorted	Coarse skewed	Very platykurtic	

4.3.2 Binary plots

Samples from the top of the WA09 core down to 170 cm are likely to have been deposited in a quiet water environment. From 170 cm to 200 cm the relationship between median grain size and sorting seems to indicate that these samples were deposited with the influence of a higher energy environmental influence, perhaps river or wave influenced deposition. The bottom sample at 210 cm core depth displays median grain size and sorting parameter values that seem to indicate a quiet water depositional environment (*Figure 17*).

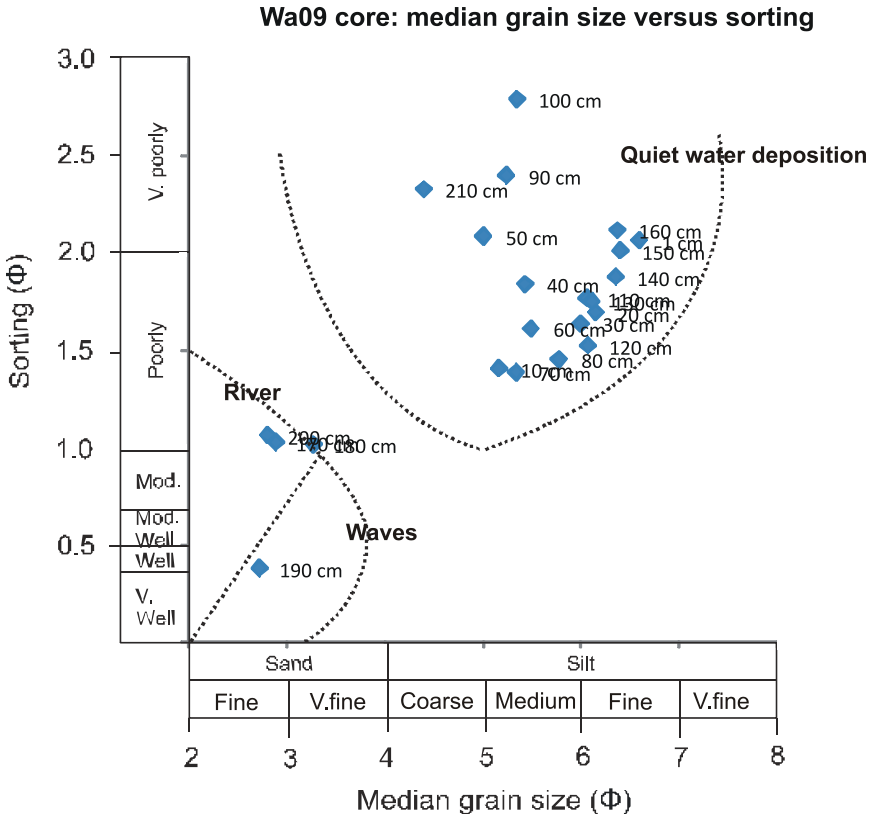

Figure 17: WA09 core: Median grain size versus sorting, with boundaries used by Thoms and Williams (2006).

Samples from both the WA1 and Te Koru cores are all likely to have been produced in a quiet water environment such as a lake or lagoon (*Figure 18* & *19*). Some samples fall outside the quiet water boundary on these plots. However, these samples occur outside the finer side of the boundary, indicating they were probably produced in quite water environments.

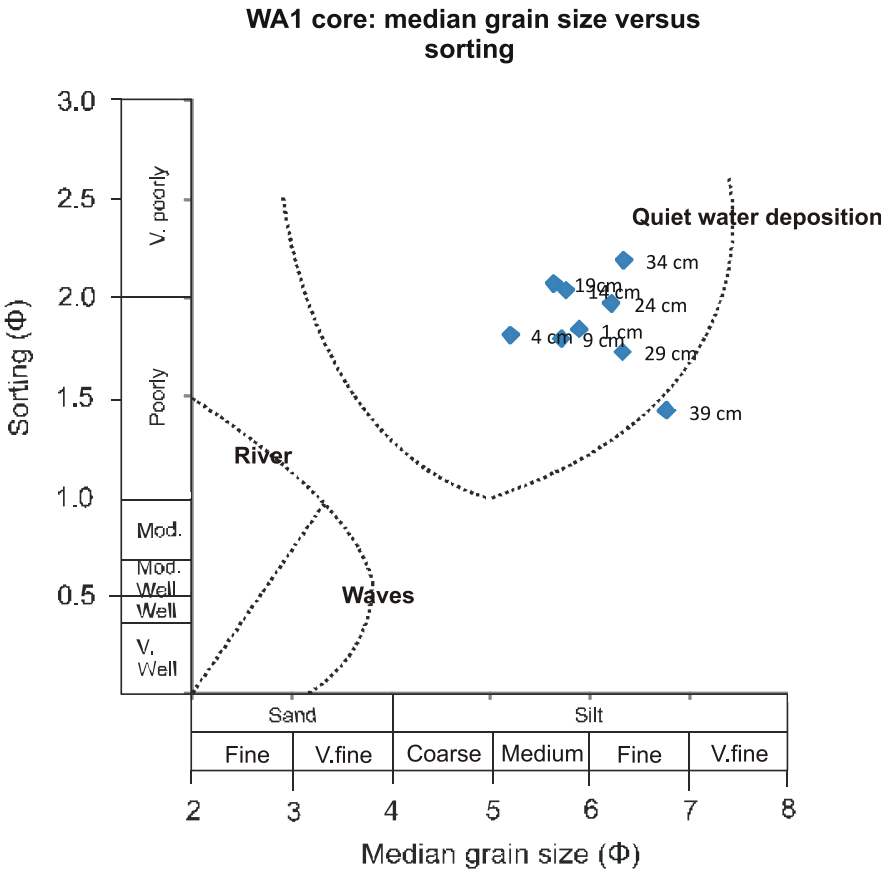

Figure 18: WA1 core: Median grain size versus sorting, with boundaries used by Thoms and Williams (2006).

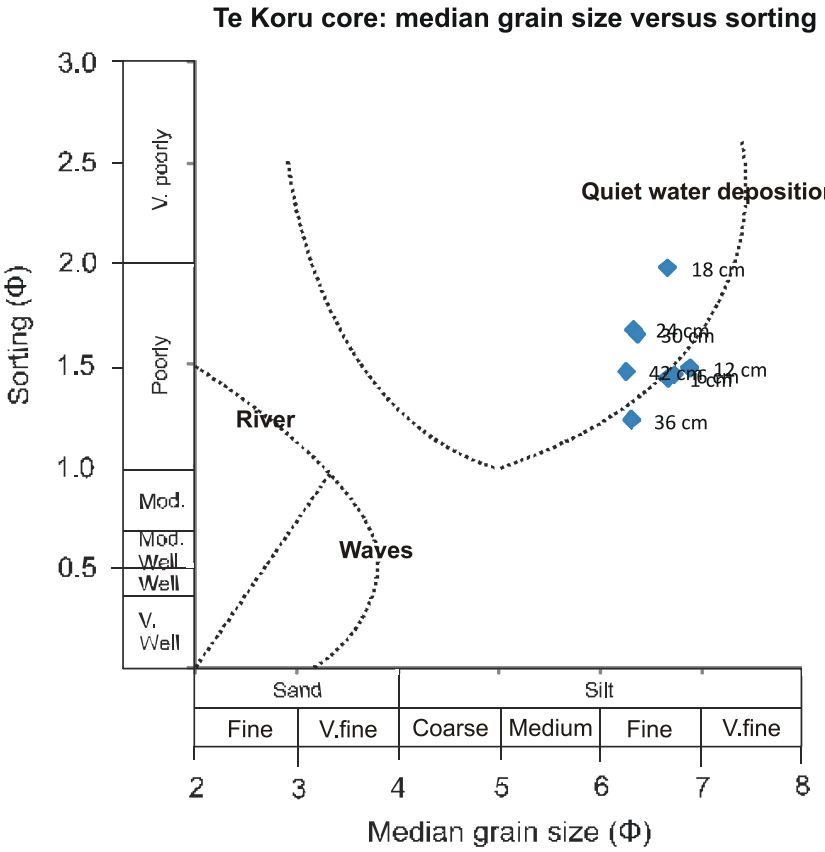

Figure 19: Te Koru core: Median grain size versus sorting, with boundaries used by Thoms and Williams (2006).

4.4 Loss on ignition methods

Methods described below are based on work by Heiri et al. (2001) and Bengtsson and Enell (1986). LOI was carried out on the WA09, WA1 and Te Koru cores.

(1) Ceramic crucibles cleaned, and dried in a drying oven overnight at 80°C.
(2) Crucibles cooled to room temperature and weighed on digital scales.
(3) Around 2g of wet sediment added to each crucible and weighed to obtain a crucible plus wet sediment weight value.
(4) Crucibles and wet sediment placed in a drying oven overnight at 80°C.
(5) Crucibles removed and cooled to room temperature, then weighed in order to produce water content and dry weight values (DW80).
(6) Furnace heated to 550°C and crucibles containing dry sediment placed within furnace, using appropriate safety equipment (gloves and tongs).
(7) Crucibles removed from furnace after 4 hours, as recommended by Heiri et al. (2001), cooled to room temperature and weighed to obtain an LOI550 value (DW550).

LOI550 is calculated from the values above using the formula:
LOI550 = ((DW80–DW550)/DW80)*100

The percentage weight loss calculated from this formula is a representation of the percentage of organic carbon within the sediment samples.

(8) Furnace heated to 950°C and crucibles and sediment placed within furnace. In this step carbonate is evolved to carbon dioxide (Heiri et al. 2001).
(9) Crucibles removed after 2 hours as recommended by Heiri et al. (2001), cooled to room temperature and weighed to obtain an LOI950 value (DW950). Weight loss is multiplied by 1.36 to estimate carbonate in the sample, due to the difference in molecular weight of CO_2 versus CO_3.

LOI950 is calculated from the values above using the following formula:
LOI950 = ((DW550–DW950)/DW80)*100

(10) Diagrams of LOI550 and LOI950 produced for the three cores (*Figures 20, 21, 22*).

4.5 Loss on ignition results

Summary diagrams of core description results have been created for each core, including sediment colour, components, texture and LOI (section 4.6). These diagrams display LOI results and have been referred to in the description of LOI results below.

4.5.1 WA09 core LOI

LOI550 appear to be relatively stable below 40 cm depth but appears to increase above 40 cm depth (*Figure 20*). According to Meyers and Teranes (2001), it is common for LOI550 to increase as sediment size decreases. Indeed, regression analysis revealed a significant effect of median particle size on LOI550 ($F = 0.028$) ($\alpha = 0.05$). Therefore, although there appears to be an increase in LOI550 above 40 cm depth, this may be partly a function of particle size.

LOI950 appears variable throughout the core. However, fluctuations only occur over a small scale, between 0 and 1.054% (*Figure 20*). There is no significant effect of median particle size on LOI950. There appears to be a significant inverse relationship between LOI950 and LOI550 ($F = 0.016$). However, examination of a scatter-plot revealed one data point that had a disproportionate influence on the data. Removal of this data point (0-1 cm depth) revealed no evident relationship through the rest of the core. This suggests that, neither particle size nor varying organic components have an effect on LOI950, and the small fluctuations observed may be minute random variation, or small changes in depositional environment.

4.5.2 WA1 core LOI

LOI550 in this core appears to indicate a homogenous depositional environment. However, there is some variation in LOI950 (*Figure 21*), which appears not to be affected by either particle size ($F = 0.643$), or LOI550 ($F = 0.545$) ($\alpha = 0.05$). Examination of core material revealed large concentrations of gastropod remains (*Potamopyrgus antipodarum*), particularly around 19-20 cm depth. It is likely that these calcareous remains cause this spike at 19-20 cm and less visible fragments occur between 9 and 30 cm depth (*Figure 21*).

4.5.3 Te Koru core LOI

LOI550 and LOI950 in the Te Koru core indicate a homogenous depositional environment in this core. No significant variation in these parameters with depth is observed (*Figure 22*).

4.6 Core description summary diagrams

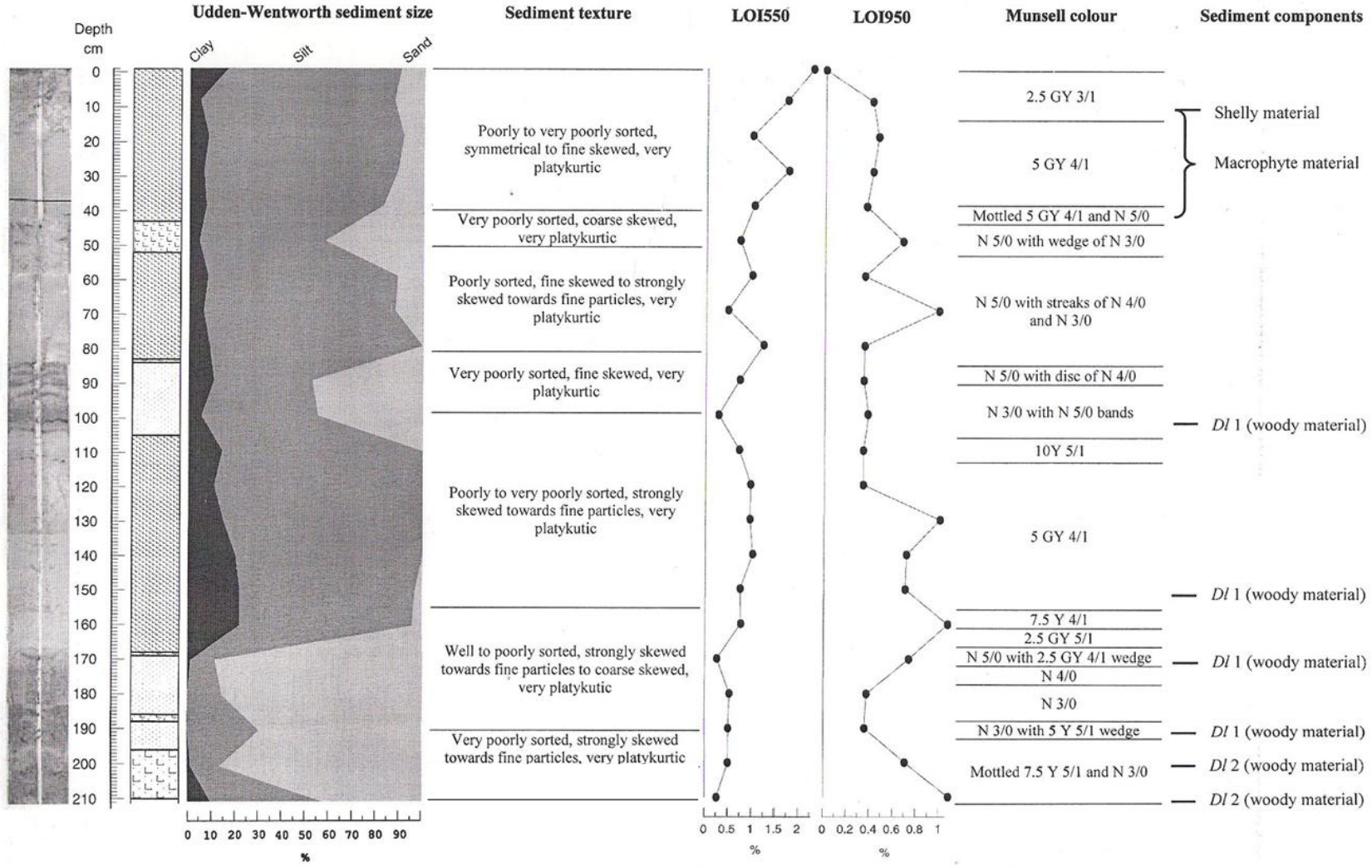

Figure 20: WA09 core sediment description summary.

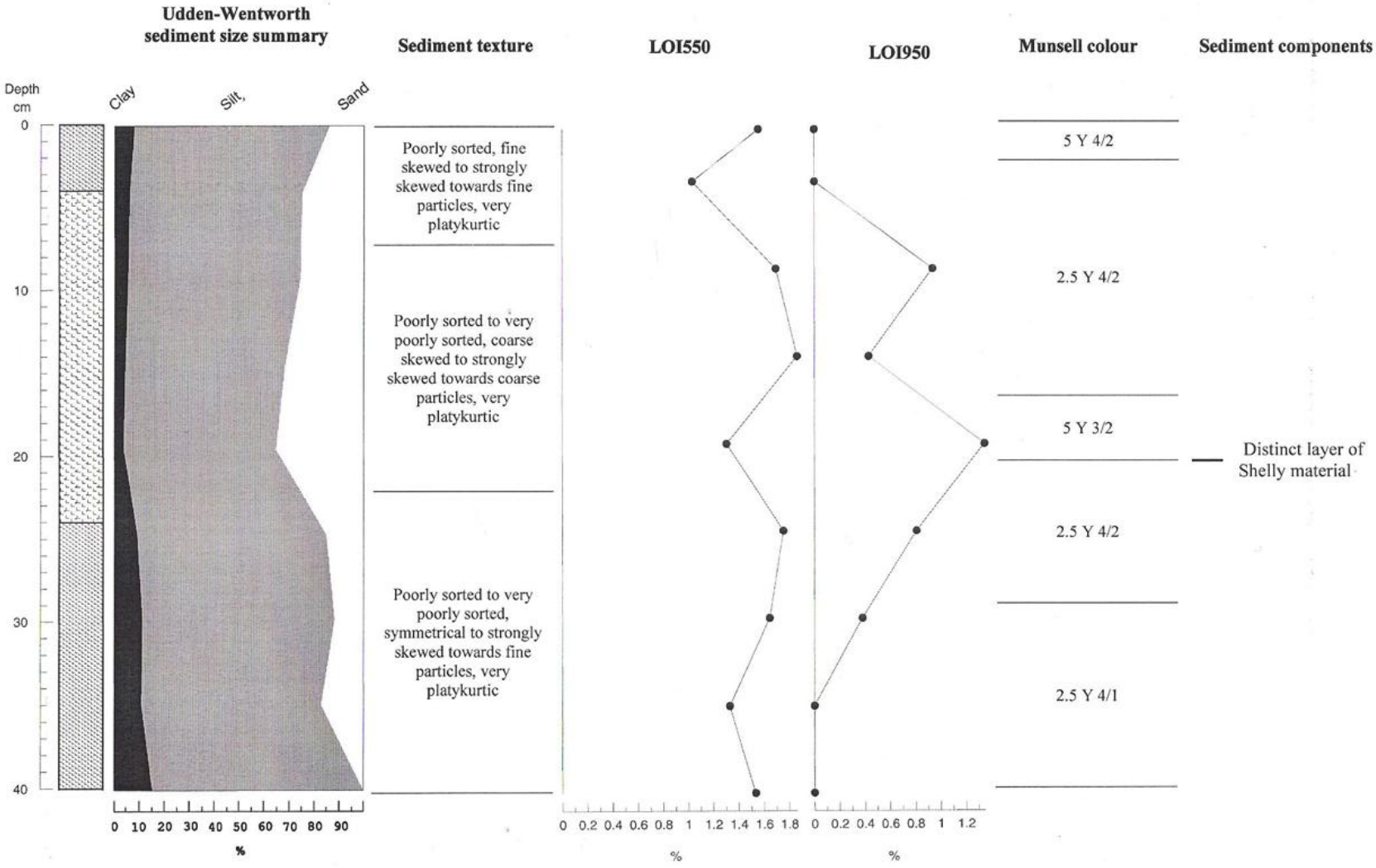

Figure 21: WA1 core sediment description summary.

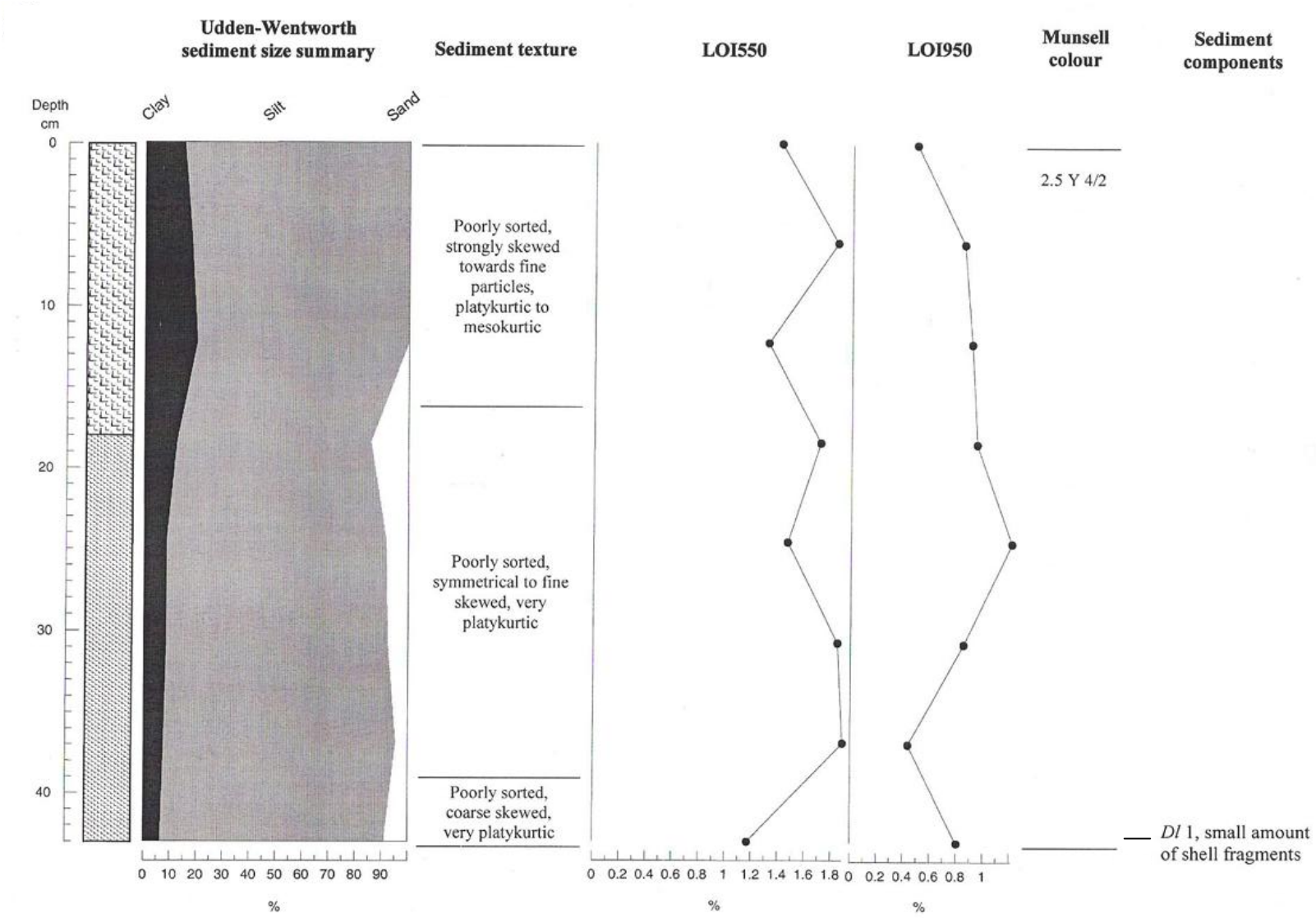

Figure 22: Te Koru core sediment description summary.

Chapter 5 Palynology

5.1 Introduction to palynology

Palynology includes the examination of angiosperm and gymnosperm pollen, spores of cryptograms (ferns and fern allies), as well as additional material that is isolated during pollen laboratory preparation. Non-pollen materials are referred to as non-pollen palynomorphs (NPP's) and include cryptogram spores, algae remains, cyanobacteria remains, fungal remains and macroinvertebrate remains. What follows is a description of the theory behind palynology and some background to the interpretation of NPP material.

Terrestrial plants (true plants) and cryptograms (lower plants) produce pollen and spores respectively, that are extremely resistant to chemical alteration and biological and chemical degradation. These pollen grains and spores are readily transported by wind, water and animals. They are commonly observed microfossils when examining lake sediments and peat bog material and give an indication of the plant taxa present at the time the pollen was produced. Thus, pollen grains and spores are a good proxy for vegetation changes through time (Moore et al. 1991).

Pollen grains are produced by seed plants including both angiosperms and gymnosperms, while spores are produced by cryptograms including pteridophytes and bryophytes. These grains represent the sexual stage in terrestrial plant life cycles and contain gametophytes involved in fertilization and the production of a new generation of sporophytes (Gray 1965; Moore et al. 1991). In some cryptograms, both males and females originate from morphologically identical spores. These plants are called homosporous and the spores they produce are called 'isospores'. In more advanced cryptograms, the female spore is larger than the males spore. The male spores are referred to as 'microspores', and the female spores, 'megaspores'. In true plants, the megaspore remains within the parent plant to form a seed and are fertilized (pollinated) by a microspore referred to as a pollen grain (Muir & Sarjeant 1977).

The resistant wall of both spores and pollen grains is referred to as the exine. It is this exine that remains after the rest of the spore/grain naturally decays. The exine is composed of a material known as sporopollenin (C90 H140 O18) (Muir & Sarjeant 1977). It is this resistant

material that is examined by the researcher. Identification of the parent plant can be made due to the retainment of a taxon specific exine structure, including grain/spore shape, symmetry, number/structure of colpi, number/structure of pores and surface texture (Muir & Sarjeant 1977) (*Figure 23*).

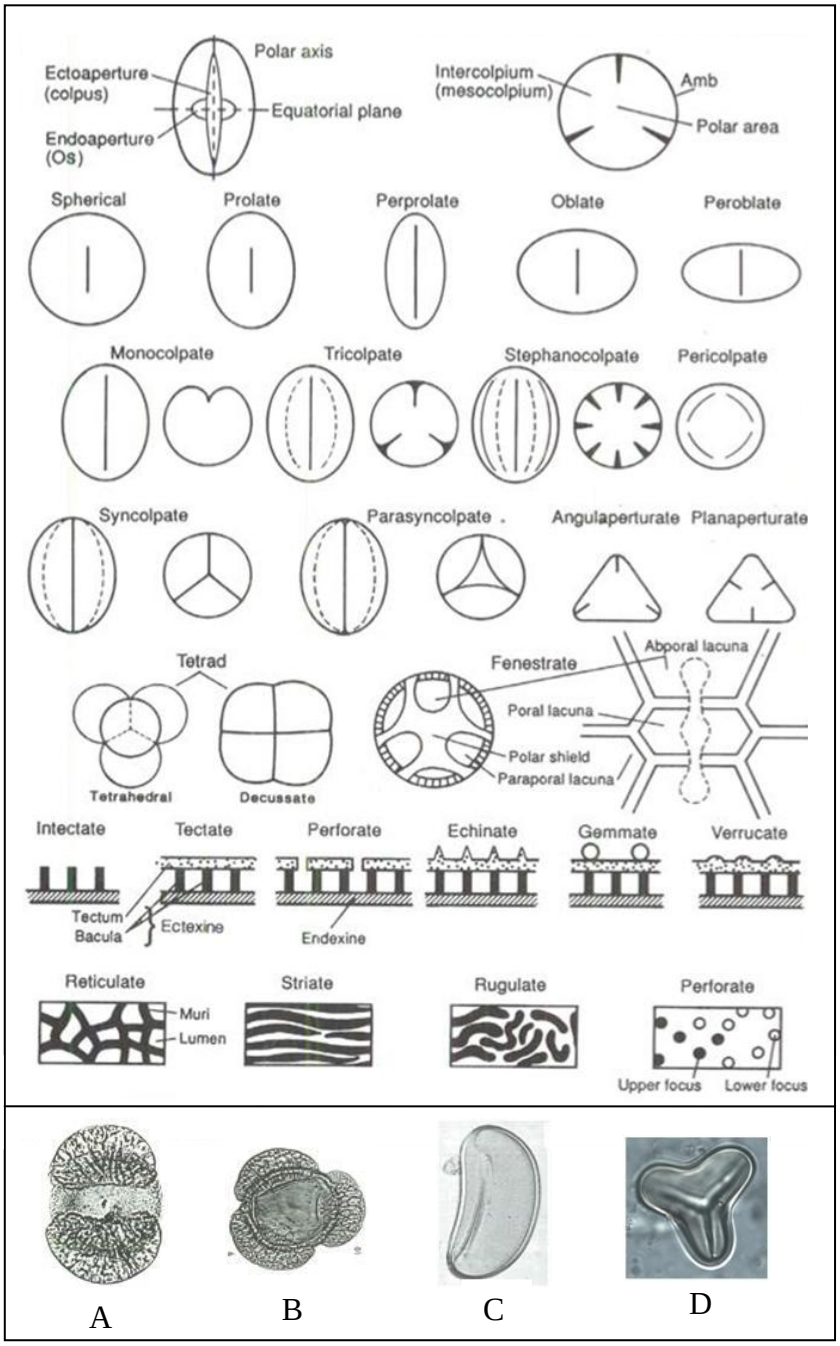

Figure 23: Illustrations of exine structures used in pollen and spore identification. Photomicrographs show (A) Podocarp pollen grain with two sacci, (B) Podocarp pollen grain with three sacci, (C) monolete fern spore, and (D) trilete fern spore. Images above sourced from Moar (1993 p. 179), images A, B below sourced from Cranwell (1953 p. 86), C sourced from Large & Braggins (1991) and D obtained during this thesis.

These pollen grains and spores are transported into lake systems such as Waihora through short distance transport from local vegetation (such as riparian vegetation) and from greater distances through wind transport, fluvial transport, erosion and animal transport, or a combination of these. Grains/spores transported following erosive processes may have already spent time preserved in sediment prior to being deposited into the lake. Grains/spores of plants that produce wind dispersed pollen and those of plants that are prolific pollen producers may be over represented (Moore et al. 1991). Also, grains/spores at a particular core depth may not be of the same age, due to the reworking and deposition of fossil grains/spores (Thorburn 1974). *Figure 24* displays these possible sources of pollen in a lake environment, which are considered when interpreting pollen diagrams.

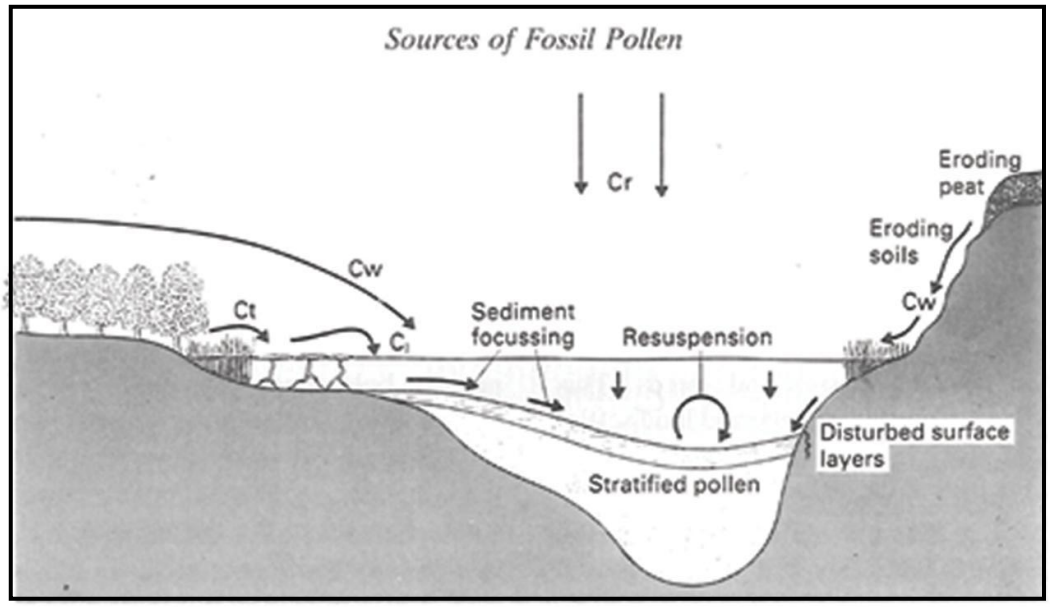

Figure 24: The sources of pollen in a lake and its behaviour within the lake. Cw = secondary sources, Cl = local sources, Cr = rain component, Ct = trunk space component, Cw = secondary component. From Moore et al. (1991, p.19).

5.1.1 Historical catchment vegetation:

Pollen/spore records obtained during this study are interpreted in relation to known changes in vegetation through the period examined. Known vegetation changes through time have been determined through coring studies similar to this one as well as the examination of historical records post human settlement. Relating pollen/spore composition changes in this study to known changes though time enables the allocation of tentative dates through the cores.

Before human settlement (~700 B.P according to McGlone and Wilmshurst (1999)), vegetation in the Waihora catchment consisted of beech trees (*Nothofagus spp.*), mountain toatoa (*Phyllocladus alpinus*), totara (*Podocarpus totara*) and matai (*Prumnopitys taxifolia*) in the mountains and foothills, kahikitea (*Dacrycarpus dacrydioides*) forest in lowland wet areas, scrub species in the stony areas, and tussock communities (comprised of *Poa* and *Festuca*) on the flood plains (Petrie 1963; Woodward and Shulmeister 2005).

Pre-human vegetation on Banks Peninsula consisted primarily of podocarp-broadleaf forest. Vegetation at lower altitudes was dominated by podocarps such as kahikitea, lowland totara and matai above a broadleaf canopy. Vegetation at higher altitudes was dominated by thin barked totara (*Podocarpus hallii*). Stands of beech forest existed, particularly on the south-west of the peninsula, although this forest type was restricted in distribution (Petrie 1963; Woodward and Shulmeister 2005).

Human occupation in New Zealand is a relatively recent occurrence. Palynology has provided a tool for determining the timing of Polynesian arrival in New Zealand. Prior to the arrival of people in New Zealand it is believed that burning events were uncommon, although fires induced by volcanism and lightning did occur occasionally (Ogden et al. 1998). McGlone and Wilmshurst (1999) provide evidence that extensive human induced burning events dramatically reduced the cover of native forest. Mäori used fire as a tool for hunting moa and land clearance to aid travel and encourage the growth of the edible bracken, *Pteridium esculentum*. Radiocarbon dates of material within sediment at times of pollen or charcoal inferred burning events gives an indication of the timing of human arrival at around 700 B.P. However, evidence such as radiocarbon dates of bone gelatine from Pacific rats (*Rattus exulans*) suggests an arrival date as early as 2000 years B.P. (Ogden et al. 1998). This debate continues, but regardless of the actual time of Polynesian arrival in New Zealand, the signal of burning events often occurs around 750-550 calendar years B.P. according to radiocarbon dates (McGlone and Wilmshurst 1999). Therefore, these signals within cores can be used as indications of sediment deposition time.

Pollen records also provide evidence of vegetation changes post human arrival. Land clearance by fire led to the increased dominance of early successional taxa that rapidly colonise disturbed areas. These taxa include manuka (*Leptospermum scoparium*), bracken (*Pteridium esculentum*) and *Coriaria spp*. and are used as indicators of disturbance in New

Zealand pollen records (McGlone and Wilmshurst 1999; Ogden et al. 1998). An increase in pollen grains of these species may indicate a disturbance event such as a fire. However, an increase in these relative to pollen inferred podocarp abundance and charcoal particle counts can give a more comprehensive picture.

Changes in vegetation following the colonisation of the Canterbury region by Europeans are well documented. Banks Peninsula was covered in podocarp-broadleaf forest. After 1860, large tracts of this land were cleared for timber and converted to pastoral farming (Bank Peninsula Landscape Study 2007; Petrie 1963; Woodward and Shulmeister 2005) (*Figure 3*). Forest clearance such as this is likely to be represented in the pollen record in nearby lake sediments. Indeed, Woodward and Shulmeister (2005) noted a decline in grains of large canopy trees in their Wairewa – Lake Forsyth core study, associated with Banks Peninsula deforestation.

Pinus radiata was first introduced to New Zealand in the late 1850s. Planting remained small scale until the 1920s and 1930s, when a boom in planting of this species occurred (Berg 2009). This species is a prolific pollen producer and comprises a large proportion of modern pollen fallout. The occurrence of *Pinus* in pollen records is consequently an indicator of European settlement. However, time lags between; (1) settlement and plantation and (2) between plantation and representation in a pollen record, must be taken into account.

5.1.2 Non-Pollen Palynomorphs

The value of non-pollen material in palynology is becoming increasingly recognised. Palynomorphs other than pollen grains and pteridophyte spores, such as animal remains, algae remains, dinoflagellate remains, fungal elements and macroinvertebrate remains can provide information relevant to solving paleoecological problems (Boyd and Hall 1998). These are resistant to pollen extraction procedures and are isolated and mounted during pollen preparations. Therefore, no additional preparation is necessary (see pollen analysis methods section 5.2, pp. 70-73 and Appendix II, pp. 184-185 for details on laboratory treatments). Background material on the commonly observed non-pollen palynomorphs is displayed below.

Pediastrum:

These coccal green algae belong to the family Hydrodictyaceae. Taxa are identified by the shape of the radially symmetrical coenobia (the arrangement of cells common within taxa), the shape of individual cells and the texture of individual cells. These taxon specific characteristics enable relatively easy identification of many taxa within the genus. Work by Jankovská and Komárek (2000) is particularly useful in the identification of taxa within this genus. Further research into ecological preferences/tolerances of particular *Pediastrum* species is required in order to fully utilize this genus in paleoecological research (Jankovská and Komárek 2000). However, as a genus *Pediastrum* is an indicator of freshwater input (Limaye et al. 2007; Medeanic 2006), freshwater, eutrophic conditions (Medeanic 2006) and occurs in lakes and slow moving rivers (Bertini 2006; Rull et al. 2008).

Algal zygospores:

The zygospores belong to taxa within the family Zygnemataceae. Genera within this family include *Mougeotia*, *Zygnema*, *Spirogyra*, *Debarya* and others. It is recognised that identification of these remains should be carried out with caution, as zygospore remains can closely resemble other resistant material such as certain fungal spores and pteridophyte spores. However, algal zygospores can identified as separate to spores of pteridophytes and fungi due to the large size of the algal zygospores compared to monolete and fungal spores and also due to shape and texture patterns of algae zygospores, as displayed in Van Geel (2001) and Medaenic (2006). According to Jarzsen (1978, p. 24) the occurrence of zygospores of Zygnemataceae are indicative of "…oxygen-rich, stagnant, shallow fresh water which must have been fairly warm in order to allow for zygospore formation". Thus, these remains are likely an indication of shallow, freshwater of high productivity.

Cyanobacteria:

Cyanobacteria (formally known as Blue-green Algae) remains are commonly observed on slides prepared for pollen analysis. These organisms are photosynthesising bacteria (prokaryotes) which produce resistant heterocysts, akinetes and sheaths that are readily preserved in the sediment. Cyanobacteria form colonies that grow various substrates such as plants, soil, stones or sometimes occur in the plankton (Batten and Van Geel 1985).

Gloeotrichia (genus) remains have been shown to increase in lake sediments following lake eutrophication. They have also been demonstrated to be an early coloniser in waters low in nitrogen, due to their nitrogen fixation ability (Van Geel et al. 1994; Batten and Van Geel 1985). Most are freshwater species; although Batten and Van Geel (1985) note that the sheaths of rivulariaceans may perform a protective function for taxa that are subjected to tidal inundation.

Fungal spores:

Literature such as Prager et al. (2006), Limaye et al. (2007) and Van Geel (2001) is useful in identifying fungal remains. However, these references describe remains from Europe only and any attempts at reconstruction using high taxonomic resolution data based on this literature would yield dubious results. This is due to the high level of endemism in NZ fungi, meaning that remains of fungi from a New Zealand setting may appear similar to specimens in overseas references, but may belong to a separate species with different environmental preferences. In addition, many of the fungal taxa in New Zealand remain un-described (Buchanan and May 2003). Further research on New Zealand fungal spore identification and development of datasets of fungal environmental preferences is needed in order to utilize fungal remains as a paleo-environmental indicator in New Zealand.

Chironomid mouthparts:

Chironomidae (insects with aquatic larval stages) head capsules display taxon specific characteristics and taxa display distinct environmental preferences/tolerances. These insects occupy a large range of habitats, including a range of temperature, oxygen, salinity, current velocity, pH, depth and productivity gradients (Armitage et al. 1995). Thus, they are often targeted in paleolimnological studies (e.g. Woodward and Shulmeister 2005). *Chironomus zelandicus* is dominant in an adjacent lake when brackish conditions occur (Woodward and Shulmeister 2005). Therefore, mouthparts of this taxon are likely to be common within sediment from Waihora.

5.2 Palynology methods:

Pollen analysis was carried out on three cores; WA09, WA2 and Te Koru. 1 cm^3 of sediment was removed from sample intervals displayed in *Table 2*, p. 40. Care was taken to ensure that no contamination of samples and between samples occurred. This was done by flaming the spatula used in removal and conducting all treatment in a clean, ventilated palynology laboratory. Treatment of sediment for pollen analysis is described below.

5.2.1 Pollen extraction and mounting

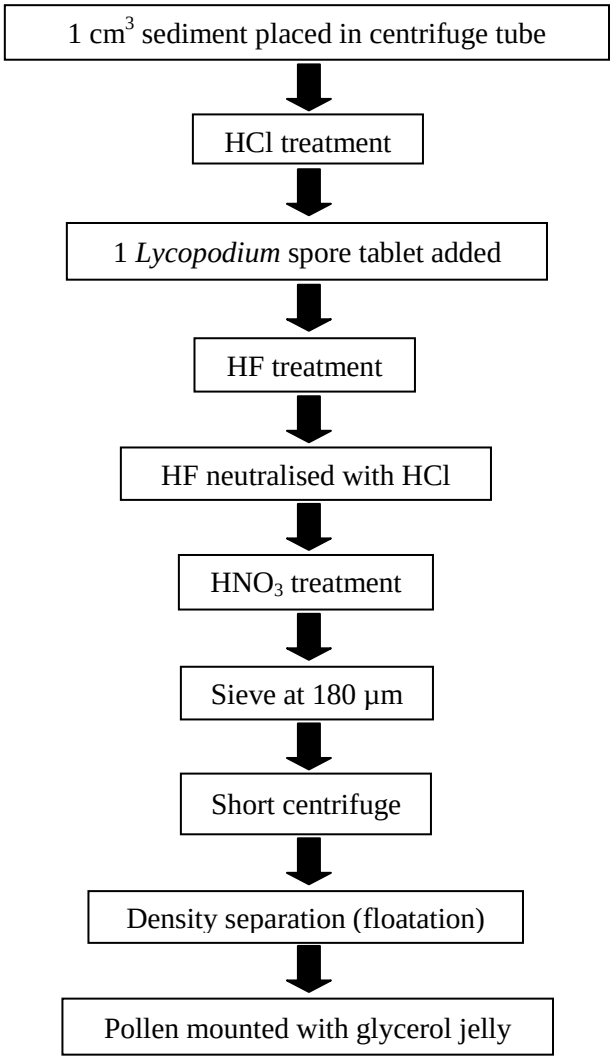

Figure 25: Flow chart of methods used in pollen preparation for microscopy.

A summary of methods used in pollen extraction for this study is displayed in *Figure 25*, while a full description of the methods used is outlined in Appendix II. The pollen extraction and mounting methods used are those outlined by Moore et al. (1991), with the following modifications:

- Acetolysis in order to remove cellulose was not conducted. This step is primarily used in the treatment of peat samples, while Waihora samples contained little of this cellulose material.
- An additional step involving oxidation using nitric acid was conducted. This step was used to remove lignin material observed on a trial mount.
- A density separation step was conducted in order to remove residual siliceous material.

5.2.2 Pollen microscopy

Pollen grains and spores were identified to the lowest possible taxonomic grouping. Moar (1993) was used to identify pollen grains of Dicotyledons, Cranwell (1953) was used to identify pollen grains of Monocotyledons and Large and Braggins (1991) was used to identify spores of ferns and fern allies. Grains/spores were also identified with the assistance of Professor James Shulmeister, currently University of Queensland, Australia. Pollen grains were examined using a Zeiss binocular light microscope under 400x magnification (10x ocular lens, 40x objective lens). Photomicrographs of pollen grains were taken using a Differential Interference Contrast (DIC) microscope, at 1000x magnification (Appendix VII, 224-231). A count of 250-300 grains per slide was targeted. However, in some instances pollen concentration was too low to achieve this.

5.2.3 Pollen diagrams

Pollen diagrams were produced using ‘Psimpoll version 4.27’ (Bennett 2009). These diagrams are used to illustrate the changes in local and catchment vegetation over time. This study is concerned with changes in all types of vegetation. Therefore, all pollen/spore types (e.g. trees, shrubs, herbs, ferns, aquatic plants) are included in the pollen sum, as they are each important to interpretation in this study.

5.2.3.1 Format of pollen diagrams

Pollen values are expressed as percentages in diagrams produced. For each the WA09 and WA2 cores, two pollen diagrams were produced. One displays only pollen/spore types that were represented in ≥ 2% of the pollen/spore assemblage in any one or more samples. The other displays taxa that show significant changes in abundance and/or taxa of particular indicative importance, as well as a summary plot of plant groups. For the Te Koru core, only a diagram of pollen/spore types that were represented in ≥ 2% of the pollen/spore assemblage was produced due to the lack of change in pollen/spore abundance throughout this core.

The sequence of pollen types in the '≥ 2%' diagrams is in the order; introduced species, trees, shrubs, herbs, and finally, ferns. Whereas, the summary diagrams are in an order perceived to best display the information intended to be expressed. Namely in the order; introduced taxa and grasses, Chenopodiaceae, ferns, and finally, Podocarpaceae. Summary diagrams include changes in pollen concentration in samples taken throughout the core. This gives an indication of (1) pollen flux and/or (2) sediment deposition rate. This was calculated using the following equations:

Total pollen grains per sample

$$= \frac{Lycopodium \text{ introduced x pollen grains counted}}{Lycopodium \text{ counted}}$$

Total pollen grains per gram sediment dry weight

$$= \frac{\text{Total pollen grains per sample}}{\text{Dry weight of sample}}$$

A plot is included in each summary diagram displaying the sums of pollen groups. Pollen/spores are grouped into sums of introduced plants and grass, trees, ferns, shrubs, sedges/rushes/flax, herbs and saltmarsh plants (Chenopodiaceae). All pollen/spore types counted are included in the percentage calculations of these summary diagrams. These summary plots are displayed on the right hand side of summary diagrams produced for the WA09 and WA2 cores.

Why the sum groups were chosen for the summary diagram:

- Introduced plants and grass: These were grouped due to their perceived properties as an indicator of European habitation and environmental change.
- Trees: This group does not include introduced taxa, therefore, is a good indicator of the extent of forest cover and land clearance.
- Ferns: Ferns were summed in this study, as an increase in these is perceived to be indicative of increased slope instability, increased fluvial input and increased sedimentation. Tree ferns such as *Cyathea spp.* and *Dicksonia spp.* are included in the fern sum rather that the native tree sum, as their distribution mechanisms are similar to that of other pteridophytes, rather than many angiosperms and gymnosperms.
- Shrubs: An indicator of the extent of the extent of forest cover and land clearance.
- Sedges / rushes / flax: Grouped as they give an indication of local vegetative changes
- Chenopodiaceae: These give an indication of local vegetative changes, specifically changes in saltmarsh flora.

Zonation of diagrams:

Zones displayed in the pollen diagrams have not been produced by statistical means. The zones are primarily determined by the ecological interpretation perceived within the diagrams. Although these zones may separate areas of considerable change in pollen assemblage, not all pollen types are given equal weight. Therefore, a statistically derived zonation would produce slightly different boundaries but not improve interpretation. The zones identified may not be of any significant stratigraphic use outside this study area.

5.3 Palynology results

What follows is a description of the cores analysed, separated into zones. The primary components of the zone are given, followed by a summary of the contribution of the primary pollen/spore component to the pollen sum. Finally, an interpretation of the pollen/spore counts within each zone is presented. Further interpretation of the patterns observed over all three cores is given in the discussion chapter (Chapter 7). Counts of all pollen types from the three cores can be viewed in Appendix IV, *Tables 21, 22* & *23*.

WA09 core pollen/spore taxa with ≥ 2% representation

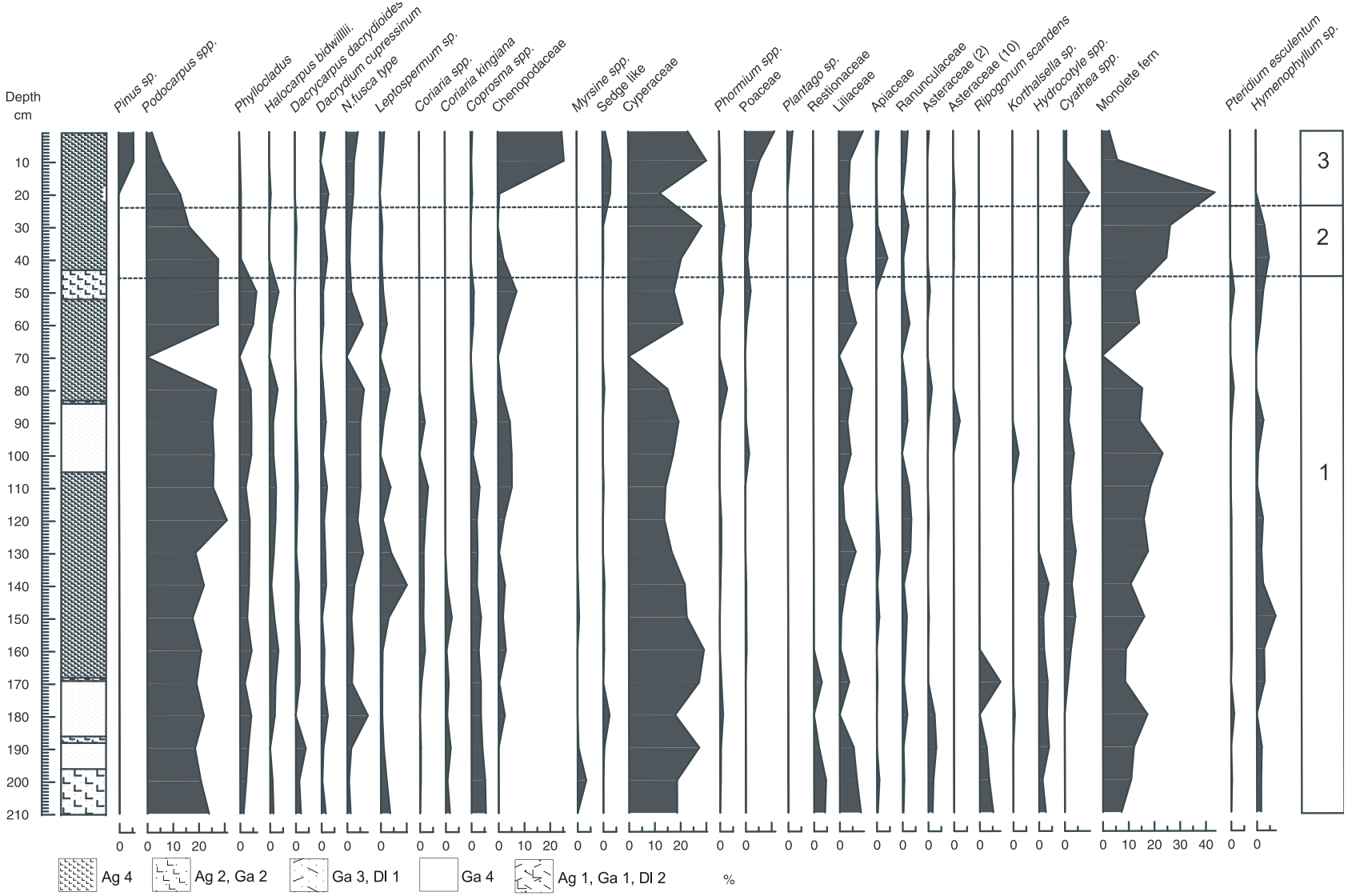

Figure 26: WA09 core pollen/spores with >2% representation in any one or more samples. Note: pollen concentration was not sufficient at 70-71 cm to obtain percentage counts.

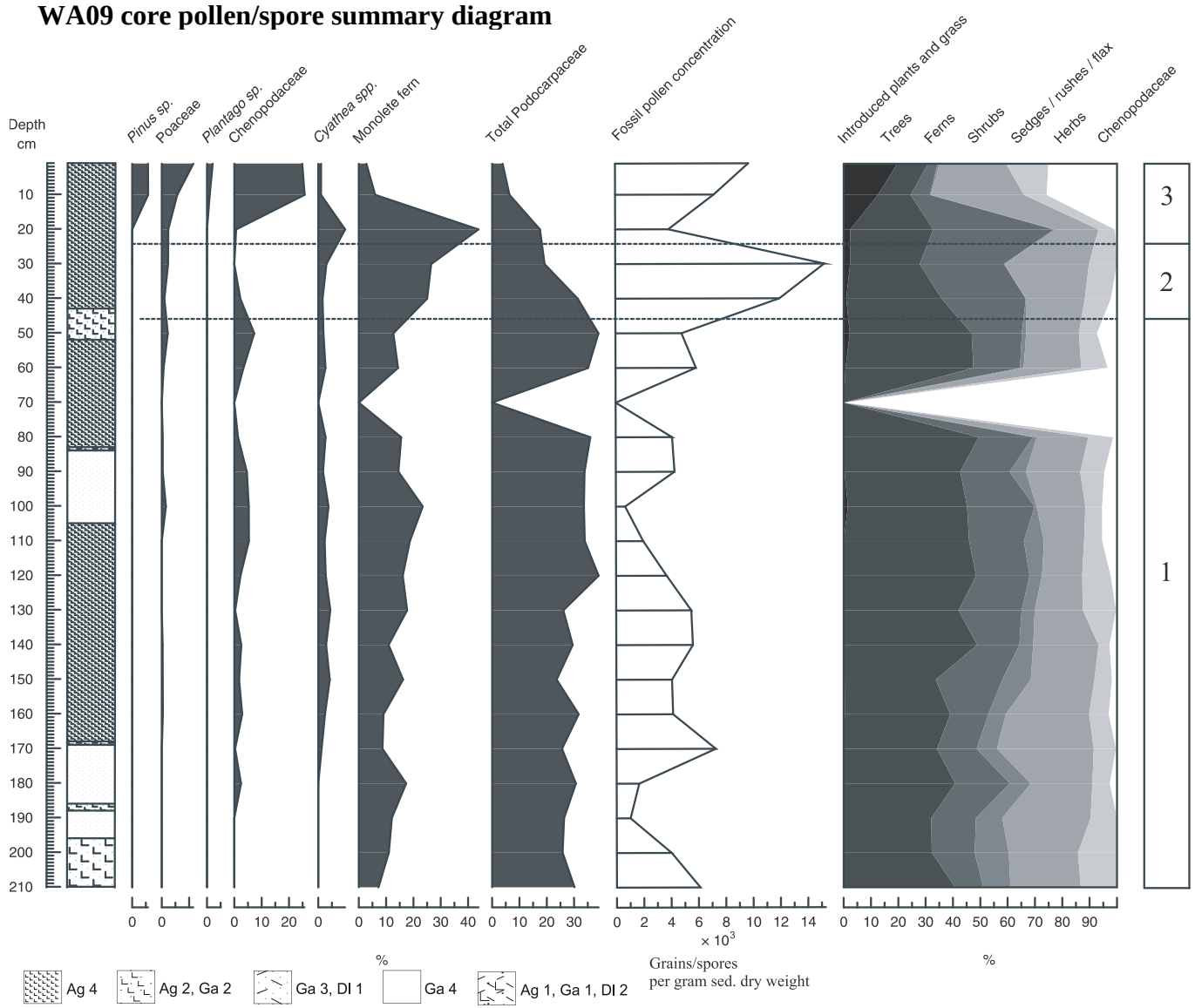

Figure 27: WA09 core pollen/spores summary diagram. Only taxa of interpretive importance and/or that display significant variation in counts are displayed. Note: pollen concentration was not sufficient at 70-71 cm to obtain percentage counts.

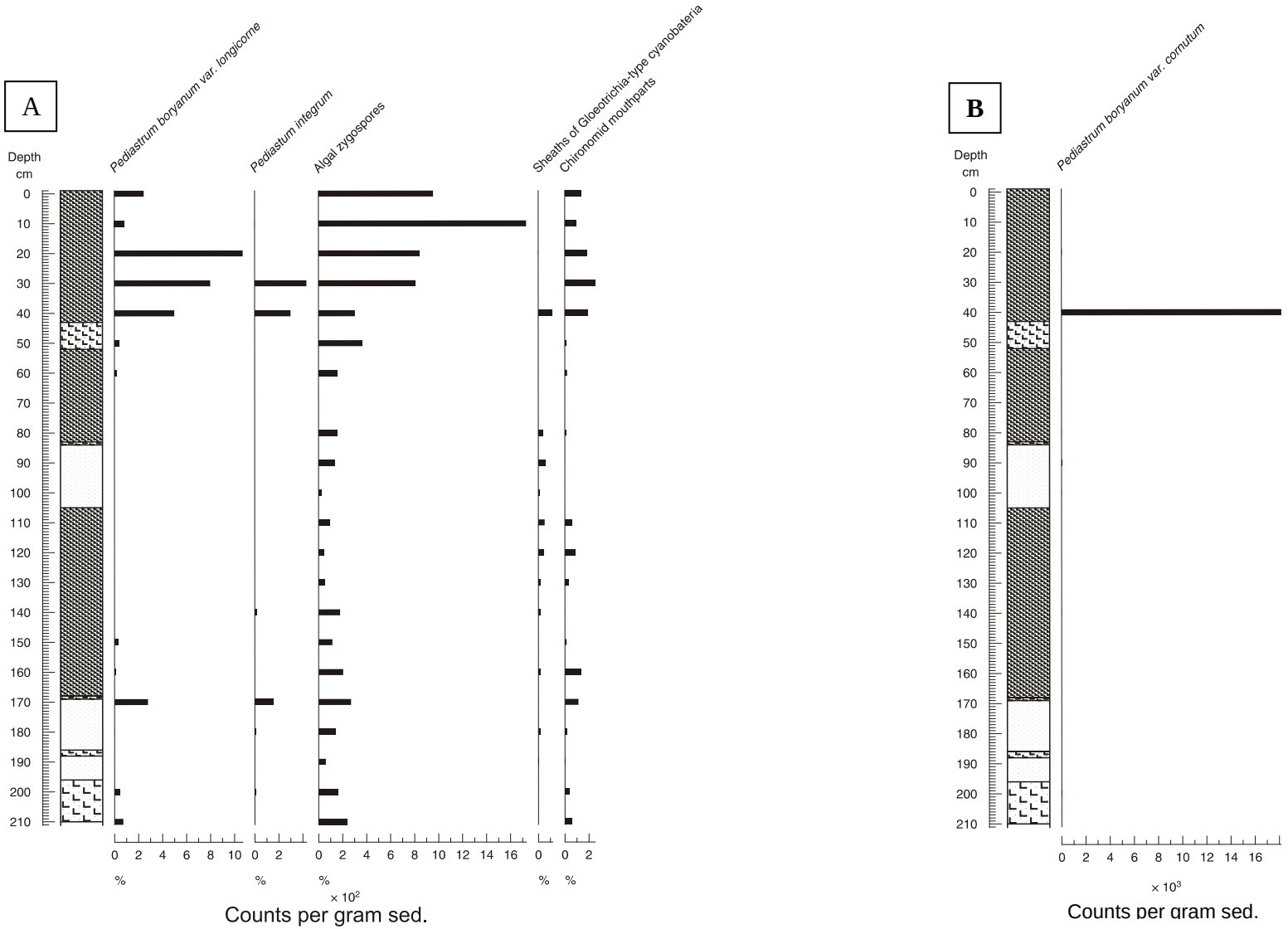

Figure 28: WA09 core non-pollen palynomorph counts. Counts presented as two diagrams (A & B) due to the comparatively large counts of the taxon, *Pediastrum boryanum var. cornutum*.

5.3.1 WA09 core pollen:

Zone 1: 210-45 cm. Podocarpaceae, Cyperaceae, monolete fern zone.

Description:

Total Podocarpaceae abundance displays minor fluctuations between 24 and 39%, while Cyperaceae and monolete fern abundance vary between 14 and 29% and 7 and 23% respectively. A spike of Leptospermum occurs at 140 cm to around 10% of the pollen sum (*Figures 26, 27*).

Zone interpretation:

Zone 1 is characterised by an abundance of Podocarpaceae and monolete fern spores, representing a combination of regional and local forest cover with ferns as an under-storey association (Macphail and McQueen 1983). The persistently high counts of Cyperaceae in this zone and throughout this core represent the local vegetation surrounding the lake, indicating an abundance of freshwater riparian vegetation throughout the lake existence (Macphail and McQueen 1983). The abundance of Podocarpaceae indicates that the deposition period represented by this zone is likely prior to human settlement, while the relatively minor changes in local vegetation types, such as Cyperaceae and Chenopodiaceae probably indicate a lack of change in the local vegetation surrounding Waihora in the same period.

A spike in Leptospermum at 140 cm depth is likely to represent a disturbance event in the vicinity of Waihora (McGlone and Wilmshurst 1999). The disturbance is likely to have been fire, either human induced or natural, although, the depth in the core at which this spike occurs suggest a natural fire event.

Zone 2: 45-25 cm. Podocarpaceae and monolete fern zone.

Description:

This zone is characterised by a decrease in Podocarpaceae including *Podocarpus spp*., from 27% in the previous zone to 17% in this zone, *Phyllocladus spp*. from 7% in the previous zone to 0.7% in this zone and *Halocarpus bidwillii* from 3% in the previous zone to 0% in this zone. Additionally, there is a decrease in the proportion of *Nothafagus fusca* type grains from 6% in the previous zone to 1% in this zone (*Figures 26, 27*).

Zone interpretation:

The decrease in *Podocarpus spp*., *Phyllocladus spp*. and *N. fusca*-type may either represent a decrease in the regional distribution of these taxa (most species in these genera are dispersed by wind long distances) and/or a decrease in these taxa on Banks Peninsula. Additionally, it is likely that the distribution of *Podocarpus spp*. is larger than appears according to these percentage counts, as according to Macphail and McQueen (1983) species within this genus tend to be underrepresented in pollen records. The decrease in *Halocarpus bidwillii* counts may represent a decrease in their abundance on the well drained alluvium east of the main divide where they currently occur (Macphail and McQueen 1983).

The beginning of an increase in monolete fern spores observed within this zone may represent either an increase in the distribution of fern species due to forest clearance, or increasing fluvial input/erosion in the catchment and sedimentation within Waihora basin (Dunbar et al. 1997; Wilmshurst and McGlone 2005; Woodward and Shulmeister 2005).

Zone 3: 25-0 cm *Cyathea spp*., monolete fern, *Pinus sp*., Poaceae and Chenopodiaceae zone.

Description:

This zone is characterised by a spike in fern spores (increase to >50% pollen sum), the appearance of introduced taxa such as *Pinus* and *Plantago* and an increase in grains of Chenopodiaceae to 26% of the total pollen sum (*Figure 26*).

Zone interpretation:

The increase in monolete fern spores in the previous zone culminates in a spike within this zone at 20-21 cm depth. As in the last zone this is interpreted as; increased fern distribution, increased fluvial input or increased erosion/sedimentation. However, the increase in poorly wind dispersed *Cyathea spp*., indicates the former is unlikely to be responsible.

At 10 cm and above there is an increase in *Pinus sp*., indicating this deposition period is post European settlement. Planting of large stands of *Pinus sp*. began around 1870 (Berg 2009; Woodward and Shulmeister 2005) and given a 25 year delay between the first planting and the first appearance of *Pinus* in the pollen record, as described by Dunbar et al. (1997), the appearance of *Pinus* in this record is likely to represent deposition occurring around the 1880's. Similarly, the increase in Poaceae above 10 cm is likely a signal of European habitation with the development of pasture lands.

From 10 cm and above there is a large increase in counts of grains belonging to taxa within the sub-family Chenopodiaceae. This is a subfamily of Amaranthaceae and the grains observed are likely to belong to *Sarcocornia quinqueflora*, which currently dominates the salt marsh flora in the South Island (Thannheiser and Holland 1995) and have been reported on saline herbfields and mudflats around Waihora (Te Waihora Joint Management Plan 2005). Although pollen of this taxon are well dispersed by wind (Macphail and McQueen 1983), this large increase in grains is likely a function of the increased distribution of *Sarcocornia quinqueflora* within Waihora's riparian margins.

5.3.2 WA09 core non-pollen palynomorphs

Algae remains:

(1) *Pediastrum:*

The occurrence of *Pediastrum spp*. remains in WA09 core samples is likely an indicator of eutrophic freshwater conditions (Limaye et al. 2007; Medeanic 2006). There is a small spike in *Pediastrum boryanum var. longicorne* and *Pediastrum integrum* at 170 cm depth (to around 2.5 and 1.7 $x10^2$ per gram sed. respectively), and more significant spikes in *Pediastrum boryanum var. longicorne* from 20 to 40 cm depth (to around 10 $x10^2$ per gram sed.) and *Pediastrum integrum* from 30 to 40 cm depth (to around 4 $x10^2$ per gram sed.). A large spike in *Pediastrum boryanum var. cornutum* occurs at 40 cm depth (to around 18 $x10^3$ per gram sed.) (*Figure 28*). Therefore, *Pediastrum spp.* spike between 40 and 20 cm core depth and to a lesser extent at 170 cm core depth.

Pediastrum counts indicate that sedimentation occurred in a freshwater environment above 40 cm depth and around 170 cm depth. Conditions were particularly conducive to *Pediastrum* growth at 40 cm and to a lesser extent, 170 cm depth. At these depths eutrophic freshwater conditions are indicated. The *Pediastrum* observed at 170 cm may be indicative of a natural increase in nutrients following lake formation. Indeed, it is unlikely that Waihora would remain an oligotrophic lake under natural conditions due to its lowland position (See diatom results, section 6.4, for more details on the nutrient conditions during deposition at this core depth).

(2) *Algal zygospores:*

Zygospores of Zygnemataceae are particularly prevalent in WA09 core samples above 40 cm depth (*Figure 28*). This indicates that shallow, stagnant, freshwater conditions occurred particularly above this depth (Jarzsen 1978). The particularly large counts of zygospores above 40 cm depth confirms that a freshwater environment was present in Waihora basin in this period.

Cyanobacteria:

Sheaths of *Gloeotrichia*-type cyanobacteria were present in small background numbers throughout most of the WA09 core. However, a small spike in the abundance of these remains occurs at 40 cm depth (*Figure 28*). The occurrence of these remains may be an indicator of freshwater, eutrophic, or low nitrogen conditions (Van Geel et al. 1994; Batten and Van Geel 1985). Although, low nitrogen concentrations leading to growth of this 'nitrogen fixer' is an unlikely scenario due to the other non-pollen palynomorphs indicating nutrient rich conditions. The small number of these remains allows only a rather ambiguous interpretation, as allochthonous sources may be involved. Although, the co-occurrence of a spike in sheaths with a spike in other eutrophic, freshwater indicators (Pediastrum and algal zygospores) at 40 cm reinforces the suggestion of eutrophic, freshwater conditions occurring at this depth.

Fungal remains:

There appears to be significant variation in the counts of total fungal remains among samples from the WA09 core. However, without reference information on environmental preferences of particular fungal types in New Zealand, interpretation of this variation is difficult. Therefore, all fungal remain data were omitted from diagrams of non-pollen palynomorphs, although, the data can be viewed in Appendix IV, Table 24, p. 196.

Chironomid mouthparts:

Mouthparts were observed during pollen analysis belonging to chironomids, with an increase in counts of these above 40 cm core depth (*Figure 28*). In most studies the mentum is used for the identification of chironomid taxa. However, in this study, only pre-mandibles were observed and genus or species level identification was not possible. Chironomids generally prefer freshwater conditions, however, the common species *Chironomus zealandicus* can tolerate elevated salinity. Therefore, it is difficult to interpret this increase in terms of salinity. Chironomids are likely to be most common in fine sediment environments, however, the lack of mouthparts in other depths of the core with fine sediments, suggests this explanation of chironomid increase in unlikely. The increase in chironomid mouthparts will be discussed in light of other evidence in the discussion chapter (Chapter 7).

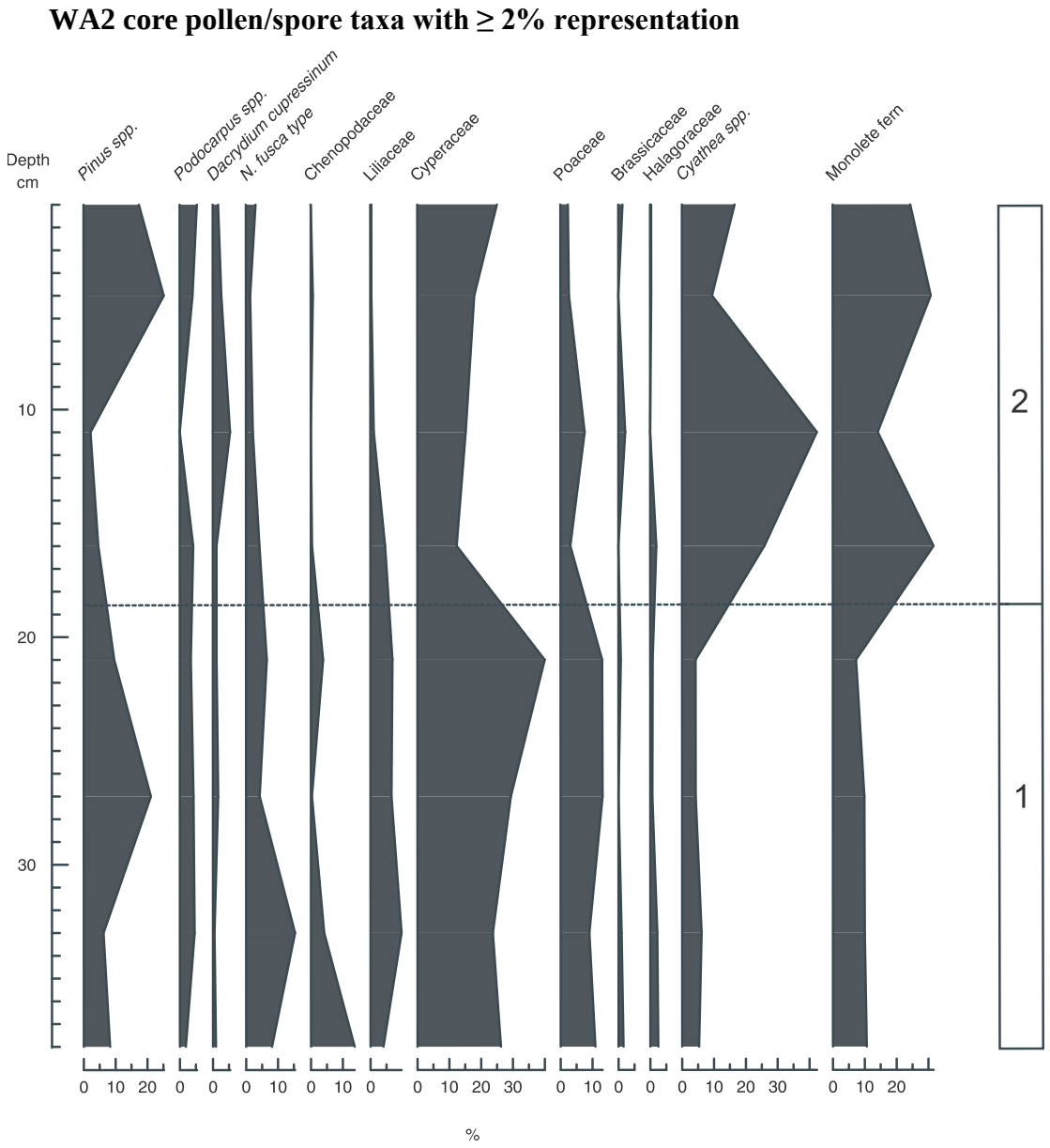

Figure 29: WA2 core pollen/spores with >2% representation in any one or more samples.

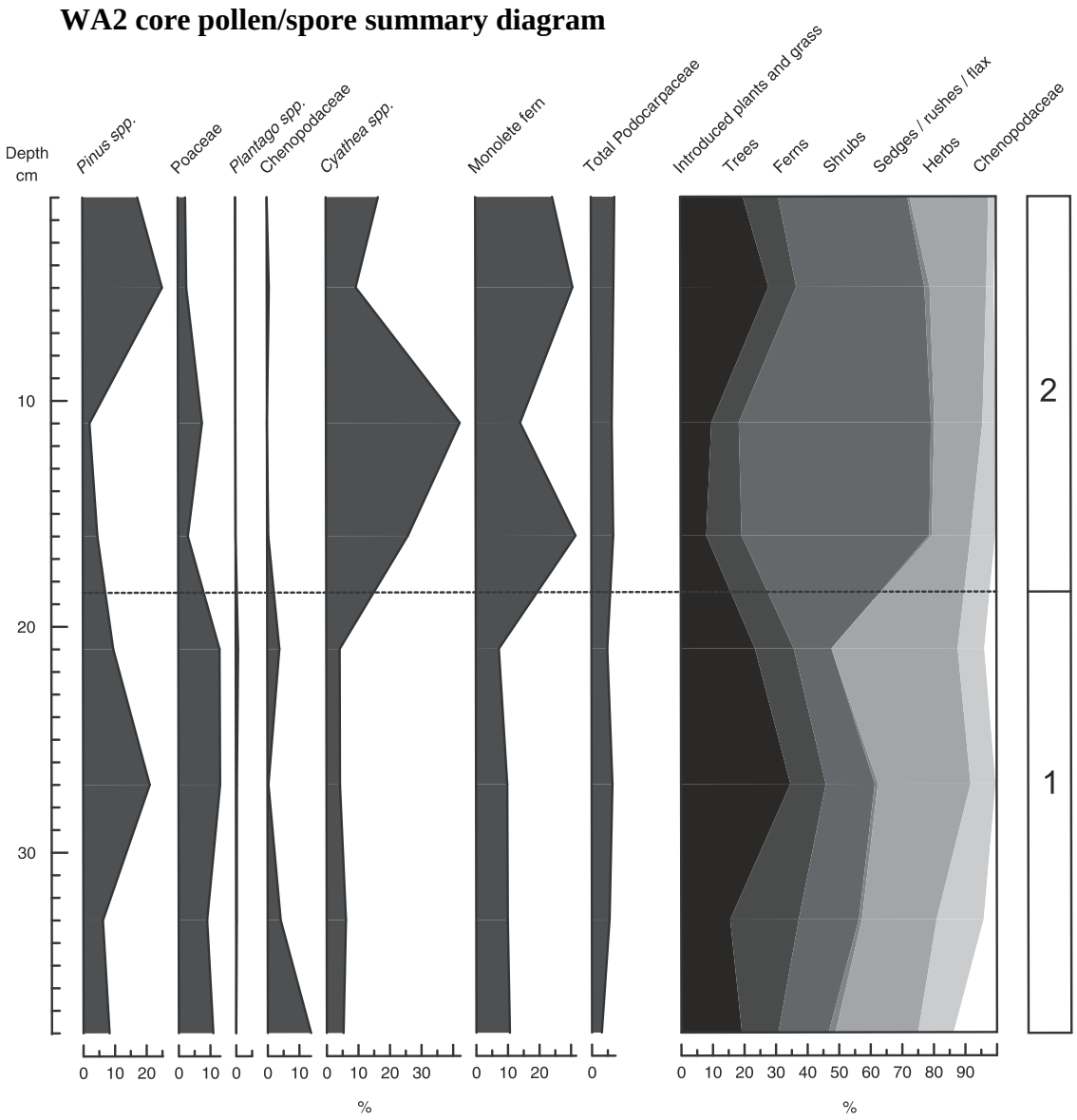

Figure 30: WA2 core pollen/spores summary diagram. Only taxa of interpretive importance and/or that display significant variation in counts are displayed.

5.3.3 WA2 core pollen

Zone 1: 38-18.5 cm *Pinus*, Cyperaceae, Poaceae zone.

Description:

Pinus sp., Cyperaceae, Poaceae and Chenopodiaceae dominate this zone. *Pinus* values range from 6 to 21%, Cyperaceae from 24 to 40%, Poaceae from 9 to 13% and Chenopodiaceae from around 15 to 0% (*Figures 29, 30*).

Zone interpretation:

The abundance of *Pinus* and Poaceae within this zone and throughout this core indicate the presence of forestry plantations and pasture. Thus, the deposition period represented by this core is post European settlement. The abundant sedge pollen within this zone represent the local vegetation surrounding the lake, indicating an abundance of freshwater riparian vegetation (Macphail and McQueen 1983). Chenopodiaceae grains occur in moderate numbers at the bottom of this zone, however, counts drop above the bottom sample to background levels. This decrease in Chenopodiaceae grain counts may be due to a decrease in the distribution of *Sarcocornia quinqueflora* within halophytic plant communities, or a decrease in the distribution of these communities surrounding Waihora.

Zone 2: 18.5-0 cm *Pinus*, Cyperaceae, *Cyathea spp*., monolete fern zone.

Description:

The contribution of Cyperaceae to the pollen sum drops from the previous zone to 12 to 15% abundance within this zone. As counts are expressed as percentages this is likely a function of increasing fern spore contribution to the pollen sum. Values for *Cyathea spp*. rise to 25 - 42% and values for monolete fern spores rise to 14 - 32%. Above 8 cm depth the contribution of *Pinus* pollen to the pollen sum increases to 25%. Cyperaceae counts contribute heavily to the pollen sum at between 18 to 25% abundance, *Cyathea spp*. counts drop to between 10 to 17% in this zone, while monolete fern spore counts remain fairly stable at between 24 to 31% of the pollen sum (*Figures 29, 30*).

Zone interpretation:

The increase in the contribution of monolete and *Cyathea spp*. spores to the pollen sum from 18.5 to 8 cm depth is indicative of either an increase in fern abundance, or more likely, increased fluvial input or increased erosion/sedimentation (Dunbar et al. 1997; Woodward and Shulmeister 2005). As *Cyathea spp*. spores are poorly wind dispersed (Macphail and McQueen 1983), an increase in fern abundance is unlikely to be responsible. The contribution of *Cyathea spp*. spores to the pollen sum decreases above 8 cm depth, indicating fluvial input or erosion/sedimentation may have decreased here. However, the continuing high counts of monolete fern spores suggest there remains some influence of elevated fluvial input, erosion and sedimentation.

Te Koru core pollen/spore taxa with ≥ 2% representation with summary diagram

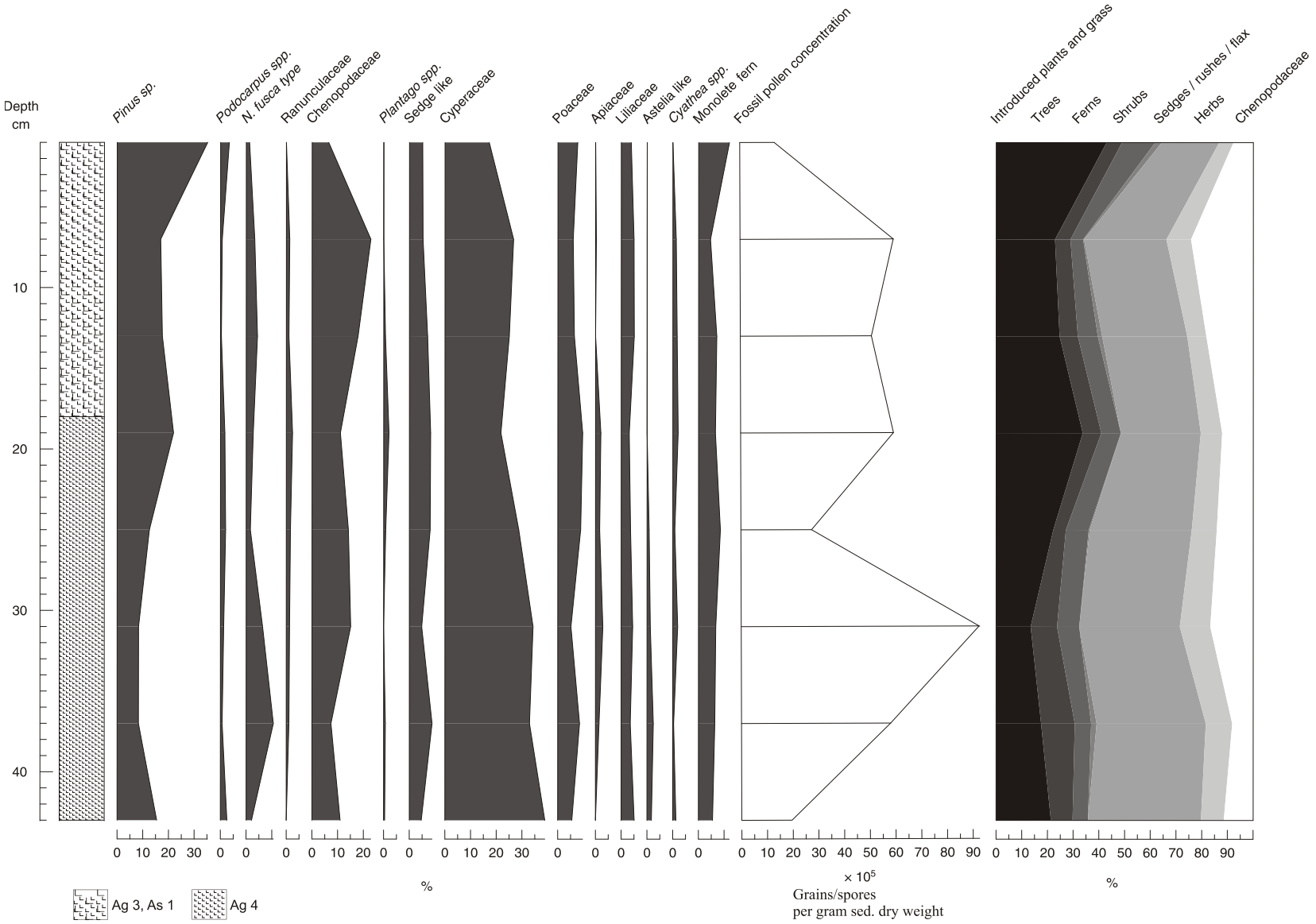

Figure 31: Te Koru core pollen/spores with >2% representation in any one or more samples and summary diagram combined.

5.3.4 Te Koru core pollen

Pollen counts throughout this core remain fairly constant. Cyperaceae, *Pinus sp.* and Chenopodiaceae contribute the most to the pollen sum throughout (17-39%, 8-35% and 6-22% respectively) (*Figure 31*). The presence of *Pinus* and *Plantago* throughout this core (*Figure 31*) indicate the presence of forestry plantations and pasture. Thus, the deposition period represented by this core is post European settlement.

The abundance of local vegetation types such as Cyperaceae and Chenopodiaceae and low counts of grains associated with regional pollen signals, such as Podocarpaceae and *N. fusca*-type (Macphail and McQueen 1983), is likely a reflection of the location at which this core was retrieved. It would be expected to observe higher counts of grains associated with a regional signal in the lake centre due to the action of sediment focusing and higher counts of grains associated with local vegetation at the Te Koru core site, due to its close proximity to the riparian margin.

Chapter 6 Diatom analysis

6.1 Introduction to diatom analysis

Diatoms are single celled, microscopic algae, generally placed in the Division Chrysophyta, Class Bacillariophyceae. Algae within this division possess a bipartite cell wall (two valves per cell in diatoms) and secrete silica at some stage of their life cycle. Diatoms are commonly observed between 20 and 200 µm in diameter, but can be smaller (<5 µm) and much larger (up to 2 mm in length). Diatoms live in aquatic environments, within the water column or attached to substrate, as free cells, colonies or chains (Round et al. 1990). The two main conditions that diatoms need for survival are water, to avoid desiccation and light for photosynthesis. Although water is necessary for diatom survival, the source of water can vary greatly, with diatoms living in rivers, lakes, estuaries, the ocean and even in moist sediment. The large range of habitats occupied by diatoms is due to the huge taxonomic diversity within this group. Taxa are often sensitive to particular environmental variables within these habitats and they respond very rapidly to any changes in these environmental variables (Cochran 2002).

The cell walls of diatoms are made of silica (SiO_2. nH_20). In all diatoms the cell wall is multipartite, consisting of two large, sculptured units called valves. Girdle elements are also often visible separating the two valves of a cell. These components together are collectively referred to as 'diatom frustules'. Each frustule contains one valve that formed after the last cell division and one older valve. Additionally, there is a pair of girdle elements to each frustule, one of which formed after the last cell division and one older. The older valve plus the older girdle element of the cell is referred to as the epitheca, while the younger of these is referred to as the hypotheca (*Figure 32*). The valves alone are referred to as the epivalve and hypovalve respectively (Parkinson and Gordon 1999; Round et al. 1990). When cell division occurs, new parts of the wall are added by exocytosis. This means that the newly formed valves and girdle elements (epitheca) are smaller than the older ones (hypotheca). Therefore, the two valves of a frustule and the girdle elements overlap, like two sides of a Petri dish (*Figure 32*) and as cell growth occurs, the epitheca and the hypotheca move apart. The production of frustule components within the frustule of the parent cell leads to a systematic reduction in mean cell size through generations (*Figure 32*). The original cell size is restored

through the production of an auxospore via sexual reproduction. This develops into a full sized frustule (Round et al. 1990).

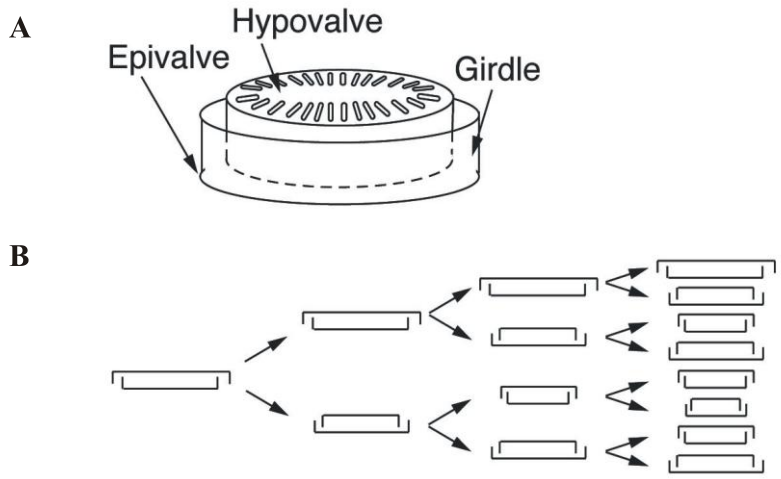

Figure 32: A: diagram of a centric diatom frustules showing the 'Petri dish' like structure each with a small and a large valve. B: diagram displaying the successive reduction in frustules size through cell division. From: Parkinson and Gordon (1999).

In live cells these structures contain the cell organelles and are often coated with organic material. When frustules are viewed under a microscope from buried sediment samples, it is only the siliceous cell wall material that remains. The characteristics of these cell walls are unique to each species, with distinguishable shape, size and ornamentation (*Figure 33*). These cell walls are well preserved in lake and marine sediments, maintaining their species specific characteristics. These remains are used by researchers to determine the species that produced them. First the valve structure can be used to identify the valve as belonging to the Classes (1) Centrales (Coscinodiscophyceae) or (2) Pennales (Bacillariophyceae), with the former tending to appear radially symmetrical, often with striae arranged in relation to a central point and the latter tending to appear bilaterally symmetrical with striae arranged in relation to a longitudinal line (*Figure 33*). The Centrales are then divided into 8 subclasses based on valve morphology. These are Thalassiosirophycidae, Coscinodiscophycidae, Biddulphiophycidae, Lithodesmiophycidae, Corethrophycidae, Cymatosirophysidae, Rhrizosoleniophycidae and Chaetocerotophycidae. The allocation of a diatom to one of these subclasses is based on valve structure. For example, Coscinodiscophycidae has no polarity to the symmetry, Rhrizosoleniophycidae has unipolar symmetry and Biddulphiophycidae has

bipolar symmetry. The Pennales are then divided into two subclasses based on valve morphology. These are Fragilariophycidae which do not possess are raphe (a slit along the long axis) and Bacillariophycidae which do possess a raphe (Round et al. 1990). These subclasses are further divided into orders, families and genera based on the intricacies of valve structure, such as the presence/absence, shape, density and pattern of striae, areolae and the raphe components (*Figure 33*). For a detailed description of these biological classifications see Round et al. (1990). In their respective environments, diatoms are often present in very large numbers. In environments such as lakes, this leads to diatom remains being preserved in large numbers in the sediment (Cochran 2002).

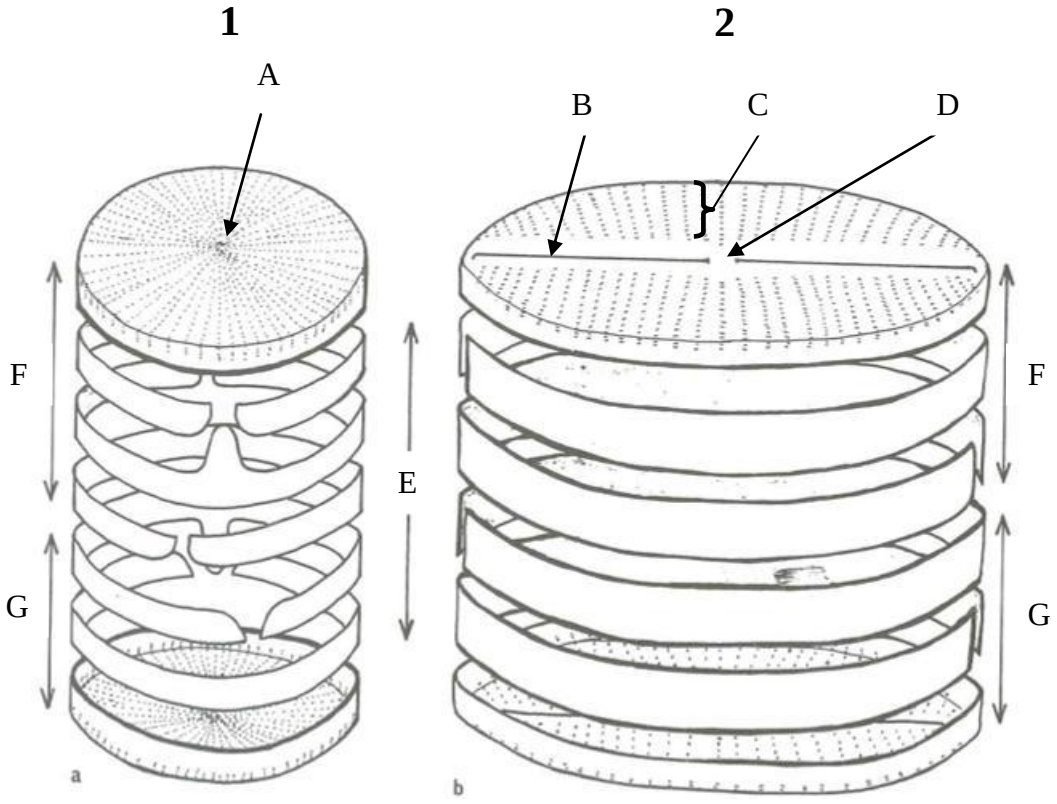

Figure 33: Diagram displaying the siliceous components of (1) centric and (2) pennate diatom frustules. A = central pole of a centric valve with striae radiating from this point. B = raphe. C = striae composed of areolae. D = central area. E = grirdle bands (copulae). F = epitheca (epivalve and epicingulum). G = hypotheca (hypovalve and hypocingulum). Modified from: Cox (1996).

In summary, it is the presence of diatoms in a wide range of environments, the sensitivity of diatoms to a range of environmental factors, their rapid response to environmental change, the taxonomically diagnostic nature of the preserved frustules and the large numbers preserved in sediment that makes diatoms a valuable tool for Paleoecological/paleoecological research (Round et al. 1990; Cochran 2002).

6.2 Diatom ecology

Much research has been conducted on the ecology of diatoms. Taxa have been classified into particular ecological groups for particular parameters, such as salinity, pH, trophic state and general environmental preference, by examining the taxa present in particular environmental settings (see section 6.3.3, pp. 94-97, for classifications used in this thesis). Much of this work has been conducted and reviewed overseas by authors such as Vos and De Wolf (1993) and Van Dam et al. (1994). This research is useful as many diatom species are cosmopolitan in nature, although research specific to New Zealand is important in order to classify species that are narrower in range. More work needs to be done on the ecology of New Zealand diatoms, although some useful work to that effect has been carried out by Cassie (1989), Cochran (2002), Foged (1979) and Reid (2005).

The ecological information obtained from modern samples can then be used to infer past environmental conditions based on the taxa of the diatom remains observed within buried sediments. Diatom species within fossil assemblages are identified, counted, and their ecological preferences determined. This is conducted on multiple samples from sediment cores to give an indication of ecological changes occurring through the deposition period of the core. This is the approach used in this study, although another method exists. Authors such as Reid (2005) and Cochran (2002) have developed diatom based transfer functions for productivity and salinity reconstructions respectively. This method of quantifying reconstructions was not used in this study, as common taxa such as *Pseudopodosira spp*. were not included in these datasets. Thus, these transfer functions are of limited usefulness here.

6.3 Diatom analysis methods

Samples were obtained from evenly spaced intervals from three cores, WA09, WA1 and Te Koru. Sampled intervals within these cores are displayed in *Table 2*, p. 40. Care was taken to ensure that no contamination of samples and between samples occurred. This was done by flaming the spatula used in removal and conducting all treatment in a clean, ventilated laboratory. Treatment of sediment for diatom analysis is described below.

6.3.1 Diatom extraction and mounting

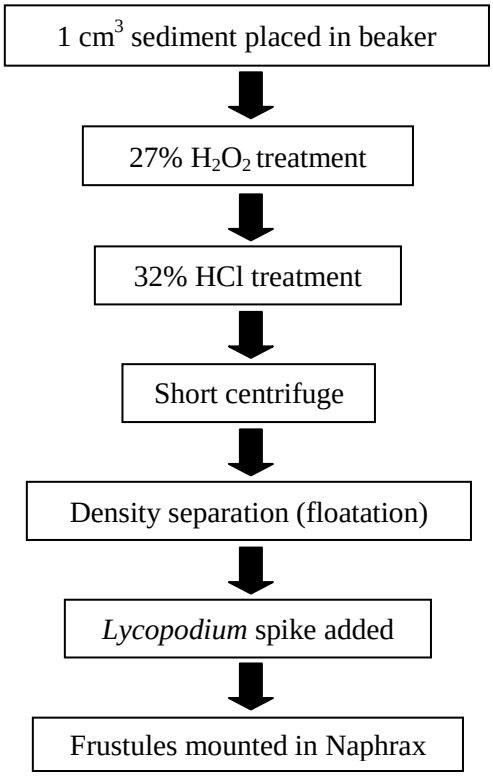

Figure 34: Flow chart summary of methods used in diatom extraction.

A summary of the methods used to prepare diatom samples is displayed in *Figure 34*, while a full description of the methods used is displayed in Appendix III, pp. 186-190. The diatom extraction and mounting methods used are mainly those outlined by Battarbee et al. (2001), with the following modifications:

- A sediment drying step is often recommended in laboratory preparation methods. However, sediment was not dried in this study as previous research, such as Flower (1993), demonstrate that drying can damage frustules. Instead, for the calculation of diatom concentration per gram dry sediment, the dry weight was calculated from water content determined during loss on ignition analysis.
- A density separation step at 2.5 s.g. was carried out in order to separate frustules from fine sediment matter.
- Diatom concentration calculated by adding *Lycopodium* spore tablets to a sub sample of the final diatom solution. This is a modification of the methods outlined by Battarbee and Kneen (1982).

See Appendix III, pp. 186-190, for further details on these modifications.

6.3.2 Diatom microscopy

Diatom remains were examined using a Zeiss binocular light microscope at 1000x magnification (10x ocular, 40x objective lens). A count of 400 valves per slide was targeted; however, the number of valves per slide was not always sufficient to achieve this. Publications used to identify diatoms included (Cassie 1989; Cleve-Euler 1968; Foged 1979; Harvey 1996; Krammer and Lange-Bertalot 1991 a, b & c; Patrick and Reimer 1966; Round et al. 1990). Photomicrographs were taken using a Differential Interference Contrast (DIC) microscope. Images of many taxa counted are displayed in Appendix VIII, pp. 232-247.

6.3.3 Ecological classification

The literature used to obtain ecological information included (Cassie 1989; Cochran 2002; European Diatom Database website (EDDI); Foged 1979; Harvey 1996; Van Dam et al. 1994; Vos and De Wolf 1993). Of these references, Harvey (1996) was particularly useful as it classifies many taxa encountered in this thesis into environmental preference categories. Thus, the classification system used by Harvey (1996 pp. 83 - 86) (modified from Van Dam et al. (1994) and Vos and De Wolf (1993)) is used here and reprinted below.

Diatoms were grouped according to their appropriate environmental variables for (1) environmental classification, (2) salinity classification, (3) saprobity classification, (4) oxygen requirements, (5) nitrogen uptake, (6) trophic level, (7) pH and (8) current classification. The percentage of valves that belong to each category for each classification is then calculated and diatom diagrams displaying these values produced.

(1) **Environment classification**:

Plankton:	Exclusively planktonic species.
Tychoplankton:	Frequently planktonic species, but also found in other habitats.
Epiphyton:	Attached to macrophytes.
Epipelon:	Mobile species which migrate through the sediment.
Episammon:	Immobile species, firmly attached to sand grains.
Aerophilous:	Benthic species adapted to regular flooding.

See *Figure 35*, which combines habitat (above) with salinity preferences, and assigns letters to each classification.

(2) **Salinity classification**:

A	Polyhalobous	(> 30‰)
B	Mesohalobous	(0.2 - 30‰)
C	Oligohalobous – halophilous	(optimum in slightly brackish water)
D	Oligohalobous – indifferent	(optimum in freshwater but tolerant of slightly brackish water)
E	Halophobous	(exclusively freshwater)

(3) **Saprobity classification**:

		Water quality class	Oxygen saturation
A	Oligosaprobous	I, I-II	>85%
B	β-mesosaprobous	II	70-85%
C	α-mesosaprobous	III	25-70%
D	α-meso/polysaprobous	III-IV	10-25%
E	Polysaprobous	IV	<10%

The saprobic classification quantifies the level of organic pollution by taking into account the presence of biodegradable organic matter and oxygen concentrations.

(4) **Oxygen requirements classification**:

A	Oxygen 100%	(continuously high, about 100% saturation)
B	Oxygen >75%	(fairly high, above 75% saturation)
C	Oxygen >50%	(moderate, above 50% saturation)
D	Oxygen >30%	(low, above 30% saturation)
E	Oxygen 10%	(very low, about 10% saturation)

(5) **Nitrogen uptake classification**:

A	Nitrogen-autotrophic : critical	(tolerating very small concentrations of organically bound nitrogen)
B	Nitrogen-autotrophic : tolerant	(tolerating elevated concentrations of organically bound nitrogen)
C	Nitrogen-heterotrophic : tolerant	(needing periodically elevated concentrations of organically bound nitrogen)
D	Nitrogen-heterotrophic : critical	(needing continuously elevated concentrations of organically bound nitrogen)

(6) **Trophic level classification**:

A	Oligotrophic
B	Oligo-mesotrophic
C	Mesotrophic
D	Meso-eutrophic
E	Eutrophic
F	Hypereutrophic
G	Oligotrophic to Eutrophic (indifferent)

(7) **pH classification**:

A	Acidobiontic	(optimum occurrence at pH <5.5)
B	Acidophilous	(mainly occurring at pH <7)
C	Circumneutral	(mainly occurring around pH 7)
D	Alkaliphilous	(mainly occurring at pH >7)
E	Alkalibiontic	(exclusively occurring at pH >7)
F	Indifferent	(no apparent optimum)

(8) **Current classification:**

A	Rheophilous	(preferring flowing water)
B	Indifferent	
C	Limnophilous	(preferring still water)

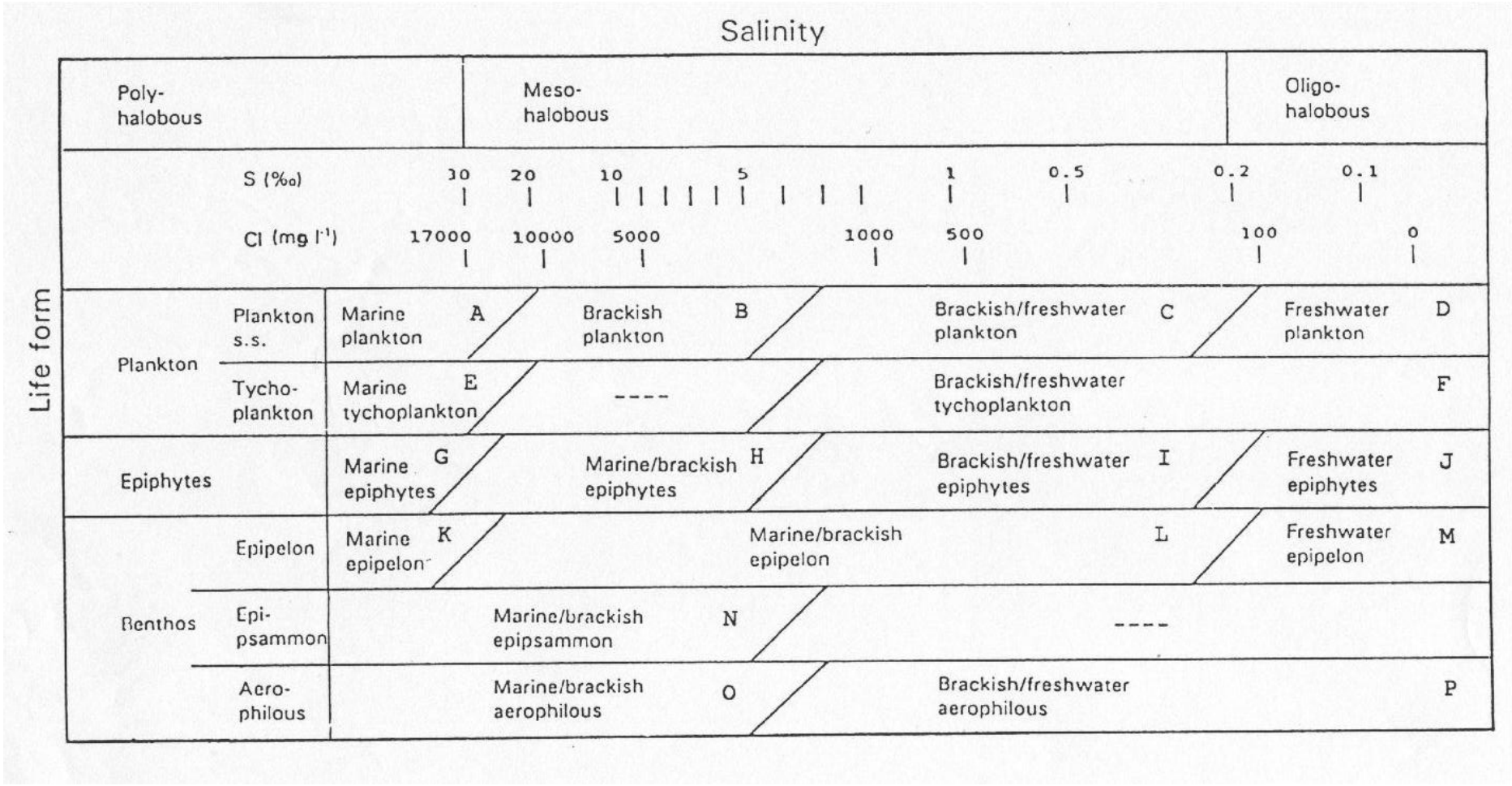

Figure 35: Environmental classification. From: Harvey (1996) based on work by Vos and De Wolf (1993).

6.3.4 Diatom diagrams

Diatom diagrams were produced using ‘Psimpoll version 4.27’ (Bennett 2009). Diagrams were produced for the environmental variables described above for each of the cores. Ecological information from all taxa observed were grouped according to these environmental preference variables. Taxa that have not been ascribed environmental preferences in the available literature have been grouped as 'unclassified'. Counts are presented as proportions (percentage counts), whereas diatom and sponge spicule concentrations are presented as concentration per gram sediment dry weight.

Shannon-Wiener diversity index values have been calculated. This index takes into account not only the number of taxa within each sample but also the numbers of each individual taxon. Values for this index are calculated using the following equation:

$H = -\sum P_i(\ln P_i)$

Where P_i = the proportion of the species in the sample (Spellerberg & Fedor 2003).

Results of Shannon-Wiener diversity index, diatom concentration and sponge spicule concentration are displayed on diagrams of taxa within >5% representation in any one or more samples.

Zones within the diatom diagrams have been determined using the method of Constrained Cluster Analysis in the program Psimpoll version 4.27 (Bennett 2009). This is a multivariate method for defining stratigraphic zones quantitatively, whereby stratigraphically adjacent clusters are considered for merging. These zones are defined by the presence or absence and abundance of taxa in samples from the core (Grimm 1987). The formation of clusters used to determine zones is displayed with a dendrogram, on each diagram to the right of the determined zones.

6.4 Diatom analysis results

It appears that there has been some variation in salinity, nitrogen, oxygen, saprobity and overall trophic level within Waihora during the deposition period represented in these three cores. This variation is described below separately for each core and within zones distinguished in each core. Although, it appears that variation exists in the aforementioned environmental parameters over time, there does not appear to be any significant variation in pH, as determined by diatom pH preferences. An overwhelming proportion of the taxa within all three cores have an alkaliphilous pH preference, indicating that the pH in Waihora has usually been ≥7 throughout the deposition period represented by these cores. The only exception to this is a spike in circumneutral and alkalibiontic taxa within the WA09 core at around 20 cm depth (*Figure 5*4) and within the WA1 core at 35 to 40 cm depth (*Figure 59*) (These depths likely represent the same deposition period according to ^{137}Cs analysis (see p. 61) and the similarity in diatom counts). This is likely to reflect a change in salinity, as the assemblages within these large spikes, are freshwater to slightly brackish plankton and tychoplankton, which are not observed in these quantities in other depths of the cores.

There is also very little distinguishable variation in the source of frustules (i.e. fluvial or lacustrine), as determined by current preferences of diatom taxa. This is not to assume that there is no true variation in the source of valves throughout the cores, rather that diatom current preference categories do not elucidate any of this variation (mainly due to most taxa being unclassified for this parameter). Therefore, diagrams depicting pH and current preferences of taxa are given little attention in this chapter, although they can be viewed in Appendix V, pp. 197-211. Additionally, in most cases diagrams of diatom flora grouped according to nitrogen, oxygen and trophic preferences can be summarised by viewing flora grouped according to saprobity preferences (a measure that includes both oxygen and level of organics). Therefore, to streamline the presentation of results, diagrams displaying counts grouped as nitrogen, oxygen and trophic preferences are displayed in Appendix V.

The taxa *Pseudopodosira westii* and *Pseudopodosira spp*. were present in large numbers in many of the samples. However, there was a lack of ecological information available for these taxa (none for *Pseudopodosira spp*.). For this reason, these taxa are displayed separately in the diagrams when no preference information was obtained. This is because more information may be attained by viewing these as taxon counts rather than counts grouped as

'unclassified'. For example, although no specific salinity preference data was obtained for *Pseudopodosira spp*., similar valves were determined to belong to a taxon preferring brackish water in Cochran (2002). Indeed, Harvey (1996) uses this taxon to infer brackish conditions. Therefore, by displaying counts of this taxon, salinity inferences can be made.

What follows is a series of diagrams followed by a description of variation within these diagrams presented as zones, for each core separately. Note that the zones within each diagram may vary to the zones presented in the description that follows each set of diagrams. Zones determined by constrained cluster analysis in each diagram were considered in order for the zones in the description to be determined by the author. A new zone begins where it appears a transition in assemblage occurs. A description of each zone is presented which includes the common and indicative taxa present, followed by an interpretation of the zone, which includes the ecological significance of the diatom assemblage. Further interpretation of the patterns observed over all three cores is given in the discussion chapter (Chapter 7). Counts of all ditom taxa from the three cores can be viewed in Appendix VI, *Tables 25, 26* & *27*, while the known ecological preferences of all the taxa counted are displayed in *Table 28*.

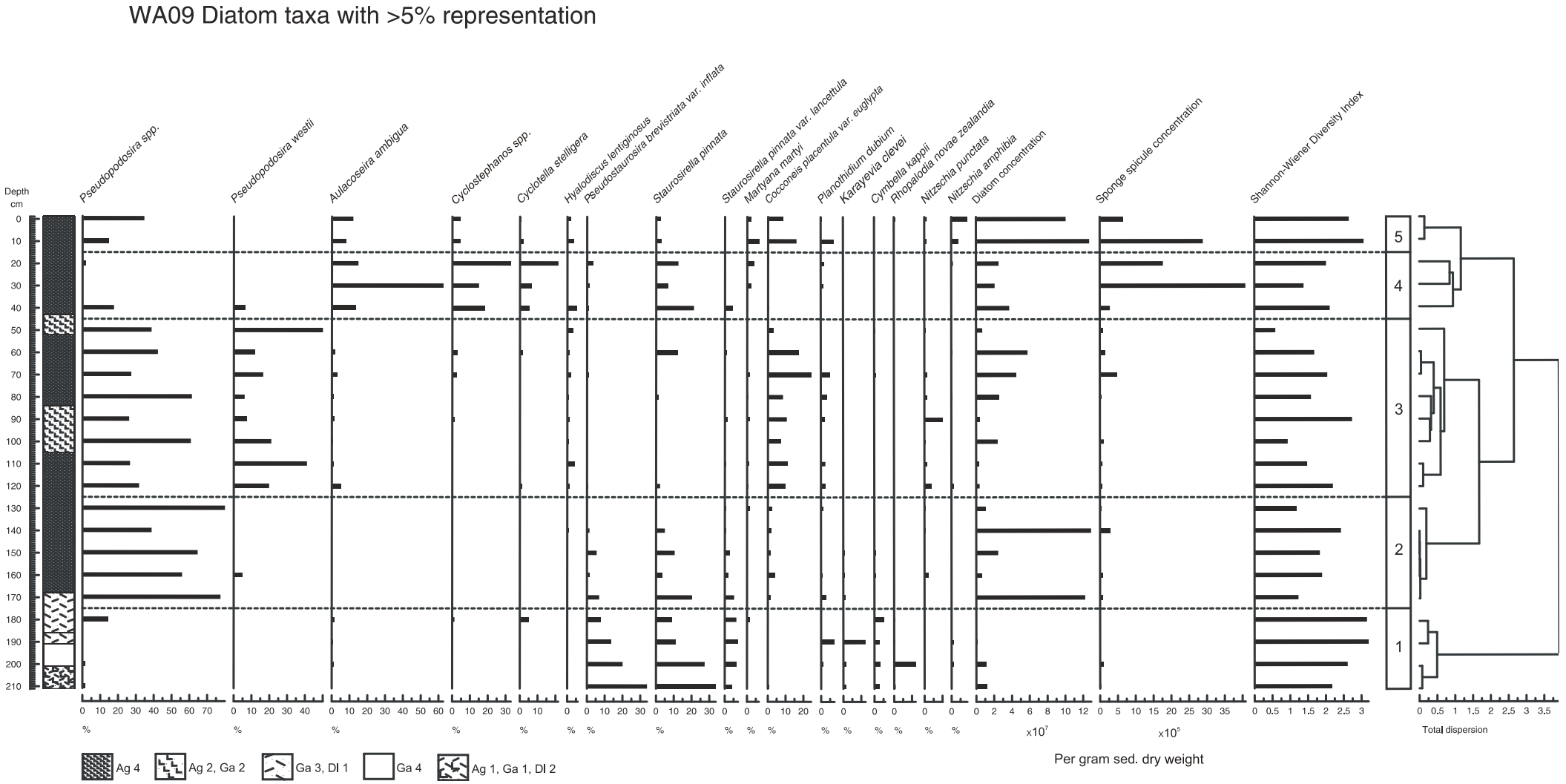

Figure 36: WA09 core diatom taxa with >5% representation in any one or more samples.

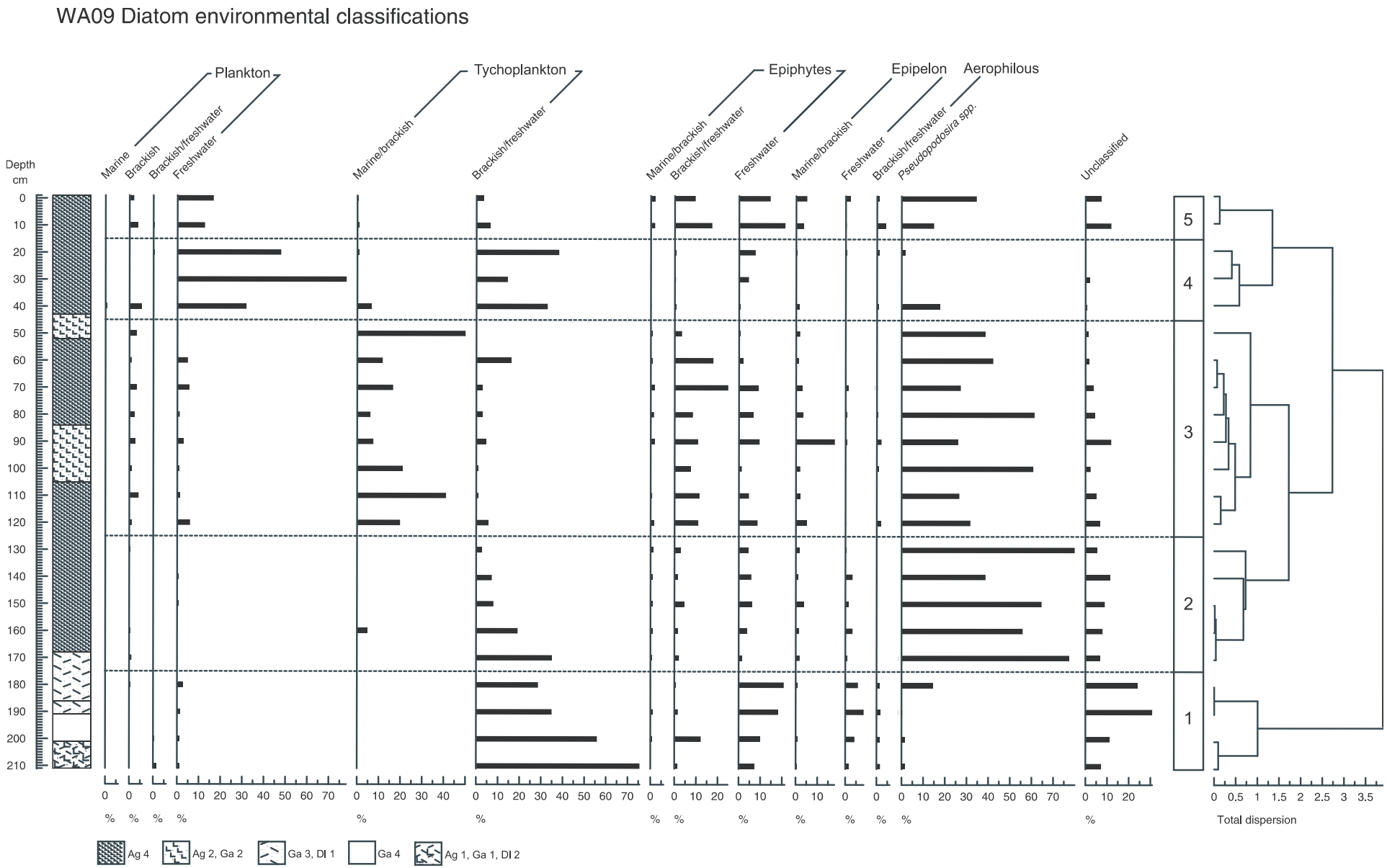

Figure 37: WA09 core diatom taxa grouped in environment preference categories.

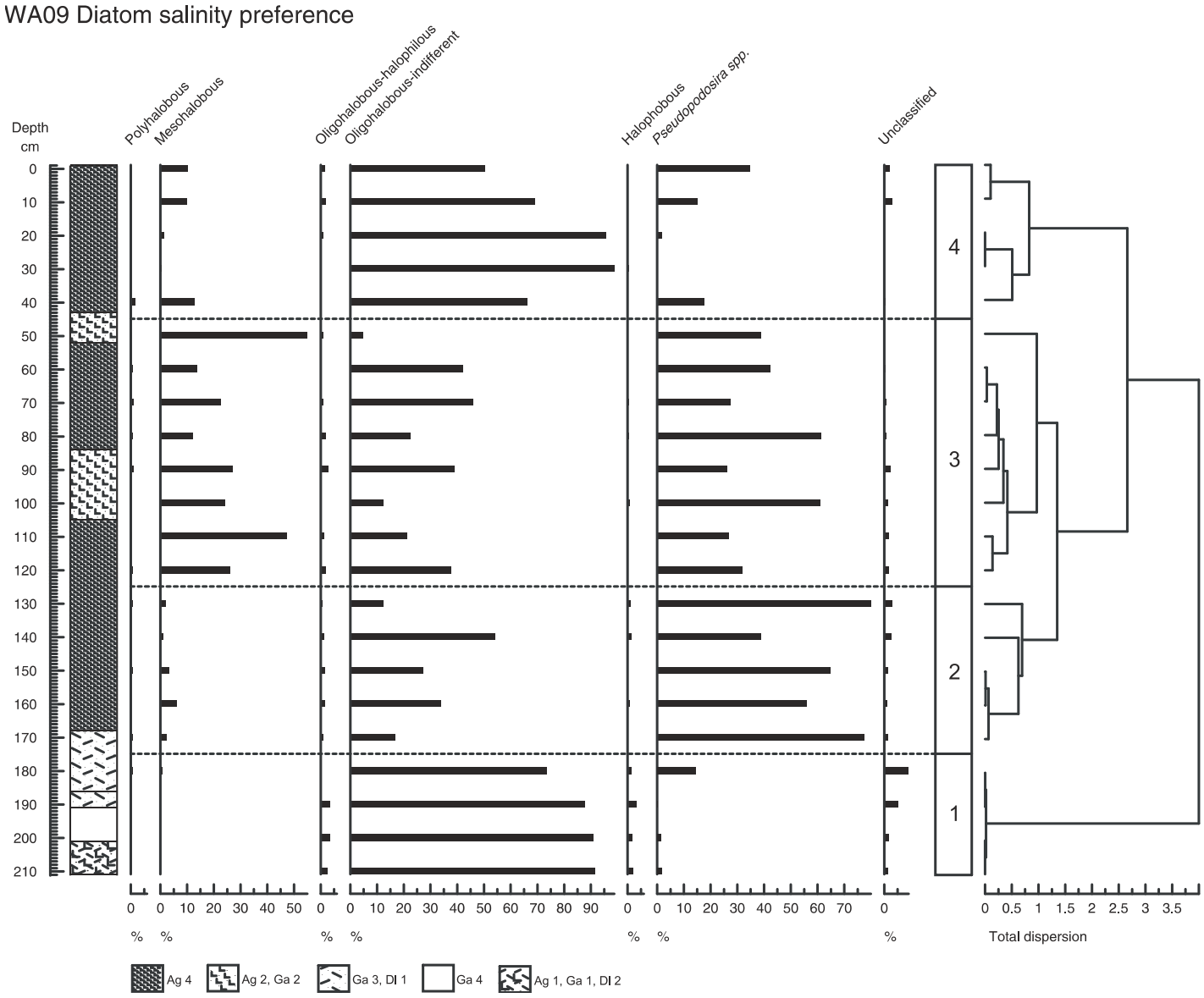

Figure 38: WA09 core diatom taxa grouped in salinity preference categories.

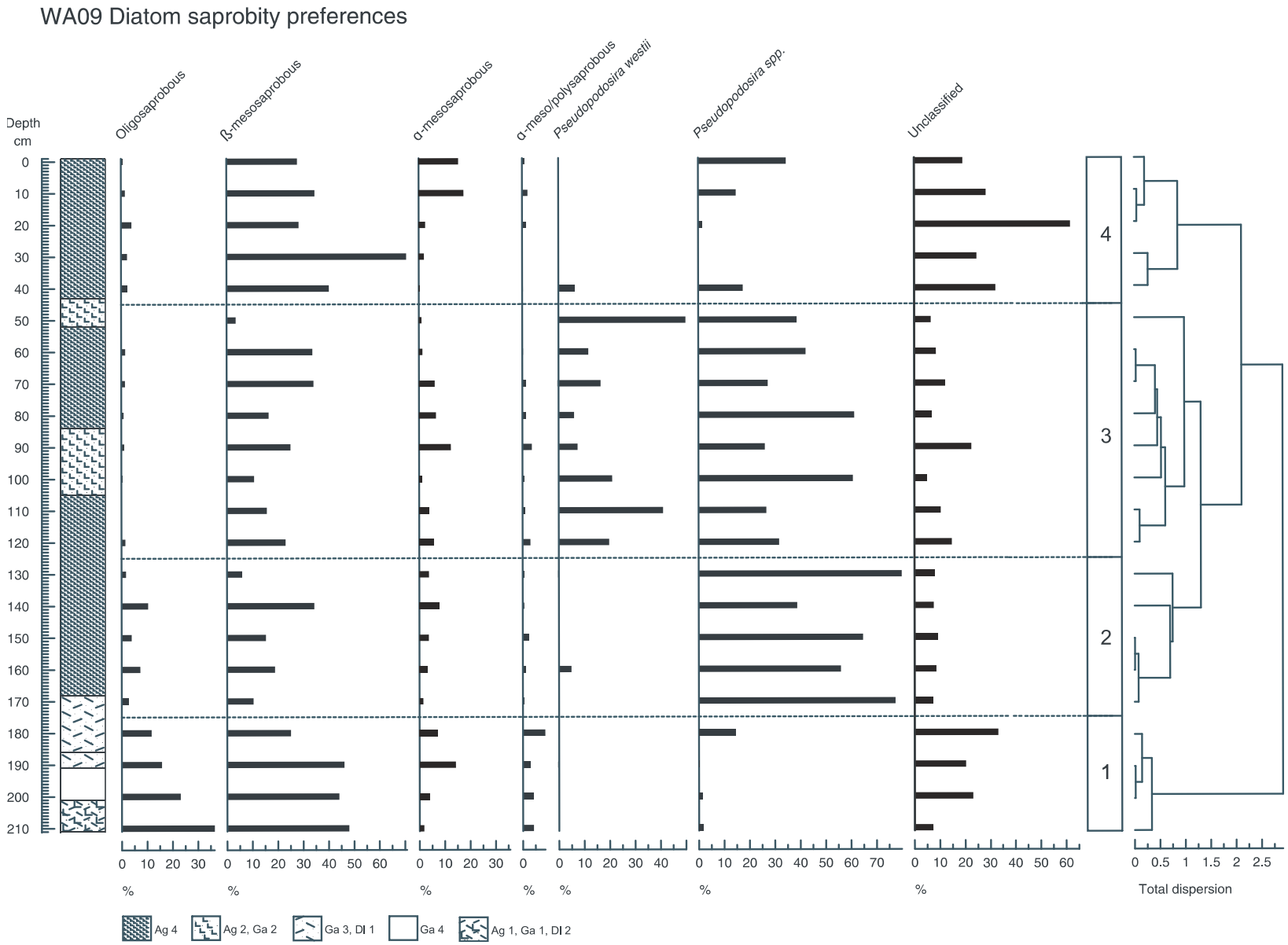

Figure 39: WA09 core diatom taxa grouped in saprobity preference categories.

6.4.1 WA09 core diatoms

Zone 1: 210 to 175 cm

- The dominant taxa within this zone are *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata (Figure 36).*
- Valves within this zone are mainly tychoplankton (*Figure 37*) that live optimally in freshwater but can tolerate slightly brackish water (oligohalobous-indifferent) (*Figure 38*). This indicates that Waihora was probably a freshwater to slightly brackish water lake within this zone.
- Freshwater epiphytes are present (up to 20%) (*Figure 37*), including *Cymbella kappii*, *Planothidium lanceolatum*, *Gomphenema parvulum*, *Synedra ulna* and *Fragilaria capucina var. vaucheriae*. This is indicative of macrophyte growth within tributaries and/or around lake margins.
- The prevalence of Oligosaprobous/ß-mesosaprobous taxa (*Figure 39*) (mainly *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata*), oxygen 100% taxa (*Figure 51*) (mainly *Staurosirella pinnata*, *Staurosirella pinnata var. lancettula*, *Pseudostaurosira brevistriata var. inflata*, and *Reimeria sinuata*) and nitrogen autotrophic: critical taxa (*Figure 52*) (mainly *Pseudostaurosira brevistriata var. inflata* and *Reimeria sinuata*) within this zone indicates this was a oxygen rich lake, low in nutrients.

Zone 2: 185 to 125 cm

- The dominant taxon within this zone is by far *Pseudopodosira spp*., although smaller proportions of *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata* are present (*Figure 36*).
- *Pseudopodosira spp*. is most likely a brackish water (mesohalobous or oligohalobous-halophilous) taxon (Cochran 2002; Harvey 1996). Therefore, the increase in this taxon and the decrease in predominantly oligohalobous-indifferent taxa (such as *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata*), in this zone, likely represents an increase in salinity within Waihora (*Figure 38*).
- The spikes in diatom concentration within this zone (*Figure 36*) may reflect a decrease in deposition rates compared to the previous zone.

Zone 3: 125 to 45 cm

- The dominant taxa within this zone are *Pseudopodosira spp*., *Pseudopodosira westii* and *Cocconeis placentula var. euglypta* (*Figure 36*).
- *Pseudopodosira westii* is classed as having a mesohalobous salinity preference. *Pseudopodosira spp*. is likely to have a mesohalobous or oligohalobous-halophilous salinity preference and *Cocconeis placentula var. euglypta* is classed as having an oligohalobous-indifferent salinity preference, but occupies a wide range of habitats and can tolerate significantly increased salinities (Vos and De Wolf 1993). Therefore, it is likely that salinity within Waihora is elevated within this zone (*Figure 38*).
- The abundance of the epiphyte *Cocconeis placentula var. euglypta* within this zone (*Figure 39*) may indicate that some macrophytes may have occurred around the lake margins in this period. Although, Vos and De Wolf (1993) note that this is a generalist taxon. It is likely that this taxon will attach to a variety of substrates.

Zone 4: 45 to 15 cm

- The dominant taxa within this zone are *Aulacoseira ambigua*, *Cyclostephanos spp.*, *Cyclotella stelligera* and *Staurosirella pinnata* (*Figure 36*).
- These are all classified as oligohalobous-indifferent taxa (*Figure 38*), although *Aulacoseira ambigua* and *Cyclostephanos spp.* are classified as freshwater plankton (Harvey 1996; Theriot et al. 1987) (*Figure 37*). This indicates that a predominantly freshwater environment prevailed within the basin in this period.
- The four dominant taxa within this zone are all plankton or tychoplankton (*Figure 37*), indicating Waihora may have been a deeper water body within this period.
- Taxa within this zone are classified as β-mesosaprobous or α-mesosaprobous (*Figure 39*), mainly oxygen 50% (*Figure 51*), nitrogen-autotrophic: tolerant (*Figure 52*) and eutrophic to hypereutrophic (*Figure 53*). This indicates that nutrient levels within Waihora may have increased compared to the previous zone.
- The abundance of spicules of a freshwater sponge species (*Heterorotula kakahuensis*) within this zone (*Figure 36*) is likely indicative of a freshwater environment, an increase in nutrients (sponges feed predominantly on organic detritus and bacteria) and perhaps low turbidity (these filter feeders generally do not tolerate high levels of suspended sediment) (Gee 1931).

Zone 5: 15 to 0 cm

- This zone is dominated by *Pseudopodosira spp*., *Cocconeis placentula var. euglypta*, *Aulacoseira ambigua* and *Nitzschia amphibia* (*Figure 36*).
- *Aulacoseira ambigua* and *Nitzschia amphibia* are classified as having an oligohalobous-indifferent salinity preference, while *Pseudopodosira spp*. and *Cocconeis placentula var. euglypta* are likely mesohalobous to oligohalobous-halophilous and oligohalobous-indifferent respectively. Therefore, the diatom assemblage in this zone indicates an increase in salinity compared to the previous zone (*Figure 38*).
- The assemblage switches from one dominated by planktonic forms in the last zone, to one with both planktonic and epiphytic forms in this zone (*Figure 37*). This may reflect an increase in epiphyton, due to an increase in macrophytes. However, this is unlikely as ^{137}Cs reveals sedimentation here is relatively recent and macrophyte growth is known to be minimal during this period (refer to chapter 1, pp. 4-5 and chapter 3, p. 46 for information on macrophyte growth and dating results). A more likely explanation is a decrease in the proportion of plankton due to the decrease in lake depth.

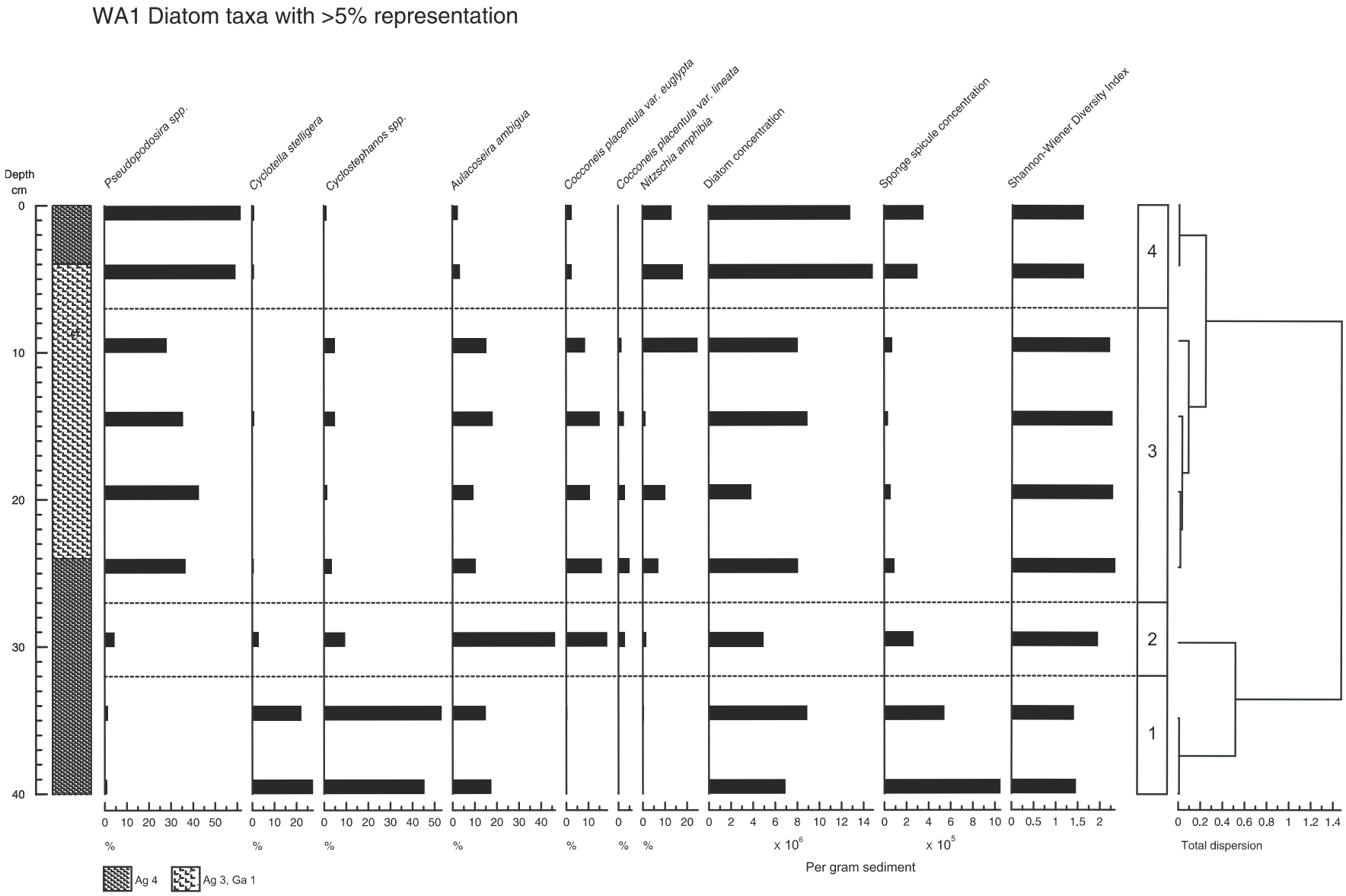

Figure 40: WA1 core diatom taxa with >5% representation in any one or more samples.

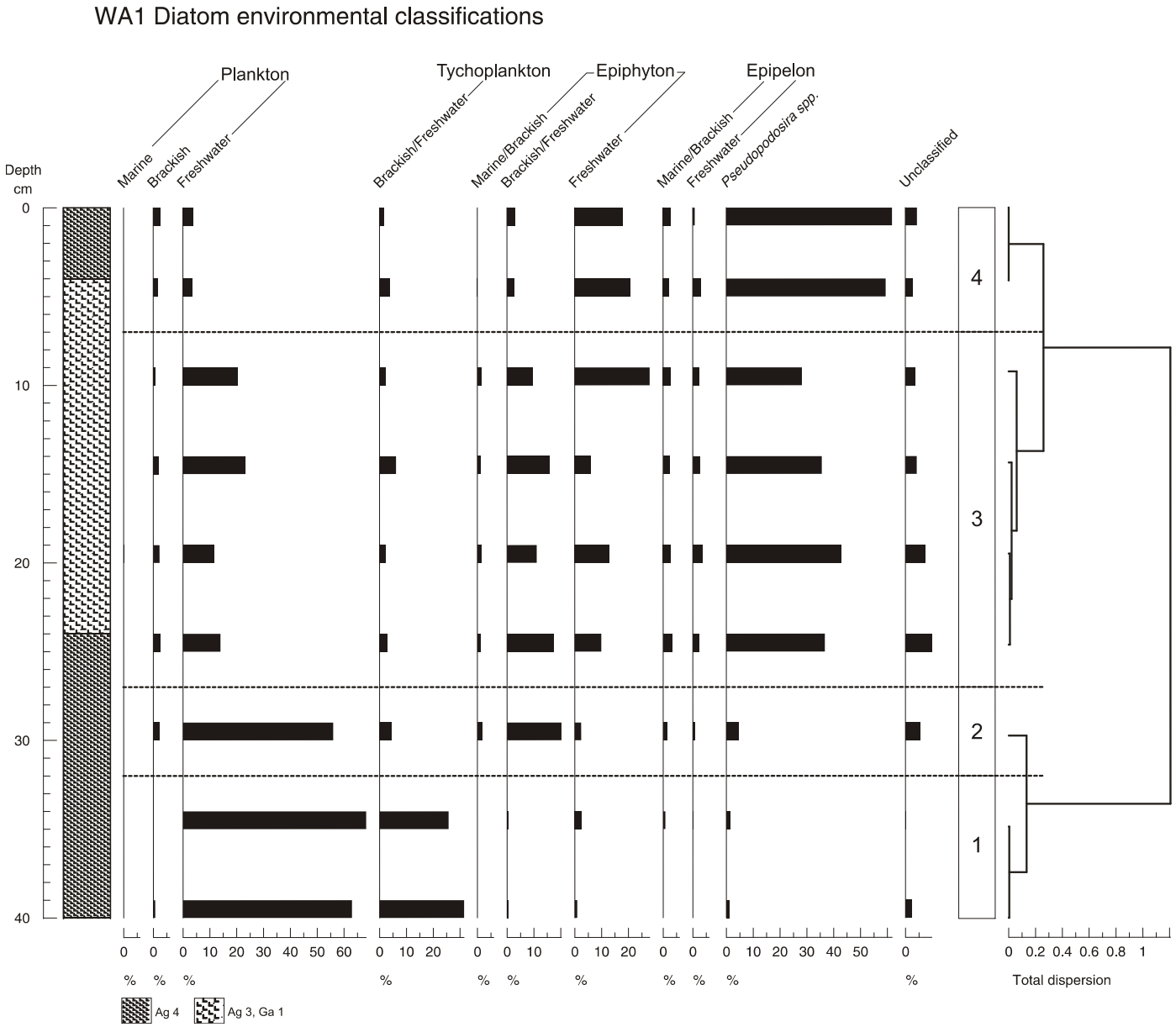

Figure 41: WA1 core diatom taxa grouped into environment preference categories.

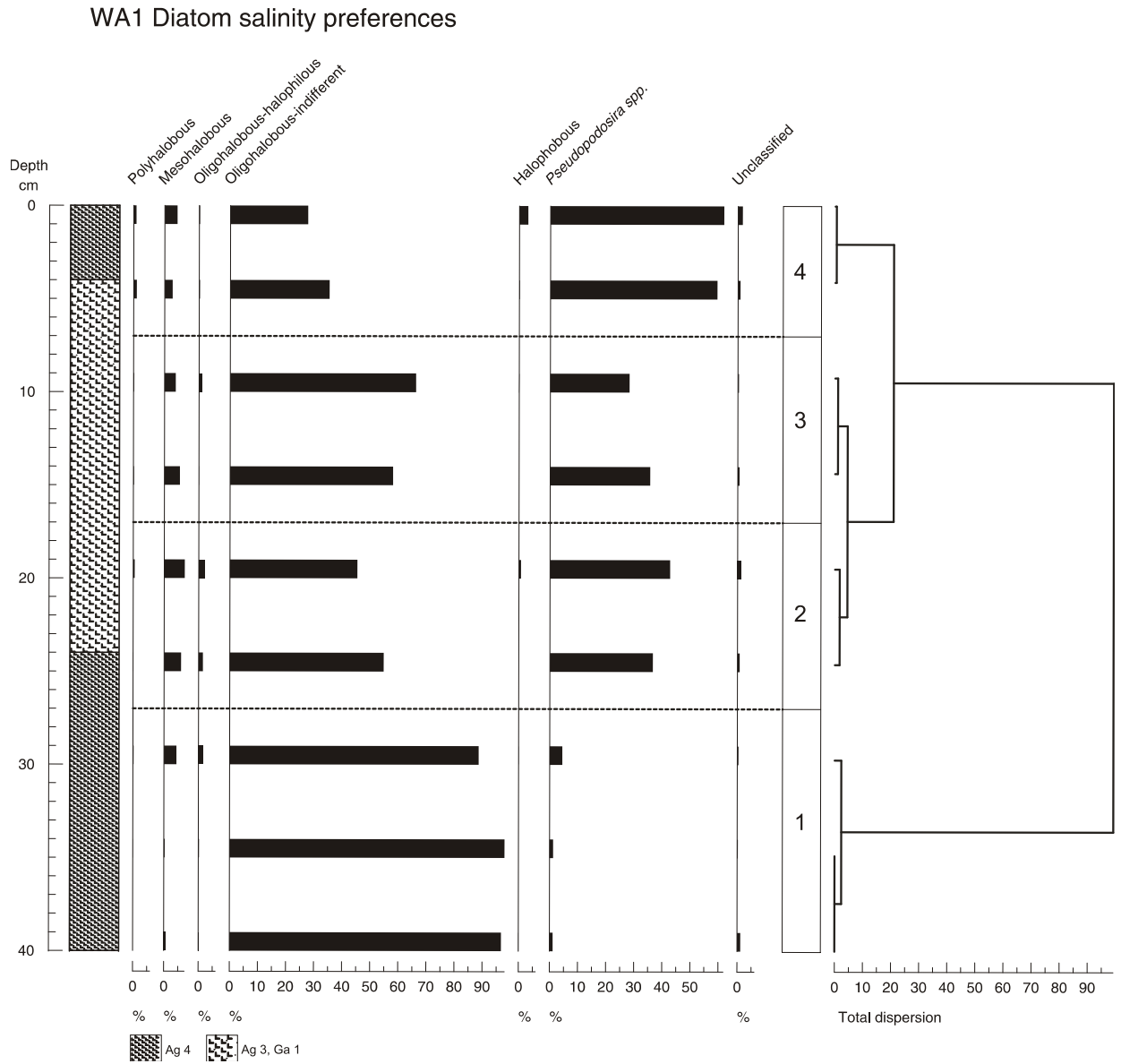

Figure 42: WA1 core diatom taxa grouped into salinity preference categories.

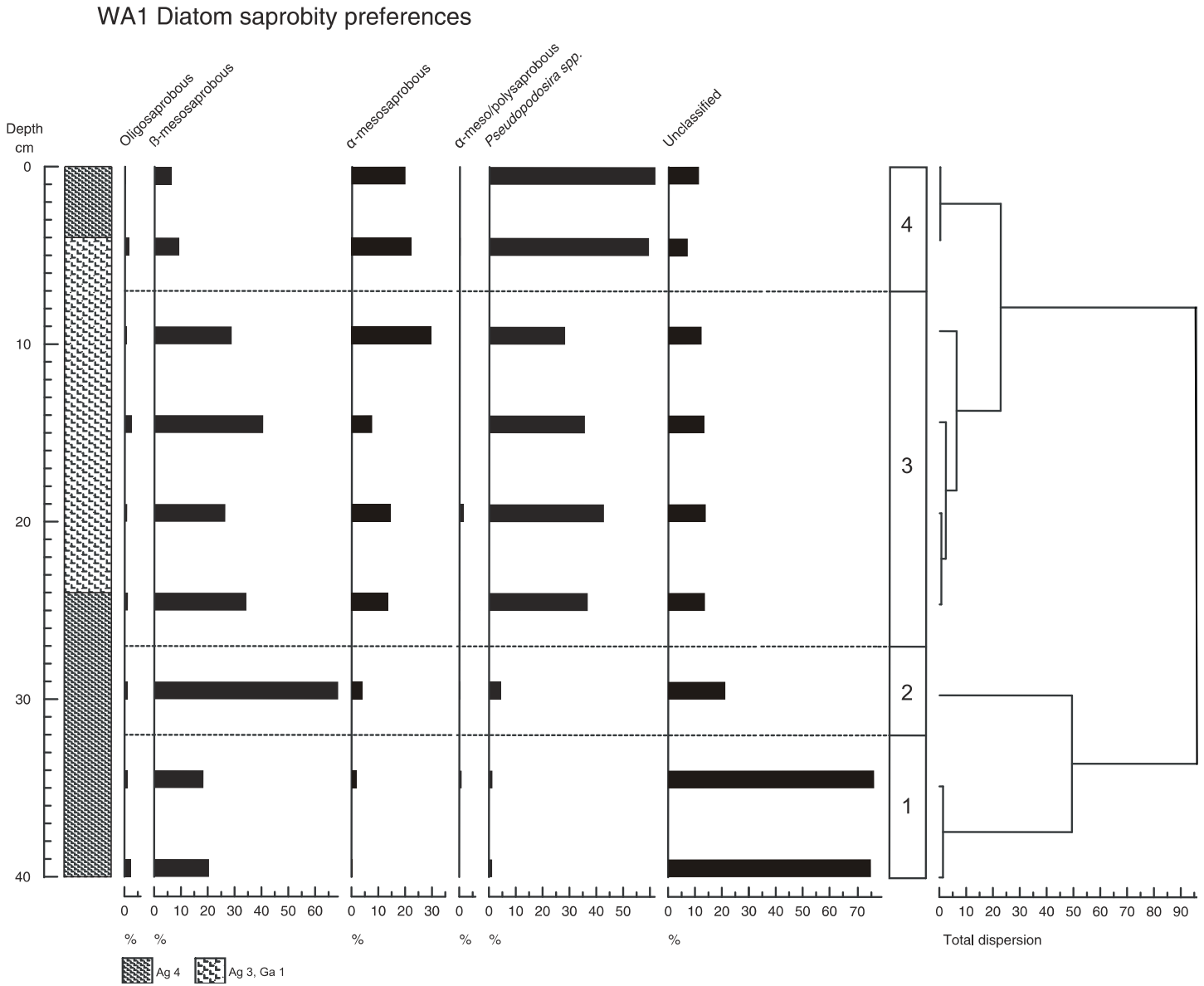

Figure 43: WA1 core diatom taxa grouped into saprobity preference categories.

6.4.2 WA1 core diatoms

Zone 1: 40 to 27 cm

- The dominant taxa within this zone are *Cyclostephanos spp.*, *Cyclotella stelligera* and *Aulacoseira ambigua* (*Figure 40*), with *Aulacoseira ambigua* being particularly prevalent in the 29-30 cm depth sample.
- These taxa are classified as oligohalobous-indifferent, although *Aulacoseira ambigua* and *Cyclostephanos spp.* have been classified as freshwater plankton by Harvey (1996) and Theriot et al. (1987) (*Figure 41*). This indicates that a predominantly freshwater environment prevailed within the basin in this period.
- These taxa are classified as planktonic or tychoplanktonic (*Figure 41*), indicating a deeper water body may have been present in this period.
- Taxa within this zone are classified as mainly α-mesosaprobous (*C. stelligera*) or β-mesosaprobous (*Aulacoseira ambigua*) (*Figure 43*), oxygen 50% (*Figure 56*) and nitrogen-autotrophic: tolerant (*Figure 57*) (e.g. *Cyclotella stelligera, Aulacoseira ambigua* and *Cocconeis placentula var. euglypta*). This seems indicate high nutrient levels within Waihora. However, taxa from 34 to 40 cm depth within this zone range from oligotrophic eutrophic (*Figure 58*), indicating that there my have been some variation in nutrient gradients across the lake.
- The abundance of spicules of a freshwater sponge species (*Heterorotula kakahuensis*) within this zone (*Figure 40*) is likely indicative of a freshwater, nutrient rich, low turbidity environment (Gee 1931).

Zone 2: 27 to 7 cm

- The dominant taxa within this zone are *Pseudopodosira spp.*, *Aulacoseira ambigua*, *Cocconeis placentula var. euglypta* and *Nitzschia amphibia* (*Figure 40*).
- This zone contains similar counts of mesohalobous to oligohalobous-halophilous (such as *Pseudopodosira spp.*) and oligohalobous-indifferent taxa (such as *Aulacoseira ambigua*, *Cocconeis placentula var. euglypta* and *Nitzschia amphibia*). Small numbers of mesohalobous taxa (such as *Cocconeis placentula var. lineata*) also occur in this zone (*Figure 42*). Therefore, higher salinities are indicated within this zone compared to the previous zone.

- There is a mix of freshwater plankton (such as *A. ambigua*), brackish/freshwater epiphytes (such as *C. placentula var. euglypta*) and freshwater epiphytes (such as *Nitzschia amphibia*) in this zone (*Figure 41*), indicating either the presence of a range of habitats within Waihora or highly changeable conditions within Waihora.
- Taxa within this zone are predominantly classified as ß-mesosaprobous/α-mesosaprobous (*Figure 43*), oxygen 50% (*Figure 56*), and eutrophic (*Figure 58*). Taxa classified as nitrogen autotrophic: tolerant, are the most common through this zone, although there is an increase in Nitrogen heterotrophic: tolerant taxa at 9-10 cm depth (*Figure 57*) (this continues through to zone 3). Therefore, it is likely that Waihora remains quite nutrient rich in this zone.

Zone 3: 7 to 0 cm

- Valves of *Pseudopodosira spp*. are particularly common within this zone. There are also high counts of *Nitzschia amphibia* (*Figure 40*). The former is likely to have salinity preferences ranging from mesohalobous to oligohalobous-halophilous, while the latter is classified as oligohalobous indifferent (Van dam et al., 1994), or as a freshwater plankton (Vos and De Wolf, 1993). The increase in *Pseudopodosira spp*. in proportion to other taxa may indicate an increase in salinity in this zone compared to the previous zone (*Figure 42*).
- Taxa within this zone are mainly α-mesosaprobous (*Figure 43*), oxygen 50% (*Figure 56*), eutrophic (*Figure 58*) and nitrogen heterotrophic: tolerant (*Figure 57*). Therefore, it is likely that nutrient concentrations remain high in Waihora through this period. It is the prevalence of Nitzschia amphibia within this zone that is contributing to this increase in nitrogen heterotrophic: tolerant taxa. This increase may be due to an increase in nitrogen within Waihora (nitrogen heterotrophic: tolerant taxa require periodically elevated nitrogen concentrations), or due to other factors such as epiphyte abundance, or salinity. However, this increase is most likely due to increased nitrogen, as it is unlikely that macrophyte abundance increased (to allow an increase in this epiphyte taxon), or salinity decreased (to allow an increase in this oligohalobous-indifferent taxon), within the period considered here (^{137}Cs reveals this is post-Wahine storm (1968) deposition).

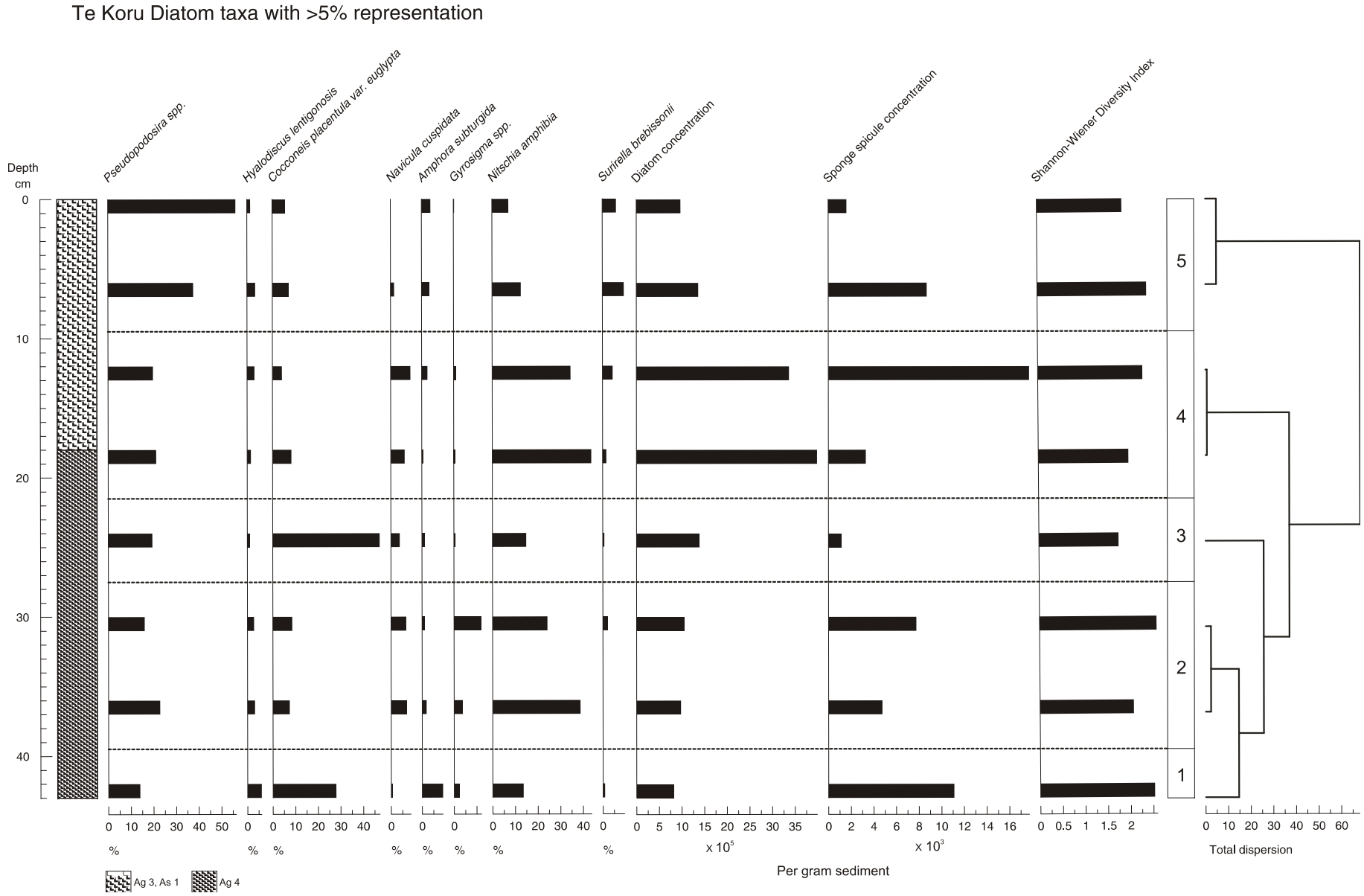

Figure 44: Te Koru core diatom taxa with >5% representation in any one or more samples.

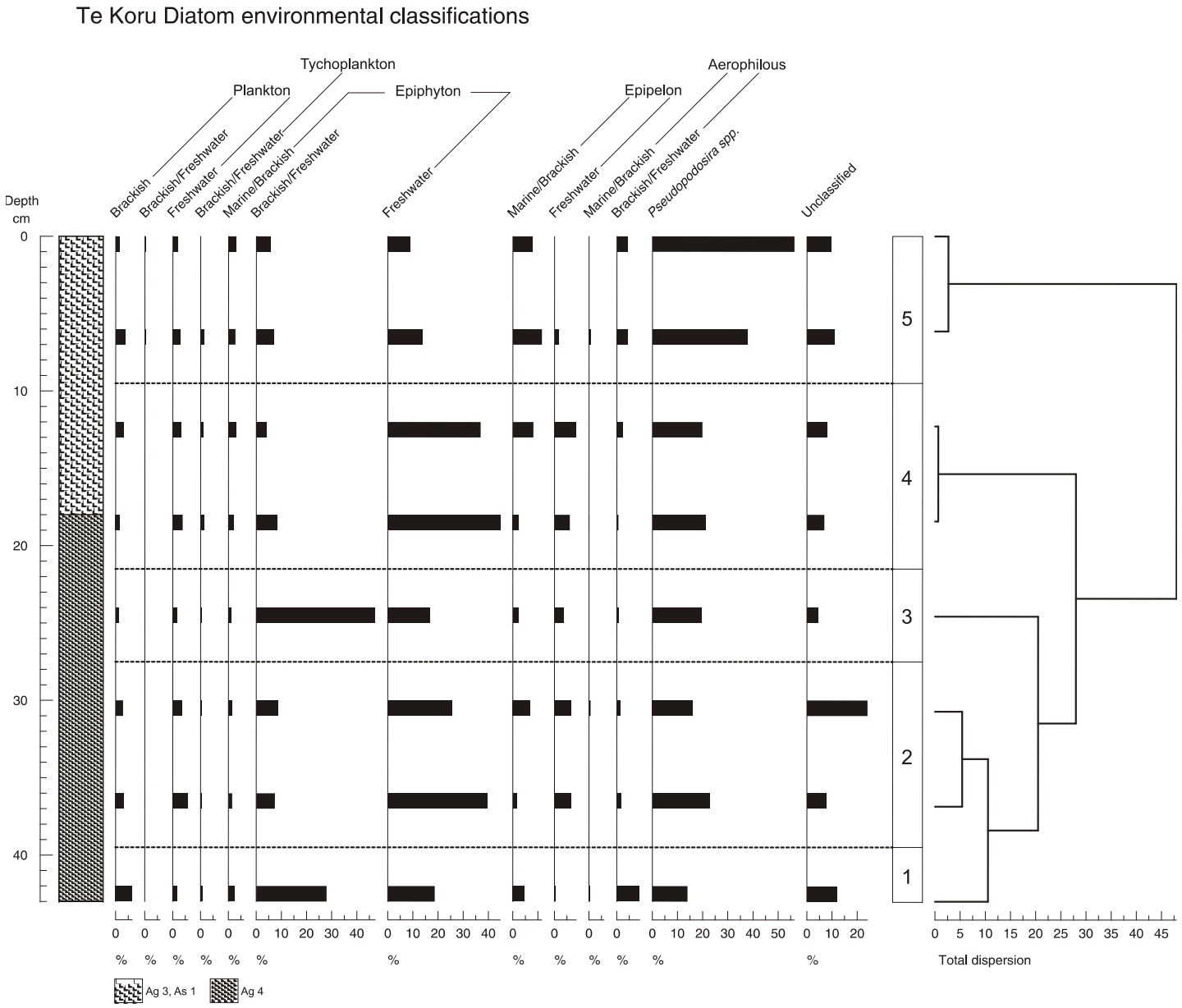

Figure 45: Te Koru core diatom taxa grouped into environment preference categories.

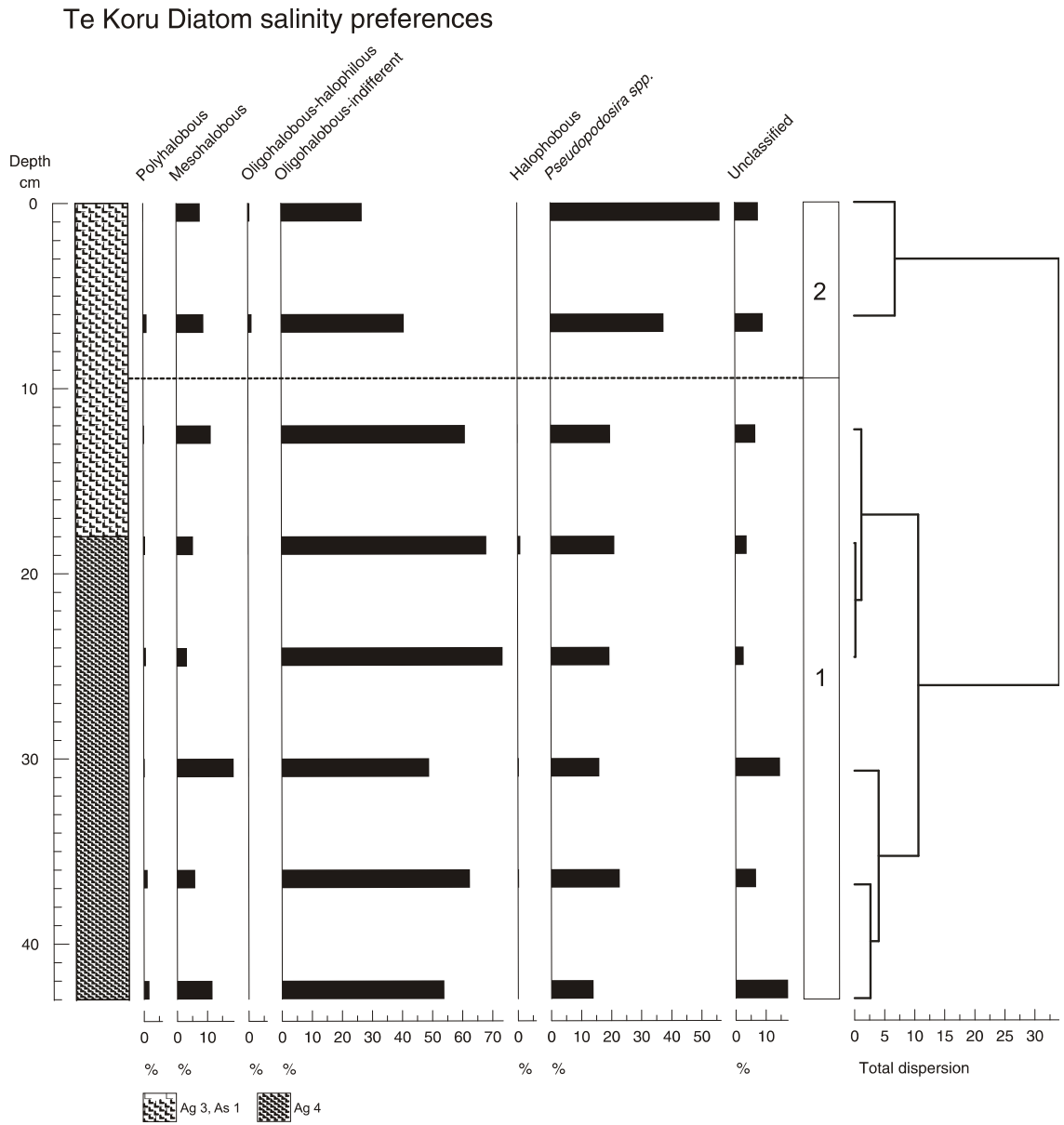

Figure 46: Te Koru core diatom taxa grouped into salinity preference categories.

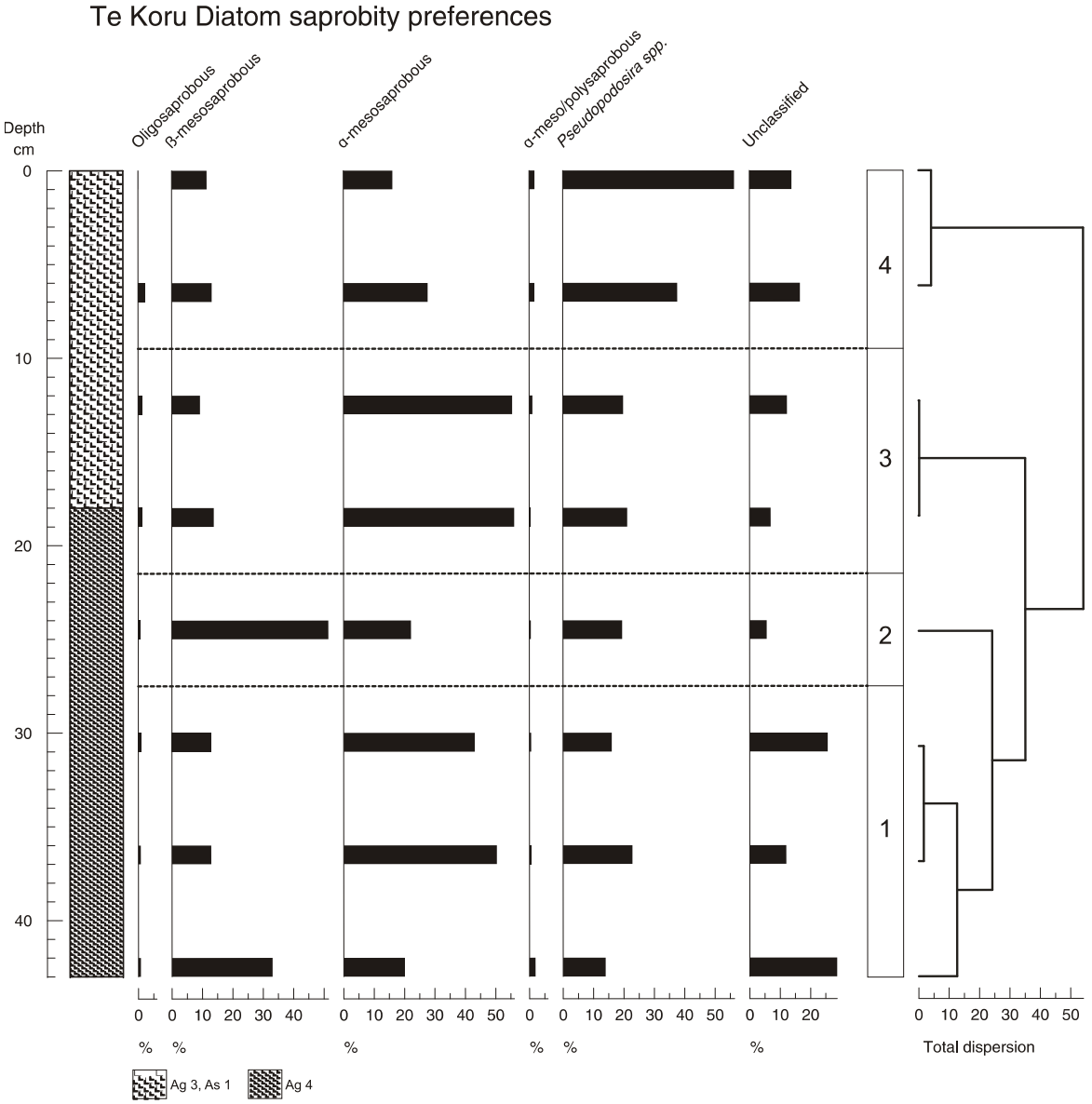

Figure 47: Te Koru core diatom taxa grouped into saprobity preference categories.

6.4.3 Te Koru diatoms

Diatom taxa composition remains fairly constant throughout this core. However, the proportionate abundance of taxa in samples, diatom concentration and sponge spicule counts appear rather variable throughout this core. It is likely that this is a reflection of variable conditions present at this site through time due to the proximity of the coring site to the location of lake openings and the regular occurrence of these openings during the deposition period of this core (^{210}Pb analysis revealed this core represents deposition ~ post 30 years ago. Shulmeister pers. comm.). Two zones were identified in this core.

Zone 1: 43 to 10 cm

- The dominant taxa within this zone are *Nitzschia amphibia*, *Pseudopodosira spp*. and *Cocconeis placentula var. euglypta* while, *Hyalodiscus lentiginosus*, *Navicula cuspidata*, *Amphora subturgida* and *Gyrosigma spp*. are also present in smaller numbers (*Figures 44, 45*).
- This is a mixture of Oligohalobous-indifferent (such as *N. amphibia* and *C. placentula var. euglypta*), mesohalobous (such as *Hyalodiscus lentiginosus*, *Tabularia fasciculata*, *Nitzschia apiculata*) and mesohalobous to oligohalobous-halophilous (*Pseudopodosira spp*.) taxa (*Figure 46*). There is little variation in the proportions of these groups throughout the core, indicating that salinity may not have changed much during the deposition period represented by this zone. Although there is little change in the diatom assemblage through this zone, the large range of salinity preferences of the taxa observed indicates either that a range of salinity gradients occurred in Waihora or salinity was changeable within Waihora through this deposition period (*Figure 46*).
- Taxa within this zone are mainly categorised as β-mesosaprobous to α-mesosaprobous, oxygen 50% (*Figure 61*) (such as *C. placentula var. euglypta* and *N. amphibia*), nitrogen autotrophic: tolerant (such as *C. placentula var. euglypta, N. cuspidata* and *A. ambigua*) to nitrogen heterotrophic: tolerant (*Figure 62*) (such as *N. amphibia*) and eutrophic (such as *C. placentula var. euglypta, N. cuspidata* and *N. amphibia*). This indicates high nutrient levels within Waihora during this deposition period. Indeed, this is the case throughout the whole of the Te Koru core. Oxygen and

trophic preferences remain stable through this zone; however, there is some variation in saprobity (*Figure 47*) and nitrogen preferences (*Figure 62*). There is a spike in β-mesosaprobous, nitrogen autotrophic: tolerant taxa and decrease in α-mesosaprobous, nitrogen heterotrophic critical taxa at 24-25 cm depth and to a lesser extent, 42-43 cm depth (*Figures 47 & 62*). This variation is caused by increased proportionate abundance of *C. placentula var. euglypta* compared to *N. amphibia* in these two samples (*Figure 44*). These changes may be related to a decrease in nutrient concentration within Waihora, or more likely, due to other factors, such as variation in salinity. Salinity variation is a likely factor, as *C. placentula var. euglypta* can probably tolerate higher salinities than *N. amphibia* (Van Dam et al. 1994; Vos and De Wolf 1993). Additionally, the close proximity of the Te Koru sampling site to the location of artificial barrier openings and the known occurrence of artificial openings during the deposition period represented here, supports this (^{210}Pb analysis revealed this core represents deposition ~ post 30 years ago. Shulmeister, pers. comm.).

Zone 2: 6 to 7 cm

- *Pseudopodosira spp*. is overwhelmingly dominant within this zone (*Figure 44*).
- The overall species composition of this zone is similar to the previous zone; however, there is a change in assemblage with the increased proportionate abundance of *Pseudopodosira spp*. (mesohalobous to oligohalobous-halophilous). It is likely that changing salinity within Waihora has caused this increase in *Pseudopodosira spp*. abundance.

Chapter 7 Discussion

This section examines the results of all proxies examined in each core separately and discusses the likely causes of these results. Inferred changes in the environmental condition within and around Waihora are explained in the context of the known environmental influences described in Chapter 1. Following this, the possible effects of these inferred environmental changes on the values of Waihora are examined. Finally, an indication of what constitutes a natural state for Waihora is given as well as some management suggestions based on the information produced here.

7.1 Examination of compiled core description, palynology and diatom data

7.1.1 WA09 core

WA09 core: zone 1 210-175 cm

- Radiocarbon analysis on woody material from 207 cm depth revealed a conventional radiocarbon age of 6760 ± 40 B.P. (calibrated: 7657 to 7491 B.P.) (*Table 3*).
- Sediment textural analysis revealed this sediment is likely to have been deposited in a lake or lagoon environment. However, there is some coarse sediment present, the characteristics of which indicates that these were likely derived from a fluvial or beach source (*Figure 17*).
- Loss on ignition analysis revealed LOI550 to be low (around 0.5%), indicating low levels of organic material preserved in the sediment of this zone (*Figure 20*).
- Despite a low LOI550 value, large quantities of organic material in the form of woody twigs and fragments occur in this zone (*Figure 20*) (see below for explanation).
- Large counts of Podocarpaceae and Cyperaceae pollen grains occur in this zone (*Figure 26 & 27*).
- Large counts of primarily freshwater (*Figure 37*), (oligohalobous-indifferent) (*Figure 38*), oligosaprobous/ß-mesosaprobous (*Figure 39*), oxygen 100% (*Figure 51*) and nitrogen autotrophic: critical taxa (*Figure 52*).
- Moderate counts of freshwater epiphytes occur in this zone (*Figure 37*).

Explanation:

The radiocarbon date from 207 cm within this zone provides valuable information on the early development of Waihora. The beginning of the WA09 record represents deposition

around 7500 B.P. (Calibrated radiocarbon result NZA 33828 from woody material in the WA09 core at 207 cm depth) (Appendix IX). It is likely that this core record includes all the lake/lagoon sediment occurring at this location in Waihora basin, as during coring an impenetrable, coarse sediment layer was reached. Therefore, the beginning of this record is likely to include the first stages of Waihora as a lake system following the initial estuarine stage of Waihora's evolution as a spit formed across the bay (see pp. 29-30 for explanation). This reveals, Waihora's existence as a lacustrine/estuarine sequence began around or just prior to 7500 B.P. The uncalibrated (conventional) radiocarbon age for this 207 cm depth sample is 6760 ± 40 B.P. This corresponds well to when sea levels approached current sea levels at this time (*Figure 48*). Thus, barrier formation began when sea levels were lower than present and a lake formed around the time ~ current sea levels were met. Armon (1974a) suggested this scenario based on the height of hooked ridges at the north-east end of the barrier. He suggested that these low lying ridges had to be formed at sea levels lower than present. Additional evidence of barrier formation during early-mid Holocene, when sea levels were lower than present, exists in the form of radiocarbon dates on shelly material at depths of between -36 and -18 m above MSL on the mid section of the barrier. These yielded ages between 9500 to 8000 ^{14}C years B.P. and suggests that barrier formation began at least before 8000 ^{14}C years B.P. (Brown unpublished data 1991, reported in Soons et al. 1997).

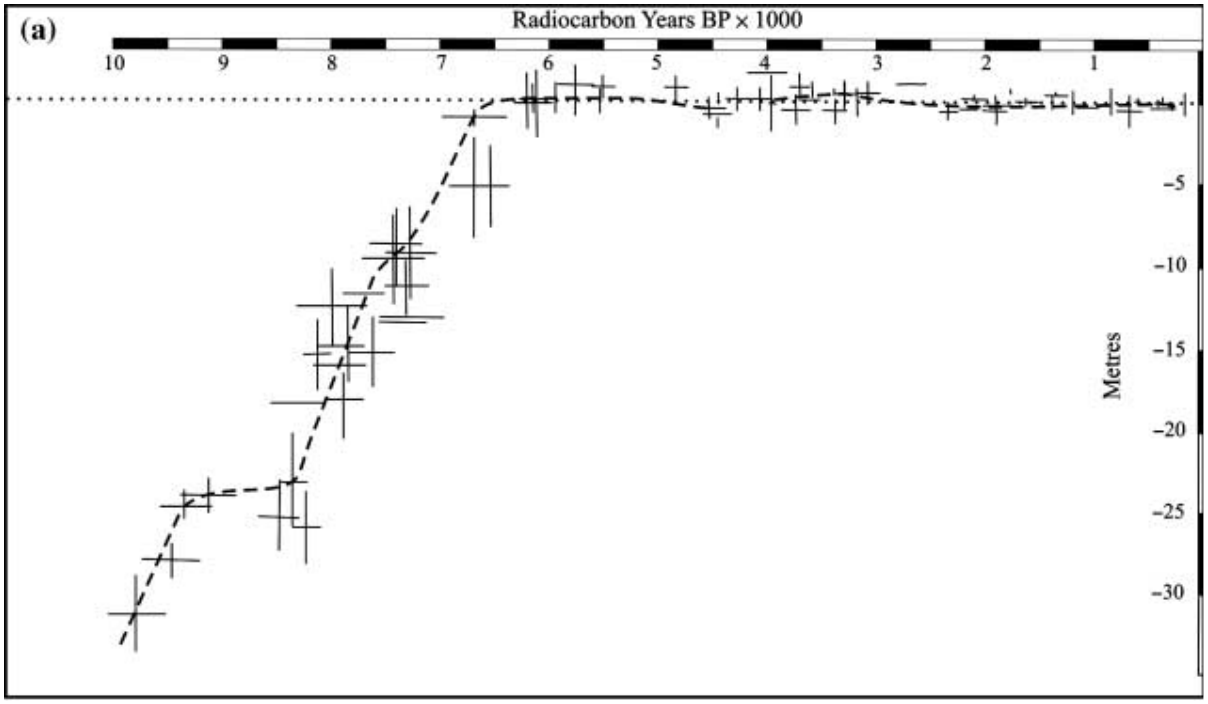

Figure 48: New Zealand sea level changes in the Holocene, produced by Gibb (1986). Conventional radiocarbon ages are displayed on the x-axis.

Diatom analysis reveals an abundance of *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata* remains in this zone, indicating that during this deposition period Waihora was a freshwater to slightly brackish lake, low in nutrients and high in oxygen. This is also reflected in the LOI550 results with low levels of organics indicated within this zone. The moderate counts of freshwater epiphytes indicates that macrophytes were present in Waihora during this time. In addition, the abundance of Cyperaceae pollen grains from the beginning of this zone indicates that soon after the basin was flooded with freshwater (following barrier closure) freshwater riparian vegetation flourished.

Although LOI550 indicated low levels of organic material in this zone, organics were present in the form of woody twigs and fragments. It is conceivable that the small amount of sediment used for LOI analysis enabled this organic matter to be missed during sampling. The abundance of woody fragments within this sediment (*Figure 20*) is probably associated with the flooding of the area surrounding the basin following barrier closure, or being washed in by a fluvial source. Water levels would have been determined by tide during the previous estuarine period, whereas, upon barrier closure lake levels were determined by the height at which overtopping would occur. Thus, the size of the water body increased, inundating the surrounding landscape and leading to the erosion and deposition of surrounding sediments and plant matter. This is also reflected in results of sediment texture analysis, with sediment present characteristic of a fluvial or beach source (*Figure 17*). It is likely that this fluvial and beach material was reworked and deposited in the basin.

WA09 core: zone 2 175-125 cm

- The abundance of poorly to very poorly sorted, fine skewed, very platykurtic silts and clays reveals this sediment is likely to have been deposited in a lake or lagoon environment (*Table 5*).
- LOI550 increases slightly in this zone compared to the previous zone (*Figure 20*). This is likely a reflection of decreased sediment size (see Chapter 4 pp. 59 for explanation).
- Counts of Podocarpaceae and Cyperaceae pollen grains remain high and a small spike in *Leptospermum* occurs at 140-141 cm depth (*Figure 26 & 27*).
- Diatom analysis reveals that *Pseudopodosira spp.* dominates the diatom assemblage during the period represented by this zone (*Figure 36*), while moderate counts of primarily freshwater (*Figure 37*) (oligohalobous-indifferent) (*Figure 38*),

oligosaprobous/ß-mesosaprobous (*Figure 39*), oxygen 100% (*Figure 51*) and nitrogen autotrophic: critical taxa (*Figure 52*) occur but gradually decline to zero towards the top of this zone.

Explanation:

The abundance of the brackish *Pseudopodosira spp*. and the decline to disappearance of the freshwater, low nutrient level preferring *Staurosirella pinnata* and *Pseudostaurosira brevistriata var. inflata*, is probably an indication of increased salinity within Waihora compared to the previous zone. For such a salinity increase to occur, there must have been an increase in the exchange of seawater between the sea and the lake. Seawater enters Waihora through four main mechanisms; airborne seawater exchange (sea spray), seepage through the barrier, overtopping and barrier breaches. However, it is recognised that the former two are likely to have minimal influence and it is unlikely that overtopping alone would cause the inferred salinity increase observed here. Thus, a permanent breach in the barrier existed in the period represented by this zone. Evidence within the lakes sediments of periods of higher salinity have been recorded by authors such as Soons et al. (1997), Hemmingsen (1997) and Harvey (1996). These authors suggest that the permanent barrier opening that led to these conditions was caused by the discharge of a large river, most likely the Waimakariri River into Waihora.

It is well documented that the large braided rivers on the east coast of the South Island have travelled along different paths in the past. These rivers form fans in the shape of cones of shingle where the rivers exit deep sided valleys to flow over more gently sloping surfaces. Slope decreases in a downstream direction and as it does, the force available to carry sediments decreases and they are deposited. The build up of an alluvial fan in this manner is called aggradation. Under natural conditions the deposition of shingle in the main bed of the river causes the channel course to change rapidly. The river then flows down a different path, a phenomenon known as channel avulsion. This usually occurs during a flood event following a period of aggradation (Boyle and Surman 2007).

It has been suggested by a number of authors such as Griffith (1991), Harvey (1996), Hemmingsen (1997), Holmes (1998), Johnston (1958) and Soons et al. (1997) that channel avulsion has led to the Waimakariri River discharging into Waihora basin in the past. Indeed,

evidence of Waimakariri River discharge into Waihora exists in the form of paleochannels (Griffith, 1991; Johnston, 1958) barrier breach geomorphologic features (Hemmingsen, 1997; Holmes (1998) and estuarine/marine sediment deposits (Hemmingsen 1997; Harvey 1996; Soons et al. 1997). The evidence presented in this thesis adds to the evidence of previous studies, that a large river has indeed discharged into Waihora in the past and subsequently a water body of increased salinity formed due to increased head volume maintaining a lasting barrier opening. Under these conditions, the lake drained, became tidal and freshwater discharged over a wedge of salt water entering the lagoon, causing brackish conditions.

Silt and clay is abundant within this zone suggesting that material reaching Waihora basin is either a fine fraction of sorted material brought in with the river, that the river carried with it mainly fine sediment to be deposited here, or that the inflow of the Waimakariri River had little effect on the size of sediment in the basin and the sediment there reflects lake/lagoon sedimentation processes only. The lack of valves belonging to freshwater, fluvial diatom taxa suggests the latter is true.

The abundance of Podocarpaceae pollen grains within this zone suggests that catchment vegetation has not been modified by human presence. Although, it should be mentioned that the large catchment area (256,000 ha), the large area covered by Waihora (16,000 to 24,200 ha) (Hemmingsen 1997) and its exposure to winds from many directions would lead to a large regional pollen signal in this lake. This could contribute to a muting of the classic Mäori burning induced Podocarpaceae pollen decrease that is seen in many more locally derived pollen records (Ogden et al. 1998). Additionally, Banks Peninsula remained heavily forested until the 1870's and the continual transport of pollen from this source would contribute to the muting of such as signal.

A spike in pollen grains of *Leptospermum* occurs at 140-141 cm depth within this zone. Spikes in grains of this taxon are often associated with disturbance events such as fire (McGlone and Wilmshurst 1999; Ogden et al. 1998). Without reliable time constraints on this zone of the core, it is difficult to determine if this spike is associated with a natural disturbance event or a human induced disturbance event such as fire ignited during early Mäori inhabitancy of the region, although the depth of this sample suggests the former is more likely to be true.

WA09 core: zone 3 125-45 cm

- Poorly to very poorly sorted, fine skewed, very platykurtic silts and sands are present through this zone indicating a lake/lagoon depositional environment (*Table 5*). However, the clay component is decreased compared to the previous zone and there are two sandy zones, indicative of high energy influence in the basin. The first of these sandy zones spans from 105 cm to around 83 cm core depth, while the second exists as a sand lens between 52 and 43 cm core depth (*Table 5 & Figure 20*).
- LOI550 is highly variable within this zone. This is likely a reflection of the variability in sediment size observed here (*Figure 20*).
- Counts of Podocarpaceae and Cyperaceae remain high, although, there is a slight decrease in the contribution of Cyperaceae and a slight increase in contribution of Chenopodiaceae grains to the pollen sum (*Figure 26 & 27*).
- Of the diatom taxa, the brackish water preferring *Pseudopodosira spp*. remains the most abundant, followed by the mesohalobous tychoplankton species *Pseudopodosira westii*, which only occurs in significant numbers within this zone (*Figure 36*).
- The brackish/freshwater epiphyte *Cocconeis placentula var. euglypta* occurs in moderate numbers within this zone, perhaps an indication of macrophyte presence during this deposition period (*Figure 36*).

Explanation:

The abundance of *Pseudopodosira spp. and Pseudopodosira westii* within this zone indicates a marine influence within Waihora. The moderate abundance of the oligohalobous-indifferent epiphyte *Cocconeis placentula var. euglypta* may be an indication of macrophyte growth around the lake margins. Although, it is noted by Vos and De Wolf (1993) that this taxon lives in aquatic environments of various salinities and it is also known that this taxon lives attached to a variety of substrates. Therefore, as *C. placentula var. euglypta* is the primary component of the freshwater epiphyte taxa in this zone, it cannot be inferred conclusively that freshwater conditions and prominent macrophyte growth occurred during this period, unlike zone 1 where the freshwater epiphyte taxa were more categorically so.

The change in the brackish diatom assemblage compared to the previous zone suggests either (1) a change in the dynamics of the permanent barrier opening system that occurred in the previous zone (so both zone 2 and 3 represent the same avulsion event) or (2) that this zone and zone 2 represent separate river avulsions into Waihora with a hiatus in sedimentation at the zone boundary.

Scenario 1:

It is reasonable to assume that upon channel avulsion towards the south, the Waimakariri River discharged into Waihora from the lowest topographical entry point. The Selwyn River currently occupies the interfan depression between the Rakaia and Waimakariri River fans. It is likely that upon avulsion southwards, the Waimakariri River would flow towards and then along this interfan depression. Evidence of a discharge point here exists as sediment associated with the development of a delta at the LII River mouth (Harvey 1996). Following this, aggradation may have led to the northward migration of the lower channel, to the position currently occupied by the Halswell River mouth, where it is reasonably well documented that the Waimakariri River entered Waihora in the past (Griffith 1991; Johnston 1958). If these zones represent a single occurrence of the Waimakariri River discharge into Waihora then northward migration could lead to a change in deposition condition within Waihora basin and a change in the diatom assemblage. However, as the appearance of *Pseudopodosira westii* is an indicator of either increasing salinity or increasingly tidal conditions in the basin (Vos and de Wolf 1988; Woodward and Shulmeister 2005), it seems more likely that this change in diatom assemblage would be caused by a shift in the position of the barrier opening, with the position of the barrier opening becoming closer to the lake basin.

Harvey (1996), Hemmingsen (1997) and Soons et al. (1997) propose that a mid Holocene breach in the barrier would have occurred at the Banks Peninsula end of the barrier when this end of the barrier was narrow, prior to the seaward transgression of the barrier here, due to the coast effectively turning on a hinge point. Conversely, a more recent barrier opening is likely to have occurred at the south-western end near Taumutu where the barrier is currently at its narrowest. Zone 2 may represent deposition while the barrier is open at the Banks Peninsula end, while zone 3 may represent deposition when the barrier is open at the south-western end. This scenario seems unlikely, as zone 3 appears to be more representative of a barrier opening close to the lake basin.

Movement of the barrier breach from an opening near Taumutu to one further north due to the action of longshore drift could lead to the influence of the barrier opening increasing at the basin core site due to its closer proximity. As *Pseudopodosira westii* is common in tidal inlets and large tidal channels (Vos and de Wolf 1988), the shift in discharge and barrier

breach position could have led to such conditions occurring in the basin during the zone 3 deposition period.

Alternatively, the dynamics of the barrier opening may have changed in a way that increased the influence of tides and seawater throughout the lake, leading to an increase in the abundance of *Pseudopodosira westii*. This is supported by the slight increase in Chenopodiaceae (halophytic flora) and the slight decrease in freshwater riparian vegetation (represented by a decrease in Cyperaceae) within this zone.

Scenario 2:

Zone 2 and zone 3 could represent separate occurrences of Waimakariri River discharge into Waihora if; following zone 2 deposition the Waimakariri River avulsed northwards to a discharge point north of Banks Peninsula and a freshwater environment prevailed, with freshwater deposits accumulating. The Waimakariri River avulsed again to a discharge point into Waihora and this led to the complete scouring of the freshwater deposits. Therefore, deposition during the second avulsion period occurred directly on top of sediment from the previous avulsion period. Consequently, it appears that there is only one period of increased salinity from 175 to 45 cm, however, this could represent more than one avulsion event. Indeed, it has been suggested by Hemmingsen (1997) and Soons et al. (1997) that the Waimakariri River has discharged into Waihora at least three times in the past, leading to the creation of estuarine conditions in Waihora basin. If the scenario outlined above is true then two of these events are likely to have occurred during the lakes history.

The information presented in section 1.6 (the history of Te Waihora according to previous research) provides clues towards when this/these avulsion event/events occurred. Soons et al. (1997) recorded the presence of sediments containing a brackish diatom assemblage below sediment derived from a freshwater lake dated at pre ~1500 years ago. Therefore, Waihora was a brackish water body sometime before ~1500 years ago and probably near the mid Holocene according to Soons et al. (1997) due to the discharge of a large river (probably the Waimakariri River) into the lake.

Evidence of a second avulsion event exists in the form of dates on estuarine shells of 775 ± 58 ^{14}C yr B.P, 561 ± 57 ^{14}C yr B.P. (Soons et al. 1997) and 670 ± 67 ^{14}C yr B.P.

(Hemmingsen 2001). Dates on woody material buried in a Waimakariri River paleochannel and within estuarine sediments revealed ages of 1190 ± 50 AD and 1265 ± 65 AD (^{14}C) (Johnston, 1958) and 937 ± 38 ^{14}C yr B.P (Soons et al. 1997) respectively. In summary, the dates presented above provide evidence for the occurrence of a Waimakariri River discharge induced brackish/estuarine lake condition between around 900 and 500 ^{14}C years ago.

The two sections of increased sediment size within this zone (one from 105 cm to around 83 cm and between 52 and 43 cm core depth) are likely to either represent increased energy associated with increased fluvial input or represent storm events that occurred while a channel between Waihora and the sea existed. It is difficult to distinguish between the two with the proxy data produced within these zones.

WA09 core: zone 4 45-15 cm

- Poorly sorted, symmetrical to fine skewed, very platykurtic silts and clays occur in this zone indicating a lake/lagoon depositional environment (*Table 5*).
- LOI550 increased slightly compared to the previous zone to around 1.5%, indicating an increase in organic content within the sediment (*Figure 20*).
- An increase in the remains of macrophyte material between 40 and 10 cm core depth
- Counts of Podocarpaceae pollen grains and those of other large trees begin to decline.
- A spike in fern spores occurs at 20-21 cm depth (*Figure 26 & 27*) indicating increased fluvial input/erosion/sedimentation (Wilmshurst and McGlone, 2005a; Woodward and Shulmeister, 2005).
- Large counts of *Pediastrum spp.* and the presence of algal zygospores and sheaths of *Gloeotrichia*-type cyanobacteria (determined though analysis of non-pollen palynomorphs) (*Figure 28*) indicate a nutrient rich, freshwater environment.
- Large counts of primarily freshwater (*Figure 37*), β-mesosaprobous/α-mesosaprobous (*Figure 39*), oxygen 50% (*Figure 51*), nitrogen-autotrophic: tolerant (*Figure 55*), eutrophic to hypereutrophic (*Figure 53*) tychoplankton and plankton (*Figure 37*).
- Large counts of sponge spicules (*Figure 36*).

Explanation:

Following the avulsion of the Waimakariri River to a discharge point north of Banks Peninsula a freshwater lake once again formed. The diatom assemblage within this zone consists almost exclusively of freshwater plankton forms (mainly *Aulacoseira ambigua*,

Cyclostephanos spp., *Cyclotella stelligera* and *Staurosirella pinnata*) that prefer high nutrient level conditions, indicating the occurrence of a predominantly freshwater, nutrient rich lake in this period. This is supported by the increase in LOI550 and the abundance of phytoplankton remains, such as *Pediastrum spp.*, *Gloeotrichia* type cyanobacteria and increasing algal zygospores within this zone, determined through the analysis of non-pollen palynomorphs. Therefore, with the decrease in hydraulic head upon the avulsion of the Waimakariri River to a discharge point north of Banks Peninsula, the barrier closed due to the action of longshore drift separating Waihora from the sea once again. The high abundance of planktonic forms compared to benthic forms (epiphytes, epipelon, episammon) is likely an indicator of either a deeper lake (deeper than modern lake) (Soons et al. 1997). The abundance of macrophyte material remains within bottom of this zone (*Figure 20*), indicates that upon barrier closure conditions conducive to macrophyte growth occurred. These remains are not present in the most recent sediment, at the top of this core, reflecting the lack of macrophytes within the lake in recent times.

Sponge spicule counts dramatically increase in this zone (*Figure 36*). The spicules observed here were also observed by Harvey (1996) and were determined to belong to *Heterorotula kakahuensis*. This is a freshwater sponge species that is widespread throughout New Zealand. The presence of this sponge species within Waihora during this deposition period is likely an indicator of freshwater conditions. Additionally, sponges feed on organic particles, plankton and bacterial suspended in the water column, so an abundance of these may indicate nutrient rich freshwater conditions. Moreover, sponges do not survive well in muddy water containing large amounts of solid matter (Gee 1931). Therefore, the abundance of sponges during this period may be an indicator of low turbidity within Waihora.

The contribution of Podocarpaceae pollen grains to the pollen sum decreases from the beginning of this zone (*Figure 27*). As described in the zone 2 explanation, grains of Podocarpaceae present within this core are likely to have a wide ranging source, and may be highly influenced by the vegetation of Banks Peninsula. Therefore, the decrease in these grains from around 30 cm core depth (*Figure 27*) is likely associated with the intensive European deforestation of the catchment and Banks Peninsula.

An increase in spores of monolete ferns and *Cyathea spp.* (tree ferns) is observed at around 20 cm depth. This increase in fern spore contribution to the pollen sum may be due to an

increase in fern abundance around Waihora (*Cyathea spp.* spores are poorly wind dispersed) (Macphail and McQueen 1983). However, previous literature suggests other reasons for such spikes in pollen records. Spikes in fern spores are associated with an increased fluvial input and increased deposition of catchment soil (Wilmshurst and McGlone 2005; Woodward and Shulmeister 2005). This is due to the high resistance to deterioration of fern sores within sediment due to their thick exines and high sporopollenin content. Consequently, fern spores tend to be over-represented in catchment soils, and with increased erosion and deposition of these catchment soils within lakes, fern spore counts increase (Wilmshurst and McGlone 2005). This increase in sedimentation is also reflected in ^{210}Pb results, with a decrease in ^{210}Pb activity in the WA09 core from around 30 to 10 cm core depth (*Figure 16*). This decrease is caused by the increase in sedimentation of older ^{210}Pb depleted sediment. ^{137}Cs analysis on sediment from the WA09 core indicates a date of 1965 around 10 cm depth. Given that the spike in fern spores occurs before this date is likely to be a signal representing increased catchment erosion and deposition in Waihora following the deforestation of Banks Peninsula from the 1870's, and/or channelisation of the Halswell, LII and Selwyn Rivers (1890 – 1940's).

WA09 core: zone 5 15-0 cm

- Poorly sorted, symmetrical to fine skewed, very platykurtic silt and clay indicating a lake/lagoon depositional environment (*Table 5*).
- LOI550 increases compared to the previous zone to >2% in the top sample of the core (*Figure 20*), indicating an increase in organic content.
- Pollen grains of exotic taxa such as *Pinus* and *Plantago* appear in the pollen record, indicating European habitation and European influenced environmental modification (*Figure 26*).
- The contribution of Podocarpaceae grains to the pollen sum continues to decrease, likely as a result of continued deforestation and the replacement of native trees by exotic flora (*Figure 26*).
- The contribution of Chenopodiaceae pollen grains increases dramatically to around 20% of the pollen sum (*Figure 26 & 27*).
- The abundance of algal zygospores is increased compared to the previous zone (*Figure 28*).
- An increase in the abundance of *Pseudopodosira spp*. valves occurs in this zone (*Figure 36*).
- The abundant freshwater (*Figures 37, 38*), β-mesosaprobous/α-mesosaprobous (*Figure 39*), oxygen 50% (*Figure 51*), nitrogen-autotrophic: tolerant (*Figure 52*),

eutrophic to hypereutrophic (*Figure 53*) tychoplankton and plankton (*Figure 37*) in the previous zone are replaced by mesohalobous to oligohalobous-indifferent (*Figure 38*) plankton and epiphytes (*Figure 37*) in this zone.

- The abundance of nitrogen heterotrophic: tolerant diatom taxa begin to increase in this zone (*Figure 52*).

Explanation:

From 10 cm and above in the WA09 core and from 27 cm and above in the WA1 core the diatom assemblage changes from one representing the lake state described in the previous zone to one dominated by *Pseudopodosira spp*. This transition is interpreted as a change in conditions within Waihora, from a freshwater lake, deeper than the current lake, to a brackish, shallow water body that exists today. This transition is described in detail in WA1 core: zone 2 27-7 cm, pp. 135-137.

A change in flora surrounding Waihora is apparent in the pollen record of the WA09 core. At 10 cm and above there is a large observable increase in pollen grains of Chenopodiaceae, most likely *Sarcocornia quinqueflora*, commonly known as glasswort (Thannheiser and Holland, 1995). This is a dominant species of the salt marsh flora surrounding Waihora (Te Waihora Joint Management Plan 2005). The increase in the contribution of *Sarcocornia quinqueflora* grains to the pollen sum may be caused by one or more of the following factors:

1. Distribution of saline herbfields and brackish mudflats is unchanged. Instead, there has been a recent increase in the distribution of *Sarcocornia quinqueflora* within the halophytic communities. This could be due to this species out-competing others in recent environmental conditions because of:
    (a) Increased salinity in the previously saline sediments.
    (b) Favourable climatic conditions for *Sarcocornia quinqueflora* growth.
    (c) Increased predation on other halophytic species
2. Overall increase in the distribution of saline herbfields and brackish mudflats due to:
    (a) Climatic variation
    (b) Increased regularity of herbfield and mudflat inundation
    (c) Increased lake salinity

Interspecific competition between halophytic plant species may contribute to the recent increase in *Sarcocornia quinqueflora* pollen grains. A study of the halophytic vegetation surrounding Waihora carried out by Evans (1953) found that four species occupied areas of similar salinity around Waihora; *Triglochin striata* (arrow-grass), *Puccinellia stricta* (salt grass), *Hordeum marinum* (sea barley grass) and *Sarcocornia quinqueflora* (glasswort), (although, Evans (1953) reported the latter as *Salicornia australis*). As each of these species occupy areas of similar salinity, this is not considered a critical factor towards competitive exclusion.

The possibility of climatic variation affecting either; the abundance of *Sarcocornia quinqueflora* within saline herbfields and brackish mudflats, or an overall increase in the distribution of saline herbfields and brackish mudflats, has been examined. Climate is fairly uniform around Waihora, therefore small scale climatic variation is unlikely to be a contributing factor here (Evans 1953). However, it is likely that there has been some change in climate in recent times (NIWA National Climate Database 2010). However, as salt marsh flora are highly climate tolerant, this is not considered an important factor here.

Sarcocornia quinqueflora may out-compete the other halophytic species if these other species are preferred by grazing or browsing animals. However, according to Evans (1953) this scenario is unlikely, as grazing waterfowl such as Canadian geese do not adversely affect halophytic plants, cattle feed on higher elevated zones and although sheep do feed on *Triglochin striata* and *Puccinellia stricta*, these plants "…do not seem to have been greatly modified by their grazing…animals do not seem to have exerted any decisive influence on vigour and composition of the vegetation…" (Evans 1953, pg. 107).

It is likely that the increase in the contribution of *Sarcocornia quinqueflora* grains to the pollen sum is due to an overall increase in the distribution of saline herbfields and brackish mudflats around Waihora. This may be caused by increased regularity of herbfield and mudflat inundation-drainage-evaporation cycles and/or an increase in lake salinity. It is demonstrable through analysis of the available lake opening data from 1901 onwards that the number of lake openings per year has increased (*Figure 6*). So the lake has been subjected to an increase in the occurrence of inundation-drainage-evaporation cycles.

Water levels within Waihora naturally increase with fluvial and groundwater inputs (inundation) and when the lake is opened to the sea and waters containing salts subside (emergence). As they do so pooling of waters around the lake margins occurs. These shallow pools are left to evaporate, which leads to concentration of salts. This process occurs every time the lake is opened to the sea, which prior to human control of lake levels only occurred every 5-6 years or so, through natural overtopping and subsequent channel creation (Horrell 1992). Current lake level management practices have lead to an increase in the occurrence of this process, thus salinisation of lake margin soils.

It is likely that the increase in overall lake salinity in recent times, due to lake level management (as indicated by diatom analysis (*Figures 37, 38*)) increases the salinisation effect caused by the inundation-drainage-evaporation cycle described above. The pooled water, left after lake level decrease, has a higher chloride content, due to the increased regularity of seawater intrusion with increasing regularity of lake openings. Therefore, it is likely the combination of increasingly regular inundation-drainage-evaporation cycles and an increase in average lake salinity that is causing an increase in salinity of sediments surrounding the lake, leading to an increase in the distribution of saline herbfields and brackish mudflats. It is recognised that halophytic plants (particularly *Sarcocornia quinqueflora*) have been a common component of the plant community surrounding Waihora for some time. The study by Evans (1953) reports large numbers of these plants. Therefore, it can be surmised that the increase in *Sarcocornia quinqueflora* (as indicated in the pollen record) is likely to have occurred prior to 1953 and thus, prior to the modern lake level management practices that have been implemented since 1947. This suggests that lake level management and increased lake salinity, prior to the modern management regime led to an increase in the abundance of halophytic plants surrounding Waihora. The abundance of these around the 1980's is noted in *Figure 49*. Pollen analysis suggests it is likely that they had a wider distribution sometime prior to this date.

Nitrogen heterotrophic: tolerant diatom taxa (particularly *Nitzschia amphibia*) increase within this zone. This is likely to represent an increase in nitrogen within Waihora and is described in further detail in the corresponding depth of the WA1 core: zone 3 7-0 cm, pp. 137-138.

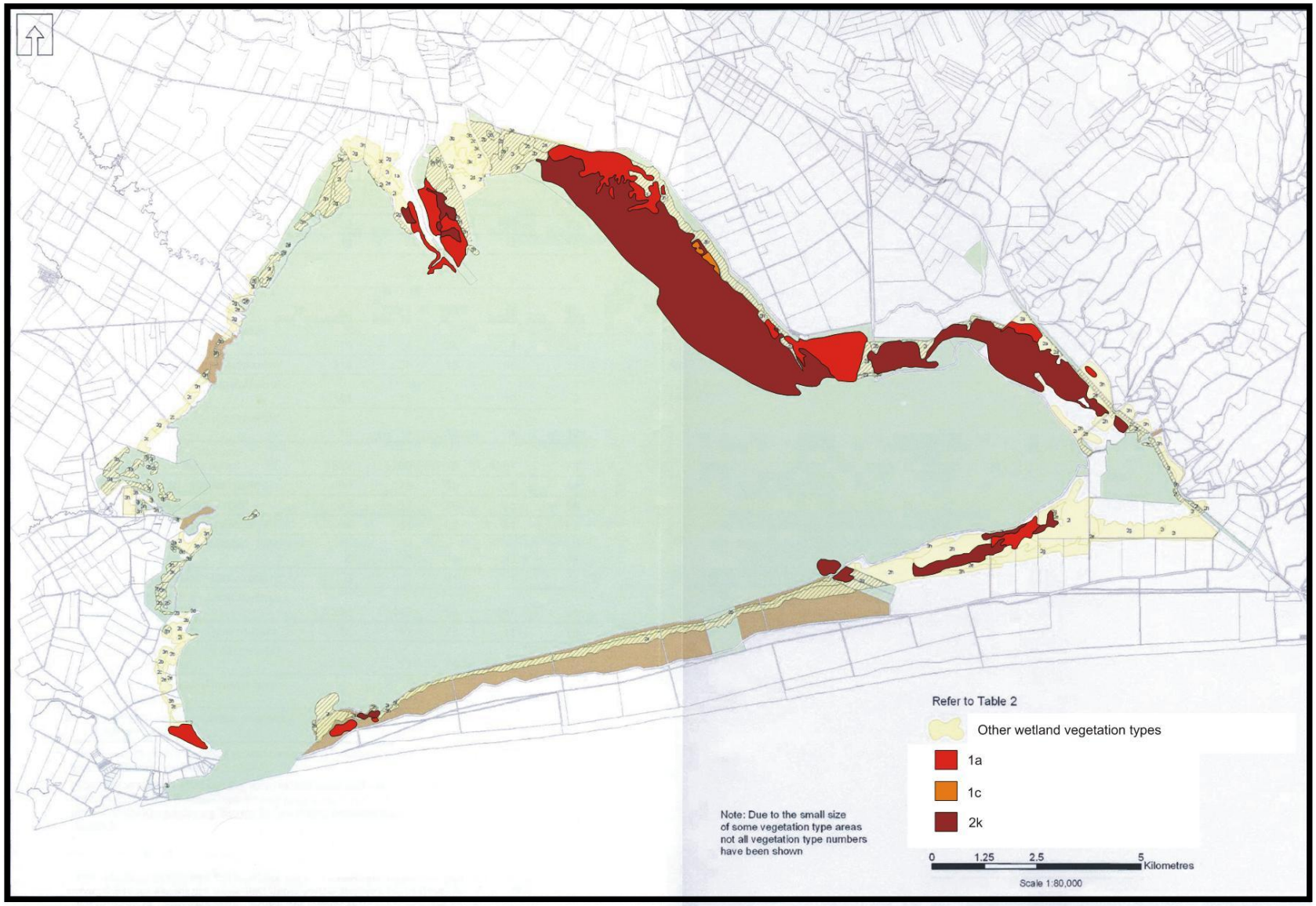

Figure 49: Distribution of vegetation types containing *Sarcocornia quinqueflora*. 1a = Saline herbfield. 1c = Saline mudflat. 2k = Brackish mudflat. Modified from: Te Waihora Joint Management Plan (2005).

7.1.2 WA1 core

WA1 core: zone 1 40-27 cm

- Poorly sorted to very poorly sorted, symmetrical to strongly skewed towards fine particles, very platykurtic silt with smaller amounts of sand and clay (*Table 6*), indicating a lake/lagoon depositional environment.
- Large counts of primarily oligohalobous-indifferent (*Figure 42*), α-mesosaprobous-mesosaprobous (*Figure 43*), oxygen 50% (*Figure 56*), nitrogen-autotrophic: tolerant (*Figure 57*) plankton and tychoplankton (*Figure 41*).

Explanation:

This zone corresponds to zone 4 of the WA09 core (determined through ^{137}Cs dating and the similarity in diatom zonation). Analysis of sediment characteristic and diatom valves reveals deposition during this period occurred in a freshwater, nutrient rich lake environment. For further details on this zone refer to 'WA09 core: zone 4, 45-15 cm' explanation on pp. 128-129.

WA1 core: zone 2 27-7 cm

- Poorly sorted to very poorly sorted, coarse skewed to strongly skewed towards coarse particles, very platykurtic silt and sand, indicating a lake/lagoon depositional environment with some higher energy input (*Table 6*).
- Decreased ^{210}Pb activity from around 20 to 10 cm core depth (*Figure 16*).
- Moderate counts of oligohalobous-indifferent (*Figure 42*), ß-mesosaprobous/α-mesosaprobous (*Figure 43*), oxygen 50% (*Figure 56*), nitrogen autotrophic: tolerant (*Figure 57*) plankton and tychoplankton (*Figure 41*).
- *Pseudopodosira spp*. appears in this zone and is the most common taxa encountered (*Figure 40*).

Explanation:

Freshwater plankton that prefer nutrient rich waters remain moderately abundant in this zone. However, there are also large counts of *Pseudopodosira spp.* (brackish taxon) and small numbers of mesohalobous taxa, indicating an increase in lake salinity compared to the

previous zone. ^{137}Cs is present in the sediment record from sample 25-26 cm and above, but not in sample 31-32 cm and below. Thus, the appearance of ^{137}Cs in the record occurs somewhere between 26 and 32 cm depth in the WA1 core. Nuclear testing began in the southern hemisphere in 1952 and ended in 1974 (Reiser pers. comm.). Therefore, this transition in diatom assemblage probably occurred between the late 1940's and early 1950's. This predates modern monitoring practices undertaken within Waihora, which began in earnest in 1983. However, examination of possible influences upon the lake occurring around this time provides clues towards the cause of this environmental change (this information is presented in Chapter 1). Documentation of lake opening data such as height at opening, height at closure, duration of opening, number of openings, has been recorded since 1901. A significant change in lake management practice occurred in 1947 (*Figure 6*). In this year, an arrangement was made between the Ellesmere Land Drainage Board and the North Canterbury Catchment Board, that the lake would be opened when the level reached 1.05 m above mean sea level during summer months from August to March, and 1.13 m above mean sea level in winter from April to July. This led to an increase in the number of lake openings per year and a decrease in the average height (above MSL) the lake is opened each year (*Figure 6*). Thus, the transition from a largely freshwater lake to one with increased salinity as indicated by diatom data (*Figures 41 & 42*), is likely due to increased occurrences of saltwater intrusion into Waihora with the increasing regularity of lake openings. Additionally, from 1957 onwards the lake has been maintained at lower levels (*Figure 6*). This may have contributed to the decrease in planktonic diatoms and an increase in benthic forms (*Figure 41*). This regime of lake level management continues today.

A shell hash layer occurred at 19-20 cm depth containing mainly remains of *Potamopyrgus antipodarum*. This layer was probably formed during a significant or catastrophic event. The appearance of ^{137}Cs at between 26 and 32 cm depth suggests this layer was deposited during/following the Wahine storm of 1968 (a large storm that sunk a ferry named the Wahine). Sediment texture analysis reveals that sediment from 20 to 9 cm has been subject to some higher energy influence (poorly sorted to very poorly sorted, coarse skewed to strongly skewed towards coarse particles, very platykurtic silt and sand). Additionally, ^{210}Pb analysis reveals a decrease in ^{210}Pb activity from around 20 to 10 cm core depth (*Figure 16*), indicating increased deposition of older ^{210}Pb depleted catchment sediments here, during and following this high energy event. Thus, it is likely that 20cm is the base of Wahine storm affected material and finer materials were mixed and deposited above this layer to a depth of

9 cm. The effects of this mixing is displayed in Shannon-Weiner diversity values, which are increased in this zone (*Figure 40*). This is likely a reflection of mixing recent and older sediments as well as the deposition of valves from various locations (various environments) around the lake through sediment focusing. Consequently, the material from 20 to 9 cm depth was likely deposited during and soon after the Wahine storm and it is the zone above this, from 7-0 cm depth that indicates post-Wahine lake conditions. These conditions are described in 'WA1 core: zone 3 7-0 cm' below.

WA1 core: zone 3 7-0 cm

- Poorly sorted, fine skewed to strongly skewed towards fine particles, very platykurtic silt and sand occurs here, indicating a lake/lagoon depositional environment (*Figure 6*).
- *Pseudopodosira spp*. are particularly common in this zone at around 60% of the diatom assemblage (*Figure 40*).
- Oligohalobous indifferent (*Figure 42*), α-mesosaprobous (*Figure 43*), oxygen 50% (*Figure 56*), eutrophic (*Figure 58*) and nitrogen heterotrophic: tolerant (*Figure 57*) taxa are common within this zone.

Explanation:

This zone represents recent, post-Wahine storm deposition. Valves of *Pseudopodosira spp.* are overwhelmingly common in this zone (*Figure 40*), probably due to increasingly brackish conditions occurring during this recent deposition period. This increase in salinity is likely due to the continuation of regular lake openings in order to protect farmland from inundation (*Figure 6*) (see explanation on p. 136 above).

The increase in nitrogen heterotrophic: tolerant diatom taxa in this zone (*Figure 57*) (primarily *Nitzschia amphibia*) is likely an indication of increasing nutrient levels within Waihora. Analysis of Environment Canterbury Monitoring Data (Wilks pers. comm.) reveals that there has been no obvious trend in total nitrogen or total phosphorus concentrations within Waihora basin since monitoring began in 1983. Therefore, this is likely a signal of increased nitrogen input into Waihora which began before the start of monitoring in 1983. In addition, this increase in nitrogen heterotrophic: tolerant diatom taxa occurs above shell hash layers at 10 cm in the WA09 core and at 19-20 cm in the WA1 core, which are interpreted as

Wahine storm (1968) deposits. Thus this increase in nitrogen within Waihora occurred before modern monitoring began (1983) but around the time or soon after the Wahine storm occurred (1968). Examination of historical records (see Chapter 1, pp. 4-15) reveals an increase in agricultural intensity and abstraction in the catchment from the 1970's. It is most likely this change in land use that caused this recent increase in nutrients within Waihora.

Nitrogen within Waihora is likely to be influenced by increased sedimentation and the increase in farming intensity in the catchment. It is likely that sedimentation within Waihora has increased since land reclamation of wetlands around the lake began around the 1880's (Bowden et al. 1983). This facilitates increased erosion in that area and also allows for direct transport of nutrient rich sediment to the lake. Farming within the catchment has intensified since the early 1970's, particularly with an increase in dairy agriculture. Dairy agriculture requires large volumes of water for irrigation and as groundwater became more accessible in the 1970's the intensity of this farming practice increased (Bowden et al. 1983). Thus, it is likely that the continued destruction of wetlands and the increase in intensity of agriculture and abstraction since the 1970's, has led to an increase in nitrogen levels within Waihora. It should also be noted that although proxies were not used to surmise levels of phosphorus in this study, it is probable that phosphorus concentrations have increased through the same mechanisms as described above. This is due to the strong correlation between total nitrogen and total phosphorus in Waihora, since monitoring began in 1983 ($F = 0.00$, $\alpha = 0.05$).

7.1.3 WA2 core

WA2 core: zone 1 38-18.5 cm

- Abundant *Pinus* and Poaceae are present throughout this core indicating this core represents post-European settlement deposition (*Figures 29 & 30*).
- Cyperaceae pollen grains are abundant through this core, indicating the presence of wetland riparian vegetation throughout this deposition period (*Figure 29 & 30*).
- Chenopodiaceae grain counts are moderate at the beginning of this core, but decrease to background levels above the bottom sample (*Figure 29 & 30*).

Explanation:

This gravity core captures recent changes in vegetation in the catchment and around Waihora. Indeed, the presence of indicators of European environmental modification such as *Pinus* and Poaceae pollen grains throughout this core indicates that deposition of this sediment occurred post-European settlement. The abundance of Cyperaceae indicates that throughout this relatively recent deposition period, freshwater wetland flora was common around the lakes riparian margins. However, the moderate counts of Chenopodiaceae pollen grains (probably *Sarcocornia quinqueflora*), at the beginning of this zone, also indicates the presence of halophytic flora in this area. These counts decreases above the bottom sample from this core to background levels, indicating a decrease in the distribution of the halophytic flora component of Waihora's riparian vegetation. As described in 'WA09 core: zone 5 15-0 cm, p. 132 (above) it is likely that the prevalence of these grains was due to an increase in the halophytic flora surrounding Waihora due to increased sediment salinities caused by the increase in inundation-drainage-evaporation cycles associated with modern lake management. The subsequent decrease in these plant types, as indicated in this core, may be due to the lake being managed in a way (post-1947) that decreased the area of land that was subjected to this cycle. From this date, the lake is opened at a lower height (above MSL) and more regularly. Thus, the area of land subject to regular flooding decreased, leading to a decrease in the area of saline sediments and a decrease in the distribution of halophytic plants that occupy this environment. Indeed, Hughey and Taylor (2009) report a decrease in the distribution of brackish wetland over the last 25 years.

WA2 core: zone 2 18.5-0 cm

- *Cyathea spp*. and monolete fern spores spike at around 11 cm core depth and remain common to the top of this core (*Figures 29 & 30*).
- Counts of *Pinus* and Poaceae grains decrease between 20 and 10 cm due the increased proportion of fern spores, although the contribution of *Pinus* to the pollen sum increases once again above 5 cm core depth due to the decrease in *Cyathea spp*. spore counts (*Figures 29 & 30*).

Explanation:

The spike in fern spores at 11 cm core depth is likely due to an increase in sedimentation within the lake basin. Assuming the two gravity cores from the lake basin represent the same period of depostion (WA1 and WA2 are core replicates) then ^{137}Cs analysis from the WA1 core can be tentatively used to infer the timing of deposition within the WA2 core. This suggests that the beginning of zone 2 in the WA2 core at 18.5 represets the timing of the Wahine storm (1968) and the increase in fern spores above this is due to increased erosion of sediment around the lake margins and increased deposition of this material within the lake basin.

7.1.4 Te Koru core

Te Koru core: zone 1 43-10 cm

- Cyperaceae and Chenopodiaceae are common within this zone and throughout this core (*Figure 31*).
- A mixture of Oligohalobous-indifferent and mesohalobous diatom taxa occurs within this zone (*Figure 46*).
- Taxa within this zone are mainly β-mesosaprobous to α-mesosaprobous (*Figure 47*), oxygen 50% (*Figure 61*), nitrogen autotrophic: tolerant to nitrogen heterotrophic: tolerant (*Figure 62*) and eutrophic (*Figure 63*), indicating high nutrient level and productivity.

Explanation:

Pollen grains of local vegetation types such as Cyperaceae and Chenopodiaceae are common throughout this core, indicating a high proportion of the pollen deposited at the Te Koru core site is sourced from local vegetation. The abundance of Cyperaceae and Chenopodiaceae indicates the presence of both freshwater and halophytic riparian flora in the area in recent times. It is probable that these occur here in a stratified nature, with Chenopodiaceae on the lower margins near the lake and Cyperaceae on the higher margins. The abundance of Chenopodiaceae here in recent times is likely a function of this core sites close proximity to the location of barrier openings, with this area being particularly subject to elevated salinities.

The diatom assemblage throughout this zone remains constant and is indicative of brackish, nutrient rich conditions. The only notable exception to this is the increased counts of *Cocconeis placentula var. euglypta* at 42-43 and 24-25 cm core depth (*Figure 44*). As this taxon is more tolerant of increased salinities than the other common epiphyton taxa (Vos and De Wolf 1993), it is likely that these increased counts are attributed to lake salinity change with artificial lake openings. The Te Koru core site is adjacent to the location of barrier openings, therefore is subject to frequent salinity changes. The abundance of *Cocconeis placentula var. euglypta* at those depths may be related to the frequency or duration of lake openings during the deposition period represented.

Te Koru core: zone 2 6-7 cm

- An increase in the proportionate abundance of *Pseudopodosira spp*. is observed in this zone (*Figure 40*).

An increase in counts of the brackish *Pseudopodosira spp*. occurs, while the proportion of freshwater epiphyte taxa decreases in this zone. Macrophyte abundance is known to be low during this deposition period as ^{210}Pb analysis revealed deposition at the bottom of this core occurred around 1970 (Shulmeister pers. comm.). Therefore, the increase in *Pseudopodosira spp*. and decrease in epiphyte forms is probably due to the maintenance of brackish conditions in this area of the lake throughout is opening and closure cycles rather than a decrease in the abundance of macrophytes (macrophyte abundance had already declined due to the Wahine storm, 1968).

7.2 Summary of lake changes according to this study

Natural lake changes

- Waihora as a lake formed not long before ~7500 B.P. (conventional ^{14}C 6760 ± 40 B.P.), when similar to current sea levels were met, following the growth of Kaitorete 'spit' at lower that present sea levels.
- Upon barrier closure the basin was flooded with freshwater and a freshwater lake, low in nutrients, with abundant macrophyte growth and surrounding wetland vegetation prevailed.
- The freshwater lake state was interrupted due to the avulsion of the Waimakariri River from a discharge position north of Banks Peninsula to a discharge point south of Banks Peninsula and into Waihora. This caused a permanent barrier opening and brackish, tidal conditions to prevail.
- A second brackish lagoon state is represented in the record. This suggests that either:
    (1) Following deposition during the previous brackish lagoon state, a change in the position of the barrier opening occurred. Diatom data suggests the barrier opening was closer to the lake basin during this second brackish lagoon state.
    (2) Following deposition during the Waimakariri River inflow period, the river avulsed back to a discharge position north of Banks Peninsula. Subsequent freshwater deposition occurred, but this was lost through scouring as the Waimakariri River again avulsed to a discharge position into Waihora. A brackish lagoon once again formed and deposition during this state occurred on top of the previous brackish lagoon deposition.
- The Waimakariri River avulses to a discharge point north of Banks Peninsula and the barrier once again separates Waihora from the sea. A freshwater lake high in nutrients forms. It is likely the depth of this lake was determined by the height at which the lake would naturally breach the barrier (4 m above MSL according to Armon (1974a)). Thus, this lake was deeper and more expansive than the current modified lake.

Recent and human induced lake changes

- It is difficult to determine when Mäori occupation of the area began relative to core depth as it is unlikely that Mäori burning events would produce a clear signal in the pollen record from this lake. The decrease in Podocarpaceae pollen grains in this record is likely to be associated with intensive deforestation of Banks Peninsula and the wider catchment by Europeans post 1870. Thus Mäori arrival may have occurred during the Waimakariri River avulsion induced brackish lagoon state or soon after the freshwater lake formed following this.
- Following the deforestation of Banks Peninsula (from around 1870) and/or channelisation of Waihora's tributaries (1890–1940's), sedimentation within Waihora basin increased dramatically.
- The distribution of halophytic plant communities increased around Waihora due to increased inundation-drainage-evaporation cycles post 1901 when lake level becomes regularly controlled.
- A transition occurs from a deeper, freshwater lake to a shallower, brackish lake due to modern lake level management practices post 1947.
- The distribution of halophytic flora surrounding the lake decreased sometime after 1947 due the narrowing of the lake margin area affected by inundation-drainage-evaporation cycles.
- The Wahine storm of 1968 led to a reworking of large amounts of lake sediments as well as extensive erosion of lake marginal and catchment soils, leading to an increase in sedimentation within the basin.
- Nutrient levels within Waihora have increased from around the 1970's, due to an increase in agricultural intensity.

7.3 What is a natural state for Waihora?

This research shows that the natural state of Waihora has changed dramatically over time. In terms of lake management, this research provides clues towards what condition the lake was in prior to human modification. Non-pollen palynomorph and diatom data provide evidence of Waihora's condition following the avulsion of the Waimakariri River to a discharge point north of Banks Peninsula. The lack of historical records of this discharge into Waihora suggests that this probably did not occur during the time of European habitation, although, radiocarbon dates produced by Hemmingsen (2001) and Soons et al. (1997) suggest that this may have occurred within the time Maori have occupied the area. Therefore, the non-pollen palynomorph and diatom indicated freshwater conditions that occurred after the avulsion of this river to a discharge point north of Banks Peninsula, probably represents the conditions that occurred in the lake prior to human modification. Here the lake is in a freshwater, eutrophic condition. Additionally, the lake would have been deeper/larger under the natural opening cycle that occurred, with a lake level reaching around 4 m, or even 5 m above MSL before a natural breach occurred (Armon 1974a; Hemmingsen 1997). This is contrasting to human modified lake conditions, which non-pollen palynomorph and diatom data suggest has been subject to increased in nutrient levels, increased salinity and decreased lake depth. Additionally, the change in frequency of lake openings from a natural state to a human managed state has had an influence on the flora surrounding the lake (affecting the distribution of freshwater and halophytic riparian vegetation). Therefore, it can be surmised that a natural condition for the lake is one with lower nutrient levels, lower salinity and greater depth/area than the current lake, with a large distribution of freshwater riparian vegetation and little halophytic vegetation.

7.4 How have the recent lake changes described affected lake values?

This section describes the possible impacts on lake values caused by the lake changes inferred from proxies during this study. This is not an exhaustive report on the impacts of all known lake changes, only those that were represented by physical and biological proxies within these cores. Possible impacts on ecological values are presented first, as it is primarily these values that contribute to the cultural recreational and commercial values within and around Waihora. Only ecological values pertaining to the lake and riparian area are examined, as wider ecological changes, such as catchment deforestation, are outside the scope of this study. Possible changes to particular cultural, recreational and commercial values are then examined.

7.4.1 Ecological values

(1) Sedimentation

It has been suggested that an increase in fine sediment within Waihora has led to an increase in the abundance of *Chironomus zealandicus* and oligochaete species (Wood 2008). A spike in fern spore counts at 20 cm core depth (WA09) (*Figure 26*) is likely an indicator of increased sedimentation. However, fine sediment was present through much of the long (WA09) core (*Figure 20*), probably due to its retrieval location from the lake basin. The sediment that reaches the lake basin is likely to have been sorted into the fine size class. In order to determine the extent of this change to fine sediment, additional cores would be needed to be retrieved from various areas of the lake.

(2) Lake Salinity

This research clearly shows that modern lake level management has led to increased salinity and decrease in lake depth post 1947. It is clear that increased salinity is having an effect on the diatom assemblage, and thus the primary producers within the lake. This may have a ‘bottom-up’ ecological effect (change in low trophic level species effecting high trophic level species) on the fauna within Waihora. However, further research is needed in order to fully understand this effect. Additionally, this increase in salinity is likely to have directly influenced the macroinvertebrate fauna within Waihora. For example, brackish water preferring calanoid copepods (two species) are now common in the lake, but may not have

been common in the lakes previous freshwater state (pre 1947) (Taylor 1996). In addition, Wood (2008) reports a significant positive correlation between salinity and the density of polychaete worms. Therefore, the distribution of these has likely increased with increased lake salinity post 1947. Also, there is some evidence to suggest that increased salinity within Waihora has led to a decrease in certain freshwater species. Armon (1974b) reports the discovery of shells belonging to the freshwater mussel, *Hyridella menziesii* in sediments along the lakes margins. Current salinity levels within Waihora are too high to support a population of these bivalves. However, diatom inferred salinity suggests that this has only been true relatively recently. It is likely that these mussels were abundant during the freshwater, high nutrient lake state recorded from 45-15 cm core depth (WA09) (*Figures 39 & 52*) and 40-27 cm core depth (WA1) (*Figures 43 & 57*). Indeed, these mussels were outlined as a principle mahinga kai species in an 1880 document (Taiaroa 1880, reported in Hughey and Taylor 2009). It is possible that an increase in salinity is responsible for the disappearance of this species, although increased turbidity is also likely to decrease the success of this filter feeder. Further work on salinity tolerances of New Zealand macroinvertebrates is necessary before further suggestions are made of possible effects of increased salinity on these organisms and to establish possible bottom-up effects of these changes on vertebrates such as fish and avifauna.

(3) Lake level + Wahine storm

It has been suggested by authors such as Hughes et al. (1974) and Wood (2008) that the near complete disappearance of macrophyte beds from Waihora has been a major factor effecting ecological change within the lake. It is unlikely that an increase in salinity alone is responsible for this, as according to Sim et al. (2006) *Ruppia megacarpa* can germinate and at salinities up to 30 ‰. Thus, salinities currently present within the lake (between 5 and 8 ‰ according to Leipe (2009)) are unlikely to effect the growth of this species. In addition, *Potamogeton pectinatus* is commonly encountered in brackish lakes (Van Wijk et al. 1988). Therefore, salinity is unlikely to be the only reason for the decline in this species.

It is likely that a combination of low lake levels (due to modern lake level management) and disturbance during the Wahine storm (1968) led to lake hysteresis. Decreased average lake depth from 1947, due to lake level being maintained at a shallow depth (below 1.13 m above MSL), increased the systems susceptibility to hysteresis. Decreased lake depth allowed wind

driven turbulence to be of a high energy down to the lake bed. In the previously deeper lake, the energy of the wind driven turbulence within the water column would be lower near the sediment-water interface. Upon the occurrence of the Wahine storm, Waihora was already in a vulnerable state and high turbulence during the storm led to the macrophyte beds present at the time to be 'ripped out' as well as the suspension of large quantities of bottom sediment, blocking out the light reaching the sediment-water interface prohibiting macrophyte reestablishment.

The effects of the Wahine storm remain apparent today, with the lack of macrophyte growth on the lake bed and around the lake margins. This facilitates the continued unstable state of the lake bed, therefore, the continued remixing of bottom sediments through the water column. Under deeper lake conditions the turbulence reaching the sediment-water interface would probably be lower in energy (although, increased wave size with increased lake depth is a possibility). Thus, less sediment would be re-suspended, leading to deeper light penetration through the water column and increased macrophyte growth. This increased macrophyte growth would, in turn, increase the stability of the lake bed and margins. However, the current lake state is also maintained by the abundance of phytoplankton growth within the water column. Therefore, a deeper lake may lead to decreased sediment within the water column, but under the current high nutrient conditions within the lake, the increased light penetration would lead to increased phytoplankton growth. The phytoplankton dominant state would be maintained due to the lack of light penetrating through to the benthos. Therefore, a combination of increased lake depth and decreased nutrient inputs within the lake is necessary to cause a reverse switch in lake state.

The loss of macrophytes within Waihora is likely to have facilitated further changes within the lake ecosystem. Under freshwater conditions the dominance of phytoplankton usually leads to decreased algal diversity (*Figure 50*). However, the high variability of salinity within Waihora has likely lead to the increase in diversity displayed in the diatom assemblage (*Figure 36*). Nonetheless, the loss of macrophytes is likely to have had a significant effect on the abundance of other organisms within the lake. An early study conducted by Yeates (1965) (reported in Wood (2008)) demonstrated a high abundance of *Potamopyrgus antipodarum*, the amphipod *Paracalliope fluviatilis* and tubificid worms prior to the Wahine storm. However, studies by Kelly and Jellyman (2007) and Wood (2008) conducted post-Wahine storm, demonstrated a high abundance of *Chironomus zealandicus* and Oligochaete species,

while *Paracorophium excavatum* and the *Potamopyrgus antipodarum* were present but in lesser abundance that the aforementioned taxa.

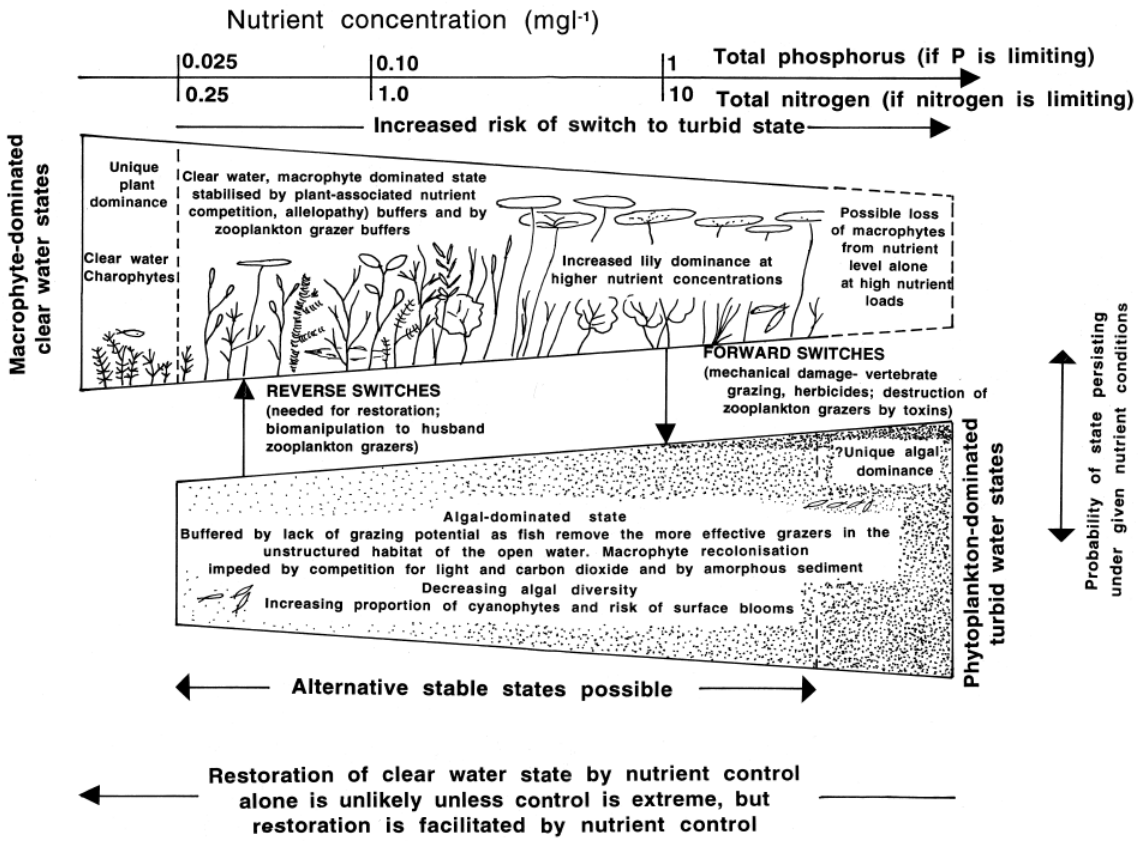

Figure 50: Diagram depicting the dynamics of two alternative stable lake states, a macrophyte-dominated state and a phytoplankton-dominated state. From: Moss (1999).

(4) Decreased lake level

The reduction in wetland area surrounding Waihora from the 1880's due to land reclamation for farming practices has had a dramatic effect on the lakes avifauna. Several species became locally extinct, such as the brown teal (*Anas chlorotis* or Pateke) and the fern bird (*Bowdleria punctata* or Kōtātā), while others such as the Australasian bittern became greatly reduced in abundance (Hughey and Taylor 2009). Since the destruction of much of the lakes wetland, modern lake levels are likely to be an important driver in the distribution of bird species. *Table 8* displays the likely effects of particular lake level practices on several species from different guilds (Hughey and Taylor 2009). It is clear that lake level management affects various species differently and it is likely that lake level management had dramatic effects on the abundance of certain species within and around Waihora. However, it should be noted

that since early European occupation of the area the diversity of species recorded in the lake has increased, likely due to an increase in the number of habitat types in and around Waihora associated with variable lake levels and salinity gradients (Hughey and Taylor 2009).

Table 8: Generalised relationship between various wildlife guilds and lake level. Modified from: Hughey and Taylor (2009)

Guild	**Example species (common name)**	**Lake level regime of the most benefit**	**Lake level regime of the most harm**
Open water divers	Little shag	**High** lake permanently	**Low** lake permanently
Deep water waders	Pied stilt	**Seasonally adjusted** levels incl. moderate to low levels in spring and autumn	**High** lake permanently
Shallow water waders	Banded dotterel	**Seasonally adjusted** levels incl. moderate to low levels in spring and autumn	**High** lake permanently
Dabbling waterfowl	Black swan	**High** lake permanently	**Low** lake permanently
	Canada goose	**High** lake permanently	**Low** lake permanently
Arial hunting gulls and terns	Black-billed gull	**High** lake permanently	**Low** lake permanently
Swamp specialists	Australasian bittern	**High** lake permanently	**Low** lake permanently
Riparian wetland species	Kingfisher	**High** lake permanently	**Low** lake permanently

(5) Lake level fluctuation

This study demonstrates how the increase in the frequency of lake openings since the early 1900's has influenced the flora surrounding Waihora (*Figures 26 & 27*). The frequency at which the lake margins are inundated with brackish water and drained, increased leading to an increase in the distribution of halophytic plants surrounding the lake. Following this increase, it appears that the distribution of halophytic plants has again decreased (*Figures 29 & 30*), probably due the narrowing of the area affected by the inundation-drainage-evaporation cycles post 1947. This variation in vegetation surrounding Waihora due to lake level fluctuation is likely having flow on effects to other organisms, such as the nesting and feeding of wetland birds.

Wood (2008) suggests that fluctuating lake levels are likely to have an impact on benthic invertebrate fauna. Those species that occur in the littoral zone and cannot migrate or withstand periods of desiccation are likely to be lost in these ephemeral zones of the lake during drainage. Indeed, in many lakes it is this littoral zone, with increased substrate size, aquatic plants and riparian plants that provides areas for feeding and shelter for many

macroinvertebrates. Therefore, the increase in frequency of lake level fluctuations is likely affecting the distribution of fauna within Waihora.

(6) Increased nutrients

There has been an increase in nutrient levels within Waihora post 1970 according to analysis of non-pollen palynomorphs (increase in algal zygospores) (*Figure 28*) and diatoms (increase in nitrogen heterotrophic: tolerant taxa) (*Figure 52*). This has led to the lake being in its current hypereutrophic condition, with an assemblage of microbial primary producers, typical of such conditions. This change in the assemblage of primary producers within Waihora probably has some bottom-up effects on the fauna therein, however, further research is necessary in order to elucidate relationships between species and understand such effects.

The high levels of nutrients (indicated by analysis of non-pollen palynomorphs and diatoms) is clearly having an effect on the phytoplankton taxa present within the lake. However, this may not have the effect of increasing primary production overall, as Waihora is generally regarded as light limited (Kelly and Jellyman 2007). This poses a problem for lake management, because if Waihora is controlled at a deeper level in the future, light limitation may decrease, leading to an increase in the use of available nutrients by phytoplankton. The subsequent increase in phytoplankton biomass may lead to the continued reduction of light reaching the benthic environment. This may continue to inhibit macrophyte growth due to low light levels near the benthos. Additionally, an increase in lake level would potentially accelerate erosion around the lake margins, leading to an increase in the availability of sediment for re-suspension. In order to prevent this, a healthy riparian margin would need to be in place (to decrease erosion), before lake levels were increased (Hemmingsen pers. comm.)

7.4.2 Cultural values

Ecological values and cultural values of Waihora are not mutually exclusive. The mauri (life force) of Waihora includes the health of the ecosystem, such as the presence of indigenous flora and fauna and the overall life supporting capacity of the area. Thus, given the ecological changes that have occurred in the lake, it is clear that its cultural values have been heavily affected. European modification of the lake, as recorded within the cores studied here, such

as destruction of wetland areas through drainage and river channelisation, increased sedimentation, decreased lake levels, increased salinity, modification of wetland flora and increased nutrient levels, has led to the mauri of the lake being impaired.

The changes mentioned above are likely to have affected not only the life supporting capacity of Waihora, but also the ability of Ngäi Tahu to welcome visitors to the area by providing food and resources from the lake. The trade of this mahinga kai is a way of asserting authority over those resources as well as meeting the needs of hapü and whänau. In the past tuna (eels), pätiki (flounder), käkahi (freshwater mussels), wetland birds (including eggs), and numerous plants such as raupö, harakeke and pingao were important mahinga kai (Te Waihora Joint Management Plan 2005). It is clear from the ecological changes described above that the distribution of many of these has been reduced. In summary, freshwater mussels have disappeared, likely due to an increase in lake salinity, the distribution of wetland flora such as raupö, harakeke has declined due to wetland reclamation, the abundance of important wetland birds has likely been altered with the local extinction of brown teal, reduced abundance of other wetland birds and the decline in black swans, due to wetland reclamation, lake level control and the Wahine storm (Hughey and Taylor 2009; Taylor 2006). The abundance of eels and distribution of pingao has also been altered, but due to other anthropogenic means; namely overfishing and exotic species introduction, respectively (Partridge 1995; Todd 1980). For a comprehensive understanding of how lake changes have affected cultural values this author recommends readers communicate with mana whenua of the area.

7.4.3 Recreational values

Fishing

Brown trout numbers have declined dramatically in the Waihora catchment from 1971 (Hughey and Taylor 2009). It is likely that the loss of macrophytes has influenced the decrease in brown trout (*Salmo trutta*) abundance within the Waihora catchment. The previously abundant macrophyte beds within the lake provided shelter for juvenile trout and it is likely the destruction of these weed beds led to a decrease in juvenile recruits (Hughey and Taylor 2009).

Other factors, only indirectly observed within cores examined are also likley to be responsible for the decline in brown trout within this catchment. The effects of increased abstraction are observed in the WA09 and WA1 cores as an increase in nutrients, due to the relationship between increased abstraction and increased agriculture intensity (from around the 1970's). This increase in abstraction led to an increase in the occurrence of low river flows, causing fish entrapment and often death in isolated pools, particularly in the Selwyn River. In addition, increased agriculture has led to an increase in siltation of important spawning gravels in the rivers such as the Selwyn and the LII (Taylor and Good 2006).

With the reduction of resident trout numbers in the catchment, the recreational fishery now relies heavily on runs of sea-run trout during lake openings. Thus, under current environmental and management conditions, the success of the fishery from season to season probably depends heavily on the timing of lake openings (Taylor et al. 1996; Hughey and Taylor 2009).

Game bird shooting

Records of swan and geese abundance have been well documented. This data demonstrates that Canada geese numbers have been maintained close to their target abundance (6500 birds) since around 1996. This target level is set as this species is regarded as a pest as well as a valuable game bird and with the number of birds being maintained at this level the recreational value of the species here is maintained. Black swan numbers have declined dramatically since the Wahine storm (1968) (see Chapter 1, p. 18 for explanation) (Hughey and Taylor 2009). This decline has had a significant effect on the lakes recreational values. In addition, *Table 8* shows that dabbling water fowl abundance would be greatest if the lake were maintained at a higher level (Hughey and Taylor 2009). Thus, the modern lake management practice of maintaining the lake at a low level is likely having some impact on the abundance of other water fowl species and thus, an impact on the lakes recreational game bird shooting value.

Water based sports

In the past sailing, water skiing, powerboat racing, windsurfing, kite-surfing, kayaking and canoeing has been popular in the lake (Palmer 1982). The feasibility of sailing, water skiing and powerboat racing has decreased with decreased lake depth since the 1940's. Also the highly turbid nature of the lake due to decreased lake depth and the Wahine storm means that these visitors cannot see the lake bottom or other obstacles, making these pastimes hazardous under current lake conditions. Also, the abundance of suspended sediment and phytoplankton gives the lake an unappealing appearance, decreasing its aesthetic qualities and the likelihood people will wish to kayak, canoe, windsurf or kite-surf there despite its handy location to the people of Christchurch.

7.4.4 Commercial values

It is difficult to determine how the environmental changes within Waihora (inferred from the proxies used in this study) would have affected the commercial values of the lake. The commercial value primarily arises from eel, flounder and, to a lesser extent, yellow eyed mullet fishing. The success of the latter two is primarily dependant on the timing and duration of lake openings, with no long term trend but very high seasonal variation in catch success, due to variability in timing and duration of openings (Todd 1980; Hughey and Taylor 2008). The success of the former is likely to be influenced by another factor. Eel catches dramatically increased in the mid 1970's, largely due to a favourable market. However despite increased fishing effort catch rates dropped dramatically in the 1980's (Todd 1980; Jellyman et al. 2003). As this commercial fishery began in earnest when the lake was already in a highly modified state, it is likely that intense fishing pressure in the 1970's lead to the decline in the eel population in Waihora. Unlike the eel fishery, the success of the flounder and yellow eyed mullet fisheries are likely influenced more by the timing of lake openings, rather than fishing pressure (Todd 1980; Hughey and Taylor 2008).

7.5 Management suggestions:

- This research reveals some baseline information that can be used if management is targeted towards restoring the lake to something resembling its natural state. This study does not approach the question of whether or not lake restoration should be an objective, but provides some information to what should be done if this is an objective.

- One of the biggest management challenges, if restoration is targeted, is the transition from the current phytoplankton-dominated lake state back to a macrophyte-dominated lake state. For this to occur, the lake must be maintained at a greater depth than current management practices permit. Additionally, the riparian margins of the lake would need to be enhanced with planting programs, in order to maintain the stability of sediments around the lake margin (minimise erosion) upon lake level increase. Nutrient input into the lake would also need to be lower than present in order to decrease the likelihood of nuisance algae blooms with increased light penetration due to a decreased concentration of suspended sediment, upon increased lake depth and decreased benthic wind mixing.

- In order to restore Waihora's natural, less saline condition, the frequency of lake openings to the sea should be decreased (as the current brackish state is caused by the regular occurrence of saltwater intrusion during frequent barrier openings).

- Pre-human vegetation surrounding Waihora was primarily freshwater wetland vegetation. Therefore, if restoration of riparian vegetation is to be targeted at something resembling pre-human conditions, the establishment of conditions conducive to freshwater wetland vegetation, rather than halophytic vegetation growth, should be the objective.

- Further research is needed towards finding out whether or not restoration objectives (such as macrophyte re-establishment, higher lake levels and abundant freshwater wetland plant growth) would improve lake values. For example, the decrease in environments where halophytic plants grow, such as saline herbfields and mudflats,

due to the restoration of conditions conducive to freshwater wetland growth, may decrease the lake's ecological value. This is because these areas provide valuable habitat to certain bird species, such as shallow waders and swamp birds (Taylor, 1996).

- Whether the management target is lake restoration or simply an improvement of environmental conditions in order to protect and enhance lake values, a decrease in nutrient input into Waihora and increased riparian planting should certainly be targeted. Under current lake conditions there is a threat of toxic algae blooms made possible by high nutrient concentrations. Indeed, such a bloom was observed in February 2009, with the cyanobacteria, *Nodularia* blooming (Environment Canterbury, 2009). Additionally, the high concentrations of nutrients lead to a high biomass of primary producers, the decomposition of which (after death) can lead to anoxic conditions in lake sediments (Ekdahl et al., 2004). The threat of toxic algae blooms and sediment anoxia will be elevated if the lake is to be managed at a higher lake level in the future.

- Riparian planting projects are being carried out in areas such as the margins of the Halswell River (Waihora Ellesmere Trust, 2010). Further planting projects around Waihora's tributaries and the lake margin should be carried out in order to stabilise sediments in the catchment and surrounding the lake, re-establish the buffer margin between the catchment and the lake (decrease sediment and nutrient input) and increase the mahinga kai value of the area due to increased distribution of valued species such as harakeke and waterfowl.

Chapter 8 Conclusions

This chapter demonstrates that the study's aims and objectives have been achieved and summarises findings, as well as implications of these findings. The aims and objectives are revisited below, with a note on the sections within which each is discussed in this conclusion.

8.1 Aims and objectives revisited

The aims and objectives of this study are to determine and discuss:

- The timing of initial lake formation and conditions within/around the lake following this (refer to section 8.2).
- The timing and effects of known Waimakariri River discharge events into Waihora (refer to section 8.2).
- Changes in the vegetation surrounding Waihora and conditions within Waihora through time (refer to section 8.2).
- Whether the current lake state is attributed to natural or anthropogenic forces (refer to section 8.2).
- What constitutes a natural state for Waihora (refer to section 8.3).
- The effects of lake changes on lake values (refer to section 8.4).
- Management suggestions based on information presented (refer to section 8.5).

8.2 The environmental history of Te Waihora

Radiocarbon analysis on woody material from 207 cm depth (WA09 core) revealed a conventional radiocarbon age of 6760 ± 40 B.P. (calibrated: 7657 to 7491 B.P.). This suggests a time of initial lake formation at around 7500 years ago, when current sea levels were met. Diatom analysis reveals that upon this initial lake formation, a freshwater lake, low in nutrients prevailed. Following this the freshwater lake state was interrupted by one or more Waimakariri River discharge induced brackish, tidal, lagoon states. Previous research suggests that one such discharge period occurred near the mid Holocene (Soons et al. 1997) and the most recent period of Waimakariri River discharge into Waihora occurred between around 900 and 500 ^{14}C years ago (Hemmingsen 2001; Johnston, 1958; Soons et al. 1997). Following the avulsion of the Waimakariri River to a discharge point north of Banks

Peninsula a freshwater, eutrophic, deeper lake prevailed (according to non-pollen palynomorph and diatom data).

Following this, human induced changes in the state of Waihora become evident; indicating the current condition of the lake is largely influenced by anthropogenic forces. Firstly, sedimentation within Waihora basin increases following deforestation of Banks Peninsula (from around 1870) and/or channelisation of Waihora's tributaries (1890–1940's) (Palmer 1982), as indicated by pollen and ^{210}Pb data. Secondly, an increase in the frequency of inundation-drainage-evaporation cycles due to lake level management post-1901, lead to an increase in the distribution of halophytic plants around Waihora's margins, such as *Sarcocornia quinqueflora*. Thirdly, it is clear that a change in lake management in 1947 to the current regime (opening the lake to the sea when it reaches 1.13 m above MSL in summer and 1.05 m above MSL in winter) has had an effect on the lake state. From this date the lake has been opened to the sea more regularly and at a lower level than previously. This has (a) led to an increase in lake salinity due to the increased occurrence of saltwater intrusion into the lake during more regular lake openings, (b) led to a decrease in average lake level (shallower and more restricted in area) and (c) a decreased in the distribution of halophytic plants around Waihora due to a narrowing to the area affected by inundation-drainage-evaporation cycles. Fourthly, a combination of low lake levels due to lake level management and the Wahine storm of 1968, led to the destruction of the lake's macrophyte beds and the re-suspension of lake bed and marginal sediments (increased sedimentation indicated by pollen and ^{210}Pb data). Thus, a transition occurred, from macrophyte-dominated lake to a turbid, phytoplankton-dominated lake. This lake state remains today, reinforced by the maintenance of low lake levels with lake management practices and high nutrient input. Finally, an increase in agricultural intensity in the catchment and the area directly surrounding Waihora, from around 1970, has led to an increase in nutrient input into the lake, as indicated by non-pollen palynomorph and diatom data.

8.3 The natural state of Te Waihora

This data provides evidence towards what constitutes a natural state for Waihora. It is likely that the freshwater lake that prevailed following the most recent avulsion of the Waimakariri River to a discharge point north of Banks Peninsula, is most representative of lake conditions prior to human modification. The beginning of this freshwater state probably occurred prior

to European settlement in the area, but perhaps during times of Mäori settlement. LOI, palynological and diatom data suggest that a natural condition for the lake is one with lower nutrient levels, lower salinity and greater depth/area than the current lake, with a large distribution of freshwater riparian vegetation and little halophytic vegetation.

8.4 The affects of recent lake changes on lake values

The recent, human induced changes in lake state described above have had some significant impacts on the lake's values. Ecological values have been affected by the decrease in wetland area surrounding the lake, due to land reclamation for agriculture post-1880. This would have affected the composition of Waihora's avifauna and increased sedimentation. It is likely that increased sedimentation due to land reclamation/tributary channelisation, the deforestation of Banks Peninsula and the Wahine storm has led to an increase in the distribution of fine sediment within Waihora. This has probably led to conditions favouring certain benthic invertebrates, such as Chironomidae and Oligochaeta. Additionally, the increased distribution of Chironomidae and Oligochaeta and decreased distribution of *Potamopyrgus antipodarum* has been facilitated by the transition from a macrophyte-dominated state to a phytoplankton-dominated state following the Wahine storm (hysteresis) (Wood 2008).

The increase in salinity through modern lake management post-1947 has also affected the lakes ecological values, with a demonstrable increase in brackish diatoms, a probable increase in brackish water preferring copepod species and polycheates and a reduction in freshwater preferring invertebrates such as the freshwater mussel, *Hyridella menziesii*. Changes in the frequency of lake level fluctuations has clearly had an effect on the distribution of particular plants surrounding Waihora (altering the distribution of freshwater and halophytic plant types within the riparian community) and is probably also having an effect on the species distribution of macroinvertebrates (Wood 2008). Increased nutrients within Waihora have clearly affected Waihora's ecological values with an increase in phytoplankton indicative of hypereutrophic conditions. It is likely that further bottom-up ecological effects have occurred through changes in plankton and macroinvertebrate fauna with sedimentation, hysteresis, increased salinity, frequency of lake level fluctuation and increased nutrients. However, further research is necessary in order to elucidate these relationships.

These ecological changes have certainly affected the lakes cultural and recreational values. Changes in cultural value have occurred through the disappearance of freshwater mussels (likely due to an increase in lake salinity), a decline in the distribution of wetland flora such as raupö and harakeke due to wetland reclamation, a decline in the abundance of important wetland birds (with the local extinction of brown teal, the probable reduced abundance of other wetland birds and the decline in black swans), due to wetland reclamation (decreased nesting habitat), lake level control (most waterfowl would prefer higher lake levels (Hughey and Taylor 2009)) and the Wahine storm (decreased abundance of macrophytes as a food source).

The recreational values of Waihora have been decreased with the decline in the trout fishery due to macrophyte loss, increased abstraction and increased siltation of spawning gravels (Hughey and Taylor 2009; Taylor and Good 2006). Recreational game bird shooting has also been affected by reduced black swan numbers due to the loss of macrophytes and a probable decrease in other waterfowl (that prefer high lake levels) (Palmer 1982; Hughes et al. 1974) due to the maintenance of low lake levels with lake management. The use of the lake for water based sport such as sailing, water skiing and kayaking has reduced due to decreased lake levels and increased turbidity, making the lake dangerous and unappealing for those practicing these sports.

8.5 Management suggestions

If restoration is to be a management objective then the current lake level management regime should be changed so that there are less frequent lake openings allowing lake salinity to decrease and freshwater riparian vegetation to prevail. Additionally, a transition from a phytoplankton-dominated state to a macrophyte-dominated state should be targeted. For this to occur, the lake should be maintained at a greater depth in order to decrease sediment re-suspension through the water column and decrease turbidity. However, in order for hysteresis to occur the lake margins would need to be stabilised with extensive riparian planting practices and nutrient input would need to be decreased, so that phytoplankton driven turbidity is decreased and nuisance algae do not bloom. However, restoration of Waihora to something resembling a natural state would be difficult due to the current gaps in scientific knowledge, the large expense and trade-offs between stakeholders. The latter is particularly important to consider, as the increased lake levels and surrounding wetland distribution,

necessary for lake restoration, would decrease the available land for farming. This decreased area for farming, as well as riparian planting and drainage issues would contribute to the high cost of such a project. However, a decrease in nutrient input catchment wide and riparian planting in the area surrounding the lake should be a priority and may represent a more realistic, short term management objective.

References:

Appleby PG 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena 5: 1-8.

Armitage PD, Cranston PS, Pinder LCV 1995. The Chironomidae: biology and ecology of non-biting midges. Chapman & Hall, London, U.K.

Armon JW 1970. Recent shorelines between banks peninsula and coopers lagoon. Unpublished MA thesis, University of Canterbury, New Zealand.

Armon JW 1974a. Late quaternary shorelines near Lake Ellesmere. New Zealand Journal of Geophysics 17: 63-73.

Armon JW 1974b. Radiocarbon age for freshwater mussel shells from tuamutu. New Zealand Journal of Marine and Freshwater Research 8: 229-232.

Arnold JR, Libby WF 1946. Radiocarbon from pile graphite; Chemical methods for its concentrations. Argonne National Laboratory, United States Department of Energy (through predecessor agency the Atomic Energy Commission).

Arnold JR, Libby WF 1949. Age determinations by radiocarbon content: checks with samples of known age. Science 110: 678–680.

Banks Peninsula Landscape Study 2007. Available from: <http://resources.ccc.govt.nz/files/BPStudySectionBpt10-bplandscapestudy.pdf> Accessed: 19/01/2010.

Battarbee RW, Jones VJ, Flower RJ, Cameron NG, Bennion H, Carvalho L, Juggins S 2001. Diatoms: Laboratory procedures. In: Smol JP, Birks HJB, Last WM ed. Tracking environmental change using lake sediments. Volume 3: Terrestrial, algal and siliceous indicators. (pp. 172-180). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Battarbee RW, Kneen MJ 1982. The use of electronically counted microspheres in absolute diatom analysis. Limnology and Oceanography 27, 1: 184-188.

Battern DJ, Van Geel B 1985. Celyphus rallus, probable early cretaceous rivulariacean blue-green alga. Review of Paleobotany and Palynology 44: 233-241.

Bengtsson LM, Enell 1986. Chemical analysis. In: Berglund BE ed. Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley & Sons Ldt. Chichester 423-451.

Bennett KD 2009. 'Psimpoll' version 4.27, a program for plotting and analysis of palaeoecological data. Available from: <http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html> Accessed: 6/11/2009.

Bennet KD, Willis KJ 2001. Pollen: Laboratory treatment. In: Smol JP, Birks HJB, Last WM ed. Tracking environmental change using lake sediments. Volume 3: Terrestrial, algal and siliceous indicators. (pp. 9-16). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Benoit G, Rozan TF 2001. ^{210}Pb and ^{137}Cs dating methods in lakes: A retrospective study. Journal of Paleolimnology 25: 455-465.

Berg P 2009. Radiata pine - Plantations in New Zealand, Te Ara - the Encyclopedia of New Zealand. Available from: <http://www.TeAra.govt.nz/en/radiata-pine/2> Accessed: 19/01/2010.

Bertini A 2006. The Northern Apennines palynological record as a contribute for the reconstruction of the Messinian palaeoenvironments. Sedimentary Geology 188-189: 235-258.

Bidwell V, Lilburne L, Thorley M, Scott D 2009. Nitrate discharge to groundwater from agricultural landuse: An initial assessment for the Canterbury Plains. A technical report to the Steering Group of the Canterbury Water Management. Available from: <http://www.canterburywater.org.nz/downloads/report-on-nitrate-discharge.pdf> Accessed: 02/03/2010.

Birks HH, Birks HJB 2006. Multi-proxy studies in paleolimnology. Vegetation History and Archaeobotany 15: 235-251.

Birks HJB, Birks HH 1980. Quaternary palaeoecology. Edward Arnold, London.

Blair ID, Mugford G 1980. Lake Ellesmere - Recreational fishing and game shooting. In: Lake Ellesmere Symposium. 20 November 1980. Unpublished verbatim transcript of proceedings.

Blais JM, Kalff J 1995. The influence of lake morphometry on sediment focusing. Limnology and Oceanography 40, 3: 582-588.

Bowden MJ, Talbot JD, Ayrey RB, Curtis J, Glennie JM, Lineham IW, Mason CR, Thompson DA, Weeber JH, Lord PI, Shadbolt N 1983. Interim report on the groundwater resources of the central plains. A report prepared by the resource investigations division of the North Canterbury Catchment Board and Regional Water Board.

Bowman S 1990. Radiocarbon Dating. University of California Press/British Museum, Berkeley and Los Angeles.

Boyd WE, Hall VA 1998 Landmarks on the frontiers of palynology: an introduction to the IX International Palynological Congress Special Issue on New Frontiers and Applications in Palynology. Review of Palaeobotany and Palynology 103: 1-10.

Boyle T, Surman M 2007. Waimakariri River floodplain management strategy. Flood hazard risk assessment. Environment Canterbury, Report No. R07/2. ISBN 1-86937-628-5.

Buchanan PK, May TW 2003. Conservation of New Zealand and Australian fungi. The Royal Society of New Zealand. 41: 407-421.

Burrows CJ 1969. A handbook of background material to the ecology of the Lake Ellesmere area. Botany department, University of Canterbury, Christchurch, New Zealand.

Cambell A 1980. Bottom sediments of Lake Ellesmere In: Lake Ellesmere Symposium. 20 November 1980. Unpublished verbatim transcript of proceedings.

Canterbury Groundwater Study 2005. Findings for the Dunsandel-Te pirita area. Prepared by Aqualinc Research Ltd for DGWUA (Report number L05008/2). Available from: <http://www.maf.govt.nz/sff/about-projects/search/01-055/01055-final-report-for-dunsande-users.pdf> Accessed: 03/01/2010.

Cassie V 1989. A contribution to the study of New Zealand diatoms. Bibliotheca Diatomologica 17: 1-266.

Cleve-Euler A 1968. Die Diatomeen von Schweden und Finnland. Bibliotheca Phycologica. Verlag Von J. Cramer, 3301 Lehre, Germany.

Cochran U 2002. Direction of large Holocene earthquakes in the sedimentary record of Wellington, New Zealand, using diatom analysis. PhD thesis, Department of Geology, Victoria University, Wellington, NZ.

Cox EJ 1996. Identification of freshwater diatoms from live material. Chapman & Hall. Boundary Row, London, UK.

Cranwell LM 1953. New Zealand pollen studies. The monocotyledons. A comparative account. Bulletin of the Auckland Institute and Museum No.3, 91 pp.

Deevey ES 1965. Sampling lake sedi- ments by use of the Livingstone sampler (pp. 521-529). In: Kummel B, Raup D ed. Handbook of paleontological techniques. WH Freeman and Company, San Francisco, USA.

Dunbar GB, McLea B, Goff JR 1997. Holocene pollen statigraphy and sedimentation, Wellington Harbour, New Zealand. New Zealand Journal of Geology and Geophysics 40: 325-333.

Dwyer BP 1980. Past proposals and present openings of Lake Ellesmere. In: Lake Ellesmere Symposium. 20 November 1980. Unpublished verbatim transcript of proceedings.

Environment Canterburty 2009. Lake Ellesmere/Te Waihora health warning blue-green algal bloom. Available from: <http://www.ecan.govt.nz/news-and-notices/news/pages/lake-ellesmere-te-waihora-health-warning-blue-green-algal-bloom.aspx> Accessed: 03/02/2010.

Ekdahl EJ, Teranes JL, Guilderson TP, Turton CL, McAndrews JH, Wittkop CA, Stoermer EF 2004. Prehistorical record of cultural eutrophication from Crawford Lake, Canada. Geology 32, 9: 745-748.

Evans LT 1953. The ecology of the halophytic vegetation at Lake Ellesmere, New Zealand. Journal of Ecology 41, 1: 106-122.

Fernandes T, Tett P 2001. Marine biology: Sediment analysis – Graphical presentation and statistics. Available from: <http://www.lifesciences.napier.ac.uk/teaching/MB/phidiag01.html> Accessed: 04/02/2010.

Flower RJ 1993. Diatom preservation: experiments and observations on dissolution and breakage in modern and fossil material Hydrobiologia. 269/270: 473-484.

Foged N 1979. Diatoms in New Zealand, the North Island. Bibliotheca Phycologica 47. J. Cramer, FL-9490 Vaduz, Germany. 225 pp.

Gee NG 1931. Freshwater sponges. The Hong Kong Naturalist. 124-131.

Gibb JG 1986. A New Zealand regional Holocene eustatic sea-level curve and its application to determination of vertical tectonic movements. Bulletin of the Royal Society of NZ 24: 377-395.

Goff JR, Whitehead NE, Ditchburn RG 1998. ^{210}Pb chronology from Wellington Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research 32: 181-186.

Google Earth (1010) Google Earth 5.0. Dowloadable from: <http://earth.google.com/#utm_campaign=en&utm_medium=ha&utm_source=en-ha-apac-nz-bk-eargen&utm_term=google%20earth> Accessed: 10/06/2010.

Gray J 1965. Extraction techniques (pp. 471-481). In: Kummel B, Raup D ed. Handbook of paleontological techniques. WH Freeman and Company, San Francisco, USA.

Grimm EC 1987. CONSISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sums of squares. Computers & Geosciences 13: 13-35.

Haast JV 1864. Formation of the Canterbury Plains with geological sketch map and geological sections. Press office, Cashel Street, Christchurch. Pp. 14-53. Cited in Hemmingsen MA 1997. The coastal geomorphology of Te Waihora (Lake Ellesmere). Unpublished MA thesis, University of Canterbury, New Zealand.

Harvey MC 1996. A paleolimnological study of Lake Ellesmere (Te Waihora), South Island, New Zealand. Unpublished Msc thesis, University of Canterbury, Christchurch, New Zealand.

Hatch FH, Rastall RH 1965. The petrology of sedimentary rocks. George Allen and Unwin Ltd, Great Britain.

Heiri O, Lotter AF, Lemcke G 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25: 101-110.

Hemmingsen MA 1997. The coastal geomorphology of Te Waihora (Lake Ellesmere). Unpublished MA thesis, University of Canterbury, New Zealand.

Hemmingsen MA 2001. Radiocarbon age for estuarine shells from Lakelands, Lake Ellesmere (Te Waihora), New Zealand. New Zealand Journal of Marine and Freshwater Research 35: 329-334.

Hewitt AE 1996. Estimating surface erosion using ^{137}Cs at a semi-arid site in Central Otago, New Zealand. Journal of the Royal Society of New Zealand 26, 1: 107-118.

Horrell GA 1992. Lake Ellesmere water balance model: Variable analysis and evaluation. Unpublished Msc thesis. University of NSW, Australia.

Hsu KJ 1989. Physical principles of sedimentology – A readable textbook for beginners and experts. Springer-Verlag Berlin Heidelberg.

Hughes HR, McColl RHS, Rawlence DJ 1974. Lake Ellesmere, Canterbury, New Zealand. A review of the lake and its catchment. Ecology Division, DSIR, Wellington.

Hughey KFD, Taylor KJW (ed.) (2009) Te Waihora/Lake Ellesmere: State of the Lake and Future Management. EOS Ecology, Christchurch. 150pp.

Irwin J, W Del Main 1989. Lake Ellesmere bathymetry 1:25000. N.Z. Oceanographic Institute chart. Lake series.

Ives D 1973. Nature and distribution of loess in Canterbury, New Zealand. New Zealand Journal of Geology and Geophysics 16: 587-610.

Jankovská V, Komárek J 2000. Indicative value of Pediastrum and other coccal green algae in Palaeoecology. Folia Geobotanica 35: 59-82.

Jarzen DM 1978. Zygospores of Zygnemataceaea in the Paleocene of Southern Saskatchewan (Canada). Review of Palaeobotany and Palynology. 28: 21-25.

Jellyman DJ, Graynoth E, Beentjes MP, Sykes JRE 2003. A review of the eel fishery in Te Waihora (Lake Ellesmere). A New Zealand fisheries assessment report 2003/51. ISSN 1175-1584.

Jellyman DJ, Todd PR 1998. Why are migrating male shortfinned eels (*Anguilla australis*) in Lake Ellesmere, New Zealand, getting smaller but not younger? Bulletin Français de la Pêche et de la Pisciculture 349: 141-152.

Johnston JA 1958. Recent climatic changes in south island, New Zealand. A geographic analysis. Unpublished MA thesis, University of Canterbury, New Zealand.

Kelly DJ, Jellyman DJ 2007. Changes in trophic linkages to shortfin eels (*Anguilla australis*) since the collapse of submerged macrophytes in Lake Ellesmere, New Zealand. Hydrobiologia 579,1: 161-173.

Kirk RM 1994. The origins of Waihora/Lake Ellesmere. In: Davies JDG, Galloway L, Nutt, AHC ed. Te Waihora Lake Ellesmere. Past present and future. Lincoln University Press. ISBN 0-473-02907-3.

Kirk RM (1991) River-beach interaction on mixed sand and gravel coasts. A geomorphic model for water resource planning. Applied Geography 11: 267-287.

Kirk RM, Lauder GA 2000. Significant coastal lagoon systems in the South Island, New Zealand. Coastal processes and lagoon mouth closure. Science for Conservation. Department of Conservation, Wellington, New Zealand.

Kirk RM, Lauder GA 1994. Guidelines for managing lagoon mouth closure on significant coastal/wetland lagoon systems – Coastal processes investigation. A report to the Department of Conservation, Sciences and Research Division, Wellington, New Zealand.

Krammer K, Lange-Bertalot H 1991a. Bacillariophyceae. 3.Teil: Centrales, Fragilariaceae, Eunotiaceae. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D ed. Süßwasserflora von Mitteleuropa 2/3, Stuttgart: Gustav Fischer Verlag. 576 pp.

Krammer K, Lange-Bertalot H 1991b. Bacillariophyceae. 4.Teil: Achnanthaceae. Kritische Ergänzungen zu Navicula (Lineolate) und Gomphonema. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D ed. Süßwasserflora von Mitteleuropa 2/4, Stuttgart: Gustav Fischer Verlag. 437 pp.

Krammer K, Lange-Bertalot H 1991c. Bacillariophyceae. Part 5: English and French translation of keys. In: Büdel B, Gärtner G, Krienitz L, Lokhorst GM ed. Süßwasserflora von Mitteleuropa 2/3, Spektrum Akademischer Verlag, Heidelberg, Berlin. 576 pp.

Krinsley D, Kaldi J 1978. In: Fairbridge RW, Bourgeois J ed. The Encyclopedia of sedimentology. Dowden, Hutchinson and Ross, Inc, USA.

Large MF, Braggins JE 1991. Spore atlas of New Zealand ferns and fern allies. SIR Publishing. Wellington. ISSN 0028-825X. ISBN 0-908654-30-8.

Last WM 2001. Textural analysis of lake sediments (pp. 41-81). In: Last WM, Smol JP ed. Tracking environmental change using lake sediments. Volume 2: Physical and geochemical methods. Kluwer Acedemic Publishers, Dordrecht, The Netherlands.

Leipe C 2009. Tracking human impact on Lake Ellesmere (Te Waihora) using pollen and Chironomidae (Diptera). Diplomarbeit, Humboldt-Universität zu Berlin, Geographisches Institut.

Libby WF 1955. Radiocarbon dating, 2nd edition. University of Chicago Press, Lincoln, New Zealand.

Limaye RB, Kumaran KPN, Nair KM, Padmalal D 2007. Non-pollen palynomorphs as potential palaeoenvironmental indicators in the Late Quaternary sediments of the west coast of India. Current Science 92, 10: 1370-1382.

Lineman IW 1983. Eutrophication of Lake Ellesmere: A study of phytoplankton. Unpublished Phd thesis, Canterbury University, Christchurch, New Zealand.

Macphail MK, McQueen DR 1983. The Value of New Zealand Pollen and Spores as Indicators of Cenozoic Vegetation and Climates. Tuatara 26, 2: 37-56.

Martins LR 1965. Significance of skewness and kurtosis in environmental interpretation. Journal of Sedimentary Research 35: 768-770.

McFadgen BG, Goff JR 2005. An earth systems approach to understanding the tectonic and cultural landscapes of linked marine embayments: Avon-Heathcote Estuary (Ihutai) and Lake Ellesmere (Waihora), New Zealand. Journal of Quaternary Science 20: 227-237.

McGlone MS, Wilmshurst JM 1999. Dating initial Mäori environmental impact in New Zealand. Quaternary International 59: 5-16.

Medeanic S 2006. The palynomorphs from surface sediments of intertidal marshes in the estuarine part of the Patos lagoon. Ser. Botany Porto Alegre 61: 49-62.

Ministry of Fisheries 2010. Freshwater eels in Lake Ellesmere (ANG13). Available from: <http://fs.fish.govt.nz/Page.aspx?pk=8&stock=ANG13&ey=2010> Accessed: 18/03/2010.

Meyers PA, Teranes JL 2001. Sediment organic matter. In: Last WM, Smol JP ed. Tracking environmental change using lake sediments. Volume 2: Physical and geochemical methods. Kluwer Acedemic Publishers, Dordrecht, The Netherlands.

Moar NT 1993. Pollen Grains of New Zealand Dicotyledonous Plants. Manaaki Whenua Press. Lincoln, New Zealand. ISBN 0-487-04500-X.

Moore JA, Borrie DN 1987. Phosphorus and Lake Ellesmere: Sources, movement and management practices. NZAEI, Lincoln, New Zealand.

Moore PD, Webb JA, Collinson ME 1991. Pollen Analysis. Second edition. Blackwell Scientific Publications, Oxford.

Moss B 1999. British Phycological Society Presidential Address. From algal culture to ecosystem; from information to culture. European Journal of Phycology 34: 3, 193-203.

Muir MD, Sarjeant WAS 1977. Editors comments on papers 1 through 5. In: Muir MD, Sarjeant WAS ed. Palynology part I: Spores and pollen. Dowden, Hutchinson & Ross, Inc., USA.

Munsell AH 1912. A Pigment Color System and Notation. The American Journal of Psychology 23: 236-244.

Myrbo A, Wright HE 2008. Livingston-bolivia. Limnological Research Centre Core Facility, SOP series. Draft v.3.1. Available from: <http://lrc.geo.umn.edu/livingstone-bolivia.pdf> Accessed: 15/04/09.

Nakagawa T, Brugiapaglia E, Digerfeldt G, Reille M, Beaulieu JL, Yasuda Y 1998. Dense media separation as a more efficient pollen extraction method with use for organic sediment/deposit samples: comparison with the conventional method. Boreas 27: 15-24.

Ngai Tahu Claims Settlement Act 1998. No 97 (as at 01 November 2008), Public Act. Available from: <http://www.austlii.edu.au/nz/legis/consol_act/ntcsa1998268.pdf> Accessed: 20/03/2010.

NIWA National Climate Database 2010. Data downloadable from: <http://www.niwa.co.nz/news-and-publications/news/all/2009/nz-temp-record/temperature-trends-from-raw-data> Accessed: 16/05/2010.

Norton AC 1980. The lake and flood protection development – A historical summary. In: Lake Ellesmere Symposium. 20 November 1980. Unpublished verbatim transcript of proceedings.

Ogden J, Basher L, McGlone M 1998. Fire, forest regeneration and links with early human habitation: evidence from New Zealand. Annals of Botany 81: 687-696.

Pace ML, Cole JJ, Carpenter SR, Kitchell JF, Hodgson JR, Van de Bogert MC, Bade DL, Kritzberg ES, Bastviken D 2003. Whole-lake carbob-13 additions reveal terrestrial support of aquatic food webs. Nature 427: 240-243.

Palmer JD 1982. Ellesmere a critical area. Coastal resource investigation. Department of Lands and Survey, New Zealand.

Parris AS, Bierman PR, Noren AJ, Prins MA, Lini A 2010. Holocene paleostorms identified by particle size signatures in lake sediments from the northeastern United States. Journal of Paleolimnology 43: 29-49.

Parkinson J, Gordon R 1999. Beyond micromachining: the potential of diatoms. Tibitech 17: 190-196.

Passega R 1964. Grain size representation by CM patterns as a geological tool. Journal of Sedimentary Petrology 34, 4: 830-847.

Passega R 1957. Texture as a characteristic of clastic deposition. American Association of Petroleum Geologists Bulletin 41: 1952-1984.

Patrick R, Reimer CW 1966. The diatoms of the United States, exclusive of Alaska and Hawaii, Volume 1-Fragilariaceae, Eunotiaceae, Achnanthaceae, Naviculaceae. Academy of Natural Sciences of Philadelphia Monograph No. 13. 688 pp.

Partridge TR 1995. Interaction between pingao and marram on sand dunes: completion of permanent plot studies. Science for Conservation: 3, Depatrment of Conservation, Wellington, New Zealand.

Pennington W, Cambray RS, Fisher EM 1973. Observations on lake sediments using fallout ^{137}Cs as a tracer. Nature 242: 324-326.

Petrie LM 1963. From bush to Cocksfoot: An essay on the destruction of Banks Peninsula's forest. Unpublished MSc thesis, Department of Geography, University of Canterbury, Christchurch, New Zealand.

Prager A, Barthelmes A, Theuerkauf M, Joosten H 2006. Non-pollen palynomorphs from modern Alder carrs and their potential for interpreting microfossil data from peat. Review of Paleobotony and Palynology 141: 7–31.

Reid M 2005. Diatom-based models for reconstructing past water quality and productivity in New Zealand lakes. Journal of Paleolimnology 33: 13-38.

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Freidrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Ramsay CB, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, Plicht JV, Weyhenmeyer CE 2004. INTCAL04 terrestrial radiocarbon age calibration, 0-26 Cal kyr BP. Radiocarbon 46, 3: 1029-1058.

Round FE, Crawford RM, Mann DG 1990. The diatoms. Biology and morphology of the genera. Cambridge University Press. Cambridge, United Kingdom.

Royse CH 1970. An introduction to sediment analysis. Sediment Analysis, 1046 Bluebell Lane, Tempe, Arizona, USA. 180 pp.

Rull V, López-Sáez JA, Vegas-Vilarrúbia TV 2008. Contribution of non-pollen palynomorphs to the paleolimnological study of a high-altitude Andean lake (Laguna Verde Alta, Venezuela). Journal of Paleolimnology 40: 399-411.

Sim LL, Chambers JM, Davis JA 2006. Ecological regime shifts in salinised wetland systems. I. Salinity thresholds for the loss of submerged macrophytes. Hydrobiologia 573: 89-10.

Sly PG, Thomas RL, Pelletier BR 1982. Comparison of sediment energy-texture relationships in marine and lacustrine environments. Hydrobiologia 9: 71-84

Smith MB 2003. The hydrogeology and hydraulics of artesian springs in Canterbury. Unpublished Msc thesis, Department of Geology, University of Canterbury, Christchurch, NZ.

Smith SM 1979. Ellesmere soil resources. Applied science thesis. Lincoln College, New Zealand.

Soons JM, Shulmeister J, Holt S 1997. The Holocene evolution of a well nourished gravelly barrier and lagoon complex, Kaitorete "Spit", Canterbury, New Zealand. Marine Geology 138: 69-90.

Speight R 1950. An eroded coastline – the coastline of mid-Canterbury. Transactions of the Royal Society of New Zealand 78, 1: 3-15.

Speight R 1930. The Lake Ellesmere Spit. Transactions of the New Zealand Institute 61: 147-169.

Spellerberg IF Fedor PJ 2003. A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. Global Ecology & Biogeography 12: 177-179.

Stewart HB 1958. Sediment reflections on depositional environments in San Miguel Lagoon, Baja California, New Mexico. Bulletin of the American Association of Petroleum Geologists 42: 2567-2618.

Stockmarr J 1971. Tablets with Spores used in Absolute Pollen Analysis. Pollen et Spores 13: 615-621.

Suggate RP 1968. Postglacial sea level rise in Christchurch, New Zealand. Geologie in Mijnbouw 47, 4: 291-297.

Swanson KM 1985. Paleontological Laboratory Techniques. Steam Press. University Of Canterbury, New Zealand.

Tait P, Cullen R 2010. Some External Costs of Dairy Farming in Canterbury. Available from: <http://www.lincoln.ac.nz/Documents/2347_tait_s6599.pdf> Accessed: 16/05/2010.

Taylor KJW ed. 1996. The natural resources of Lake Ellesmere (Te Waihora) and its catchment. Canterbury Regional Council, New Zealand. Report 96 (7), ISBN 1-86937-262-X.

Taylor M, Good M 2006. Brown trout spawning in the Lake Ellesmere (Te Waihora) tributaries and some surrounding catchments. Environement Canterbury, New Zealand. Report No. U06/79.

Taylor WA 1944. Waihora. Mäori associations with Lake Ellesmere. Reprinted from the Ellesmere Guardian, Leeston, Canterbury. Available from: <http://christchurchcitylibraries.com/Heritage/Publications/Waihora/Waihora1944.pdf> Accessed: 19/03/2010.

Te Waihora Joint Management Plan 2004. Te Rünanga o Ngäi Tahu, Department of Conservation. ISBN: 0-478-22503.

Te Waihora joint management plan 2005. Published by: Te Rünanga o Ngäi Tahu and Department of Conservation Te Papa Atawhai. ISBN: 0-478-14059-2. Available from: <http://www.doc.govt.nz/upload/documents/conservation/land-and-freshwater/wetlands/te-waihora-full.pdf > Accessed: 31/01/2010.

Thannheiser D, Holland P 1995. The plant communities of New Zealand salt meadows. Global Ecology and Biogeography Letters 4, 4: 107-115.

The European Diatom Database (EDDI). Available from: <http://craticula.ncl.ac.uk/Eddi/jsp/> Accessed: 22/09/2009.

Theriot E, Hakansson H, Kociolek JP, Round FE, Stoermer EF 1987. Validation of the Centric Diatom genus name Cyclostephanos. European Journal of Phycology 22: 4, 345-347.

Thoms MC, Williams WD 2006. The siliceous sediment of Lake Cantara South, a saline lake in South Australia. International Journal of Salt Lake Research 2, 1: 29-40.

Thorburn DF 1974. Palynology of Lake Hayes, Cental Otago, New Zealand. Unpublished Msc thesis, University of Canterbury, Christchurch, New Zealand.

Tierney LD, Richardson J, Unwin MJ 1987. The relative value of North Canterbury rivers to New Zealand Anglers. New Zealand freshwater fisheries report 89. Freshwater Fisheries Centre, Ministry of Agriculture and Fisheries, Wellington, New Zealand.

Todd PR 1980. Fish and fisheries in Lake Ellesmere. In: Lake Ellesmere Symposium. 20 November 1980. Unpublished verbatim transcript of proceedings.

Troels-Smith J 1955. Karakterisering af løse jordarter. Characterization of unconsolidated sediments. Dan Geol Unders IV Raekke 3: 39-73.

Valia HS, Cameron B 1977. Skewness as a paleoenvironmental indicator. Journal of Sedimentary Petrology 47, 2: 784-793.

Van Dam H, Mertens A, Sinkeldam J 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28, 1: 177 -133.

Van Geel B, Mur LR, Ralska-Jasiewiczowa M, Goslar T 1994. Fossil akinetes of Aphanizomenon and Anabaena as indicators for medieval phosphate-eutrophication of Lake Gosciaz (Central Poland). Review of Paleobotany and Palynology 83: 97-105.

Van Geel B 2001. Non-pollen palynomorphs. In: Smol JP, Birks HJB, Last WM ed. Tracking environmental change using lake sediments. Volume 3: Terrestrial, algal and siliceous indicators. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Van Wijk RJ, Van Goor EMJ, Verkley JAC 1988. Ecological studies on *Potamogeton pectinalus* L. II autoecological characteristics, with emphasis on salt tolerance, intraspecific variation and isoenzyme patterns. Aquatic Botany 32: 239-260.

Vos PC, De Wolf H 1993. Diatoms as a tool for reconstructing sedimentary environments in coastal wetlands; methodological aspects. Hydrobiologia 269/270, 285-296.

Vos PC, de Wolf H 1988. Methodological aspects of paleo-ecological diatom research in coastal areas of the Netherlands. Geologie en Mijnbouw 67: 31-40.

Waihora Ellesmere Trust 2010 Available from: <http://www.wet.org.nz/> Accessed: 04/06/2010.

Waihora Ellesmere Trust 2009 Opening Te Waihora / Lake Ellesmere to the sea. A beginners guide. Available from <http://www.wet.org.nz/wp-content/uploads/2009/10/Beginners-Guide-to-opening-Te-Waihora-Lake-Ellesmere.pdf > Accessed: 05/01/2010.

Ward WT, Harris CS, Schapper HP 1964. Soils and agriculture of Ellesmere County. DSIR soil bureau bulletin 21, New Zealand.

Wilmshurst JM, McGlone MS 2005. Origin of pollen and spores in surface lake sediments: Comparison of modern palynomorph assemblages in moss cushions, surface soils and surface lake sediments. Review of Palaeobotany and Palynology 136: 1-15.

Wolfe AP 1997. On diatom concentrations in lake sediments: Results from an inter-laboratory comparison and other tests performed on a uniform sample. Journal of Paleolimnology 18: 261-268.

Wood HF 2008. The benthic ecology and food web dynamics of Te Waihora (Lake Ellesmere). Unpublished Msc thesis, University of Canterbury, Christchurch, New Zealand.

Woodward CA Shulmeister J 2005. A Holocene record of human induced and natural environmental change from Lake Forsyth (Wairewa), New Zealand. Journal of Paleolimnology 34: 481-501.

Wright HE Jr. 1967. A square-rod piston sampler for lake sediments. Journal of Sedimentary Petrology 37, 3: 975-976.

Yeates GW 1965. The benthos of Lake Ellesmere. University of Canterbury, Christchurch, New Zealand.

Zabenskie S, Gajewski K 2007. Processing arctic sediments including heavy-liquid (Sodium Polytungstate (SPT)) concentration of pollen grains. University of Ottawa. Available from: <http://www.lpc.uottawa.ca/resources/pollen%20-%20heavy%20liquid.html> Accessed: 20/01/2009.

Appendices

Appendix I Sediment description formulae, interpretation and data

Formulae used to calculate sediment statistics

Median:

The median values produced in the Micromeritics® statistical output are recalculated as a phi value (Φ_{50}) by the following formula:

$\Phi = -\log_2$ (size in mm)

Sorting:

Inclusive graphic standard deviation is used as a reference to sorting and is calculated by:

$$\sigma_I = (\Phi_{84} - \Phi_{16})/4 + (\Phi_{95} - \Phi_5)/6.6$$

Where Φ_{84} = grain size (Φ) corresponding to 84% of the cumulative frequency.

Skewness:

The extent and direction of skew in the data is calculated by:

$$Sk_I = A + B$$

$$A = (\Phi_{16} + \Phi_{84} - 2\Phi_{50})/(2(\Phi_{84} - \Phi_{16})$$

$$B = (\Phi_5 + \Phi_{95} - 2\Phi_{50})/2(\Phi_{95} - \Phi_5)$$

Kurtosis:

Kurtosis values are calculated by:

$$K_G = (\Phi_{90} - \Phi_5)/2.44(\Phi_{75}-\Phi_{25}$$

Tables used to interpret basic sediment texture statistics as texture classes

The following tables have been modified from: Fernandes and Tett (2001)

Table 9: Median diameter (phi) to Udden-Wentworth size class.

Φ_{50}	sediment type	Φ_{50}	sediment type
less than -1	granule / pebble	(-1) - 0	very coarse sand
0 - 1	coarse sand	1 - 2	medium sand
2 - 3	fine sand	3 - 3.75	muddy sand
3.75 - 5	coarse silt	5 - 6	medium silt
6 - 8	fine silt	more than 8	clay

Table 10: Inclusive graphic standard deviation to sorting class.

σ_I	degree of sorting	σ_I	degree of sorting
less than 0.35	very well sorted	0.35-0.50	well sorted
0.50-0.71	moderately well sorted	0.71-1.00	moderately sorted
1.00-2.00	poorly sorted	2.00-4.00	very poorly sorted
more than 4.00	extremely poorly sorted	-	-

Table 11: Inclusive graphic skewness to skewness class.

Sk_I	skewness
1.00 to 0.30	strongly skewed towards fine particles
0.30 to 0.10	fine skewed
0.10 to -0.10	symmetrical
-0.10 to -0.30	coarse skewed
-0.30 to -1.00	strongly skewed towards coarse particles

Table 12: K_G value to kurtosis class.

K_G	kurtosis	K_G	kurtosis
less than 0.67	very platykurtic	0.67-0.90	platykurtic
0.90-1.11	mesokurtic (nearly normal)	-	-
1.11-1.50	leptokurtic	more than 1.50	very leptokurtic

Table 13: WA09 core: Sediment texture.

							Sorting		Skewness		Kurtosis		
Sample depth (cm)	Troells-Smith size class	Percentage composition	Troells-Smith size class summary	Mean ϕ	ϕ_{50} (median)	ϕ_{50} Udden-Wentworth grade	Inclusive graphic standard deviation (σ_I)	Sorting	Inclusive graphic skewness (Sk_I)	Skewness	K_G	Kurtosis	Coarsest one percentile (Φ)
0 to 1	As	16.2083351	Ag 4	5.66566	6.59562	*Fine silt*	2.0620879	*Very poorly sorted*	0.1037491	*Fine skewed*	0.08465	*Very platykurtic*	3.223367
	Ag	74.0455655											
	Ga	9.73227383											
10 to 11	As	4.35676958	Ag 4	4.79666	5.16152	*Medium silt*	1.403900907	*Poorly sorted*	0.2934563	*Fine skewed*	-0.1022	*Very platykurtic*	1.84772
	Ag	82.8981495											
	Ga	12.6896278											
20 to 21	As	8.06081607	Ag 4	5.13695	6.15021	*Fine silt*	1.691828226	*Poorly sorted*	0.113946	*Fine skewed*	0.03153	*Very platykurtic*	1.61749
	Ag	83.2477785											
	Ga	8.69129867											
30 to 31	As	6.02825416	Ag 4	4.88982	5.99493	*Medium silt*	1.633158149	*Poorly sorted*	0.0076549	*Symmetrical*	-0.01212	*Very platykurtic*	1.468716
	Ag	82.881409											
	Ga	11.09017											
40 to 41	As	7.21368842	Ag 4	4.60929	5.42663	*Medium silt*	1.836319704	*Poorly sorted*	0.1272333	*Fine skewed*	-0.02977	*Very platykurtic*	1.672865
	Ag	75.4461355											
	Ga	17.2585105											
50 to 51	As	4.24822839	Ag 2, Ga 2	3.46769	5.00277	*Medium silt*	2.083174089	*Very poorly sorted*	-0.1167	*Coarse skewed*	-0.03637	*Very platykurtic*	1.316975
	Ag	53.643681											
	Ga	42.1079322											
60 to 61	As	8.05900596	Ag 4	5.18338	5.48875	*Medium silt*	1.60898271	*Poorly sorted*	0.3073161	*Strongly skewed towards fine particles*	-0.04462	*Very platykurtic*	3.461931
	Ag	80.9036575											
	Ga	11.0115698											
70 to 71	As	6.17136734	Ag 4	5.07194	5.33701	*Medium silt*	1.384279551	*Poorly sorted*	0.2323297	*Fine skewed*	-0.10819	*Very platykurtic*	3.534277
	Ag	81.7056738											
	Ga	12.1193672											
80 to 81	As	8.85268546	Ag 4	5.60612	5.77438	*Medium silt*	1.450366479	*Poorly sorted*	0.389552	*Strongly skewed towards fine particles*	-0.05476	*Very platykurtic*	4.232731
	Ag	90.9418958											
	Ga	0.16365509											
90 to 91	As	10.6981858	Ag 2, Ga 2	4.24195	5.2395	*Medium silt*	2.395344844	*Very poorly sorted*	0.1891641	*Fine skewed*	-0.09359	*Very platykurtic*	1.072769
	Ag	41.9967524											
	Ga	47.3045779											
100 to 101	As	5.49818585	Ag 2, Ga 2	4.18102	5.34755	*Medium silt*	2.788042255	*Very poorly sorted*	0.2567564	*Fine skewed*	0.05714	*Very platykurtic*	1.250663
	Ag	49.6967524											
	Ga	44.8045779											

Table 13: continued

110 to 111	As	14.3700295	Ag 4	5.93192	6.05601	*Fine silt*	1.76524808	*Poorly sorted*	0.4911514	*Strongly skewed towards fine particles*	0.19387	*Very platykurtic*	4.484541
	Ag	85.6295003											
	Ga	0											
120 to 121	As	11.0783824	Ag 4	5.92665	6.06854	*Fine silt*	1.521459559	*Poorly sorted*	0.4419535	*Strongly skewed towards fine particles*	-0.00728	*Very platykurtic*	4.535704
	Ag	88.9213646											
	Ga	0											
130 to 131	As	14.813757	Ag 4	6.00509	6.1078	*Fine silt*	1.748941385	*Poorly sorted*	0.5168905	*Strongly skewed towards fine particles*	0.09518	*Very platykurtic*	4.492467
	Ag	85.1791216											
	Ga	0											
140 to 141	As	20.2789432	Ag 4	6.28546	6.35698	*Fine silt*	1.873815651	*Poorly sorted*	0.5236572	*Strongly skewed towards fine particles*	0.36621	*Very platykurtic*	4.730778
	Ag	79.720566											
	Ga	0											
150 to 151	As	21.9731651	Ag 4	6.03127	6.40141	*Fine silt*	2.009642772	*Very poorly sorted*	0.4466864	*Strongly skewed towards fine particles*	0.29883	*Very platykurtic*	3.205768
	Ag	74.7399345											
	Ga	3.2160396											
160 to 161	As	21.9893646	Ag 4	5.92402	6.37124	*Fine silt*	2.114001091	*Very poorly sorted*	0.4105319	*Strongly skewed towards fine particles*	0.23386	*Very platykurtic*	3.184856
	Ag	73.5836											
	Ga	4.35330821											
170 to 171	As	1.21900348	Ga 4	2.86881	2.8879	*Fine sand*	1.02344413	*Poorly sorted*	0.3415034	*Strongly skewed towards fine particles*	-1.27095	*Very platykurtic*	1.476864
	Ag	10.3271292											
	Ga	88.4470234											
180 to 181	As	0	Ga 4	2.74565	3.26812	*Very fine sand*	1.01217736	*Poorly sorted*	-0.259604	*Coarse skewed*	-0.22977	*Very platykurtic*	1.170243
	Ag	14.6499824											
	Ga	85.3495904											
190 to 191	As	0	Ag 1, Ga 3	2.68223	2.71881	*Fine sand*	0.376095632	*Well sorted*	0.0272963	*Symmetrical*	-1.69097	*Very platykurtic*	2.011582
	Ag	30.5984724											
	Ga	69.3987277											
200 to 201	As	1.20596922	Ga 4	2.88151	2.79987	*Fine sand*	1.060775713	*Poorly sorted*	0.551003	*Strongly skewed towards fine particles*	0.07242	*Very platykurtic*	1.999874
	Ag	12.3271292											
	Ga	86.4470234											
	Gs	0.01303426											
210 to 211	As	9.6908464	Ag 2, Ga 2	3.97211	4.39562	*Coarse silt*	2.325057405	*Very poorly sorted*	0.4484226	*Strongly skewed towards fine particles*	0.00154	*Very platykurtic*	1.702792
	Ag	47.4663054											
	Ga	42.8376269											

Table 14: WA1 core: Sediment texture.

							Sorting		Skewness		Kurtosis		
Sample depth (cm)	Troells-Smith size class	Percentage composition	Troells-Smith size class summary	Mean ϕ	ϕ_{50} (median)	ϕ_{50} Udden-Wentworth grade	Inclusive graphic standard deviation (σ_I)	Sorting	Inclusive graphic skewness (Sk_I)	Skewness	K_G	Kurtosis	Coarsest one percentile (Φ)
0 to 1	As	8.09313823	Ag 4	28.25	16.88	*Medium silt*	1.838401479	*Poorly sorted*	0.2126534	*Fine skewed*	0.03174	*Very platykurtic*	2.359345
	Ag	78.0059698											
	Ga	13.8978469											
4 to 5	As	5.9938687	Ag 3, Ga 1	40.58	27.32	*Medium silt*	1.808708145	*Poorly sorted*	0.318292	*Strongly skewed towards fine particles*	-0.03424	*Very platykurtic*	2.364642
	Ag	69.1988995											
	Ga	24.7998672											
9 to 10	As	5.4750322	Ag 3, Ga 1	50.19	19.16	*Medium silt*	1.791052	*Poorly sorted*	-0.155927	*Coarse skewed*	-0.02677	*Very platykurtic*	1.252753
	Ag	69.0902892											
	Ga	25.4342418											
14 to 15	As	4.46486253	Ag 3, Ga 1	80.03	18.53	*Medium silt*	2.039244823	*Very poorly sorted*	-0.52304	*Strongly skewed towards coarse particles*	-0.00682	*Very platykurtic*	1.106116
	Ag	64.0299086											
	Ga	31.50407											
19 to 20	As	3.80744925	Ag 3, Ga 1	94.99	20.2	*Medium silt*	2.072614055	*Very poorly sorted*	-0.51207	*Strongly skewed towards coarse particles*	-0.00715	*Very platykurtic*	1.09796
	Ag	60.9971051											
	Ga	35.1940205											
24 to 25	As	9.30602223	Ag 4	29.87	13.51	*Fine silt*	1.971758751	*Poorly sorted*	0.0089013	*Symmetrical*	0.00108	*Very platykurtic*	1.893714
	Ag	75.631421											
	Ga	15.0038283											
29 to 30	As	11.3291042	Ag 4	22.35	12.49	*Fine silt*	1.723037998	*Poorly sorted*	0.3148695	*Strongly skewed towards fine particles*	0.02187	*Very platykurtic*	2.617227
	Ag	76.951837											
	Ga	11.658829											
34 to 35	As	10.9626902	Ag 4	31.66	12.38	*Fine silt*	2.190331052	*Very poorly sorted*	-0.08178	*Symmetrical*	0.00492	*Very platykurtic*	1.89933
	Ag	72.0050987											
	Ga	17.0320802											
39 to 40	As	15.3905828	Ag 4	9.319	9.19	*Fine silt*	1.422962724	*Poorly sorted*	0.6072896	*Strongly skewed towards fine particles*	0.73055	*Very platykurtic*	5.066212
	Ag	84.6055976											
	Ga	0											

Table 15: Te Koru core: Sediment texture.

							Sorting		Skewness		Kurtosis		
Sample depth	Troells-Smith size class	Percentage composition	Troells-Smith size class summary	Mean ϕ	ϕ_{50} (median)	ϕ_{50} Udden-Wentworth grade	Inclusive graphic standard deviation (σ_i)	Sorting	Inclusive graphic skewness (Sk_i)	Skewness	K_G	Kurtosis	Coarsest one percentile (Φ)
0 to 1	As	15.079472	Ag 4	10.03	9.865	*Fine silt*	-1.428833885	*Poorly sorted*	0.5128783	*Strongly skewed towards fine particles*	0.71803	*Platykurtic*	4.658984
	Ag	84.9203265											
	Ga	0											
6 to 7	As	17.9827402	Ag 4	8.776	9.417	*Fine silt*	-1.44563165	*Poorly sorted*	0.5678693	*Strongly skewed towards fine particles*	0.98682	*Mesokurtic*	5.535647
	Ag	81.9284617											
	Ga	0											
12 to 13	As	19.9711646	Ag 4	8.247	8.444	*Fine silt*	-1.479511901	*Poorly sorted*	0.5106138	*Strongly skewed towards fine particles*	0.97838	*Mesokurtic*	5.545377
	Ag	80.0286106											
	Ga	0											
18 to 19	As	12.4264541	Ag 4	26.92	9.879	*Fine silt*	-1.977563983	*Poorly sorted*	0.0122026	*Symmetrical*	0.025	*Very platykurtic*	2.347075
	Ag	73.3569959											
	Ga	14.2163755											
24 to 25	As	8.60782677	Ag 4	27.81	12.49	*Fine silt*	-1.669144803	*Poorly sorted*	0.1820658	*Fine skewed*	0.02217	*Very platykurtic*	1.87248
	Ag	83.1063192											
	Ga	8.2856986											
30 to 31	As	8.65855197	Ag 4	27.13	12.15	*Fine silt*	-1.645369594	*Poorly sorted*	0.2147895	*Fine skewed*	0.06312	*Very platykurtic*	1.833468
	Ag	83.647223											
	Ga	7.69402486											
36 to 37	As	7.62675449	Ag 4	19.68	12.67	*Fine silt*	-1.220279302	*Poorly sorted*	0.2620339	*Fine skewed*	-0.01133	*Very platykurtic*	2.052393
	Ag	87.7481332											
	Ga	4.62500211											
42 to 43	As	6.51275086	Ag 4	22.89	13.14	*Fine silt*	-1.460359948	*Poorly sorted*	-0.172739	*Coarse skewed*	-0.00906	*Very platykurtic*	2.782289
	Ag	84.5508605											
	Ga	8.92370129											

Table 16: WA09 core: Sample water content.

Sample depth (cm)	Beaker weight (g)	Combined beaker and wet sample weight (g)	Calculated wet sample weight	DW 105: Combined beaker and dry sample weight (g)	Calculated dry weight (g)	Calculated water content (g)	**Calculated water content (%)**
0 to 1	31.08	33.33	2.25	32.02	0.94	1.31	**58.22**
10 to 11	32.06	37.88	5.82	35.8	3.74	2.08	**35.74**
20 to 21	27.36	31.51	4.15	29.48	2.12	2.03	**48.92**
30 to 31	33.41	38.65	5.24	36.02	2.61	2.63	**50.19**
40 to 41	29.76	33.18	3.42	32.1	2.34	1.08	**31.58**
50 to 51	33.14	38.76	5.62	37.37	4.23	1.39	**24.73**
60 to 61	21.57	30.16	8.59	27.63	6.06	2.53	**29.45**
70 to 71	29.15	37.22	8.07	34.97	5.82	2.25	**27.88**
80 to 81	33.05	40.81	7.76	38.66	5.61	2.15	**27.71**
90 to 91	27.6	37.76	10.16	35.65	8.05	2.11	**20.77**
100 to 101	28.85	35.09	6.24	33.75	4.9	1.34	**21.47**
110 to 111	27.57	32.33	4.76	31.09	3.52	1.24	**26.05**
120 to 121	32.87	37.94	5.07	36.42	3.55	1.52	**29.98**
130 to 131	28.94	33.77	4.83	32.38	3.44	1.39	**28.78**
140 to 141	31.89	40.53	8.64	37.82	5.93	2.71	**31.37**
150 to 151	28.68	34.7	6.02	32.77	4.09	1.93	**32.06**
160 to 161	33.21	37.84	4.63	36.72	3.51	1.12	**24.19**
170 to 171	22.2	29.72	7.52	27.94	5.74	1.78	**23.67**
180 to 181	33.69	39.48	5.79	38.29	4.6	1.19	**20.55**
190 to 191	33.61	41.1	7.49	39.48	5.87	1.62	**21.63**
200 to 201	32.45	39.4	6.95	38.06	5.61	1.34	**19.28**
210 to 211	32.16	40.89	8.73	38.96	6.8	1.93	**22.11**

Table 17: WA09 core: LOI550 and LOI950 calculation data.

		LOI 550 °C, 4 hours exposure			LOI 950 °C, 2 hours exposure			
Sample depth (cm)	DW 105: Combined crucible and dry sample weight (g)	DW 550: Crucible and sample weight after 550 °C	LOI 550 (g)	**LOI 550 (%)**	DW 950: Crucible and sample weight after 950 °C	LOI 950 (g)	LOI 950 (g) x 1.36	**LOI 950 (%)**
0 to 1	3.52	3.44	0.08	**2.27**	3.44	0.00	0	**0**
10 to 11	3.48	3.42	0.06	**1.72**	3.41	0.01	0.0136	**0.40**
20 to 21	3.06	3.03	0.03	**0.98**	3.02	0.01	0.0136	**0.45**
30 to 31	3.44	3.38	0.06	**1.74**	3.37	0.01	0.0136	**0.40**
40 to 41	3.92	3.88	0.04	**1.02**	3.87	0.01	0.0136	**0.35**
50 to 51	4.16	4.13	0.03	**0.72**	4.11	0.02	0.0272	**0.66**
60 to 61	4.08	4.04	0.04	**0.98**	4.03	0.01	0.0136	**0.34**
70 to 71	4.25	4.23	0.02	**0.47**	4.20	0.03	0.0408	**0.96**
80 to 81	4.08	4.03	0.05	**1.23**	4.02	0.01	0.0136	**0.34**
90 to 91	4.13	4.10	0.03	**0.73**	4.09	0.01	0.0136	**0.33**
100 to 101	3.66	3.65	0.01	**0.27**	3.64	0.01	0.0136	**0.37**
110 to 111	4.16	4.13	0.03	**0.72**	4.12	0.01	0.0136	**0.33**
120 to 121	4.15	4.11	0.04	**0.96**	4.10	0.01	0.0136	**0.33**
130 to 131	4.2	4.16	0.04	**0.95**	4.13	0.03	0.0408	**0.98**
140 to 141	3.93	3.89	0.04	**1.02**	3.87	0.02	0.0272	**0.70**
150 to 151	3.98	3.95	0.03	**0.75**	3.93	0.02	0.0272	**0.69**
160 to 161	3.92	3.89	0.03	**0.77**	3.86	0.03	0.0408	**1.05**
170 to 171	3.78	3.77	0.01	**0.26**	3.75	0.02	0.0272	**0.72**
180 to 181	3.75	3.73	0.02	**0.53**	3.72	0.01	0.0136	**0.36**
190 to 191	3.92	3.90	0.02	**0.51**	3.89	0.01	0.0136	**0.35**
200 to 201	3.98	3.96	0.02	**0.50**	3.94	0.02	0.0272	**0.69**
210 to 211	3.88	3.87	0.01	**0.26**	3.84	0.03	0.0408	**1.05**

Table 18: WA1 core: (A) Sample water content and (B) LOI550/LOI950 calculation data.

A

Sample depth (cm)	Crucible weight (g)	Combined crucible and wet sample weight (g)	Calculated wet sample weight	DW 105: Combined crucible and dry sample weight (g)	Calculated dry weight (g)	Calculated water content (g)	**Calculated water content (%)**
0-1 cm	2.30	4.23	1.93	3.21	0.91	1.02	**52.85**
4-5 cm	2.20	3.56	1.36	2.91	0.71	0.65	**47.79**
9-10 cm	2.06	3.87	1.81	2.95	0.89	0.92	**50.83**
14-15 cm	2.18	4.09	1.91	3.22	1.04	0.87	**45.55**
19-20 cm	2.24	4.01	1.77	3.07	0.83	0.94	**53.11**
24-25 cm	2.19	4.38	2.19	3.42	1.23	0.96	**43.84**
29-30 cm	2.24	4.57	2.33	3.65	1.41	0.92	**39.48**
34-35 cm	2.16	3.82	1.66	3.01	0.85	0.81	**48.80**
39-40 cm	2.19	4.15	1.96	3.26	1.07	0.89	**45.41**

B

	LOI 550 °C, 4 hours exposure			LOI 950 °C, 2 hours exposure			
Sample depth (cm)	DW 550: Crucible and sample weight after 550 °C	LOI 550 (g)	**LOI 550 (%)**	DW 950: Crucible and sample weight after 950 °C	LOI 950 (g)	LOI 950 (g) x 1.36	**LOI 950 (%)**
0-1 cm	3.16	0.05	**1.56**	3.16	0	0	**0**
4-5 cm	2.88	0.03	**1.030**	2.88	0	0	**0**
9-10 cm	2.90	0.05	**1.69**	2.88	0.02	0.027	**0.94**
14-15 cm	3.16	0.06	**1.86**	3.15	0.01	0.014	**0.43**
19-20 cm	3.03	0.04	**1.30**	3	0.03	0.041	**1.35**
24-25 cm	3.36	0.06	**1.75**	3.34	0.02	0.027	**0.81**
29-30 cm	3.59	0.06	**1.64**	3.58	0.01	0.014	**0.38**
34-35 cm	2.97	0.04	**1.33**	2.97	0	0	**0**
39-40 cm	3.21	0.05	**1.53**	3.21	0	0	**0**

Table 19: Te Koru core: (A) Sample water content and (B) LOI550/LOI950 calculation data.

A

Sample depth (cm)	Crucible weight (g)	Combined crucible and wet sample weight (g)	Calculated wet sample weight	DW 105: Combined crucible and dry sample weight (g)	Calculated dry weight (g)	Calculated water content (g)	**Calculated water content (%)**
0-1 cm	2.18	3.91	1.73	2.84	0.66	1.07	**61.85**
6-7 cm	2.23	4.32	2.09	3.27	1.04	1.05	**50.24**
12-13 cm	2.16	4.05	1.89	3.04	0.88	1.01	**53.44**
18-19 cm	2.04	3.93	1.89	2.92	0.88	1.01	**53.44**
24-25 cm	2.28	4.40	2.12	3.41	1.13	0.99	**46.70**
30-31 cm	2.15	4.27	2.12	3.25	1.10	1.02	**48.11**
36-37 cm	2.18	4.15	1.97	3.18	1.00	0.97	**49.24**
42-43 cm	2.21	4.11	1.90	3.42	1.21	0.69	**36.32**

B

	LOI 550 °C, 4 hours exposure			LOI 950 °C, 2 hours exposure			
Sample depth (cm)	DW 550: Crucible and sample weight after 550 °C	LOI 550 (g)	**LOI 550 (%)**	DW 950: Crucible and sample weight after 950 °C	LOI 950 (g)	LOI 950 (g) x 1.36	**LOI 950 (%)**
0-1 cm	2.80	0.04	**1.41**	2.79	0.01	0.014	**0.49**
6-7 cm	3.21	0.06	**1.83**	3.19	0.02	0.027	**0.85**
12-13 cm	3.00	0.04	**1.32**	2.98	0.02	0.027	**0.91**
18-19 cm	2.87	0.05	**1.71**	2.85	0.02	0.027	**0.95**
24-25 cm	3.36	0.05	**1.47**	3.33	0.03	0.041	**1.21**
30-31 cm	3.19	0.06	**1.85**	3.17	0.07	0.095	**0.85**
36-37 cm	3.12	0.06	**1.89**	3.11	0.01	0.014	**0.44**
42-43 cm	3.38	0.04	**1.17**	3.36	0.02	0.027	**0.80**

Appendix II Pollen analysis methods

Sediment treatment

- 10 ml of 10% hydrochloric acid (HCl) added to each sample tube, mixed and left overnight to digest carbonates.

- One *Lycopodium* tablet (batch number 938934) dissolved in each sample as a reference spike, following Stockmarr (1971).

- Distilled water added to each as necessary so each tube is evenly filled for balanced centrifuging.

- Samples centrifuged at 3000 rpm for three minutes. Supernatant decanted off and tubes refilled with distilled water. This process is repeated three times to ensure no HCl remains.

- In a fume cupboard, 10 ml of Hydrofluoric acid (HF) added to each tube and mixed with a polypropylene rod. HF treatment was left overnight to digest silicates. All appropriate safety procedures are followed when using HF.

- The HF is neutralised using warm HCl. 100% HCl is heated over a Bunsen burner in a fume cupboard. Each of the sample tubes is topped up evenly with warm HCl and centrifuged at 3000 rpm for 3 minutes. The supernatant is poured off into an HF waste bucket. The tubes are then topped up with warm HCl that has been diluted to a concentration of 50%. The samples are centrifuged and the supernatant poured into the bucket. This process is repeated until the liquid is clear or slightly yellow after centrifuging. Distilled water is then added to each tube and centrifuged at 3000 rpm for three minutes and the supernatant poured off. This process is repeated three times.

- 10ml of nitric acid (HNO_3) (69%) added to each tube and left for 5 minutes to oxidise organic matter such as cellulose. Each tube is then topped up with distilled water and centrifuged for three minutes at 3000 rpm and supernatant is decanted off. This is repeated three times.

- Sediment from each tube is filtered through a 180 micron filter into a new centrifuge tube, to remove any large debris.

- Pollen is concentrated by a series of short centrifuges. The speed is gradually increased to 2000 rpm over 30 seconds. The supernatant and any suspended matter is decanted off. This is repeated three times to remove material with a density lower than sporopollenin.

- The remaining concentrated material still contained some quarts or feldspars that were not digested by HF treatment. A density separation using the heavy liquid ‘Lithium heteropolytungstates’ (LST) with a specific gravity of 2.2 (2.2sg) was used to remove these. Heavy liquid of this specific gravity was obtained using the following formula

from Swanson (1985):

$$X = \frac{Y\,(SG\ required - SG\ liquid)}{SG\ dilutant - SG\ required}$$

Where: SG = specific gravity, X = volume of the dilutant, Y = volume of the heavy liquid.

Pollen forms a 'float' in liquid of 2.2sg when centrifuged at 1800 rpm for 18 minutes as sporopollenin has a density of around 1.4 (Nakagawa et al. 1998; Zabenskie & Gajewski 2007).

- Float removed from each tube with a pipette and placed into new tubes. Ensure all pollen 'float' material is removed in order to obtain accurate pollen concentration values.

- Each tube filled evenly with distilled water and centrifuged at 3000 rpm for 3 minutes so the pollen forms a pellet. Water decanted from each tube and filled again with distilled water, centrifuged and decanted. This is done three times to remove all LST.

- A small amount of distilled water (0.5 ml) added to each tube and pellet re-suspended.

Pollen mounting

Each re-suspended pollen sample is mounted with glycerol jelly as described by Bennett and Willis (2001).

- Glycerol jelly heated in a warm water bath to liquefy the jelly. Two drops of warmed glycerol jelly added to a slide.

- One drop of concentrated pollen solution pipetted on the jelly solution, mixed and dispersed over the slide in an area the size of a cover slip.

- Slide heated on a hotplate at 150ºC until water in solution evaporates and becomes viscous.

- A cover slip is then placed on the slide, over the solution, ensuring there are no air bubbles underneath.

- Slide removed from hotplate, cooled and cover slip sealed with nail polish.

Appendix III Diatom analysis methods

Sediment treatment

- Many methodologies state that diatoms are extracted from sediment that has first been dried. However, Flower (1993) observed that drying can damage the diatom frustules, causing fracturing and making identification more difficult. Therefore, in this test 1 cm^3 fresh sediment was removed from the core at 10 cm intervals, placed in clean beakers and weighed. The percent water content ascertained from the drying during LOI tests (Chapter 4) is used to calculate what the dry weight of the fresh samples would be. Thus the dry weight of the samples used can be calculated without damaging the frustules. The calculation to do this is as follows:

$$\text{Water content of fresh sample} = \frac{\%\ \text{water content}}{100}\ \text{X}\ \text{fresh sample weight}$$

$$\text{Dry sample weight} = \text{fresh sample weight} - \text{water content of fresh sample}$$

- 15 ml of 27% Hydrogen peroxide (H_2O_2) added to samples in the morning and surveillance maintained while reactions occurred in a fume cupboard. This step is used to oxidise organics within the sample. In addition to ensuring the samples did not dry out, surveillance is necessary to ensure samples did not overflow during violent reactions. Most samples reacted slowly for about an hour, then a sudden and violent exothermic reaction would take place. To ensure that no material is lost during these reactions, samples are mixed and placed in a cold water bath.

- Samples are mixed periodically until all visible reactions cease. These samples are then placed in a warm water bath, on a hotplate at 50 degrees Celsius. Visible reactions occur once again and a sheet of paper is placed over these to stop 'spitting' of material between samples.

- After visible reactions have ceased 10 ml of 32% Hydrochloric Acid (HCl) added to each beaker to digest carbonates.

- When reactions have ceased the samples are removed from the water bath, left to cool, then poured into 10 ml centrifuge tubes with the aid of squirts of distilled water. For most samples two tubes or three tubes are required. These are centrifuged at 3000 rpm and combined. Each sample is then centrifuged and decanted with distilled water three times to clean.

- Initially a density separation was attempted on two samples using the heavy liquid 'Lithium heteropolytungstates' (LST) at a specific gravity of 2.3. A 'float' of diatom frustules is produced upon centrifugation when the specific gravity of the liquid is more than that of the diatoms. According to Battarbee et al. (2001) a LST specific

gravity of 2.2 should be used to separate diatoms. Though, according to Harvey (1996) a specific gravity of 2.3 should be used. Therefore, a specific gravity of 2.3 was initially used in this density separation step. However, upon mounting, these samples still had large amounts of very fine mineral matter. Hence, It was determined that a clay removal step would be needed to produce clean samples, before a density separation step. In addition, aliquots of the density separated material were taken at different levels down the centrifuge tube and mounted. It was determined that large numbers of diatoms remained in the lower depths of the liquid following centrifugation. Therefore, a LST specific gravity of 2.3 may be too low to separate all diatoms in the sample and a LST specific gravity of 2.5 was tried. This produced much better results so was used for the density separation step following centrifugation.

- Fine clay particles are removed as follows: 10 ml centrifuge tubes each containing samples are filled with distilled water. Two drops of calgon were added to these tubes, mixed thoroughly using a vortex mixer for 30 seconds and centrifuged at 1500 rpm for 3 minutes. The supernatant containing the clay particles is decanted off. This process is repeated until the supernatant is clear and was carried out up to 10 times in Waihora samples, due to the prevalence of clay particles in the sediment.

- Density separation using LST at a specific gravity of 2.5 is then carried out on samples. This specific gravity is produced by diluting the supplied LST (2.85 specific gravity) with distilled water, the volume of which is calculated using the formula below (Swanson 1985). Each centrifuge tube is filled to the 10 ml mark with LST solution. These are mixed thoroughly using a vortex mixer until all material is disaggregated, then centrifuged at 1800 rpm for 6 minutes.

$$X = \frac{Y\,(\text{SG required} - \text{SG liquid}}{\text{SG dilutant} - \text{SG required}}$$

Where: SG = specific gravity, X = volume of the dilutant, Y = volume of the heavy liquid.

- Samples are removed carefully from the centrifuge to ensure the float material is not disturbed. All float material is removed from the tubes using a wide bore pipette and placed in separate clean centrifuge tubes for each sample. Density separation and float material removal is carried out twice more to ensure all diatom remains in the samples are collected. Distilled water is then added to the removed float material (fill tubes), centrifuged at 3000 rpm for 3 minutes, decanted and repeated three times more to clean samples.

- The resulting pellet of diatom material is diluted to an appropriate concentration. Diatom solution concentrations from various sediment samples were examined on a wet mount. The solution was diluted to level that an appropriate count concentration could be obtained (about three valves per view is appropriate according to Battarbee et al. (2001)). The volume of the diluted suspension was noted down for each sample

in order to calculate diatom concentration. The volume of final diluted solution for each sample is displayed in *Table 20*, below. Samples 50 – 51, 180 – 181, 190 – 191 and 200 – 201 in WA09 had visibly lower diatom concentrations. Therefore, these samples were diluted less and this was accounted for during diatom concentration calculations.

Table 20: Volume of diluted diatom solution for each core.

WA09 core		**WA1 core**		**Te Koru core**	
Sample depth (cm)	Sample depth	Sample depth (cm)	Volume of diluted solution	Sample depth (cm)	Volume of diluted solution
0 – 1	12 ml	0 – 1	12 ml	0 – 1	12 ml
10 – 11	12 ml	4 – 5	12 ml	6 – 7	12 ml
20 – 21	12 ml	9 – 10	12 ml	12 – 13	12 ml
30 – 31	12 ml	14 – 15	12 ml	18 – 19	12 ml
40 – 41	12 ml	19 – 20	12 ml	24 – 25	12 ml
50 – 51	2 ml	24 – 25	12 ml	30 – 31	12 ml
60 – 61	12 ml	29 – 30	12 ml	36 – 37	12 ml
70 – 71	12 ml	34 – 35	12 ml	42 – 43	12 ml
80 – 81	12 ml	39 – 40	12 ml		
90 – 91	12 ml				
100 – 101	12 ml				
110 – 111	12 ml				
120 – 121	12 ml				
130 – 131	12 ml				
140 – 141	12 ml				
150 – 151	12 ml				
160 – 161	12 ml				
170 – 171	12 ml				
180 – 181	2 ml				
190 – 191	2 ml				
200 – 201	2 ml				
210 – 211	12 ml				

Calculating diatom concentration with Lycopodium spore spike

There are several methods used to estimate diatom concentration. Battarbee (1982) describes three of these methods. The first is the pipette or aliquot method which involves counting the total number of diatoms on a slide after a known volume of suspension is mounted. However, the distribution of valves mounted in this manner is non-random. Therefore, the whole slide must be counted making this method very time consuming.

A similar method can be used which produces a random distribution of diatom valves on a slide. This is the evaporation tray method, which involves the evaporation of a known volume of diatom suspension. A portion of the slide can be counted which is representative of the

diatom density on the slide. This count can then be extrapolated, making counting less time consuming. However, slide preparation can be time consuming with this method (Battarbee, 1982).

A method commonly used to calculate microfossil concentrations involves the addition of a known quantity of external markers, as commonly utilized by palynologists. With this method a known concentration of markers are added to a sample and homogenised. The number of the target microfossil is calculated from the ratio of markers to target microfossils. In this thesis the marker spike solution was produced by adding a commercially available tablet that contains a known quantity of *Lycopodium* spore (Battarbee 1982).

The *Lycopodium* spore tablet spike was chosen, largely due to its convenience and well documented use in published methodologies. In palynological studies, a known quantity of *Lycopodium* is added to the raw sediment at the beginning of processing (usually one to two tablets) (Bennet and Willis 2001). However, during diatom preparation, *Lycopodium* can only be added after all processing has finished, to avoid losses due to the variation in specific gravity of *Lycopodium* compared to diatom valves (Battarbee et al. 2001). Consequently, *Lycopodium* was only added in this test after all sediment separations had been completed. Ideally *Lycopodium* spike would be added to the final diatom solution in a ratio of about one *Lycopodium* spore to every diatom valve (Wolfe 1997). However, with the concentration of diatoms obtained from the Waihora samples, large numbers of *Lycopodium* tablets would be required for each sample. Therefore, a method of adding a known concentration of *Lycopodium* to a small sub-sample of the final diatom solution was developed to limit tablet use.

0.5 ml is removed from each sample of diluted diatom solution (*Table 20*), with a wide bore pipette. 12 dissolved *Lycopodium* tablets are added to each 0.5 ml sub sample. This number of tablets was established through trial and error to produce a similar concentration of *Lycopodium* spores to diatom valves. Each tablet from batch number 938934 contains 10,679 ± 953 spores. Therefore, each 0.5 ml sample had 128,148 spores added. The number of diatoms per 0.5 ml of sample can then be calculated using the following formula from Battarbee and Kneen (1982):

$$\text{Total diatom valves per 0.5 ml} = \frac{\textit{Lycopodium}\text{ introduced x Diatom valves counted}}{\textit{Lycopodium}\text{ counted}}$$

This is then multiplied by the number of times 0.5 ml goes into the volume of the final solution. For example if the volume of final diatom solution produced for a particular sample was 12 ml (*see Table ?*) then the value produced by the formula would be multiplied by 24. This gives the diatom valve concentration per sample. This is then divided by the calculated dry weight used to give a concentration per gram dry weight.

Mounting diatom frustules

The diatom/*Lycopodium* solution is mounted using the following procedure from methods outlined in Battarbee et al. (2001).

- Slides and cover slips are warmed on a hotplate. One slide and two cover slips are required for each sample.
- For each sample one drop of diatom/*Lycopodium* solution is added to one of the two cover slips. Two drops are added to the second cover slip.
- 10 micropipette drops of water is added to each slip, so that the slip is covered in solution. These slips are heated on a warm hotplate until the water has evaporated. The diatom frustules are now attached to the surface of the cover slip.
- One drop of 'Naphrax' is added to each side of a slide (left and right), so that two cover slips can be mounted.
- With the help of a toothpick each cover slip is inverted into a drop of Naphrax.
- The slides are heated on the hotplate until the toluene in the Naphrax solution has bubbled off. When bubbling is ceased the slide is removed from the hotplate and tapped with a toothpick to remove any air bubbles. The Naphrax cools down and hardens rapidly.

Appendix IV Pollen data

Table 21: WA09 core pollen counts.

	Sample depth (cm)																					
Taxa	0 to 1	10 to 11	20 to 21	30 to 31	40 to 41	50 to 51	60 to 61	70 to 71	80 to 81	90 to 91	100 to 101	110 to 111	120 to 121	130 to 131	140 to 141	150 to 151	160 to 161	170 to 171	180 to 181	190 to 191	200 to 201	210 to 211	Plant type
Podocarpus spp.	6.0	18.0	38.5	50.0	88.0	87.5	83.0	0.0	80.0	72.0	34.5	77.0	96.5	59.5	69.0	50.0	51.0	61.5	35.5	47.5	62.5	73.0	Native tree
N. fusca type	13.0	9.0	8.0	5.0	4.0	6.0	19.0	0.0	20.0	15.0	7.0	16.0	13.0	20.0	9.0	5.0	6.0	6.0	13.0	4.0	2.0	4.0	Native tree
Phyllocladus *spp.*	0.0	1.0	2.0	2.0	2.0	2.1.0	16.0	0.0	13.0	13.0	6.0	7.0	12.0	12.0	11.0	8.0	11.0	6.0	7.0	8.0	7.0	4.0	Native tree
Halocarpus bidwillIii	0.0	0.0	2.0	0.0	0.0	11.5	3.0	0.0	9.5	4.0	2.0	7.5	7.0	5.0	2.0	5.0	8.0	7.0	3.0	0.0	3.0	4.0	Native tree
Metrosideros spp.	0.0	0.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	0.0	0.0	1.0	0.0	1.0	2.0	4.0	Native tree
Dacrycarpus dacrydioides	0.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	1.0	1.0	1.0	3.0	2.0	1.0	4.0	3.0	4.0	5.0	0.0	1.0.0	4.0	6.0	Native tree
Dacrydium cupressinum	5.0	0.0	9.0	4.0	8.0	3.0	3.0	0.0	3.0	5.5	1.0	7.0	3.5	5.0	6.0	1.0	3.0	3.0	4.0	2.0	1.0	5.0	Native tree
Leptospermum scoparium	5.0	3.0	0.0	3.0	2.0	4.0	8.0	0.0	11.0	4.0	0.0	12.0	3.0	13.0	32.0	9.0	2.0	2.0	1.0	3.0	7.0	11.0	Native tree
N. menziesii type	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	Native tree
Quintina serrata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native tree
Coriaria spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	1.0.0	7.0	5.0	5.0	4.0	5.0	2.0	0.0	1.0	1.0	0.0	Native shrub
Coriaria kingiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	7.0	1.0	4.0	1.0	5.0	2.0	5.0	Native shrub
Coprosma spp.	2.0	1.0	2.0	0.0	0.0	4.0	3.0	0.0	2.0	6.0	1.0	1.0.0	7.0	8.0	7.0	11.0	7.0	12.0	6.0	11.0	16.0	17.0	Native shrub
Forstera bidwillii	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Pseudowintera sp.	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Plagianthus/Hoheria	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	3.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	0.0	3.0	Native shrub
Melicytus angustifolius	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Ericaceae/Epacridaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0	2.0	0.0	2.0	0.0	0.0	0.0	Native shrub
Myrsine spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	1.0	1.0.0	0.0	Native shrub
Scrophulariaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Gunnera spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	2.0	0.0	0.0	2.0	0.0	Native shrub
Elaecocarpiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	Native shrub
Aristotelia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	Native shrub
Geniostoma ligustrifolium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	Native shrub
Gunneraceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	Native shrub
Pittosporum spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	Native shrub
Hebe sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native shrub
Phormium spp.	0.0	1.0	1.0	6.0	2.0	5.0	0.0	0.0	9.0	1.0	0.0	0.0	2.0	2.0	1.0	0.0	0.0	2.0	2.0	1.0	1.0	0.0	Native shrub
Korthalsella sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	Lianas, parasites, vines
Korthalsella salicornioides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.0	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	Lianas, parasites, vines
Muehlenbeckia australis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	Lianas, parasites, vines
Parsonsia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	Lianas, parasites, vines
Peraxilla sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	Lianas, parasites, vines
Ripogonum scandens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0	7.0	11.0	16.0	Lianas, parasites, vines
Pinus spp.	16.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Exotic tree
Plantago sp.	6.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Exotic herb

Table 21: continued

Astelia sp.	10	0.0	3.0	2.0	2.0	3.0	0.0	0.0	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	3.0	4.0	2.0	0.0	10	0.0	Herbs and grasses
Liliaceae	27.0	13.0	110	16.0	8.0	110	20.0	0.0	15.0	9.0	6.0	4.0	6.0	20.0	8.0	2.0	10	12.0	0.0	14.0	20.0	25.0	Herbs and grasses
Forstera sedifolia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	10	0.0	0.0	0.0	3.0	Herbs and grasses
Forstera mackayi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Forstera tenella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	10	0.0	Herbs and grasses
Forstera sp.	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Apiaceae	3.0	10	10	2.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.0	10	3.0	0.0	10	0.0	0.0	3.0	10	Herbs and grasses
Ranunculaceae	7.0	5.0	10	8.0	2.0	3.0	9.0	0.0	5.0	6.0	0.0	8.0	110	10.0	2.0	5.0	3.0	2.0	3.0	10	2.0	10	Herbs and grasses
Phyllacne colensoi	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Brassicaceae	0.0	2.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Crassula moschata	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	Herbs and grasses
Oreostylidium subulatum	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Stellaria sp.	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Glossostigma elatinoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Euphorbiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	2.0	0.0	0.0	0.0	0.0	Herbs and grasses
Utricularia monanthos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	Herbs and grasses
Fabiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	Herbs and grasses
Asteraceae (1)	0.0	0.0	0.0	10	3.0	0.0	0.0	0.0	0.0	2.0	2.0	5.0	4.0	10	10	3.0	3.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (2)	2.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	5.0	10	0.0	0.0	10	0.0	0.0	10	0.0	0.0	4.0	8.0	6.0	5.0	Herbs and grasses
Asteraceae (7)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (9)	2.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (10)	0.0	0.0	2.0	10	10	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (11)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	3.0	0.0	0.0	2.0	0.0	10	0.0	10	0.0	Herbs and grasses
Poaceae	33.0	17.0	7.0	7.0	3.0	7.0	2.0	0.0	10	10	2.0	0.0	0.0	0.0	10	10	10	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Cyperaceae 'like'	3.0	10.0	9.0	10	10	0.0	0.0	0.0	2.0	0.0	0.0	10	0.0	0.0	2.0	10	10	0.0	4.0	10	0.0	0.0	Herbs and grasses
Cyperaceae	66.0	910	36.0	86.0	65.0	56.0	63.0	0.0	45.0	55.0	23.0	43.0	43.0	53.0	68.0	64.0	710	88.0	29.0	70.0	56.0	57.0	Herbs and grasses
Restionaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	5.0	14.0	13.0	Herbs and grasses
Halagoraceae	2.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	2.0	0.0	10	0.0	0.0	0.0	3.0	3.0	Aquatic plant
Hydrocotyle spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	5.0	5.0	110	5.0	10.0	4.0	8.0	Aquatic plant
Chenopodaceae	710	77.0	2.0	0.0	7.0	23.0	10.0	0.0	4.0	13.0	7.0	16.0	7.0	10	8.0	5.0	7.0	10	4.0	0.0	0.0	0.0	Saltmarsh plant
Cyathea spp.	3.0	3.0	29.0	9.0	5.0	6.0	8.0	0.0	8.0	5.0	5.0	7.0	8.5	14.0	9.0	12.0	6.0	4.0	0.0	0.0	0.0	0.0	Tree fern (Pteridophyte)
Dicksonia squarrosa	0.0	2.0	10	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	10	0.0	Tree fern (Pteridophyte)
Phymatosorus diversifolius	0.0	10	10	2.0	10	0.0	10	0.0	10	0.0	0.0	10	10	10	10	0.0	0.0	10	10	0.0	2.0	0.0	Pteridophyte
Trilete fern	2.0	10	0.0	0.0	0.0	10	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	2.0	0.0	0.0	0.0	0.0	Pteridophyte
Hymenophyllum sp.	0.0	0.0	0.0	10.0	16.0	9.0	5.0	0.0	0.0	8.0	10	10	8.0	6.0	8.0	210	7.0	10.0	0.0	5.0	5.0	5.0	Pteridophyte
Pteridium esculentum	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	4.0	10	0.0	0.0	10	10	10	10	10	0.0	2.0	0.0	10	0.0	Pteridophyte
Pellaea rotundifolia	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	3.0	3.0	10	Pteridophyte
Pellaea calidirupium	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Monolete fern	8.0	18.0	129.0	80.0	79.0	40.0	43.0	0.0	46.0	410	310	56.0	50.0	56.0	34.0	46.0	22.0	28.0	28.0	310	33.0	22.0	Pteridophyte
Hypolepsis spp.	0.0	0.0	0.0	10	0.0	2.0	10	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Botrychium biforme	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Grammitis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	2.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte

Table 21: continued

Botrychium lunaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Cystopteris fragilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Lycopodium scariosum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Native *Lycopodium*	0.0	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Pteridophyte
Lycopodium spike	45.0	54.0	910	24.0	37.0	66.0	58.5	55.0	79.0	220.5	1810	97.0	59.5	59.5	92.0	82.5	58.5	99.5	255.0	77.5	48.5	0.0	Exotic spike
TOTAL COUNT	283.5	299.5	294.5	302.0	315.0	316.0	299.0	0.0	296.5	282.5	129.5	299.5	306.5	312.5	297.0	279.0	236.0	282.5	155.5	238.5	280.5	0.0	

Table 22: WA2 core pollen counts.

	Sample depth (cm)								
Taxa	0	5.43	10.86	16.29	21.27	27.15	32.58	38	Plant type
Podocarpus spp.	16.0	12.0	0.0	11.0	9.0	13.0	19.0	6.0	Native tree
Podocarpus totara	0.0	0.0	0.0	4.0	0.0	2.0	2.0	0.0	Native tree
Dacrycarpus dacridioides	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Native tree
Dacrydium cupressinum	5.0	8.0	5.0	3.0	3.0	5.0	2.0	3.0	Native tree
Phyllocladdus sp.	0.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0	Native tree
Nothafagus fusca type	9.0	4.0	2.0	11.0	17.0	13.0	63.0	26.0	Native tree
Rhropalostylis sapida	0.0	0.0	0.0	0.0	2.0	1.0	0.0	0.0	Native tree
Meterosideros spp.	1.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	Native tree
Knightia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	Native tree
Myrsinaceae	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native tree
Leptospermum scoparium	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Native tree
Coprosma spp.	2.0	5.0	0.0	1.0	0.0	2.0	3.0	4.0	Native shrub
Phormium spp.	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	Native shrub
Malvaceae	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0	Native shrub
Nertera setulosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	Native shrub
Restionaceae	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	Native shrub
Pinus spp.	51.5	74.5	2.0	12.0	25.0	64.0	25.5	26.5	Exotic tree
Betula sp.	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	Exotic tree
Plantago spp.	0.0	0.0	0.0	0.0	2.0	1.0	1.0	0.0	Exotic herb
Liliaceae	1.0	1.0	1.0	12.0	18.0	20.0	40.0	13.0	Herbs and grasses
Cyperaceae	74.0	53.0	14.0	32.0	104.0	89.0	97.0	84.0	Herbs and grasses
Poaceae	7.0	8.0	7.0	8.0	34.0	40.0	37.0	35.0	Herbs and grasses
Apiaceae	0.0	0.0	1.0	3.0	0.0	0.0	6.0	5.0	Herbs and grasses
Brassicaceae	4.0	0.0	2.0	0.0	2.0	0.0	4.0	5.0	Herbs and grasses
Asteraceae	1.0	4.0	0.0	0.0	0.0	2.0	2.0	3.0	Herbs and grasses
Urtica spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	Herbs and grasses
Mentha cunninghamii	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Halagoraceae	1.0	1.0	0.0	5.0	2.0	2.0	9.0	8.0	Aqatic plant
Chenopodaceae	0.0	2.0	0.0	1.0	10.0	1.0	17.0	44.0	Saltmarsh plant
Cyathea spp.	49.0	28.0	39.0	67.0	11.0	13.0	25.0	17.0	Tree fern (Pteridophyte)
Dicksonia squarrosa	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	Tree fern (Pteridophyte)
Pteridium esculentum	0.0	0.0	2.0	2.0	0.0	0.0	1.0	0.0	Pteridiphyte
Monolete ferns	72.0	91.0	13.0	82.0	19.0	30.0	41.0	34.0	Pteridophyte
Trilete ferns	0.0	0.0	1.0	2.0	0.0	2.0	10.0	0.0	Pteridophyte
Native *Lycopodium sp.*	0.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	Pteridophyte
Lycopodium spike	0.0	1.0	0.0	0.0	0.0	0.0	0.0	6.0	Exotic spike
TOTAL COUNT	**295.5**	**295.5**	**92.0**	**259.0**	**260.0**	**303.0**	**409.5**	**320.5**	

Table 23: Te Koru core pollen counts.

	Sample depth (cm)								
Taxa	0 to 1	6 to 7	12 to 13	18-19	24-25	30-31	36-37	42-43	Plant type
Podocarpus spp.	8.0	2.0	1.0	5.0	5.0	4.0	2.0	6.0	Native tree
Dacrydium cupressinum	0.0	0.0	1.0	1.0	1.0	1.0	1.0	4.0	Native tree
Nothafagus fusca type	3.0	10.0	13.0	8.0	4.0	20.0	30.0	5.0	Native tree
Nothafagus menzesii type	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	Native tree
Rhropalostylis sapida	3.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	Native tree
Meterosideros spp.	0.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0	Native tree
Myrtaceae	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native tree
Leptospermum scoparium	0.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	Native tree
Coprosma spp.	4.0	1.0	2.0	0.0	1.0	0.0	2.0	0.0	Native shrub
Phormium spp.	0.0	0.0	0.0	1.0	1.0	0.0	2.0	1.0	Native shrub
Malvaceae	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Ranunculaceae	0.0	4.0	3.0	7.0	4.0	4.0	3.0	0.0	Native shrub
Coprosma chathamica ?	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native shrub
Coprosma rotundifolia ?	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native shrub
Escallonaceae	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Hebe spp.	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native shrub
Psuedowintera spp.	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Hypolepsis spp. ?	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Coriaria spp.	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	Native shrub
Acianthus reniformis	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	Native shrub
Quintinia spp.	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	Native shrub
Pinus spp.	82.0	51.0	52.0	63.5	31.0	26.0	23.5	36.5	Exotic tree
Betula sp.	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	Exotic tree
Plantago spp.	0.0	0.0	2.0	6.0	2.0	0.0	2.0	1.0	Exotic herb
Liliaceae	9.0	15.0	15.0	9.0	9.0	14.0	10.0	12.0	Herbs and grasses
Cyperaceae	52.0	96.5	98.0	89.0	97.0	122.0	118.0	103.0	Herbs and grasses
Poaceae	18.0	18.0	19.0	28.0	22.0	16.0	24.0	13.0	Herbs and grasses
Apiaceae	0.0	1.0	0.0	6.0	4.0	9.0	4.0	0.0	Herbs and grasses
Brassicaceae	4.0	1.0	0.0	0.0	0.0	3.0	0.0	0.0	Herbs and grasses
Astelia 'like'	0.0	0.0	0.0	0.0	2.0	4.0	7.0	4.0	Herbs and grasses
Asteraceae (1)	0.0	3.0	1.0	0.0	0.0	1.0	1.0	2.0	Herbs and grasses
Asteraceae (2)	0.0	2.0	0.0	0.0	1.0	2.0	2.0	1.0	Herbs and grasses
Asteraceae (3)	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (4)	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (5)	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	Herbs and grasses
Asteraceae (6)	0.0	0.0	0.0	2.0	1.0	0.0	1.0	0.0	Herbs and grasses
Asteraceae (7), *Raoulia spp.*	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	Herbs and grasses
Asteraceae (8)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	Herbs and grasses
Halagoraceae	2.0	4.0	1.0	1.0	0.0	5.0	2.0	1.0	Herbs and grasses
Chenopodaceae	15.0	69.0	53.0	32.0	35.0	47.0	21.0	26.0	Saltmarsh plant
Cyathea spp.	0.0	4.0	5.0	6.0	2.0	6.0	1.0	3.0	Tree fern (Pteridophyte)
Dicksonia squarrosa	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	Tree fern (Pteridophyte)
Monolete ferns	28.0	14.0	21.0	19.0	21.0	21.0	18.0	13.0	Pteridophyte
Trilete ferns	0.0	0.0	2.0	1.0	1.0	2.0	0.0	1.0	Pteridophyte
Phymatosorus diversifolius	2.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	Pteridophyte
Phymatosorus vulgare	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	Pteridophyte
Lastreopsis hispida	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	Pteridophyte
Lycopodium spike	93.0	27.0	31.0	26.0	48.0	18.0	26.0	64.5	Exotic spike
TOTAL COUNT	**326.0**	**328.5**	**327.0**	**315.5**	**295.0**	**330.0**	**308.5**	**301.0**	

Table 24: WA09 core: Non-pollen palynomorph counts from each sample. Counts per gram as well as raw counts are displayed.

Depth	0 to 1		10 to 11		20 to 21		30 to 31		40 to 41		50 to 51		60 to 61		70 to 80		80 to 81		90 to 91	
Count	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw
Pediastrum boryanum var. longicorne	245.65	7	83.62	3	1069.99	81	799.28	16	499.69	13	39.42	3	19.27	1	0.00	0	0.00	0	0.00	0
Pediastrum boryanum var. cornutum	0.00	0	0.00	0	32.92	2	0.00	0	18188.76	479	0.00	0	0.00	0	0.00	0	12.44	1	11.40	1
Pediastum integrum	0.00	0	0.00	0	0.00	0	431.92	9	299.81	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Undiff *Pediastrum*	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	22.81	1
Total *Pediastrum spp.*	245.65	7	83.62	3	1102.91	84	1295.76	26	18988.26	500	39.42	3	19.27	1	0.00	0	12.44	1	34.21	2
Algal zygospores	956.07	28	1732.20	72	843.88	64	809.94	16	303.81	8	367.04	24	157.37	8	0.00	0	152.88	11	136.85	9
Sheaths of *Gloeotrichia*-type cyanobateria	0.00	0	0.00	0	0.00	0	0.00	0	113.93	3	0.00	0	0.00	0	0.00	0	41.70	3	60.82	4
Total fungal matter	819.49	24	842.04	35	316.45	24	1316.15	26	949.41	25	1131.70	74	1180.26	60	0.00	0	1236.98	89	2159.19	142
Chironomid mouthparts	136.58	4	96.23	4	184.60	14	253.10	5	189.88	5	15.29	1	19.67	1	0.00	0	13.90	1	0.00	0

Table 24: continued.

100 to 101		110 to 111		120 to 121		130 to 131		140 to 141		150 to 151		160 to 161		170 to 171		180 to 181		190 to 191		200 to 201		210 to 211	
Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw	Per gram	Raw
0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	29.56	2	11.26	1	278.23	12	0.00	0	0.00	0	43.29	3	73.19	4
0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	10.82	1	0.00	0
0.00	0	0.00	0	0.00	0	0.00	0	17.98	1	0.00	0	0.00	0	158.99	7	9.31	1	0.00	0	10.82	1	0.00	0
0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	73.19	4
0.00	0	0.00	0	0.00	0	0.00	0	17.98	1	29.56	2	11.27	1	437.22	19	9.32	1	0.00	0	66.89	5	160.57	8
25.49	5	93.02	14	47.71	4	52.12	3	179.66	10	114.78	8	204.92	12	270.44	12	143.38	14	59.32	15	160.54	12	240.86	12
10.20	2	53.15	8	47.71	4	17.37	1	17.97	1	0.00	0	17.08	1	0.00	0	20.48	2	3.95	1	0.00	0	0.00	0
137.65	27	1043.13	157	2266.27	190	3162.17	182	5533.49	308	1320.02	92	5703.66	334	1555.03	69	1228.93	120	870.00	220	2501.69	187	3753.39	187
0.00	0	59.80	9	83.49	7	34.75	2	0.00	0	14.35	1	136.61	8	112.68	5	20.48	2	3.95	1	40.13	3	60.21	3

Appendix V Additional diatom diagrams

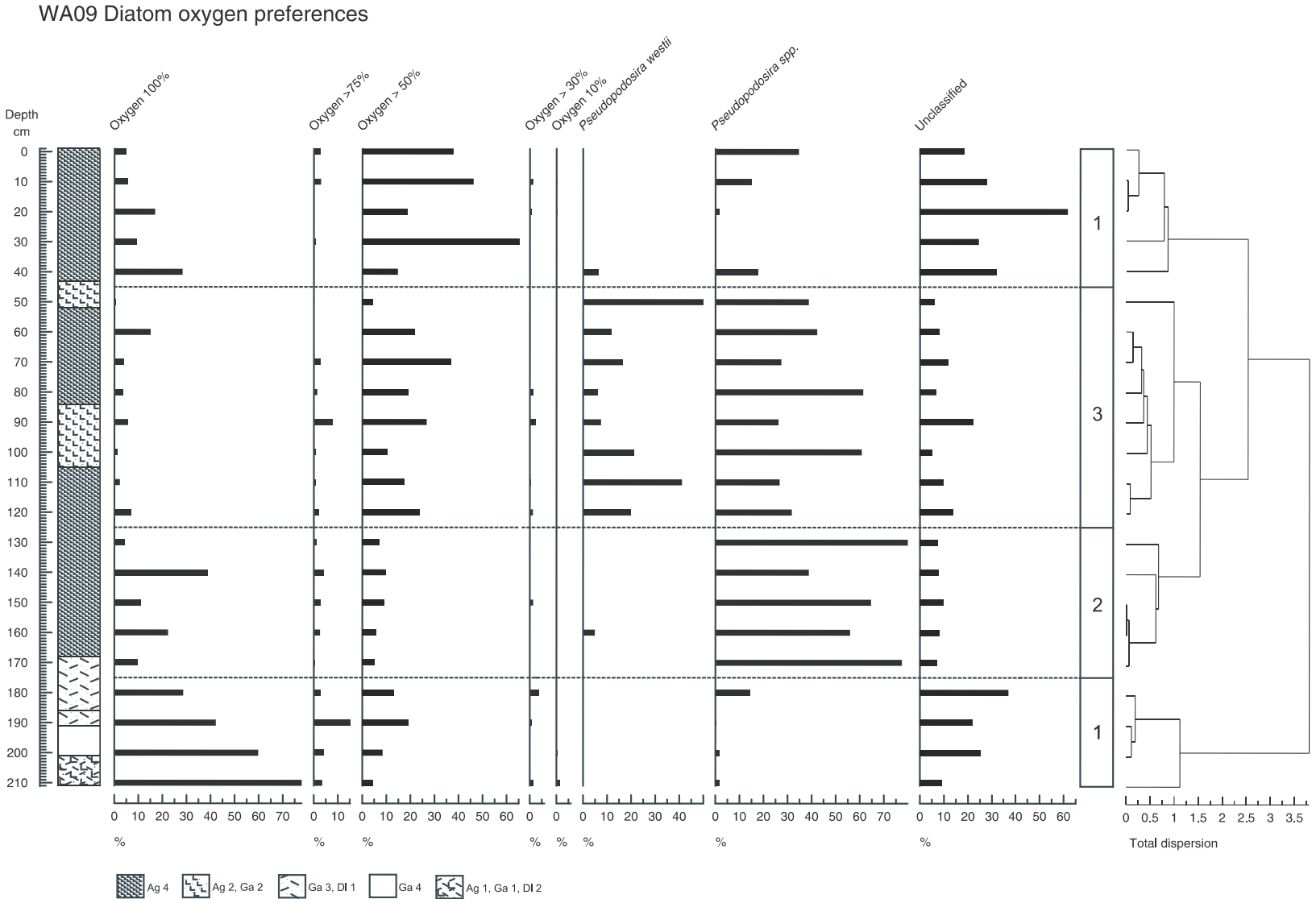

Figure 51: WA09 core diatom taxa grouped in oxygen preference categories.

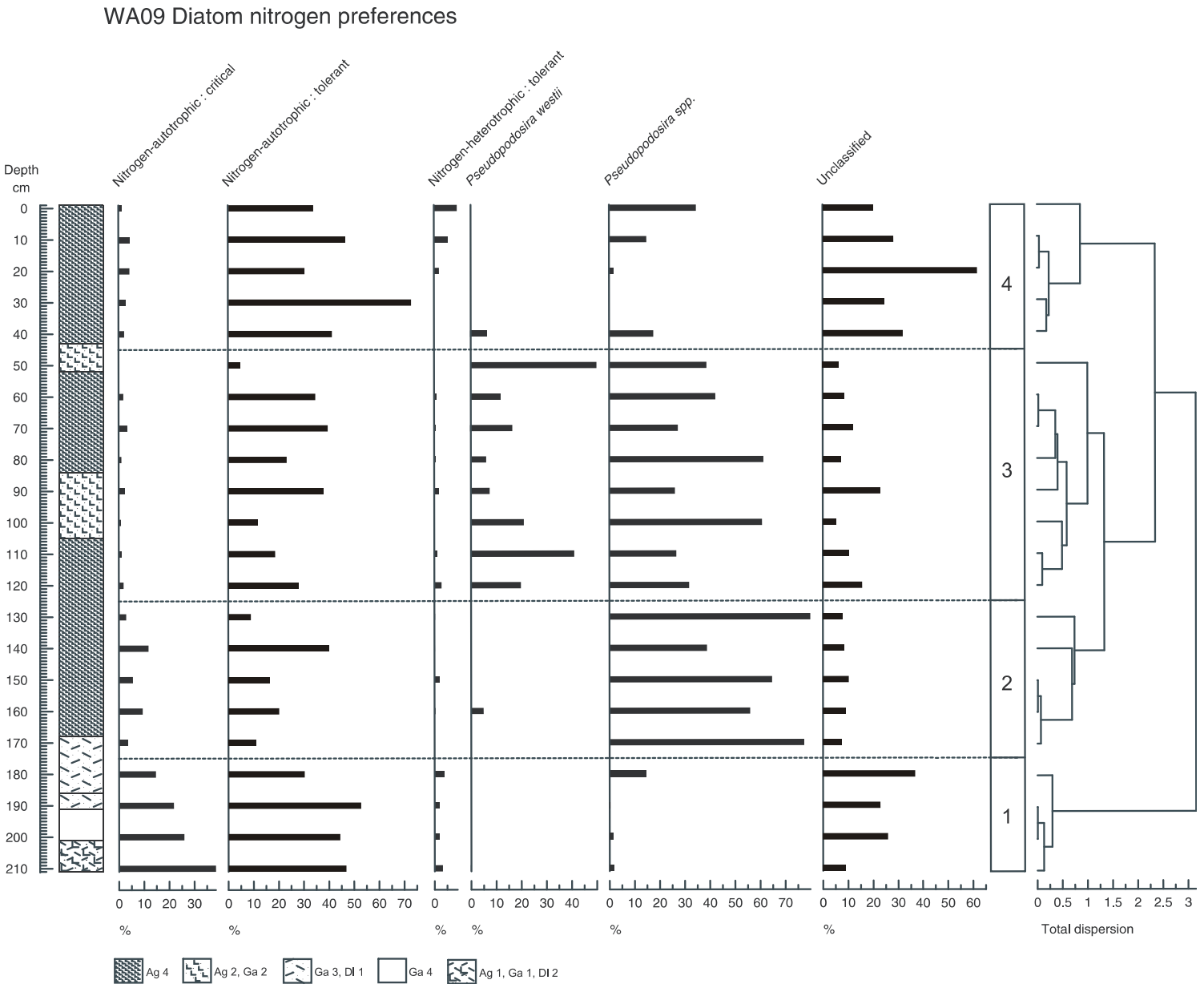

Figure 52: WA09 core diatom taxa grouped in nitrogen preference categories

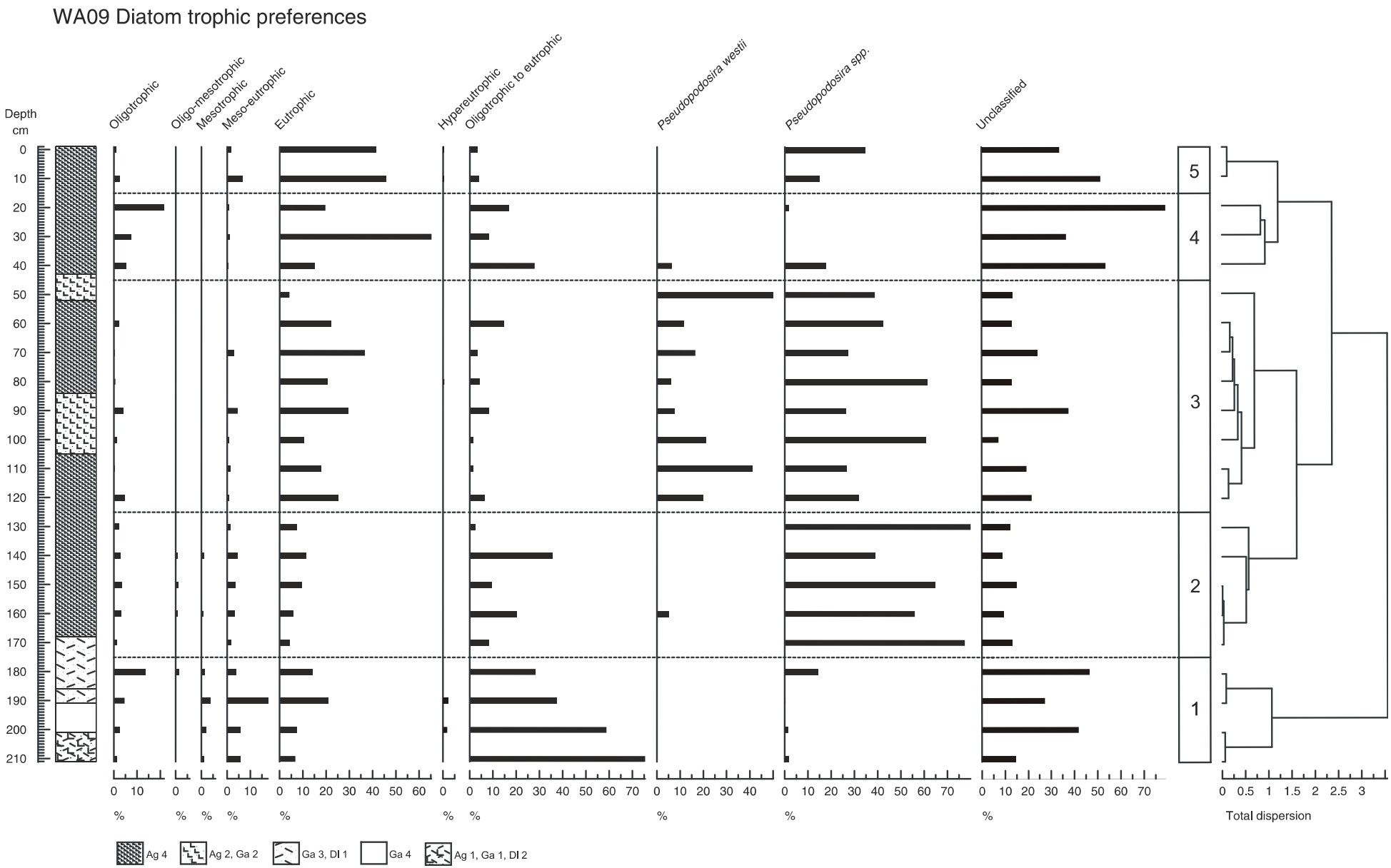

Figure 53: WA09 core diatom taxa grouped in trophic preference categories.

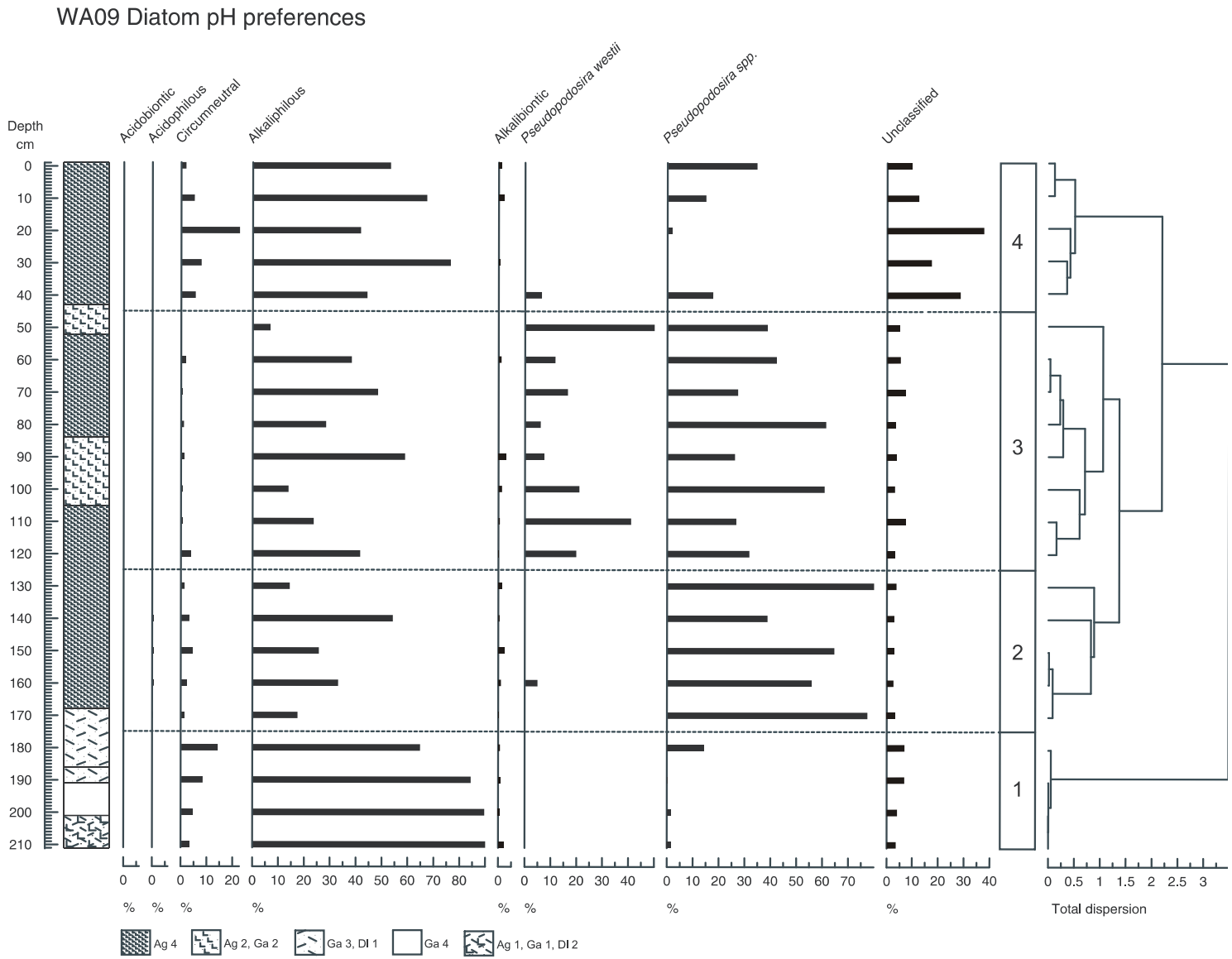

Figure 54: WA09 core diatom taxa grouped in pH preference categories.

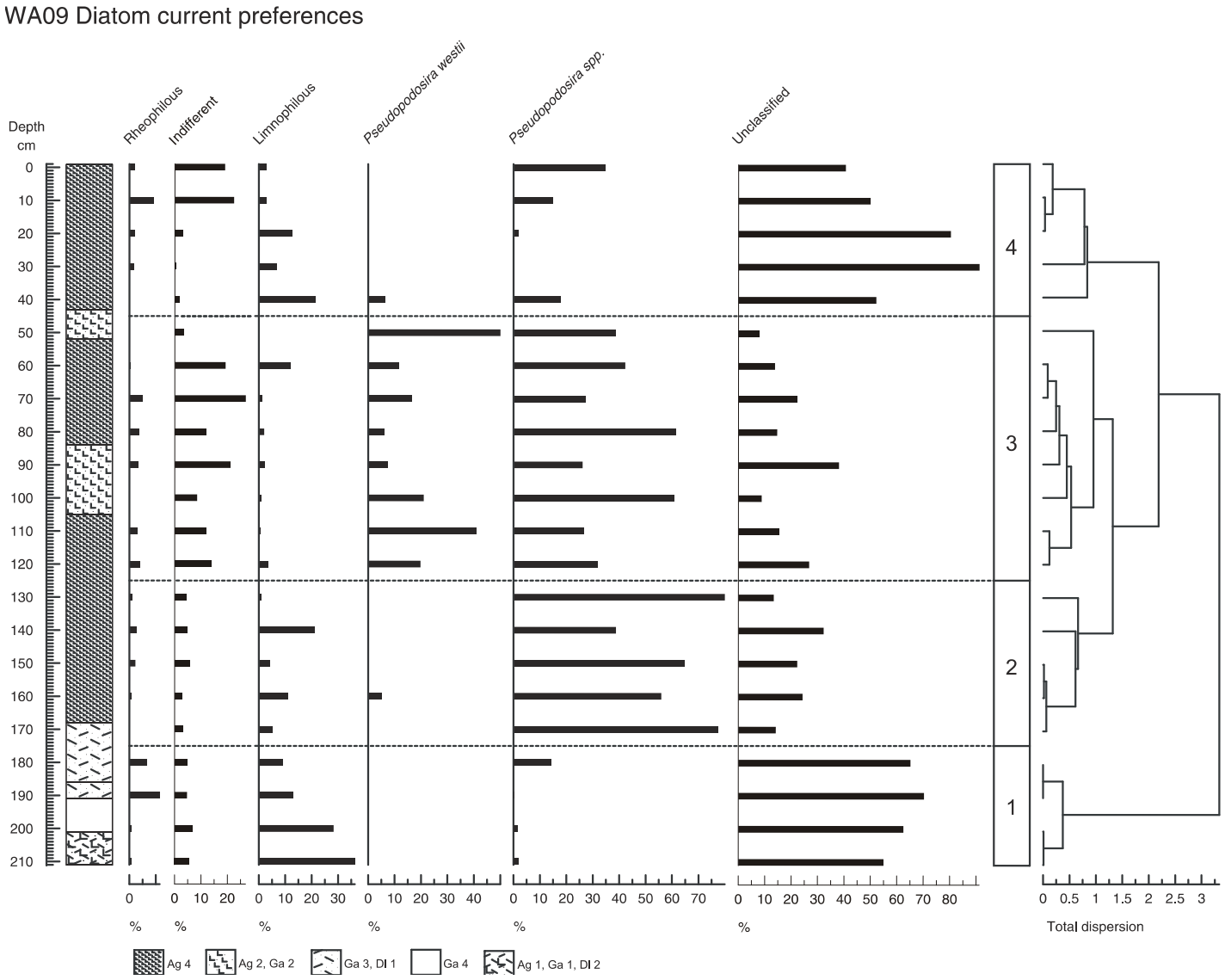

Figure 55: WA09 core diatom taxa grouped in current preference categories.

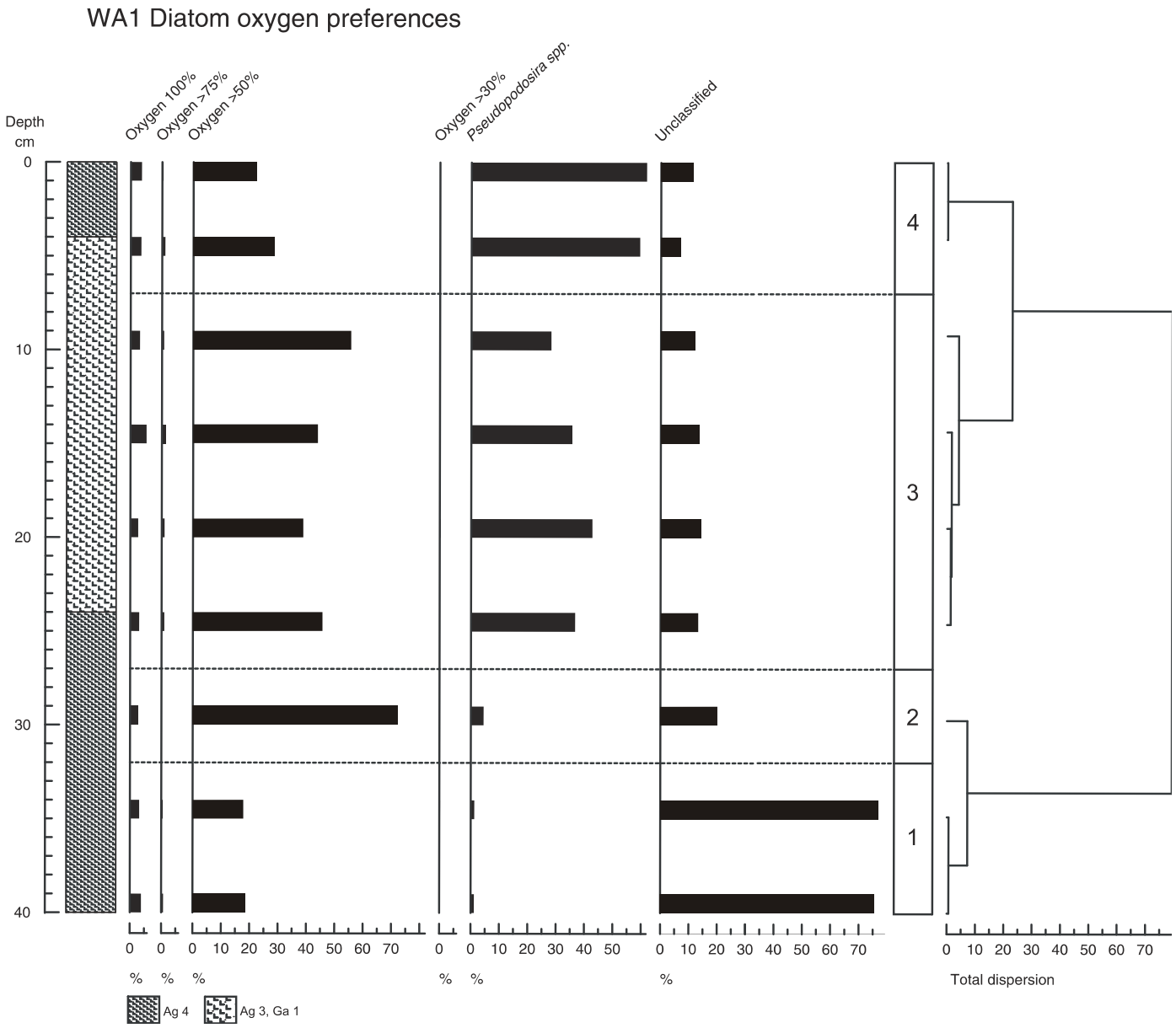

Figure 56: WA1 core diatom taxa grouped into oxygen preference categories.

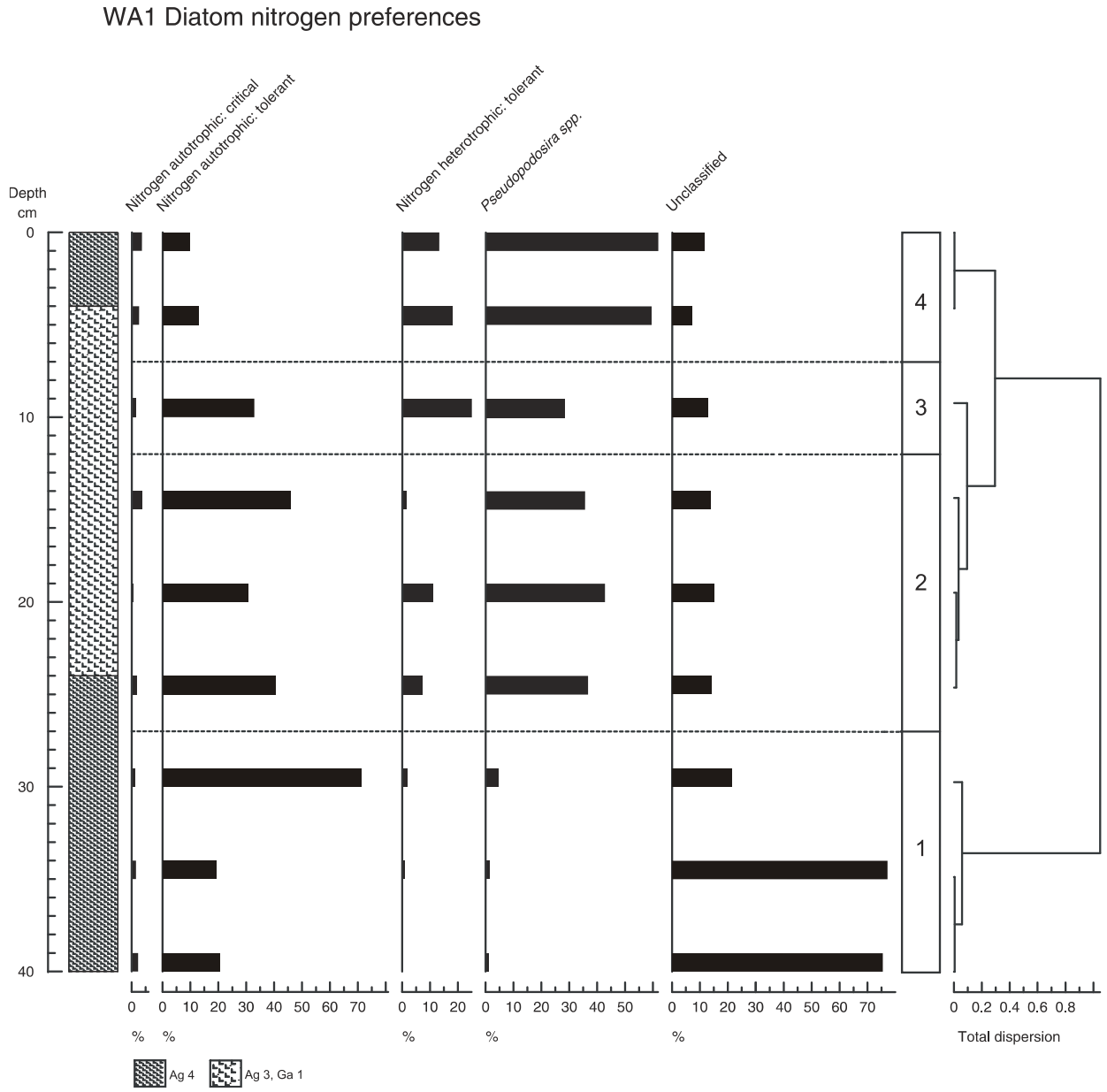

Figure 57: WA1 core diatom taxa grouped into nitrogen preference categories

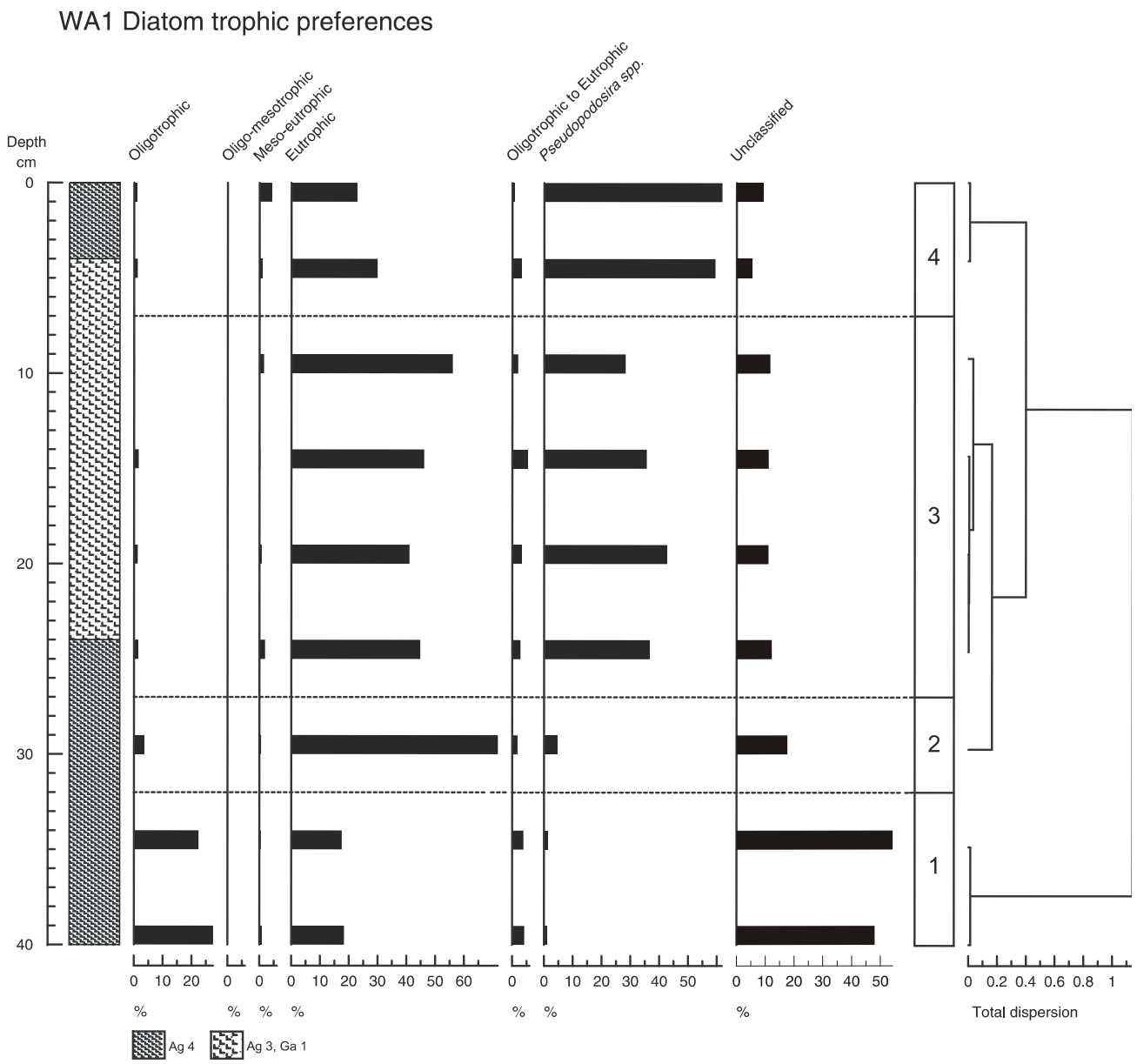

Figure 58: WA1 core diatom taxa grouped into trophic preference categories.

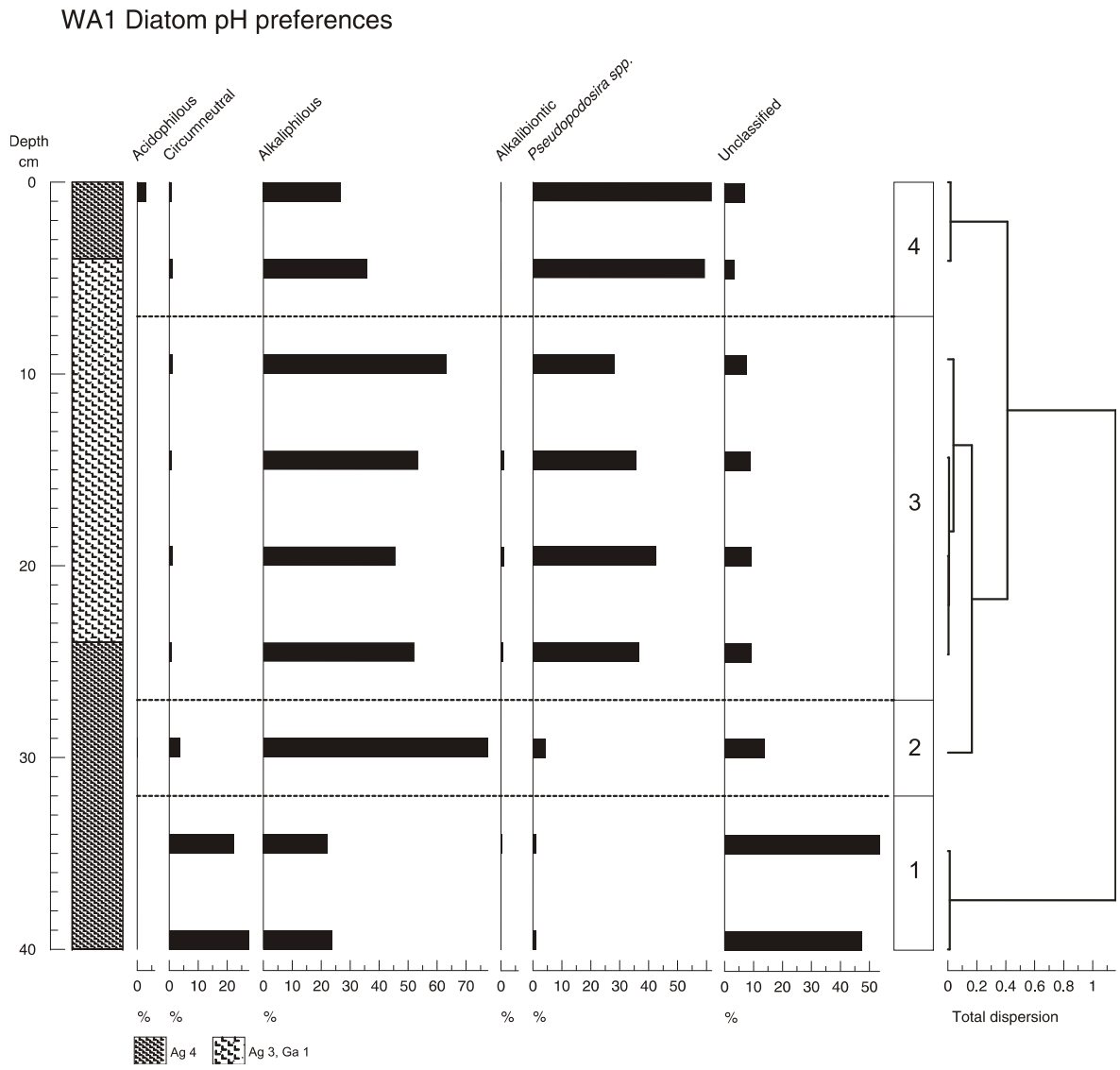

Figure 59: WA1 core diatom taxa grouped in pH preference categories.

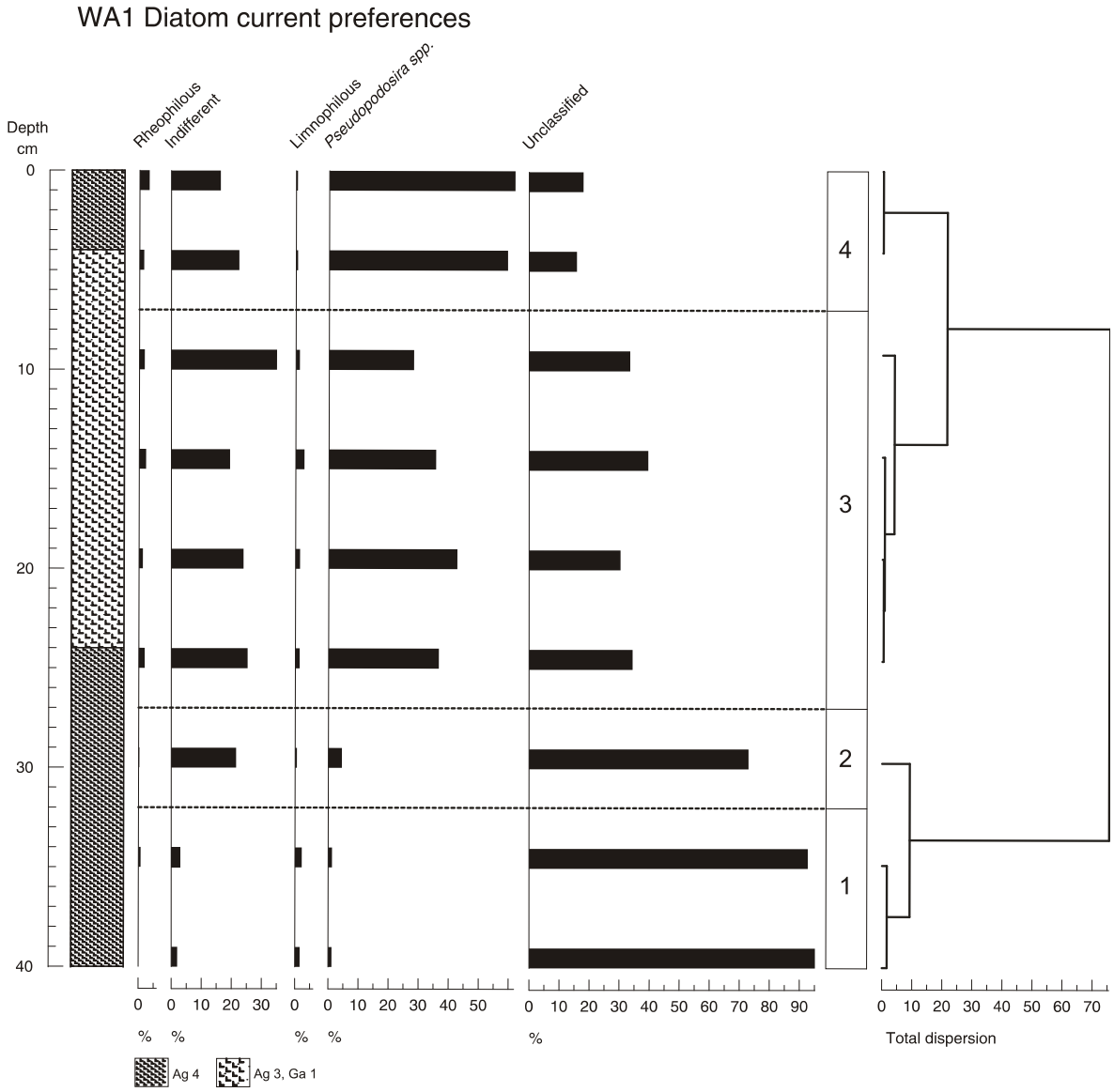

Figure 60: WA1 core diatom taxa grouped in current preference categories.

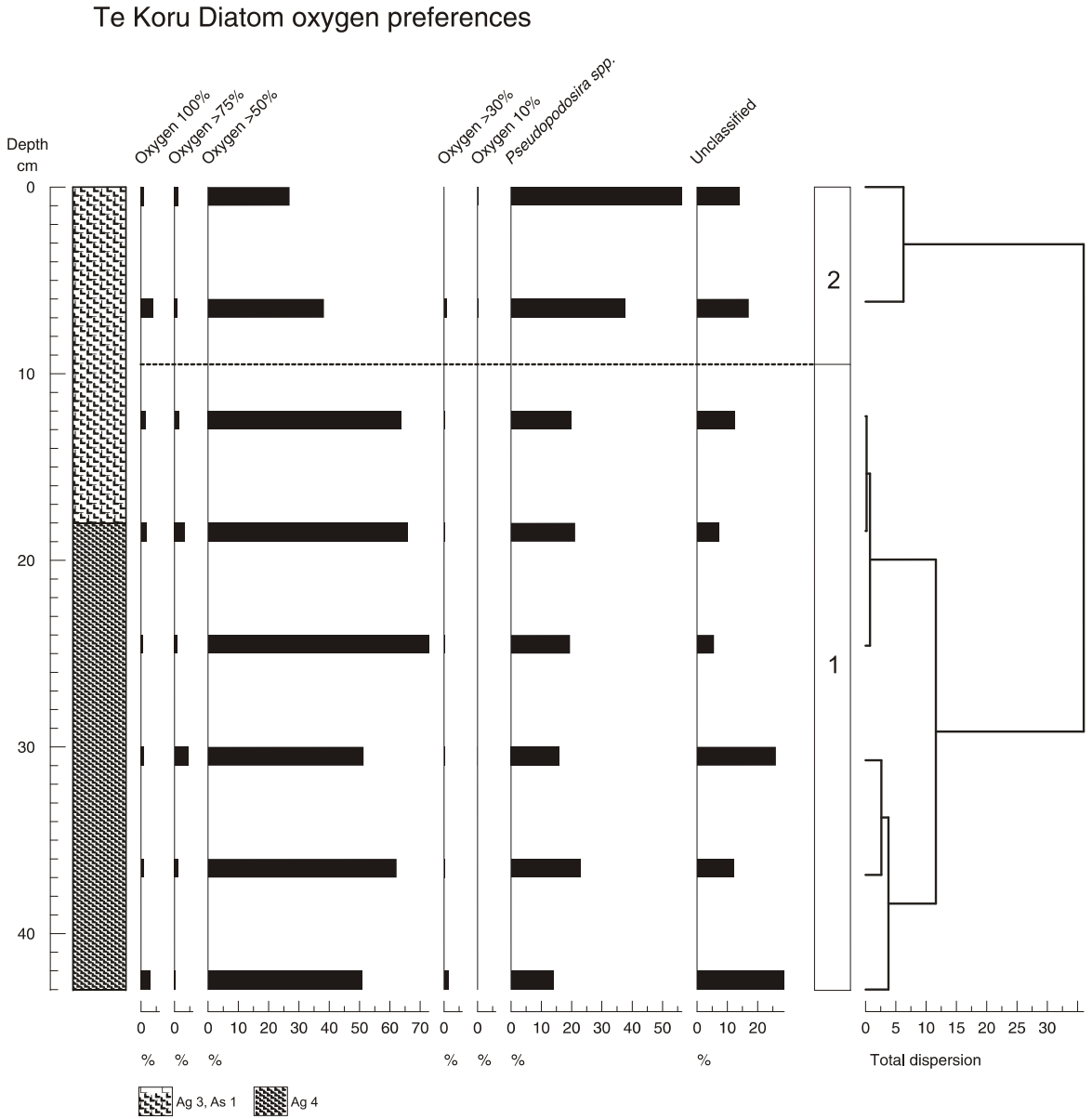

Figure 61: Te Koru core diatom taxa grouped into oxygen preference categories.

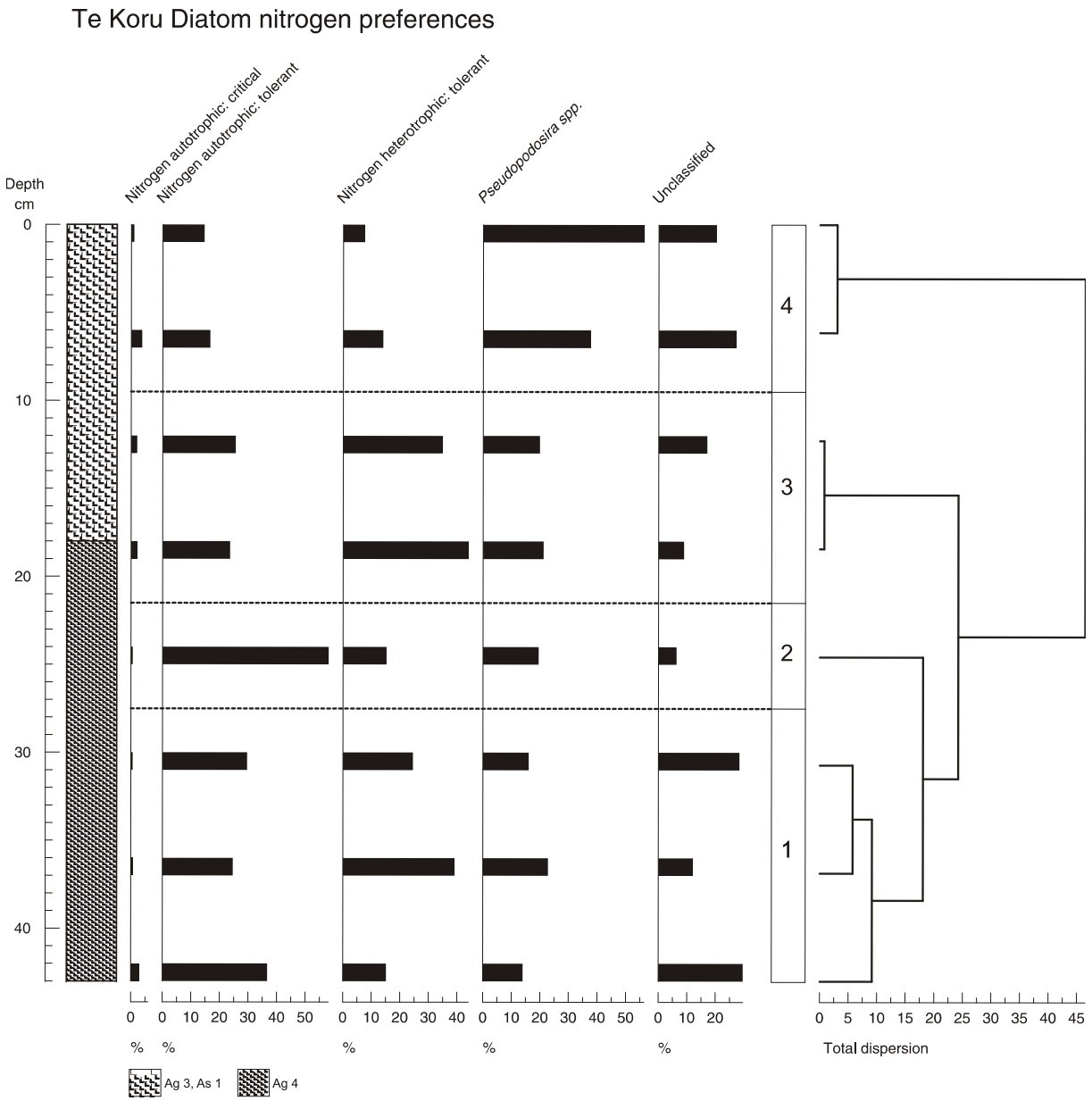

Figure 62: Te Koru core diatom taxa grouped into nitrogen preference categories.

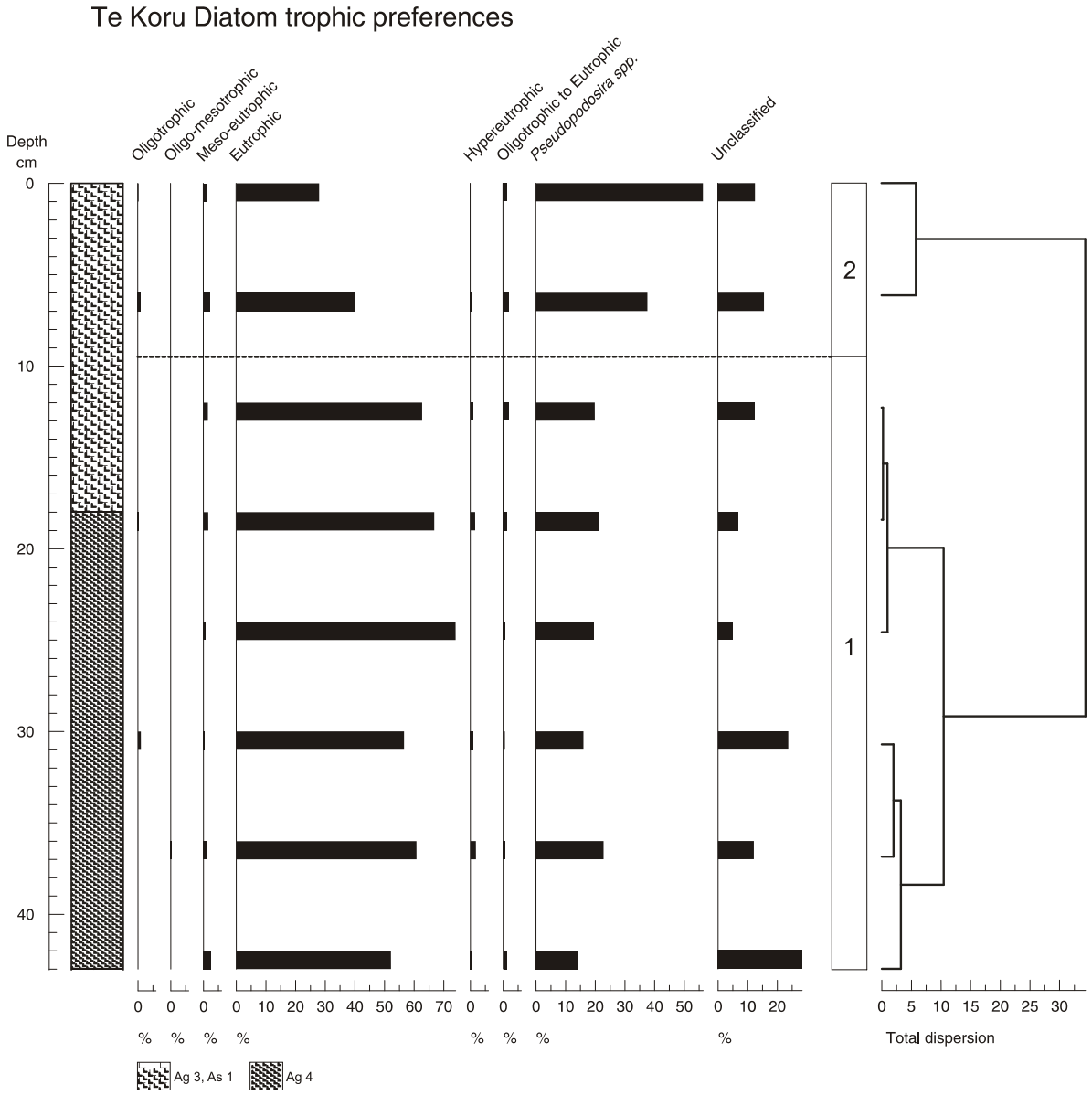

Figure 63: Te Koru core diatom taxa grouped into trophic preference categories.

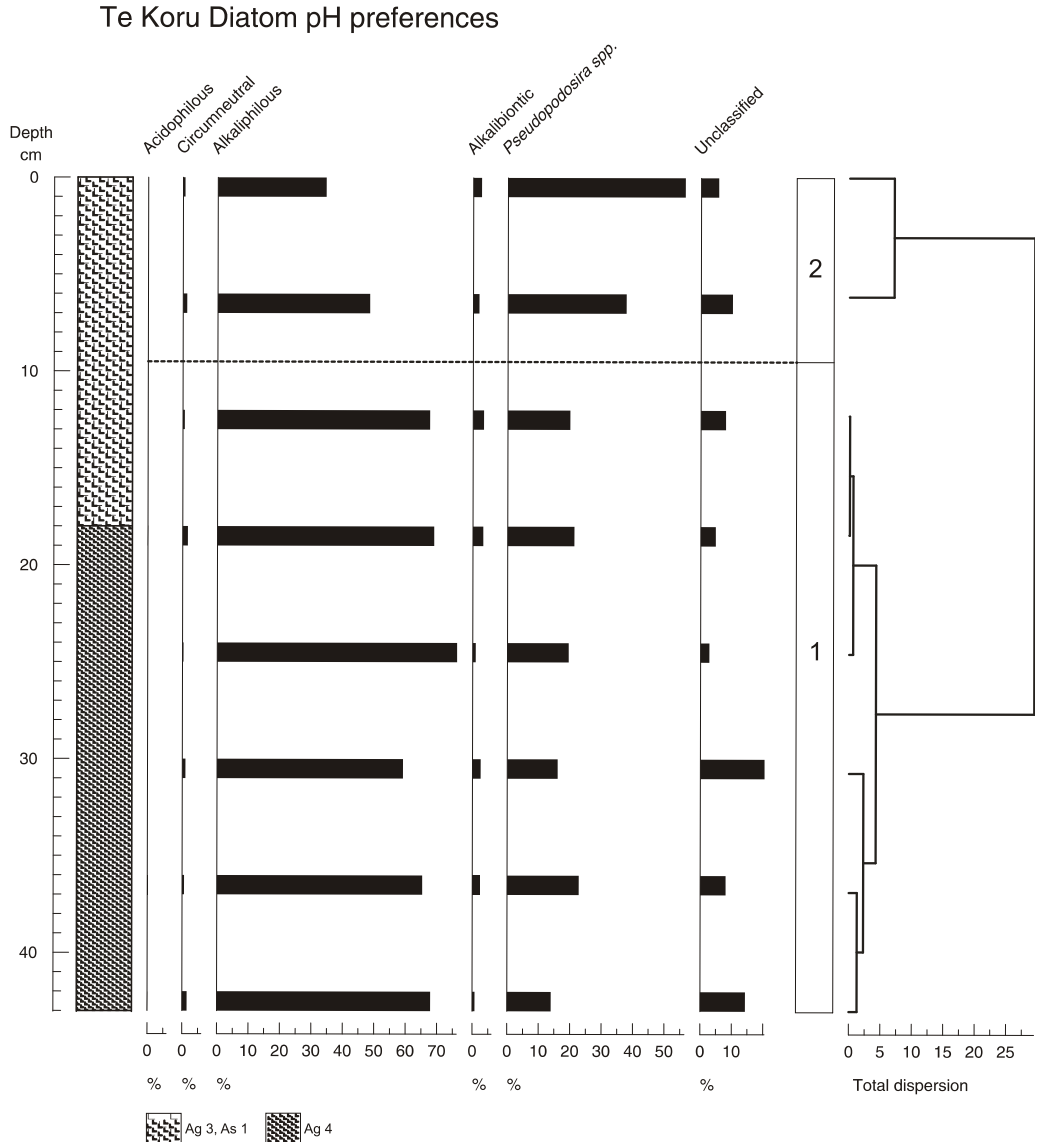

Figure 64: Te Koru core diatom taxa grouped in pH preference categories.

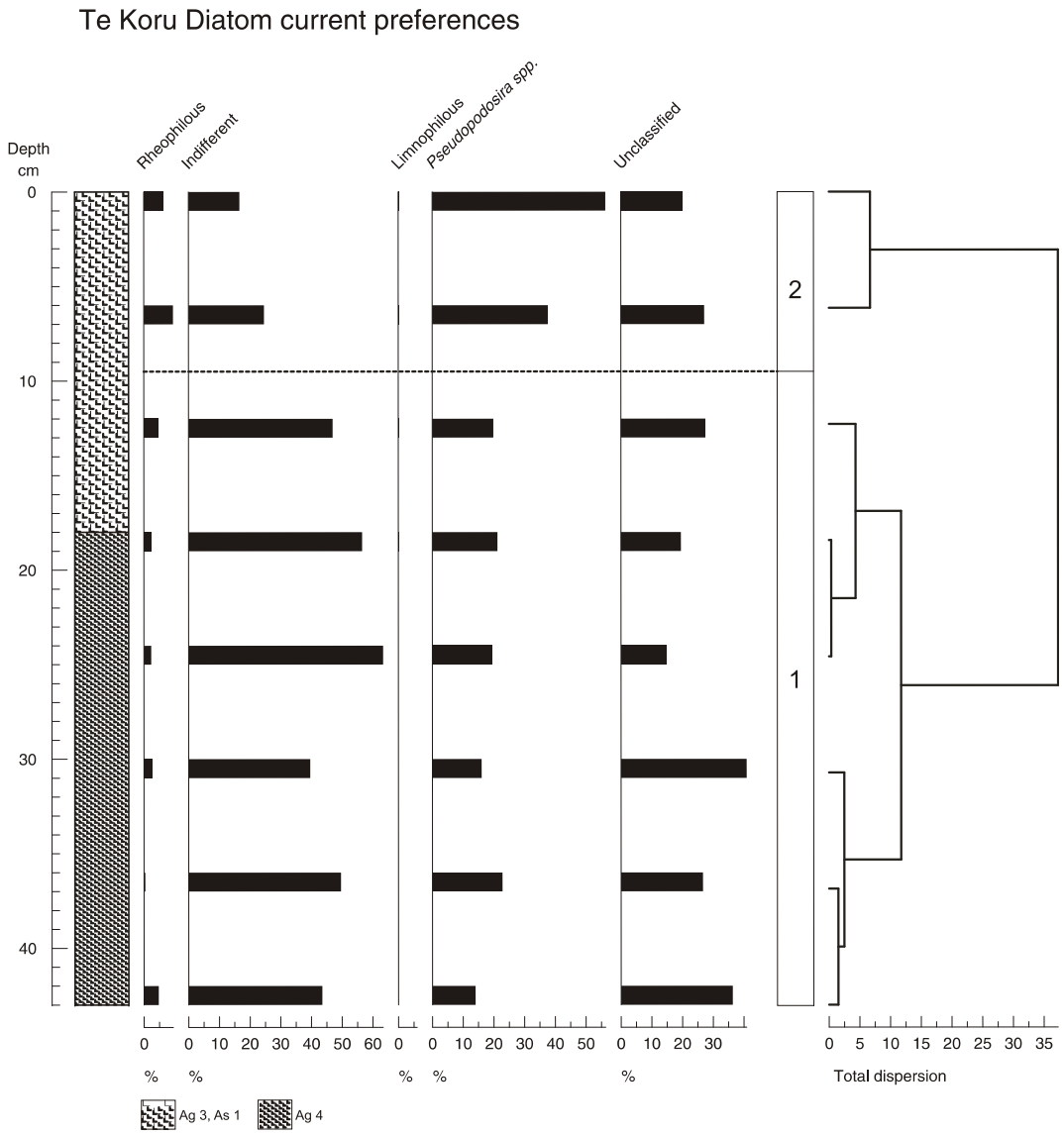

Figure 65: Te Koru core diatom taxa grouped in current preference categories.

Appendix VI Diatom data

Table 25: WA09 core diatom percentage counts.

	Sample depth (cm)																				
Taxa	0 to 1	10 to 11	20 to 21	30 to 31	40 to 41	50 to 51	60 to 61	70 to 71	80 to 81	90 to 91	100 to 101	110 to 111	120 to 121	130 to 131	140 to 141	150 to 151	160 to 161	170 to 171	180 to 181	190 to 191	200 to 201	210 to 211
Thalassiosira bramaputrae	0.0	0.2	0.0	0.0	0.3	0.0	0.0	1.2	1.4	1.6	0.2	0.3	0.3	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Cyclotella meneghiniana	0.2	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.5
Cyclotella stelligera	0.5	2.0	21.6	6.4	5.3	0.0	1.6	0.0	0.0	0.0	0.0	0.0	1.0	0.2	0.2	0.0	0.0	0.0	5.2	0.5	0.0	0.0
Cyclostephanos spp.	4.6	4.4	33.0	15.0	18.2	0.0	2.9	2.3	0.0	1.3	0.0	0.3	0.3	0.0	0.0	0.5	0.0	0.0	1.3	0.2	0.0	0.0
Pseudopodosira westii	0.0	0.0	0.0	0.0	6.4	50.0	11.7	16.5	6.1	7.5	21.0	41.0	19.8	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0
Pseudopodosira spp.	34.7	14.9	1.7	0.0	17.6	38.8	42.3	27.3	61.4	26.2	60.8	26.7	31.7	80.0	38.8	64.7	56.0	77.5	0.0	0.0	0.0	0.0
Hyalodiscus lentiginosus	2.0	3.5	0.1	0.1	5.2	3.0	1.0	2.1	0.8	1.1	0.8	4.0	1.1	0.2	0.1	0.3	0.3	1.0	0.7	0.1	0.1	0.1
Paralia sulcata	0.5	0.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aulacoseira ambigua	12.0	8.2	14.9	62.7	13.7	0.0	1.9	3.2	1.1	1.3	0.8	1.0	5.4	0.0	0.2	0.2	0.0	0.3	1.3	0.7	0.9	0.3
Aulacoseira italica	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Orthoseira roeseana	0.0	1.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Actinocyclus octonarius	0.0	0.2	0.0	0.0	0.8	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Auliscus caelatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Fragilaria capucina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.0
Fragilaria capucina var. vaucheriae	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.3	1.0	1.8	0.7	0.7	0.0	2.6	0.5	0.5	0.8
Fragilaria capucina subsp. rumpens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.0	0.0	1.3	0.2	0.0	0.0
Fragilaria nitzshiodes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosirella lapponica	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosirella leptostauron	0.0	0.7	0.3	0.0	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.8
Staurosirella leptostauron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosirella leptostauron var. dubia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.8	1.3	0.0	0.0	0.0
Staurosirella pinnata	2.6	3.0	12.5	6.6	21.2	0.0	12.1	0.6	1.6	0.8	0.2	0.0	2.3	0.0	20.3	3.4	10.5	5.0	9.1	11.0	27.4	33.6
Staurosirella pinnata	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	0.4	1.5	0.5	0.5	1.3	1.0	0.7	0.7	0.5	0.0	0.0	2.0	0.9	2.7
Staurosirella pinnata var. lancettula	0.0	0.0	0.0	0.0	4.3	0.3	1.1	0.0	0.0	1.6	0.2	0.5	0.3	0.7	5.2	2.1	2.5	0.8	6.5	7.5	6.4	3.8
Staurosira elliptica	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.8	0.3	0.0	0.4	0.9	0.2	1.0	1.3	1.2	0.0	0.0
Staurosira construens	0.2	1.1	0.3	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosira construens var. venter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.6
Pseudostaurosira brevistriata	0.0	0.2	0.3	0.0	0.8	0.0	0.8	0.0	0.7	0.8	0.0	0.0	0.0	0.2	1.3	0.2	0.2	0.0	0.0	0.5	0.0	0.0
Pseudostaurosira brevistriata var. inflata	0.0	0.0	3.4	1.4	1.0	0.0	0.5	0.9	0.2	0.0	0.0	0.0	0.8	0.0	6.9	1.6	5.5	1.4	7.8	13.5	20.1	33.8
Martyana martyi	2.5	6.7	4.1	2.1	0.0	0.0	0.3	1.5	0.7	1.6	0.0	1.0	0.8	1.5	0.0	0.0	0.0	0.3	1.3	0.0	0.0	0.0
Synedra filiformis	0.2	0.7	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra miniscula	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra ulna	0.0	0.2	0.3	0.0	0.3	0.0	0.0	0.3	0.3	0.8	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Synedra ulna fragment	0.5	0.4	0.2	0.2	0.0	0.0	0.1	1.0	0.9	2.1	0.7	0.4	1.7	0.4	0.7	0.9	0.7	0.6	4.9	2.1	3.6	1.4
Synedra ulna var. ramesi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synedra fragment	1.1	1.7	0.0	0.0	0.3	0.3	0.4	1.0	0.8	1.4	0.3	0.2	0.5	0.7	0.2	0.3	0.1	0.5	0.0	0.1	0.1	0.1
Ulnaria capitata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Ulnaria ulna var. amphirhynchus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0

Ctenophora pulchella	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tabularia fasciculata	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tabularia fasciculata var truncata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Eunotia pectinalis var. minor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3
Amphicampa mirabilis	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.5	0.0	0.5	0.3	1.3	0.7	1.9	1.6
Mastogloia elliptica	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Mastogloia pumila	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Placoneis placentula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cymbella caespitosa var. ovata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Cymbella cistula	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cymbella elginsis	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.2	3.9	0.7	0.5	3.0	0.7	1.1	1.8	2.6	0.5	4.6	3.9	2.3	0.8
Cymbella kappii	0.5	0.0	0.0	0.0	0.1	0.5	0.1	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.8	0.0	5.2	2.7	3.2	2.7
Cymbella naviculiformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Encyonema gracile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.7	0.0	0.0	0.0	0.0	0.0
Encyonema silesiacum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.3	0.0	0.2	0.3
Gomphenema parvulum	0.0	1.1	0.3	0.0	0.0	0.0	0.3	0.0	0.2	0.8	0.0	0.5	1.3	0.0	0.0	1.4	0.2	0.0	3.9	0.2	0.0	0.5
Gomphonema vibrio var. intricatum	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	0.2	0.5	0.3	2.6	0.2	0.0	0.3
Gomphoneis clevei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reimeria sinnata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	1.3	3.2	1.8	0.9
Achnanthes clevei var. rostrata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.2	0.2	0.0	1.3	0.2	0.0	0.0
Achnanthes delicatula subsp. hauckiana	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthes hustedtii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Achnanthes imperfecta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Achnanthes lemmernanni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Achnanthes thermalis	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthese pinnata	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammothidium levanderi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Planothidium dubium	0.5	7.5	1.7	1.4	0.0	0.0	0.0	5.0	3.5	2.3	0.0	2.5	2.6	1.2	2.7	0.7	0.2	0.3	0.0	7.5	0.9	0.3
Planothidium lanceolatum	1.6	0.5	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.2	0.5	0.0	2.6	3.7	0.0	0.0
Rossithidium linearis	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.2	0.3	1.3	3.0	0.7	0.3
Rossithidium pusillum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Karayevia clevei	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.3	0.0	0.0	1.1	0.9	0.7	0.3	0.0	12.5	1.6	1.4
Karayevia oblongella	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	0.0	0.5	0.0	0.0	0.2	0.0
Karayevia oblongella	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cocconeis distans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.6	0.0	0.5	0.0	0.0	0.0	0.0
Cocconeis flaviatalis	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cocconeis placentula	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.3	0.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.0
Cocconeis placentula var. euglypta	8.6	15.9	0.7	0.2	0.6	3.3	17.3	24.4	8.4	10.6	7.4	11.2	9.9	2.2	1.4	4.1	1.6	2.1	0.0	0.2	0.0	0.7
Cocconeis placentula var. euglypta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cocconeis placentula var. lineata	1.7	4.3	0.0	0.2	0.0	0.0	0.7	1.3	2.2	0.7	0.5	0.9	0.8	0.0	0.0	0.0	0.0	0.5	0.0	1.0	0.0	0.3
Cocconeis thumensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.6	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Achnanthidium exiguum var. heterovalvum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Achnanthidium microcephalum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthidium thermale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lemnicola hungarica	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diadesmis confervacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diadesmis peregrina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.4	0.2	0.0	0.8	5.2	0.0	0.0	0.0

Neidium dubium	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neidium temperei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fallacia pygmaea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.3	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia acuminata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia borealis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia brebissonii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia brevicostrata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia microstauron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Pinnularia sudetica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Pinnularia torta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Caloneis bacillum	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.7	0.0	1.3	0.0	0.5	0.0
Caloneis silicula var. truncatula	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caloneis ventricosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Diploneis smithii	0.0	0.3	0.0	0.0	0.9	0.4	0.4	0.3	0.4	1.0	0.0	0.0	0.5	0.6	0.1	0.7	0.1	0.1	0.7	0.0	0.2	0.3
Navicula anglica var. subsalsa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Navicula cryptocephala	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.5	0.3	0.0	0.2	0.5	0.1
Navicula cryptocephala var. exilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Navicula cryptotenella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.9	0.0
Navicula cuspidata	1.1	0.1	0.0	0.2	0.0	0.3	0.3	0.0	0.7	0.5	0.0	0.0	0.3	0.4	1.1	0.2	0.7	0.0	2.0	0.5	0.0	0.0
Navicula disputans	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula exigua var. capitata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Navicula fustera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0
Navicula incomposita var. minor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula kotschyi undulata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Navicula lanceolata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Navicula minima	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2	0.8
Navicula minuscula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula minuscula var. upsaliensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Navicula notha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Navicula pelliculosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula peregrina	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula peticolaspi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Navicula protracta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula pupula var. eliptica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Navicula pupula var. mutata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Navicula radiosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.5	0.6	0.3
Navicula sabiniana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula salinarium	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula sanctaecrucis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula tripunctata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Navicula viridula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sellaphora bacillum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	1.5	0.7	0.0
Sellaphora pupula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.5	0.0	0.0	0.0	0.0	0.0
Luticola mutica	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hippodonta capitata	0.7	3.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.1	0.2	0.3	0.3	0.0	0.2	0.0	0.0	0.3	0.0	0.7	0.0	0.0
Geissleria thingvallae	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	0.0

Cosmioneis pusilla																						
Cavinula lacustris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Astartiella wellsiae	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gyrosigma acuminatum	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gyrosigma eximium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stauroneis obtusa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stauroneis phoenicenteron f. gracilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Stauroneis prominula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.3	0.0	0.0	0.0
Amphora ovalis var. affinis	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.2	0.9	0.5	1.3	3.0	1.8	0.8
Amphora subturgida	1.0	1.6	0.0	0.0	0.0	0.0	0.3	0.0	0.0	2.1	0.5	0.3	1.3	0.0	0.2	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Amphora terroris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Frustulia asymmetrica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.0
Frustulia rhomboides	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tryblionella acuminata	0.2	0.2	0.0	0.2	0.3	0.1	0.0	0.0	1.0	0.5	0.0	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Tryblionella granulata	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	0.2	0.0	0.2	0.5	0.0	0.2	0.0	0.2	0.2	0.6	0.0	0.0	0.0	0.0
Tryblionella hungarica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tryblionella levidensis	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Tryblionella marginulata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia amphibia	8.9	3.9	1.0	0.0	0.0	0.0	0.5	0.0	0.4	0.5	0.0	0.3	1.5	0.0	0.2	0.5	0.2	0.3	0.0	1.0	1.4	0.4
Nitzschia apiculata	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.2	0.0	0.3	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia capitellata	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia circumsuta	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia fonticola	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia lorenziana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia palea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia plana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia punctata	1.4	1.3	0.0	0.2	0.0	0.5	0.3	1.5	1.7	10.1	0.6	1.3	3.7	0.5	0.3	2.4	0.2	0.6	0.0	0.0	0.0	0.0
Nitzschia triblionella var. obtusiuscula	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.2	0.0
Nitzschia tryblionella	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia vermicularis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia vitrea	0.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzscia clausii	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epithemia adnata	0.0	0.7	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8
Epithemia sorex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.5	0.0	0.1	0.5	0.2	0.5	0.5	0.1	0.3	0.4	0.1	0.3
Epithemia turgida	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalodia gibberula	0.7	0.3	0.0	0.0	0.0	0.4	0.3	0.7	0.4	0.3	0.0	0.5	1.0	0.3	0.8	0.5	0.9	0.3	0.0	1.1	0.7	0.0
Rhopalodia musculus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalodia novae zealandia	0.7	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.7	0.5	12.1	0.8
Surirella biseriata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Surirella brebissonii	0.2	1.3	0.0	0.0	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0
Surirella guatimalensis	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Surirella tenera	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Campylodiscus echeneis	0.4	1.1	0.3	0.0	0.6	0.9	0.3	0.2	0.1	0.3	1.0	0.2	0.3	0.0	0.0	0.0	0.2	0.4	0.3	0.0	0.0	0.0
Cymatopleura elliptica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Cymatopleura solea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0

Table 26: WA1 core diatom percentage counts.

	Sample depth (cm)								
Taxa	0 to 1	4 to 5	9 to 10	14 to 15	19 to 20	24 to 25	29 to 30	34 to 35	39 to 40
Thalassiosira bramaputrae	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyclotella stelligera	1.0	1.0	0.3	0.9	0.3	0.7	3.1	22.4	27.5
Cyclostephanos spp.	1.2	0.0	5.2	5.1	1.5	3.4	9.6	53.2	45.5
Pseudopodosira spp.	61.8	59.4	28.2	35.6	42.8	36.7	4.5	1.3	1.2
Hyalodiscus lentiginosus	2.5	1.7	0.7	2.1	2.3	2.6	2.4	0.0	0.7
Aulacoseira ambigua	2.6	3.5	15.4	18.3	9.3	10.5	46.4	15.0	17.5
Aulacoseira italica	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Orthosira roeseana	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Coscinodiscus sp.	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aulacodiscus argus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.2
Actinocyclus octonarius	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Fragilaria capucina var. vaucheriae	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.3	0.0
Staurosirella pinnata	0.5	0.5	1.3	2.3	1.3	1.2	0.6	2.3	1.6
Staurosirella pinnata var. lancettula	0.0	0.7	0.0	0.7	0.8	0.2	0.0	0.0	0.0
Staurosira construens	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Staurosira elliptica	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Pseudostaurosira brevistriata	0.0	0.5	0.0	1.6	0.0	0.7	0.6	0.8	1.4
Pseudostaurosira brevistriata var. inflata	0.2	1.0	0.5	0.6	0.0	0.0	0.3	0.3	0.9
Martyana martyi	1.5	0.7	0.5	0.5	0.3	0.2	0.0	0.3	0.7
Synedra ulna	0.1	0.3	0.3	0.1	1.1	0.4	0.4	0.6	0.2
Tabularia fasciculata	0.0	0.1	0.9	1.2	0.4	0.7	0.6	0.0	0.0
Tabellaria flocculosa	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphicampa mirabilis	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mastogloia lanceolata	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mastogloia pumila	0.0	0.0	0.0	0.2	1.1	0.0	0.0	0.0	0.0
Placoneis placentula	0.0	0.7	0.0	0.5	0.0	0.5	0.0	0.0	0.0
Cymbella elginsis	0.0	0.0	0.0	0.0	0.5	0.0	0.3	0.0	0.0
Cymbella kappii	0.0	0.0	0.8	0.5	0.0	0.0	0.0	0.3	0.0
Gomphonema vibrio var. intricatum	0.0	0.0	0.0	0.5	0.3	0.5	0.0	0.0	0.0
Encyonema gracile	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Achnanthes delicatula subsp. hauckiana	0.0	0.0	0.0	0.2	0.3	0.2	0.0	0.0	0.0
Achnanthes suchlandtii	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthes temperei	0.0	0.0	0.3	0.0	0.0	0.2	0.3	0.0	0.0
Planothidium dubium	3.0	1.0	1.5	1.6	0.5	1.0	0.0	0.0	0.0
Planothidium lanceolatum	0.0	0.5	0.0	0.5	0.5	0.7	0.3	0.3	0.0
Karayevia clevei	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.7
Cocconeis placentula var. euglypta	2.6	2.6	8.7	15.3	10.8	16.2	18.6	0.5	0.4
Cocconeis placentula var. lineata	0.2	0.0	1.6	2.7	3.0	5.1	3.0	0.0	0.2
Cocconeis thumensis	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthidium brevipes	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neidium temperei	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Fallacia pygmaea	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.2
Pinnularia borealis	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia sp	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Caloneis ventricosa	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diploneis smithii	1.0	1.1	0.3	0.2	0.3	0.1	0.3	0.0	0.0
Navicula cryptocephala	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Navicula cuspidata	0.5	2.5	1.8	1.8	2.0	2.0	0.6	0.3	0.0
Navicula minima	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0
Navicula peregrina	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Navicula radiosa	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Hippodonta capitata	0.0	0.0	0.0	0.0	0.0	1.7	0.6	0.0	0.0
Pleurosigma sp	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Gyrosigma acuminatum	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0

Gyrosigma spp	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Stauroneis anceps	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Amphora ovalis var. affinis	0.2	0.6	0.5	0.9	1.8	0.5	0.3	0.0	0.0
Amphora subturgida	0.0	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.0
Hantzschia spp.	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tryblionella acuminata	0.2	0.0	0.5	0.0	0.6	0.7	0.3	0.0	0.0
Nitzschia amphibia	13.3	18.1	24.9	1.4	10.3	7.1	1.7	0.5	0.0
Nitzschia apiculata	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia clausii	0.0	0.0	0.5	0.2	0.0	0.0	0.3	0.0	0.0
Nitzschia fragment	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Nitzschia plana	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Nitzschia punctata	0.2	0.2	1.0	0.1	0.3	1.0	0.1	0.3	0.0
Nitzschia tryblionella	0.2	0.2	0.5	0.0	0.8	0.6	0.0	0.0	0.0
Nitzschia vitrea	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Epithemia adnata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Epithemia sorex	0.0	0.1	0.0	0.6	0.3	0.2	0.0	0.0	0.0
Epithemia turgida	0.2	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0
Rhopalodia gibberula	0.0	0.0	0.5	0.0	0.5	0.5	1.1	0.0	0.0
Rhopalodia musculus	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Rhopalodia novae zealandia	0.4	0.0	1.0	0.5	0.3	1.0	1.6	0.0	0.0
Surirella brebissonii	0.2	0.0	0.3	0.2	0.3	0.2	0.0	0.5	0.0
Surirella subsalsa	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.0	0.0
Surirella sp.	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0
Campylodiscus echeneis	1.3	0.5	0.4	1.3	1.1	1.0	0.7	0.1	0.0

Table 27: Te Koru diatom percentage counts.

	Sample depth (cm)							
Taxa	0 to 1	6 to 7	12 to 13	18 to 19	24 to 25	30 to 31	36 to 37	42 to 42
Thalassiosira bramaputrae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Cyclotella meneghiniana	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Cyclotella stelligera	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Cyclostephanos spp.	0.0	0.6	0.9	1.7	0.0	1.0	1.9	0.4
Pseudopodosira spp.	56.9	38.3	20.0	21.3	19.5	16.2	22.9	14.4
Hyalodiscus lentigonosis	1.5	3.7	3.3	1.7	1.1	3.0	3.3	6.4
Aulacoseira ambigua	2.0	2.6	2.4	1.3	2.0	3.0	3.9	1.6
Aulacoseira italica	0.0	0.0	0.0	1.0	0.0	0.0	0.3	0.0
Orthosira roeseana	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurosirella leptostauron	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Staurosira elliptica	0.7	1.9	0.3	0.3	0.0	0.0	0.0	2.4
Pseudostaurosira brevistriata	0.0	1.6	1.2	1.5	0.7	0.3	0.5	0.8
Martyana martyi	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Diatoma vulgaris	0.3	0.0	0.6	0.3	0.7	0.0	0.0	0.0
Synedra filiformis	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Synedra minuscula	0.0	0.0	0.0	0.0	0.0	0.3	0.0	2.2
Synedra ulna	1.5	0.5	0.8	0.0	0.2	0.2	0.2	0.4
Tabularia fasciculata	2.8	2.5	3.2	2.3	1.3	1.6	1.5	2.4
Amphicampa mirabilis	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Placoneis placentula	0.7	0.3	0.0	1.3	0.3	1.0	0.6	0.0
Cymbella kappii	0.0	0.0	0.6	0.0	0.0	0.3	0.3	0.8
Encyonema gracile	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Encyonema silesiacum	0.3	0.3	0.0	0.3	0.0	0.0	0.0	0.0
Gomphenema parvulum	0.0	0.0	0.3	0.3	0.3	0.3	0.3	1.6
Gomphenema spp.	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthes brevipes	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthes delicatula	2.0	1.0	1.4	1.0	0.3	1.6	0.5	0.4
Planothidium lanceolatum	0.0	0.0	0.0	0.3	1.3	0.3	0.0	2.4
Cocconeis placentula var. euglypta	5.7	7.3	4.2	8.4	47.3	8.7	7.5	28.9
Cocconeis placentula var. lineata	1.7	0.3	0.9	0.0	1.3	0.0	0.6	0.8
Pinnularia acuminata	0.0	0.6	0.0	0.0	0.0	0.3	0.0	0.0
Caloneis sublinearis	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Diploneis smithii	0.2	1.2	0.0	0.3	0.8	0.3	1.2	1.8
Navicula cuspidate	0.0	1.6	8.8	6.2	3.9	6.8	6.8	0.4
Navicula minima	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula minuscula	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Navicula peregrina	1.3	0.0	0.0	0.0	0.7	1.0	0.0	0.0
Navicula tripunctata	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Hippodonta capitata	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2
Pleurosigma spp.	2.3	3.2	1.2	0.0	0.5	1.2	0.2	1.4
Gyrosigma spp.	0.3	0.0	1.1	0.7	0.7	12.1	3.8	2.3
Stauronosis anceps	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0
Craticula halophila	0.0	0.0	0.0	0.0	0.0	3.6	0.3	0.0
Amphora subturgida	4.0	3.4	2.6	0.7	1.0	1.0	1.9	9.4
Tryblionella acuminata	0.3	0.0	0.0	0.0	0.0	3.8	0.0	0.0
Tryblionella marginulata	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Nitschia amphibia	7.3	12.9	34.8	43.9	15.0	24.4	39.0	14.0
Nitzchia fragment	0.5	1.3	2.0	2.2	0.7	0.2	0.5	0.7
Nitzschia apiculate	0.0	0.8	3.6	0.3	0.0	3.6	0.3	0.0
Nitzschia punctata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Nitzschia vitrea	0.0	0.9	0.0	0.2	0.0	0.7	0.0	0.4
Epithemia adnata	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Epithemia sorex	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0
Rhopalodia gibberula	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhopalodia novae zeelandiae	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surirella brebissonii	6.2	9.7	4.5	1.7	0.7	2.1	0.1	0.9

Table 28: Accepted names, synonyms and environmental preference classification of diatom taxa observed in the three cores.

		Environment classification categories								
Accepted names	**Synonyms**	Environment	Salinity	Moisture	Nitrogen uptake	oxygen requirements	Saprobity	Trophic level	pH	Current
Thalassiosira bramaputrae (Ehrenberg) Håkansson & Locker	*Thalassiosira lacustris* (Grunov) Hasle	B	B	A	B	B	B	E	D	*
Cyclotella meneghiniana Kützing		C	C	B	C	E	D	E	D	B
Cyclotella stelligera Cleve & Grunow		F	D	A	*	*	*	A	C	*
Cyclostephanos spp.		D	D	*	*	*	*	*	*	*
Pseudopodosira westii (W. Smith) Sheshukova-Poretzskaya		E	B	*	*	*	*	*	*	*
Pseudopodosira spp.		*	*	*	*	*	*	*	*	*
Hyalodiscus lentiginosus John		B	B	A	*	*	*	*	*	*
Paralia sulcata (Ehrenberg) Cleve	*Melosira sulcata* (Ehrenberg) Kützing	E	B	*	*	*	*	*	D	*
Aulacoseira ambigua (Grun.) Simonsen		D	D	A	B	C	B	E	D	*
Aulacoseira italica (Ehrenberg) Simonsen		D	E	C	B	B	B	D	C	*
Orthoseira roeseana (Rabenhorst) O'Meara	*Melosira roeseanna* Rabenhorst	P	D	D	*	*	*	*	C	*
Coscinodiscus sp.		*	*	*	*	*	*	*	*	*
Aulacodiscus argus (Ehrenberg) A. Schmidt		*	*	*	*	*	*	*	*	*
Actinocyclus octonarius Ehrenberg.		A	A	*	*	*	*	*	*	*
Auliscus caelatus f. major A. Schmidt		*	*	*	*	*	*	*	*	*
Fragilaria capucina Desmazières		D	D	*	*	*	B	C	C	*
Fragilaria capucina var. vaucheriae (Kützing) Lange-Bertalot	*Fragilaria vaucheriae* (Kützing) J.B. Petersen	J	D	C	B	C	C	E	D	*
Fragilaria capucina subsp. Rumpens (Kützing) Lange-Bertalot		*	D	*	*	*	B	B	C	*
Fragilaria nitzshiodes Grunow		*	*	*	*	*	*	*	*	*
Staurosirella lapponica (Grunow) D.M. Williams & Round	*Fragilaria lapponica* Grunow	*	D	B	*	*	*	*	D	*
Staurosirella leptostauron (Ehrenberg) D.M. Williams & Round	*Fragilaria leptostauron* (Ehrenberg) Hustedt	P	D	B	A	A	A	D	D	*
Staurosirella leptostauron var. dubia (Grunow) Bukhtiyarova		*	D	B	*	*	*	*	D	*
Staurosirella pinnata (Skvortzov) J.C. Kingston	*Fragilaria pinnata* Ehrenberg	F	D	C	B	A	B	G	D	C
Staurosirella pinnata var. lancettula (Schumann) E.Y. Haworth & M.G. Kelly		F	D	C	B	A	B	G	D	*
Staurosira elliptica (Schumann) D.M.Williams & Round	*Fragilaria construens var. pumila* Grunow	*	D	A	A	A	B	D	D	*
Staurosira construens Ehrenberg	*Fragilaria construens* (Ehrenberg) Grunow	F	D	A	A	A	B	D	D	B
Staurosira construens var. venter (Ehrenberg) P.B. Hamilton		F	D	A	A	A	B	D	D	B
Pseudostaurosira brevistriata (Grunow) D.M. Williams & Round	*Fragilaria brevistriata* Grunow in Van Heurck	F	D	B	A	A	A	G	D	B
Pseudostaurosira brevistriata var. inflata (Pantocsek) Hartley et al.	*Fragilaria brevistrata var. inflata* (Pantocsek) Hustedt	F	D	B	A	A	A	G	D	*
Martyana martyi (Héribaud) Round	*Opephora martyi*	J	D	*	*	*	*	*	D	*
Diatoma vulgaris Bory		*	D	A	B	B	B	D	E	
Synedra filiformis J. R. Carter & P. Denny		*	*	*	*	*	*	*	*	*
Synedra minuscula Grunow		*	*	*	*	*	*	*	*	*
Synedra ulna (Nitzsch) Ehrenberg		J	D	B	B	C	D	G	D	B

Synedra ulna fragment		J	D	B	B	C	D	G	D	B
Synedra ulna var. ramesi Héribaud		*	*	*	*	*	*	*	*	*
Synedra fragment		H	B	C	B	C	C	E	D	*
Ulnaria capitata (Ehrenberg) P. Compère		*	*	*	*	*	*	*	*	*
Ulnaria ulna var. amphirhynchus (Ehrenberg) M. Aboal		*	*	*	*	*	*	*	*	*
Ctenophora pulchella (Ralfs ex Kützing) D.M. Williams & Round	*Synedra pulchella* (Ralfs ex Kützing) Kützing	I	B	*	*	*	*	E	D	*
Tabularia fasciculata (Ehrenberg) D. M. Williams & Round	*Synedra fasciculata* Ehrenberg	H	B	C	B	C	C	E	D	*
Tabularia fasciculata var truncata		*	*	*	*	*	*	*	*	*
Tabellaria flocculosa (Roth) Kützing		*	E	C	A	A	C	D	B	*
Eunotia pectinalis var. minor (Kützing) Rabenhorst		*	E	C	B	A	B	C	B	*
Amphicampa mirabilis Ehrenberg	*Eunotia serpentina* Ehrenberg	*	D	*	*	*	A	*	*	*
Mastogloia lanceolata Thwaites		*	*	*	*	*	*	*	*	*
Mastogloia elliptica (Agardh) Cleve		L	B	C	*	*	*	*	D	*
Mastogloia pumila (Cleve & J. Möller; Grunow in van Heurck) Cleve		*	B	*	*	*	*	*	*	*
Placoneis placentula (Ehrenberg) Mereschkowsky	*Navicula placentula* (Ehrenberg) Kützing	*	D	A	B	B	B	E	D	*
Cymbella caespitosa var. ovata (Kützing)		*	*	*	*	*	*	*	*	*
Cymbella cistula (Hemprich & Ehrenberg) O. Kirchner		I	D	A	A	B	B	E	D	*
Cymbella elginsis Krammer	*Cymbella tugida* (Bréb.) Van Heurck	*	D	*	*	*	*	A	D	*
Cymbella kappii Cholnoky		J	D	*	*	*	*	*	D	*
Cymbella naviculiformis Auerswald ex Heiberg		P	D	B	B	B	B	E	C	*
Encyonema gracile Ehrenberg	*Cymbella gracilis* (Rabenhorst) Cleve	*	D	C	A	A	A	B	B	*
Encyonema silesiacum (Bleisch) D.G. Mann	*Cymbella ventricosa* C. Agardh	*	D	*	*	*	B	A	C	*
Gomphonema parvulum (Kützing) H.F. Van Heurck		J	D	C	C	D	D	E	C	A
Gomphonema vibrio var. intricatum R. Ross	*Gomphonema intricatum* Kützing	*	D	*	A	A	A	A	D	*
Gomphoneis clevei (Fricke) Gil	*Gomphenema clevei* Fricke	*	*	*	*	*	*	*	*	*
Reimeria sinnata (Gregory) Kociolek & Stoermer		*	E	C	A	A	B	C	C	*
Achnanthes brevipes C. Agardh		H	B	*	*	*	*	E	*	*
Achnanthes clevei var. rostrata Hustedt		*	D	A	B	B	B	D	D	*
Achnanthes delicatula (Kützing) Grunow		*	B	*	*	*	*	*	E	B
Achnanthes delicatula subsp. hauckiana	*Achnanthes hauckiana* Grunow	*	D	*	*	*	*	A	E	*
Achnanthes hustedtii (Krasske) Reimer		*	*	*	*	*	*	*	*	*
Achnanthes imperfecta Schimanski	*Navicula poconoensis* Patrick	*	*	*	*	*	*	*	*	*
Achnanthes lemmernanni Hustedt		*	*	*	*	*	*	*	*	*
Achnanthes thermalis (Rabenhorst) Schoenfeld	*Achnanthes grimmei* Krasske	*	C	*	*	B	A	*	C	*
Achnanthes temperei M. Peragallo		*	*	*	*	*	*	*	*	*
Achnanthese pinnata Hustedt		*	*	*	*	*	*	*	*	*
Achnanthes suchlandtii Hustedt		*	E	B	A	A	A	A	C	*
Psammothidium levanderi (Hustedt) L. Bukhtiyarova & Round	*Achnanthes levanderi* Hustedt	*	E	C	A	A	A	A	C	*
Planothidium dubium (Grunow) Round & L. Bukhtiyarova	*Achnanthes lanceolata var. dubia* Grunow	J	D	C	B	C	C	E	D	A
Planothidium lanceolatum (Brébisson ex Kützing) Round & L. Bukhtiyarova	*Achnanthes lanceolata* (Brébisson ex Kützing) Grunow in Van Heurck	J	D	C	B	C	C	E	D	A
Rossithidium pusillum (Grunow) Round & L. Bukhtiyarova	*Achnanthes linearis var. pusilla* Grunow	*	*	*	*	*	*	*	*	*
Karayevia clevei (Grunow) Round & Bukhtiyarova	*Achnanthes clevei* Grunow in Cleve & Grunow	*	D	A	B	B	B	D	D	*

Karayevia oblongella (Østrup) M. Aboal	*Achnanthes saxonica* Krasske ex Hustedt	*	D	C	A	A	A	A	C	*
Cocconeis distans Gregory		*	*	*	*	*	*	*	*	*
Cocconeis flaviatalis		*	*	*	*	*	*	*	*	*
Cocconeis placentula Ehrenberg		I	D	B	B	C	B	E	D	B
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	*Cocconeis euglypta* Ehrenberg	I	D	B	B	C	B	E	D	B
Cocconeis placentula var. lineata (Ehrenberg) P. Cleve		*	D	B	B	C	B	E	D	*
Cocconeis thumensis A. Mayer		N	*	*	*	*	*	D	*	*
Achnanthidium brevipes (Agardh) Gaillon		*	*	*	*	*	*	*	*	*
Achnanthidium exiguum var. heterovalvum (G. Krasske) D. B. Czarnecki	*Achnanthes exigua var. heterovalva* Krasske	N	D	C	B	A	B	G	D	*
Achnanthidium microcephalum Kützing	*Achnanthes microcephala* (Kützing) Grunow	*	*	*	*	*	A	A	B	*
Achnanthidium thermale Rabenhorst	*Achnanthes gibberula* Grunow	*	*	*	*	*	*	*	*	*
Lemnicola hungarica (Grunow) F. E. Round & P. W. Basson	*Achnanthes hungarica* (Grunow) Grunow in Cleve & Grunow	*	D	A	B	D	C	F	D	*
Diadesmis confervacea Kützing	*Navicula confervaceae* (Kützing) Grunow	*	C	C	C	C	C	E	C	*
Diadesmis peregrina W.Smith	*Navicula confervaceae var. peregrina* (W. Smith ex Ralfs) Grunow	*	*	*	*	*	*	*	D	*
Neidium dubium (Ehenberg) Cleve		*	D	A	A	A	B	D	C	*
Neidium temperei C.W.Reimer		*	*	*	*	*	*	*	*	*
Fallacia pygmaea (Kützing) A.J. Stickle & D.G. Mann	*Navicula pygmaea* Kützing	*	C	B	C	C	C	E	E	*
Pinnularia acuminata W. Smith		*	D	C	*	A	A	A	C	*
Pinnularia borealis Ehrenberg		P	D	D	B	A	B	B	C	*
Pinnularia brebissonii (Kützing) Rabenhorst		*	E	*	*	*	*	*	*	*
Pinnularia brevicostrata Cleve		*	E	B	*	*	A	A	B	*
Pinnularia microstauron (Ehrenberg) Cleve		*	D	C	B	C	B	G	C	*
Pinnularia sudetica (Hilse) Hilse		*	E	D	*	*	A	B	B	*
Pinnularia torta (A. Mann) R.M.Patrick		*	*	*	*	*	*	*	*	*
Caloneis bacillum (Grunow) Mereschkowsky		M	D	B	A	B	B	D	D	*
Caloneis silicula var. truncatula Grunow	*Caloneis ventricosa var. truncata* (Grunow) Meister	*	D	A	A	B	A	D	D	*
Caloneis sublinearis (Grunow) Krammer		*	A	*	*	*	*	*	*	*
Caloneis ventricosa (Ehrenberg) F. Meister		*	*	*	*	*	*	*	*	*
Diploneis smithii (Brébisson) Cleve		L	A	*	*	*	*	*	D	*
Navicula anglica var. subsalsa Grunow		*	*	*	*	*	*	*	*	*
Navicula cryptocephala Kützing		L	C	B	B	C	C	G	C	*
Navicula cryptocephala var. exilis (Kützing) Grunow		*	*	*	*	*	*	*	*	*
Navicula cryptotenella Lange-Bertalot	*Navicula radiosa var. tenella* (Brébisson) Cleve & Möller	*	C	B	*	*	B	F	D	*
Navicula cuspidata Kützing		M	D	A	B	C	C	E	D	*
Navicula disputans R.M.Patrick		*	*	*	*	*	*	*	*	*
Navicula exigua var. capitata R.M. Patrick		*	D	B	A	A	B	E	D	*
Navicula fustera		*	*	*	*	*	*	*	*	*
Navicula incomposita var. minor Hagelstein		*	*	*	*	*	*	*	*	*
Navicula kotschyi undulata Hustedt	*Navicula mutica var. undulata* (Hilse) Grunow	*	*	*	*	*	*	*	*	*
Navicula lanceolata (C. Agardh) Ehrenberg		*	C	C	B	C	C	E	D	*
Navicula minima Grunow in Van Heurck		P	C	C	C	D	D	E	D	*
Navicula minuscula Grunow in Van Heurck		P	E	D	*	*	B	A	D	*

Navicula minuscula var. upsaliensis Grunow		*	*	*	*	*	*	*	*	*
Navicula notha Wallace		*	*	*	*	*	*	*	*	*
Navicula pelliculosa (Brébisson ex Kützing) Hilse		*	D	*	*	*	*	B	D	*
Navicula peregrina (Ehrenberg) Kützing		L	B	*	*	*	*	E	D	*
Navicula peticolaspi		*	*	*	*	*	*	*	*	*
Navicula protracta (Grunow in Cleve & Grunow) Cleve		N	C	C	B	C	B	E	C	*
Navicula pupula var. eliptica Hustedt		*	D	B	*	*	*	D	D	*
Navicula pupula var. mutata (Krasske) Hustedt		*	*	*	*	*	*	*	*	*
Navicula radiosa Kützing		M	D	C	B	B	B	D	C	*
Navicula sabiniana R.M. Patrick		*	*	*	*	*	*	*	*	*
Navicula salinarium Grunow		L	B	A	B	B	B	E	C	*
Navicula sanctaecrucis Østrup		*	*	*	*	*	*	*	*	*
Navicula tripunctata (O.F. Müller) Bory		*	D	C	B	B	B	E	D	*
Navicula viridula (Kützing) Ehrenberg		*	C	A	B	B	C	E	D	*
Sellaphora bacillum (Ehrenberg) D.G. Mann	*Navicula bacillum* Ehrenberg	M	D	B	A	B	B	D	D	*
Sellaphora pupula (Kützing) Mereschkovsky	*Navicula pupula* Manguin	M	D	B	B	C	C	D	C	*
Luticola mutica (Kützing) D.G. Mann	*Navicula mutica* Kützing	P	C	D	B	A	C	E	C	*
Hippodonta capitata (Ehrenberg) Lange-Bertalot	*Navicula capitata* (Ehrenberg) R. Ross	*	D	C	B	C	C	D	D	*
Geissleria thingvallae (Østrup) Metzeltin & Lange-Bertalot	*Navicula latens* Krasske ex Hustedt	*	*	*	*	*	*	*	*	*
Cosmioneis pusilla (W. Smith) D.G. Mann & A.J. Stickle	*Navicula pusilla* W. Smith	P	D	D	A	A	*	*	C	*
Cavinula lacustris (W. Gregory) D.G. Mann	*Navicula lacustrus*	*	E	*	A	*	A	*	C	*
Astartiella wellsiae (Reimer) Witkowski & Lange-Bertalot		*	*	*	*	*	*	*	*	*
Gyrosigma acuminatum (Kützing) Rabenhorst	*Gyrosigma spencerii* (W. Smith) Griffith & Henfrey	L	D	B	B	C	B	E	E	*
Gyrosigma eximium (Thwaites) Van Heurck		*	C	*	*	*	*	*	*	*
Stauroneis anceps Ehrenberg		*	D	B	B	B	B	D	C	*
Stauroneis obtusa N. Lagerstedt			E	D	A	A	A	A	C	*
Stauroneis phoenicenteron f. gracilis (Ehrenberg) Hustedt		*	D	B	B	C	B	D	C	*
Stauroneis prominula (Grunow) Hustedt	*Stauroneis ignorata* Hustedt	*	*	*	*	*	*	*	*	*
Craticula halophila (Hustedt) Czarnecki			B	B	B	B	C	E	D	
Amphora ovalis var. affinis (Kützing) Van Heurck	*Amphora libyca* Ehrenb.	M	D	*	*	*	*	E	D	*
Amphora subturgida Hustedt		P	*	*	*	*	*	*	D	*
Amphora terroris Ehrenberg		*	*	*	*	*	*	*	*	*
Hantzschia spp.		*	*	*	*	*	*	*	*	*
Frustulia asymmetrica		*	*	*	*	*	*	*	*	*
Frustulia rhomboides (Ehrenberg) De Toni		*	E	C	A	A	A	A	A	*
Tryblionella acuminata W. Smith.	*Nitzschia acuminata* (W. Smith) Grunow	*	B	*	*	*	*	*	*	*
Tryblionella granulata Grunow		L	A	*	*	*	*	*	*	*
Tryblionella hungarica (Grunow) Mann		L	C	A	B	D	C	E	D	B
Tryblionella levidensis W. Smith	*Nitzschia tryblionella var. levidensis* (W. Smith) Grunow	*	C	A	B	C	C	E	D	*
Tryblionella marginulata (Grunow) D.G. Mann		*	*	*	*	*	*	*	*	*
Nitzschia amphibia Grunow		J	D	C	C	C	C	E	D	B
Nitzschia apiculata (W. Gregory) Grunow)		L	B	B	B	C	C	E	D	B

Nitzschia capitellata Hustedt	*	B	C	*	*	D	F	D	*
Nitzschia circumsuta (Bailey) Grunow	*	B	B	*	*	*	E	D	*
Nitzschia fonticola Grunow in Cleve & Möller	*	D	A	B	B	B	D	D	*
Nitzschia lorenziana Grunow	*	*	*	*	*	*	*	*	*
Nitzschia palea (Kützing) W. Smith	J	D	C	D	D	E	F	C	B
Nitzschia plana W. Smith	*	*	*	*	*	*	*	*	*
Nitzschia punctata (W. Smith) Grunow	L	B	*	*	*	*	*	D	*
Nitzschia tryblionella var. obtusiuscula	*	*	*	*	*	*	*	*	*
Nitzschia tryblionella Hantzsch in Rabenhorst	L	C	*	*	*	*	*	*	*
Nitzschia vermicularis (Kützing) Hantzsch in Rabenhorst	*	D	B	*	A	B	G	D	*
Nitzschia vitrea G. Norman	O	B	B	*	*	*	E	D	*
Nitzschia clausii Hantzsch	L	B	C	B	B	C	E	D	*
Epithemia adnata (Kützing) Brébisson	J	D	B	A	B	B	D	E	*
Epithemia sorex Kützing	J	D	B	A	B	B	E	E	*
Epithemia turgida (Ehrenberg) Kützing	J	D	C	A	B	B	D	E	*
Rhopalodia gibberula (Ehrenberg) O.F. Müller	H	C	C	*	A	*	*	D	*
Rhopalodia musculus (Kützing) O.F. Müller	H	B	C	*	*	A	*	*	*
Rhopalodia novae zealandia Hustedt	I	D	C	*	*	*	*	D	*
Surirella biseriata Brébisson in Brébisson & Godey	*	D	A	*	*	B	E	D	*
Surirella brebissonii Krammer & Lange-Bertalot	*	C	*	*	*	*	*	D	*
Surirella guatimalensis C.G. Ehrenberg	*	*	*	*	*	*	*	*	*
Surirella subsalsa W. Smith	*	C	*	*	*	*	*	*	*
Surirella tenera Gregory	*	D	A	*	B	B	E	D	*
Campylodiscus echeneis Ehrenberg ex Kützing	L	B	C	*	*	*	*	*	*
Cymatopleura elliptica (Brébisson ex Kützing) W. Smith	L	C	A	B	B	B	E	D	*
Cymatopleura solea (Brébisson) W. Smith	M	D	A	B	C	B	E	D	*

Appendix VII Pollen and NPP photomicrographs

Images were obtained using DIC microscopy at 1000x magnification.

Plate 1:

A. *Pinus radiata*
B. *Pinus radiata*
C. Podocarpaceae
D. Podocarpaceae
E. Podocarpaceae
F. *Dacrydium cupressinum*
G. *Dacrydium cupressinum*
H. *Phylocladdus spp.*
I. *Dacrycarpus dacrydioides*
J. *Dacrycarpus dacrydioides*

Plate 2:

A. Ranunculaceae
B. Ranunculaceae
C. Chenopodiaceae
D. Halagoraceae
E. Halagoraceae
F. *Coriaria spp.*
G. *Coriaria spp.*
H. *Leptospermum scoparium*
I. *Leptospermum scoparium*
J. *Metrosideros spp.*
K. *Nothafagus fusca* type
L. *Nothafagus fusca* type
M. *Nothafagus fusca* type
N. *Coprosma spp.*
O. *Coprosma spp.*
P. Asteraceae
Q. Asteraceae
R. Asteraceae
S. Asteraceae

Plate 3:

A. Poaceae
B. Cyperaceae
C. Cyperaceae
D. Liliaceae
E. Liliaceae

Plate 4:

A. Monolete fern spore
B. Monolete fern spore
C. *Phymatosorus spp.*
D. *Cyathea spp.*
E. *Cyathea spp.*
F. *Cyathea spp.*
G. *Cyathea spp.*
H. Native *Lycopodium*

Plate 5:

A. *Pediastrum boryanum var. cornutum*
B. *Pediastrum boryanum var. cornutum*
C. *Pediastrum integrum*
D. Algae zygospore
E. Algae zygospore

Plate 6:

A. Sheath of *Gloeotrichia*-type cyanobacteria

B-G. Fungal spore
H. Fungal hyphae
I. Chiromomidae mouthpart

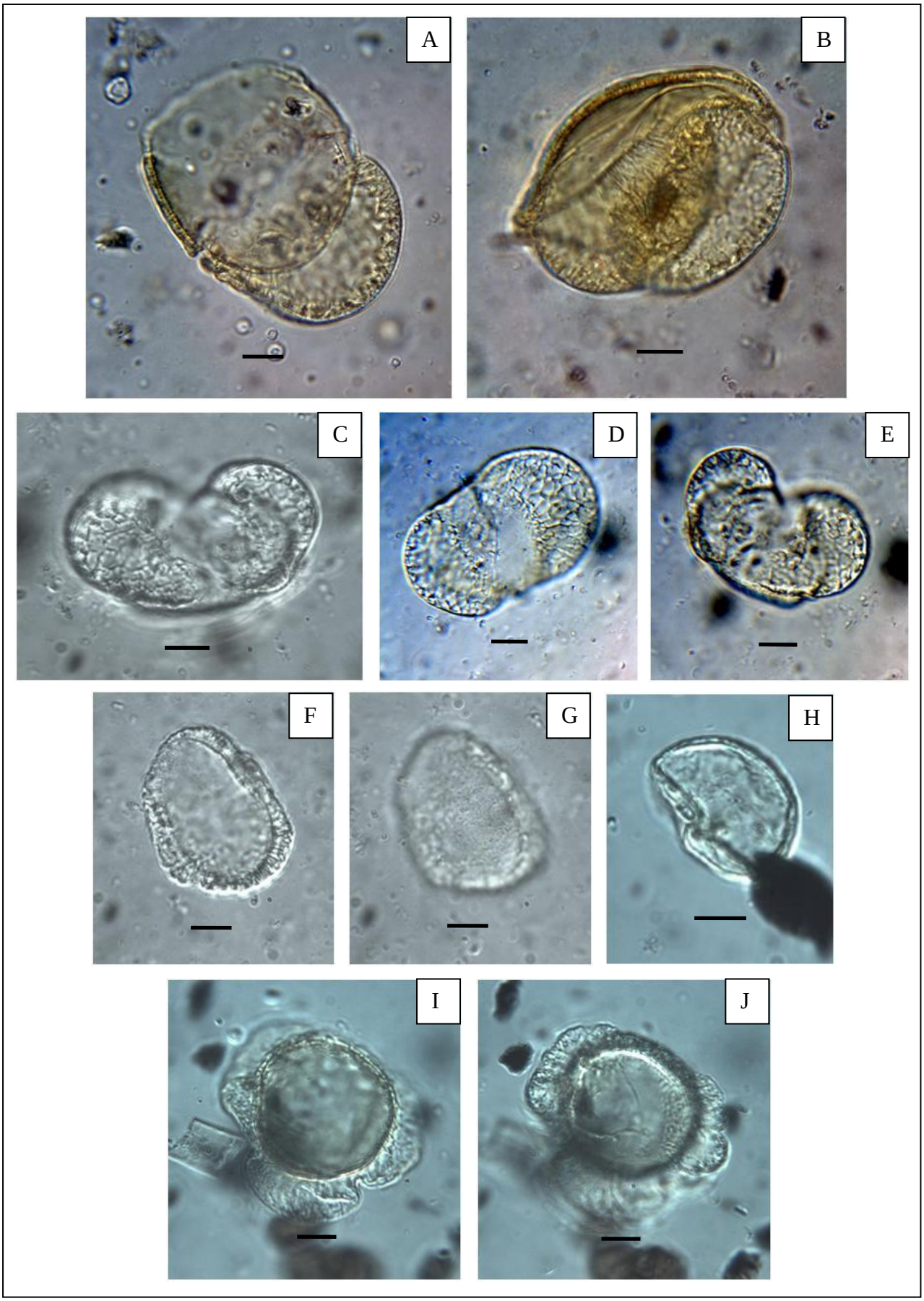

Plate 1 *Pinus* and Podocarpaceae scale = 10 µm

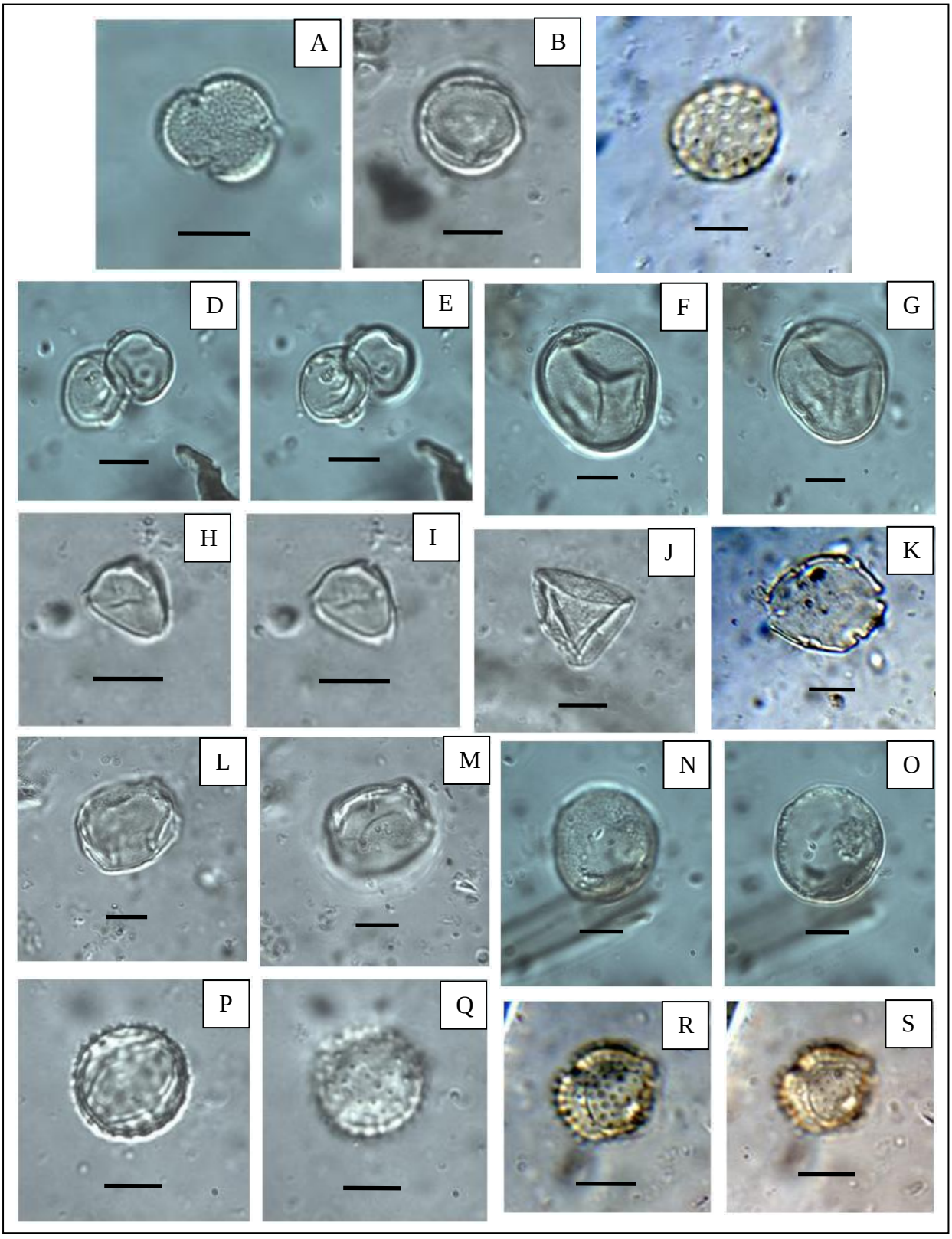

Plate 2 Dicotyledons scale = 10 µm

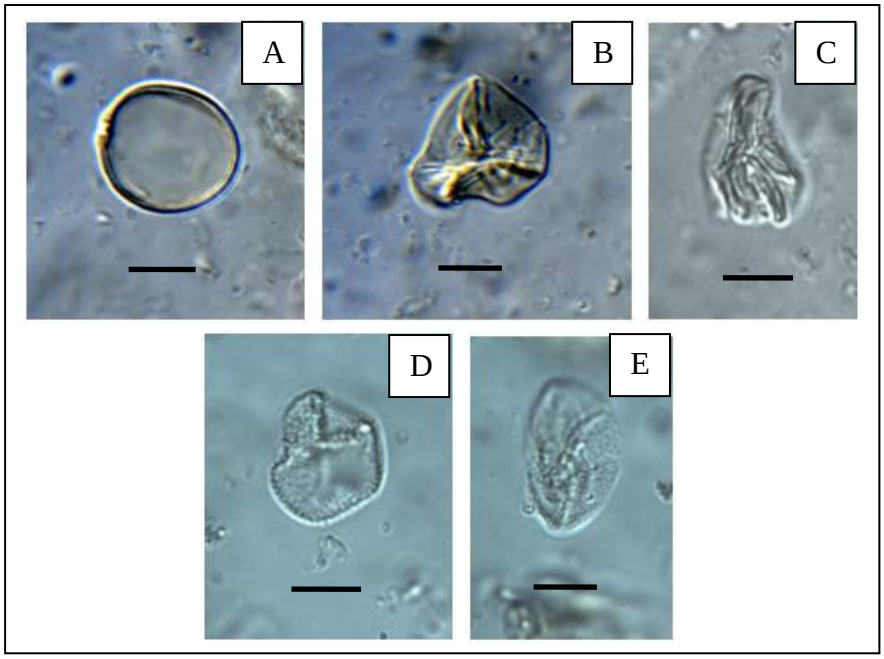

Plate 3 Monocotyledons scale = 10 µm

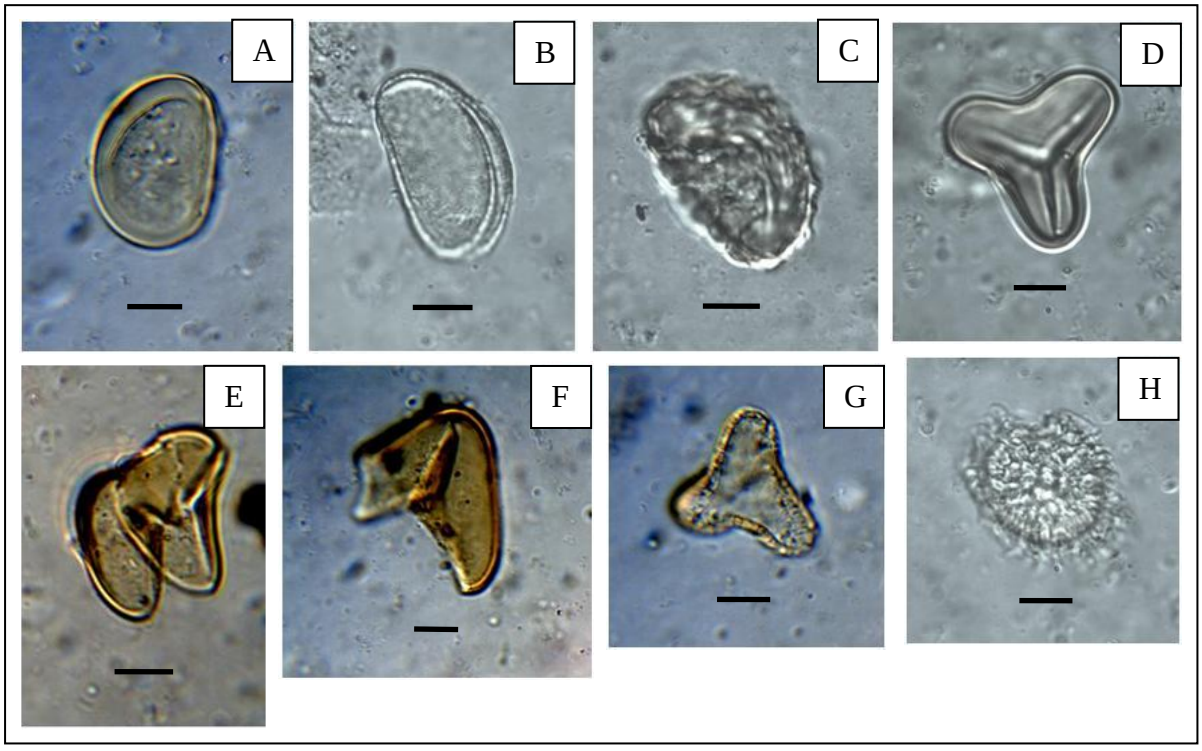

Plate 4 Pteridophytes scale = 10 µm

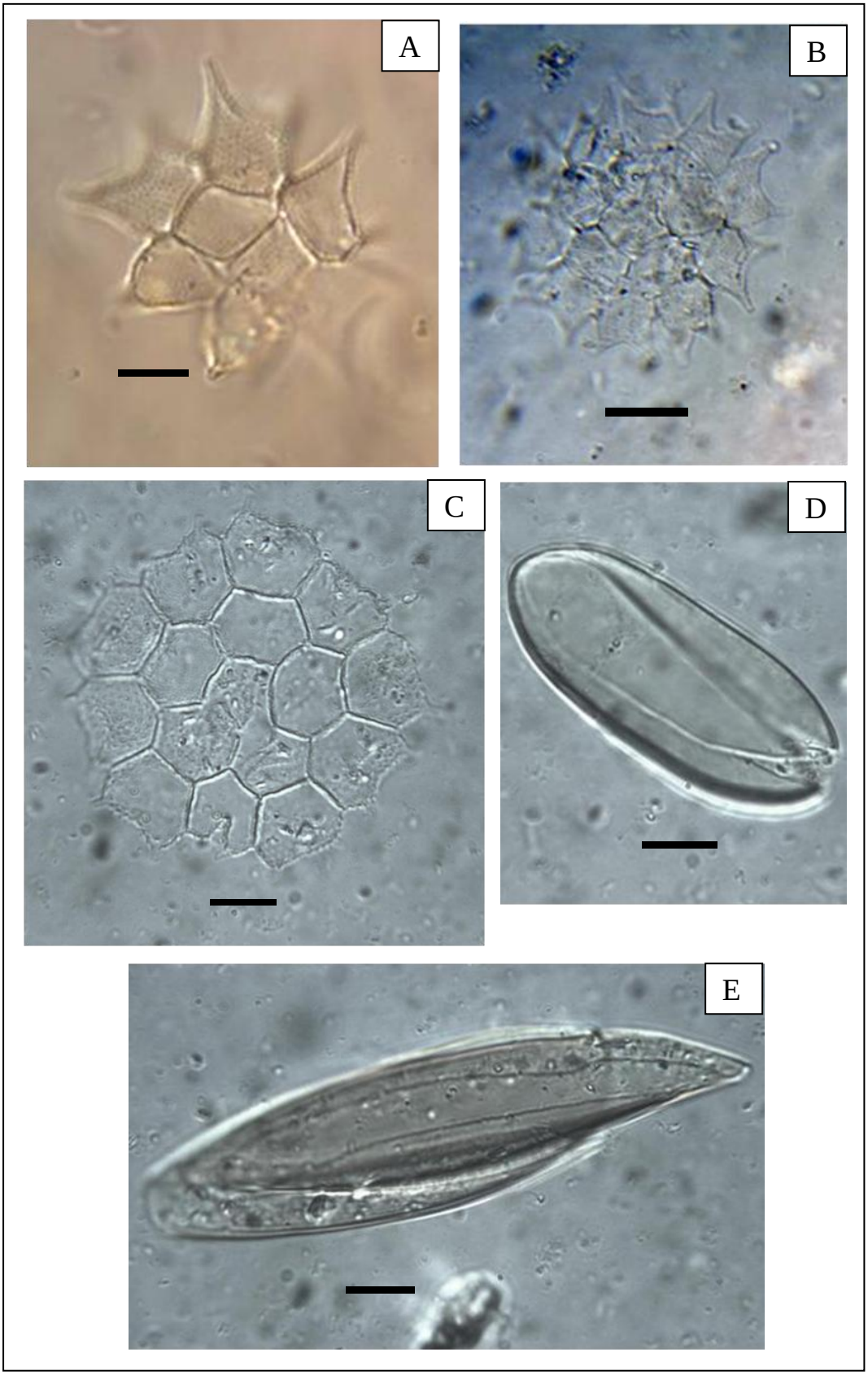

Plate 5 Scale = 10 µm

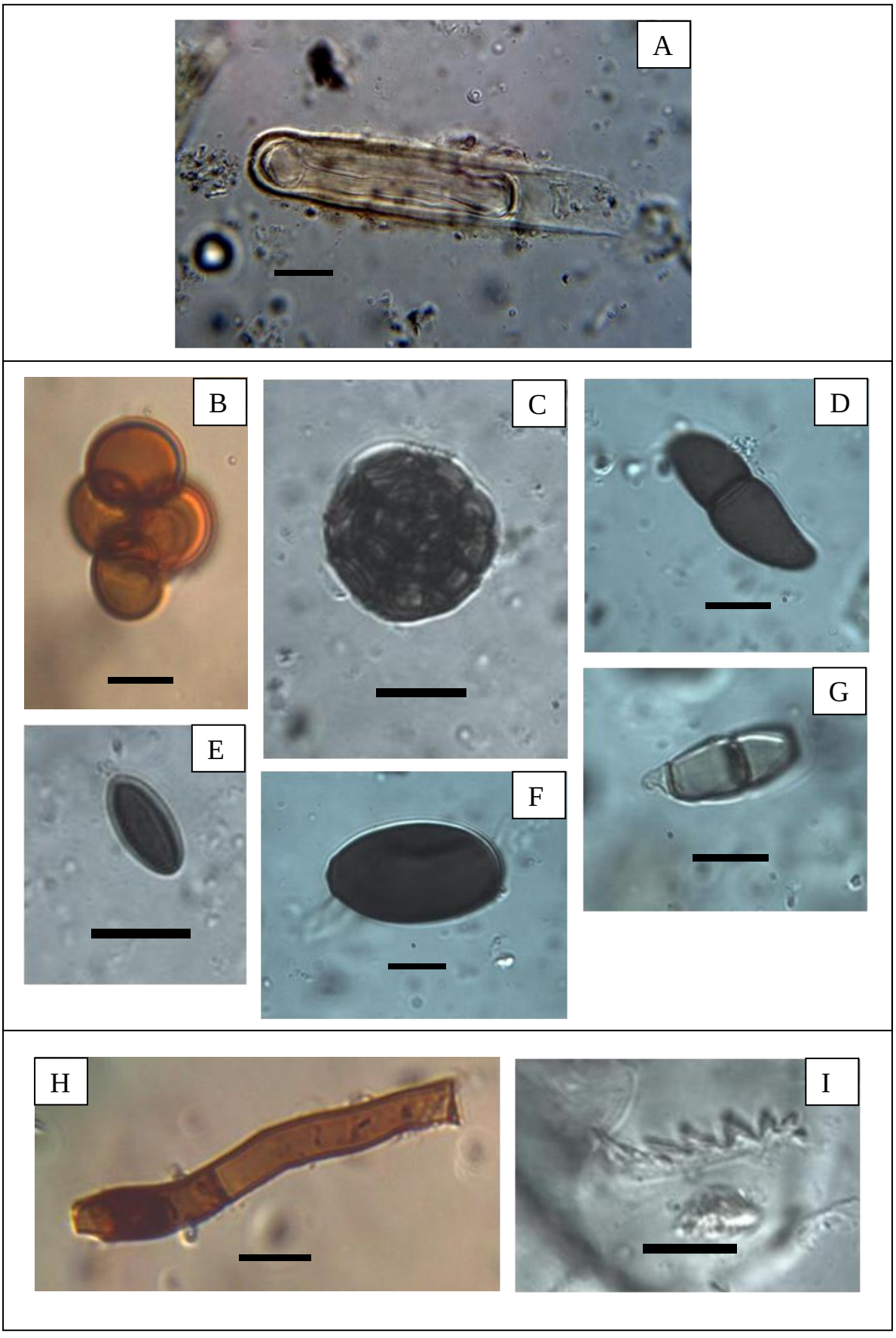

Plate 6 Scale = 10 µm

Appendix VIII Diatom photomicrographs

Images of taxa denoted with an * were obtained using scanning electron microscopy. All other images were obtained using DIC microscopy at 1000x magnification.

Plate 7:

A. *Aulacoseira ambigua* (Grunow) Simonsen.
B. *Aulacoseira ambigua* (Grunow) Simonsen *
C. *Actinocyclus octonarius* Ehrenberg.
D. *Actinocyclus octonarius* Ehrenberg. (valve face focus)
E. *Cyclotella stelligera* Cleve & Grunow.
F. *Cyclotella stelligera* Cleve & Grunow.
G. *Hyalodiscus lentiginosis* Ehrenb.
H. *Hyalodiscus lentiginosis* Ehrenb.

Plate 8:

A. *Pseudopodosira species* (Valve view)
B. *Pseudopodosira species* *
C. *Pseudopodosira species* (Girdle view)
D. *Pseudopodosira species* (Girdle view)
E. *Pseudopodosira species* (Girdle view, single valve)
F. *Pseudopodosira species* (Girdle view, single valve)
G. *Pseudopodosira westii* (Valve view)
H. *Pseudopodosira westii* (Valve view)

Plate 9:

A. *Pseudopodosira westii* (Valve view)
B. *Pseudopodosira westii* (Valve view)
C. *Pseudopodosira westii* (Girdle view)
D. *Pseudopodosira westii* (Girdle view)
E. *Cyclostephanos spp.*
F. *Cyclostephanos spp*.
G. *Pseudostaurosira brevistriata* (Grunow) D.M. Williams & Round.
Syn. *Fragilaria brevistriata*
H. *Pseudostaurosira brevistriata var. inflata* (Pant.) M. B. Edlund.
Syn. *Fragilaria brevistriata var. inflata*

Plate 10:

A. *Fragilaria capucina* Desm.
B. *Staurosira construens* Ehrenb.
Syn. *Fragilaria construens*
C. *Staurosirella pinnata* (Schum.)
Syn. *Fragilaria pinnata*
D. *Fragilaria pinnata var. lancettula* (Schum.)
E. *Fragilaria capucina var. vaucheriae* (Kütz.) J. B. Petersen.
Syn. *Fragilaria vaucheriae*
F. *Martyana martyi* (Hérib.) F. E. Round in Round, Crawford & Mann.
Syn. *Opephora martyi*
G. *Tabularia fasciculata* (C. Agardh) D. M. Williams & Round.
Syn. *Syndra fasciculata*

Plate 11:

A&B *Synedra ulna* (Nitzsch) Ehrenb.
C. *Fragilaria capucina subsp. rumpens* (Kützing) H. Lange-Bertalot.
Syn. *Synedra rumpens*
D. *Ctenophora pulchella* (Ralfs ex Kützing) D.M. Williams & Round.
Syn. *Synedra pulchella*

Plate 12:
A. *Amphicampa mirabilis* Ehrenberg.
Syn. *Eunotia serpentina*

B&C *Karayevia clevei* (Grunow in Cleve & Grunow) Round & Bukhtiyarova
Syn. *Achnanthes clevei*
D. *Achnanthidium exiguum var. heterovalvum* (Krasske) Czarn.
E. *Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot
Syn. *Achnanthes lanceolata*
F. *Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot
Syn. *Achnanthes lanceolata*
G. *Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot
Syn. *Achnanthes lanceolata*
H. *Achnanthese temperei*

Plate 13:
A. *Cocconeis placentula var. euglypta* (Ehrenb.) Grunow
B. *Cocconeis placentula var. euglypta* (Ehrenb.) Grunow
C. *Cocconeis placentula var. lineata* (Ehrenb.) Van Heurck.
(Psuedoraphe valve view)
D. *Cocconeis placentula var. lineata* (Ehrenb.) Van Heurck. (Raphe valve view)
E. *Amphora ovalis var. affinis* (Kütz.) Van Heurck ex DeToni
Syn. *Amphora libyca*
F. *Amphora ovalis var. affinis* (Kütz.) Van Heurck ex DeToni
Syn. *Amphora libyca*
G. *Amphora subturgida*
H. *Cymbella kappii*

Plate 14:
A. *Cymbella kappii*
B. *Cymbella elginsis* Krammer.
Syn. *Cymbella turgida*
C. *Encyonema silesiacum* (Bleisch ex Rabenh.) D. G. Mann in Round, Crawford & Mann. Syn. *Cymbella ventricosa*
D. *Diploneis smithii* (Brébisson in W. Smith) Cleve
E. *Diploneis subovalis*
F. *Gomphonema angustatum* (Kützing) Rabenhorst
G. *Gomphonema parvulum (Kütz.) Kütz.*
H. *Reimeria sinuata* (Gregory)

Plate 15:
A. *Gyrosigma acuminatum* (Kützing) Rabenhorst.
Syn. *Gyrosigma spencerii*
B. *Mastogloia pumila* (Cleve & J. Möller; Grunow in van Heurck)

C. *Mastogloia species*
D. *Mastogloia pumila* (Cleve & J. Möller; Grunow in van Heurck)
E. *Sellaphora bacillum* (Ehrenberg) D.G. Mann
Syn. *Navicula bacillum*
F. *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski.
Syn. *Navicula capitata*
G. *Navicula cuspidata* (Kützing) Kützing.
H. *Navicula radiosa* (Kützing) Kützing.

Plate 16:
A. *Navicula peregrina* (Ehrenberg) Kützing.
B. *Navicula peregrina* (Ehrenberg) Kützing.
C. *Sellaphora pupula* (Kützing) Mereschkovsky
Syn. *Navicula pupula*
D. *Fallacia pygmaea* (Kützing) A.J. Stickle & D.G. Mann
Syn. *Navicula pygmaea*
E. *Navicula tripunctata* (O.F. Müller) Bory
F. *Epithemia adnata* (Kützing) Brébisson.
G. *Epithemia sorex* Kützing.
H. *Epithemia sorex* Kützing.

Plate 17:
A. *Rhopalodia gibberula* (Ehrenberg) O.F. Müller.
B. *Rhopalodia gibberula* (Ehrenberg) O.F. Müller.
C. *Rhopalodia novae-zelandiae* Hustedt.
D. *Rhopalodia novae-zelandiae* Hustedt.
E. *Tryblionella acuminata* W. Smith.
Syn. *Nitzschia acuminata*
F. *Nitzschia amphibia* Grunow.
G. *Tryblionella granulata* (Grunow) D.G. Mann.
Syn. *Nitzschia granulata*
H. *Nitzschia punctata* (W. Smith) Grunow.

Plate 18:
A. *Nitzschia clausii* (Kützing) W. Smith.
B. *Nitzschia triblionella var. victoriae*
C. *Campylodiscus echineis* Ehrenberg. *
D. *Campylodiscus echineis* Ehrenberg.
E. *Surirella brebissonii* (Krammer and Lange-Bertalot)
F. *Surirella brebissonii* (Krammer and Lange-Bertalot)
G. Sponge spicule *
H. Sponge spicule

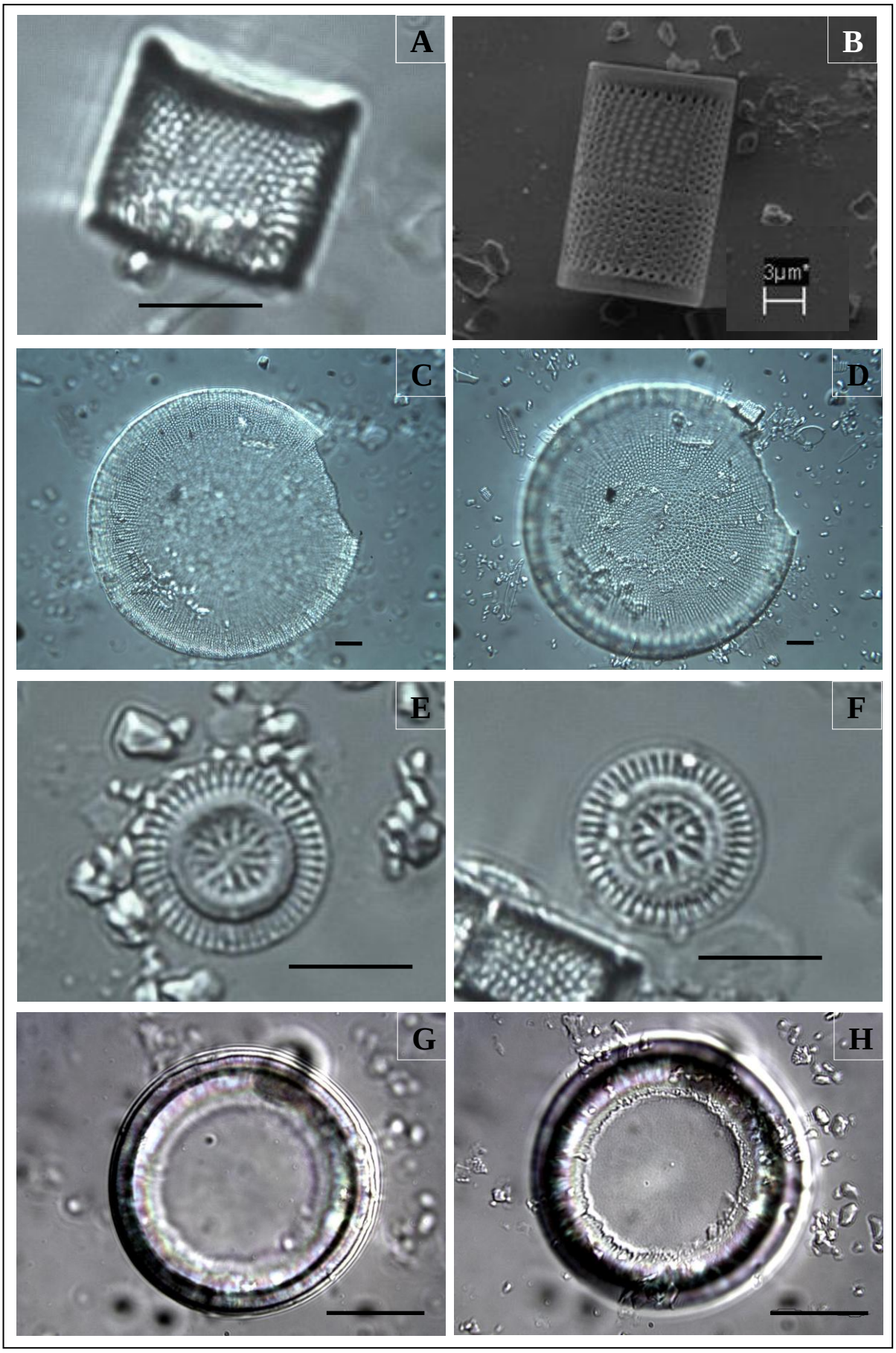

Plate 7

Scale = 10µm unless otherwise specified

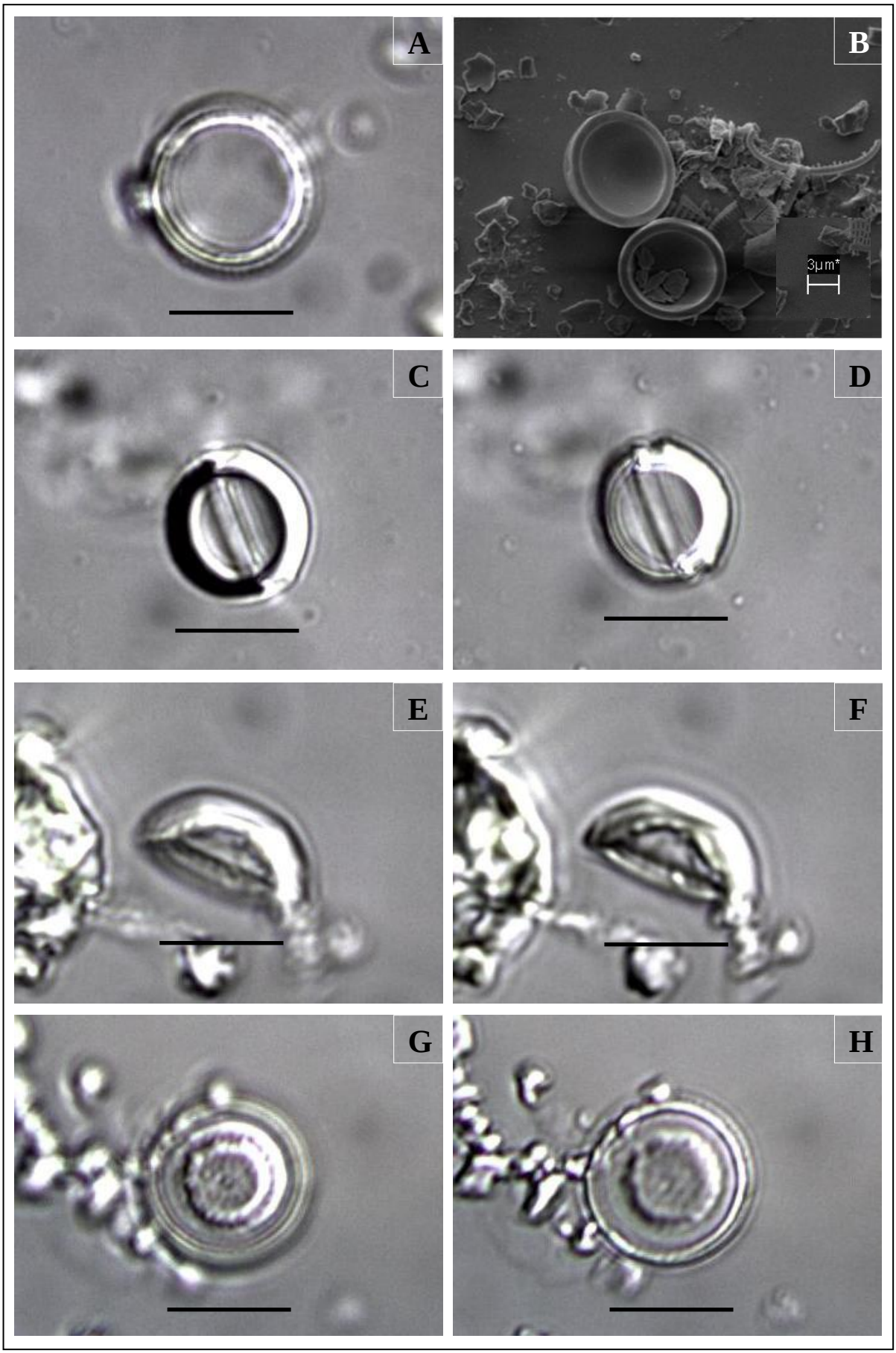

Plate 8

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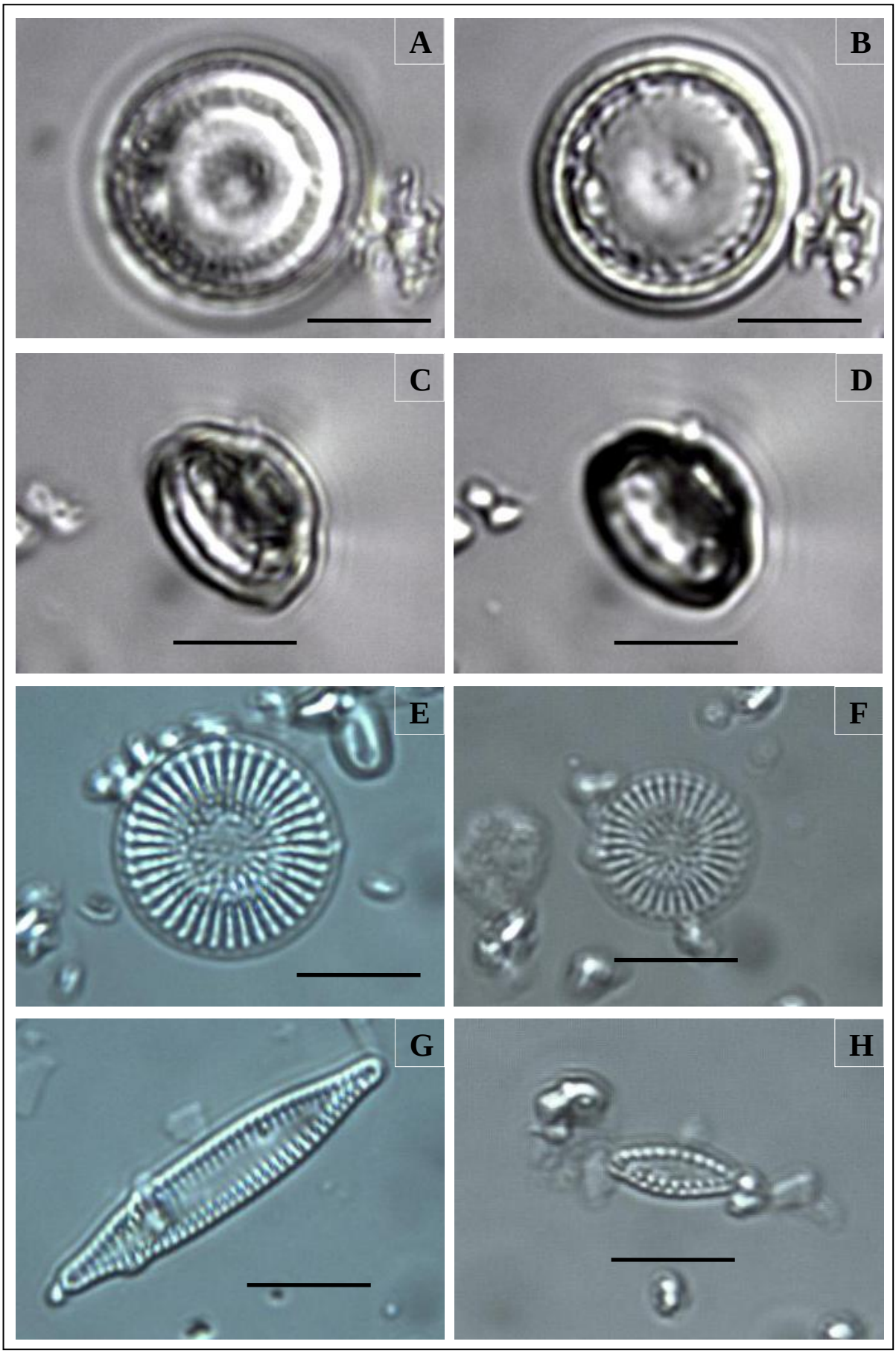

Plate 9

Scale = 10µm unless otherwise specified

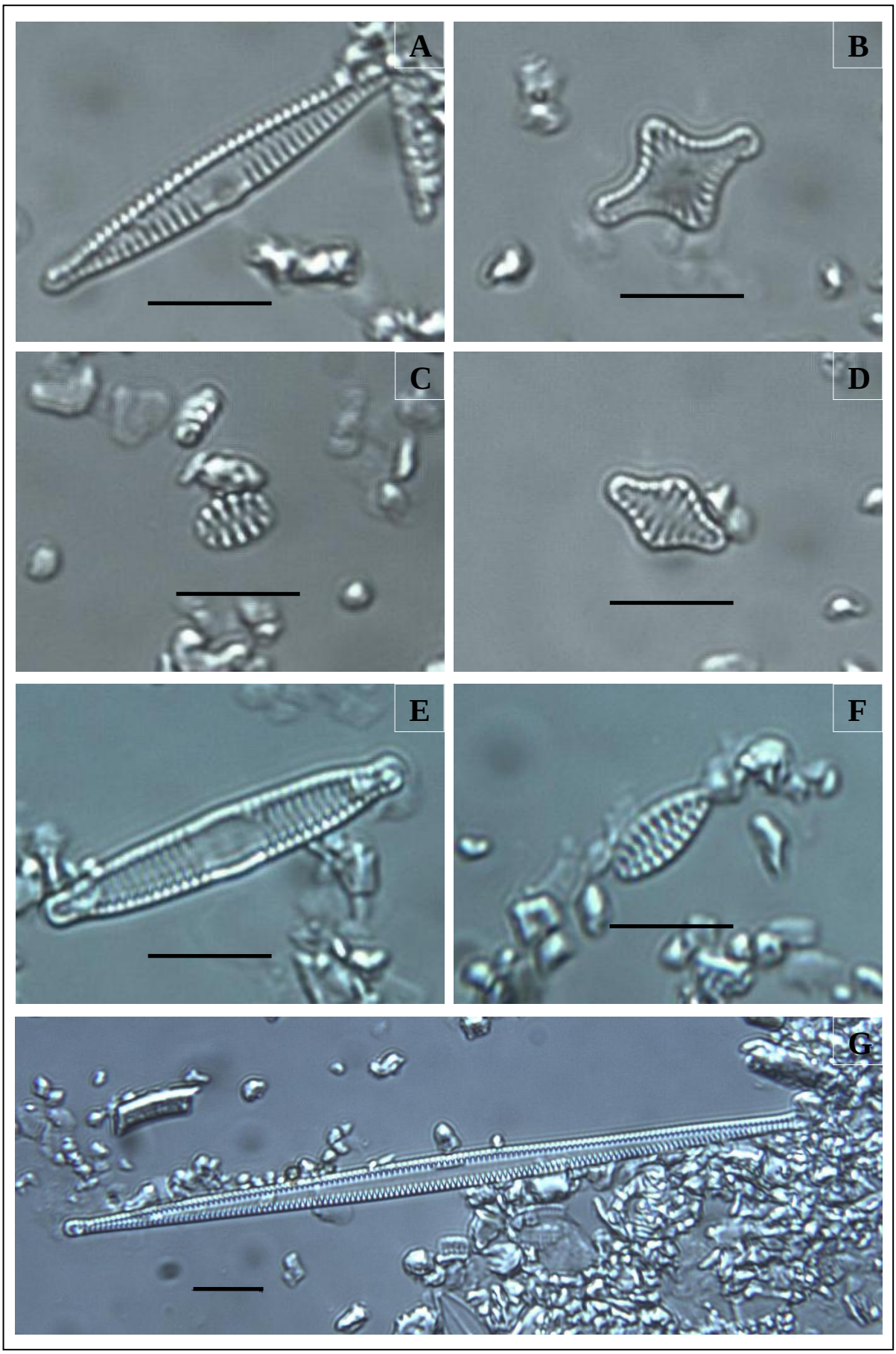

Plate 10

Scale = 10µm unless otherwise specified

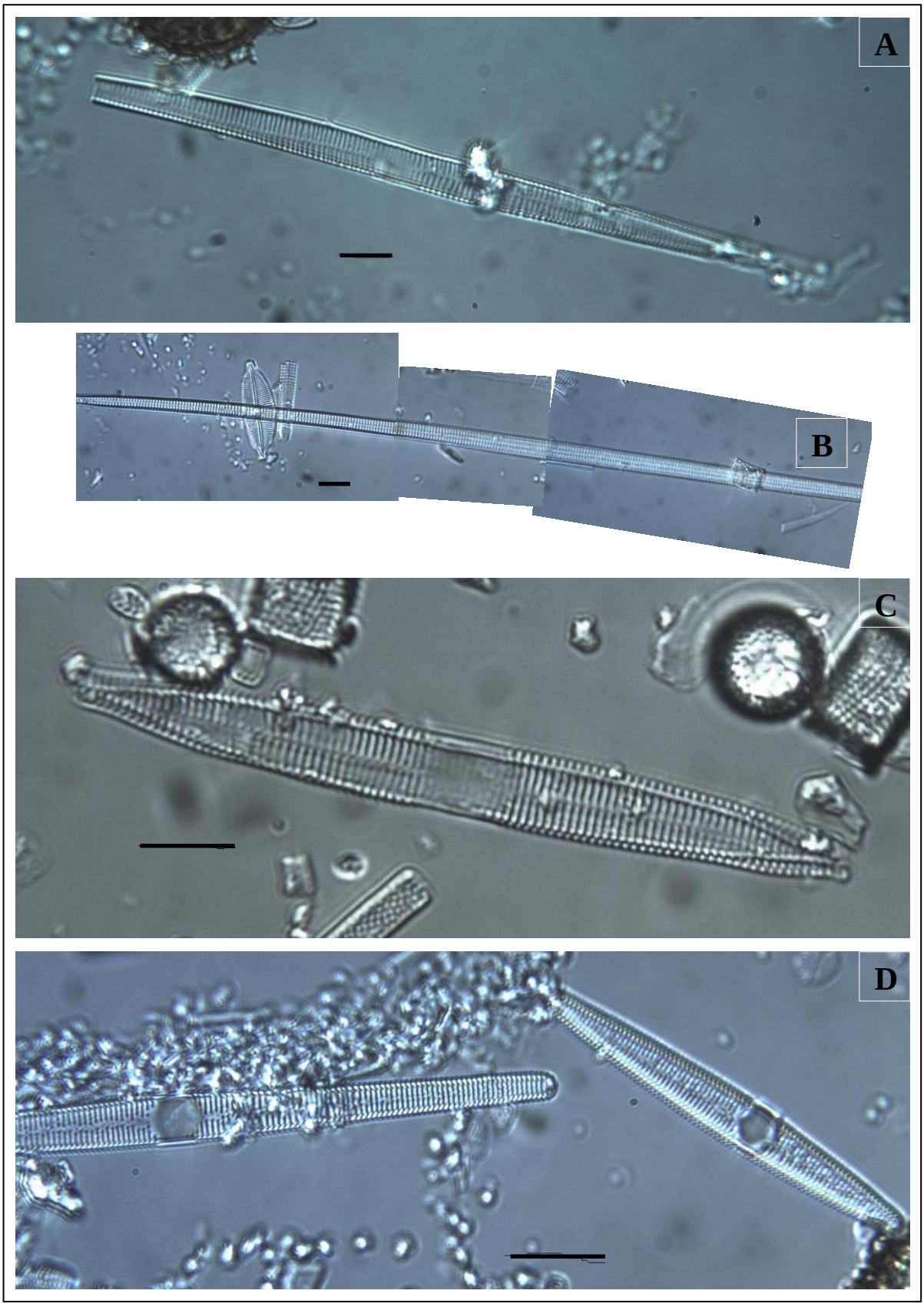

Plate 11

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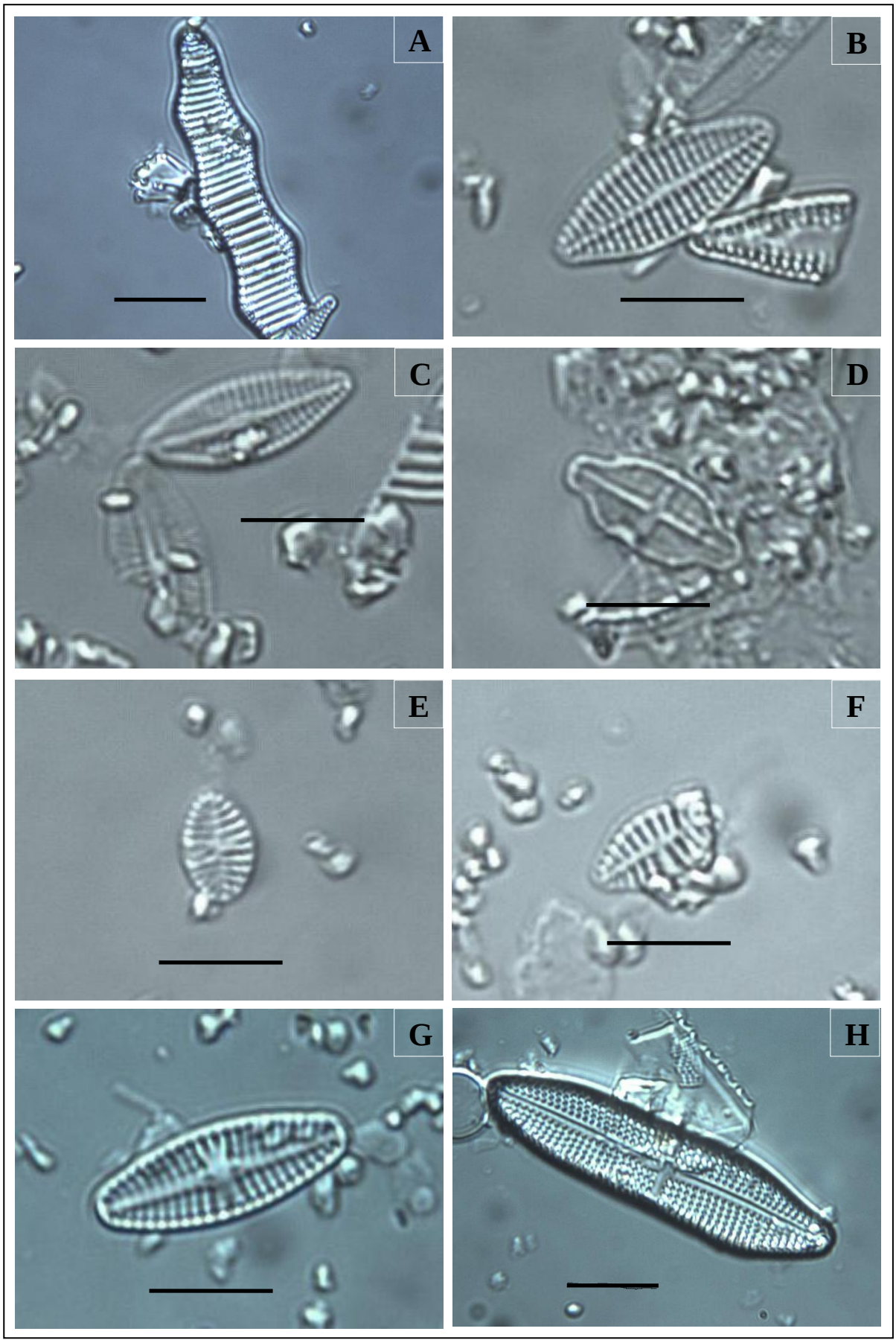

Plate 12

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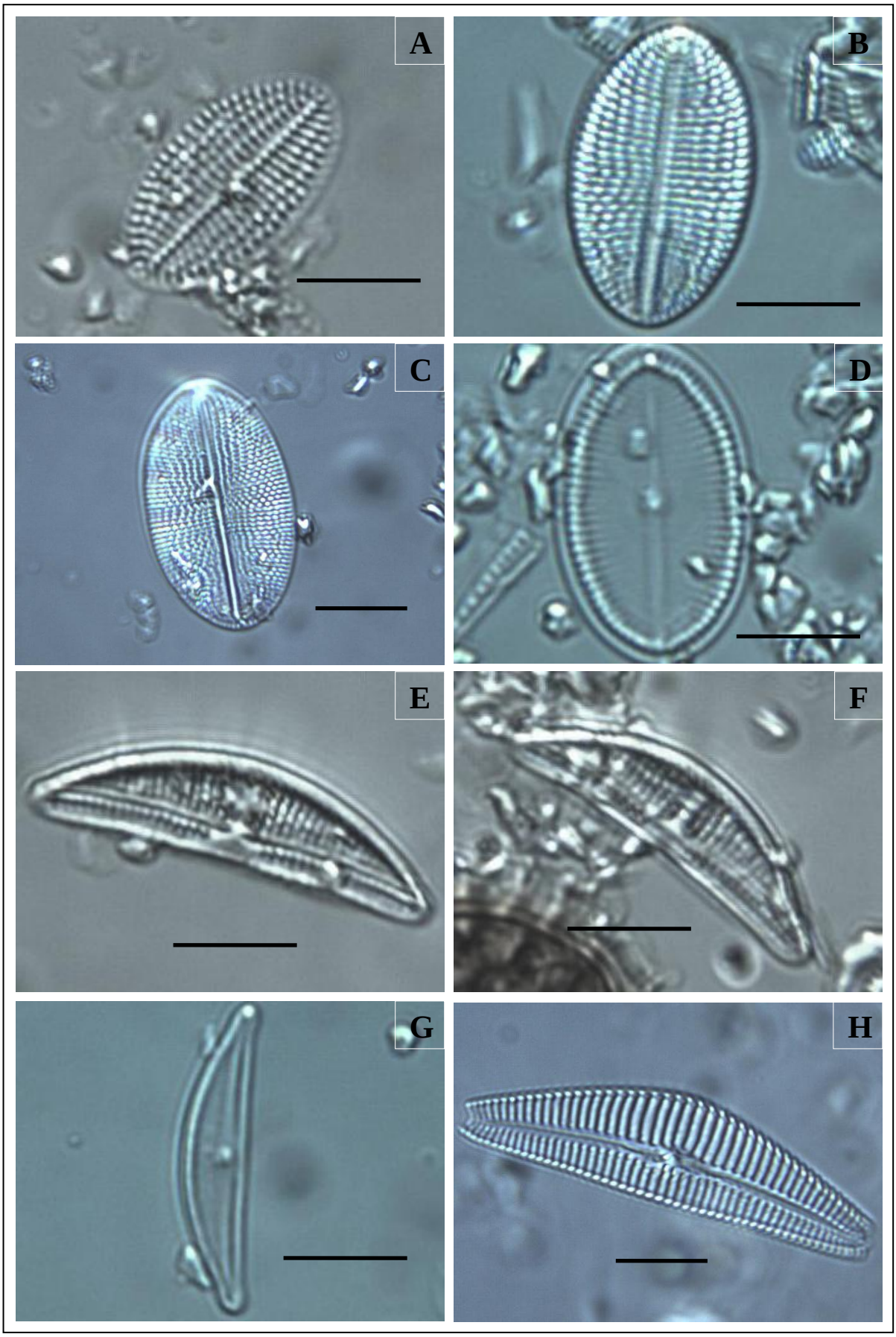

Plate 13

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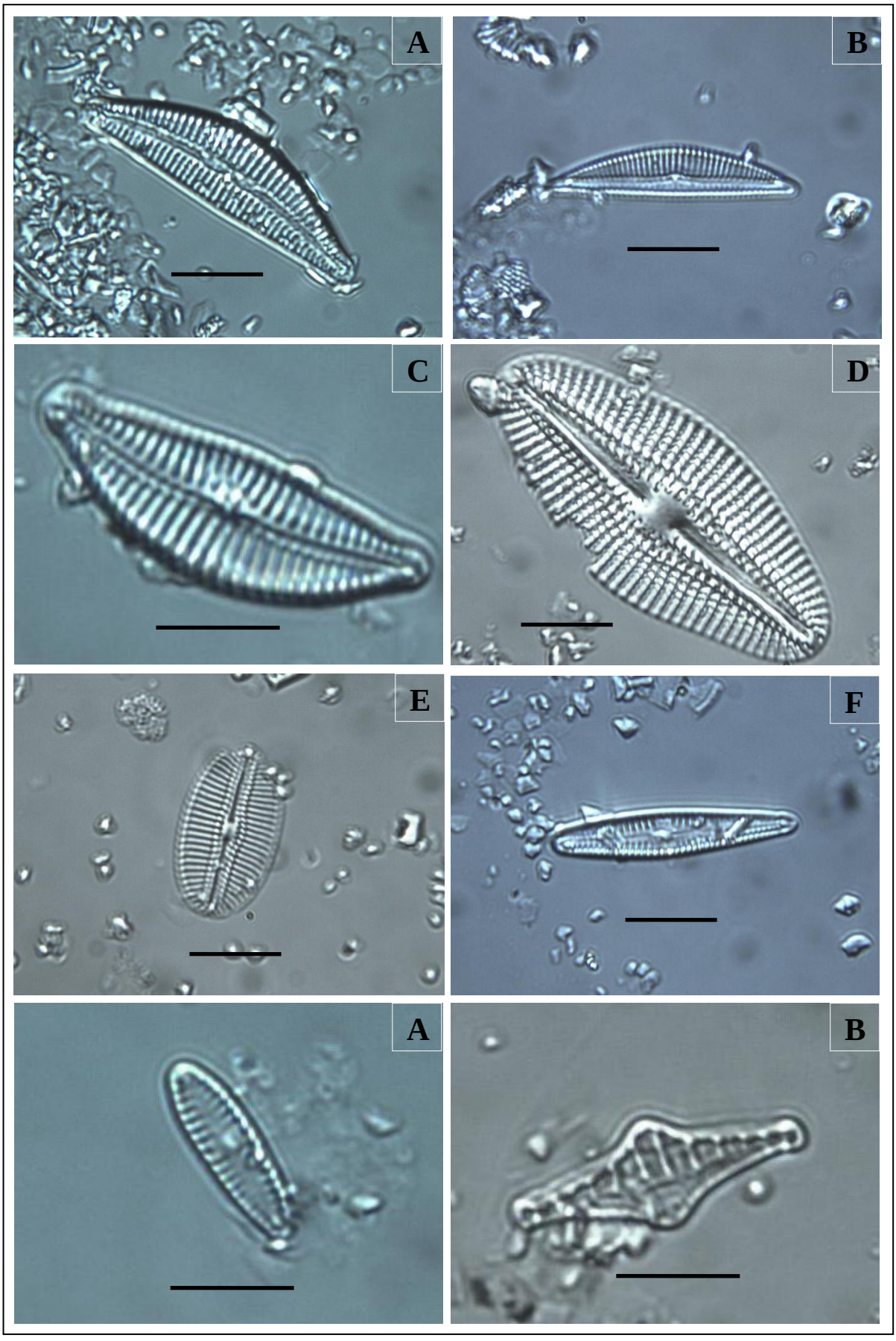

Plate 14

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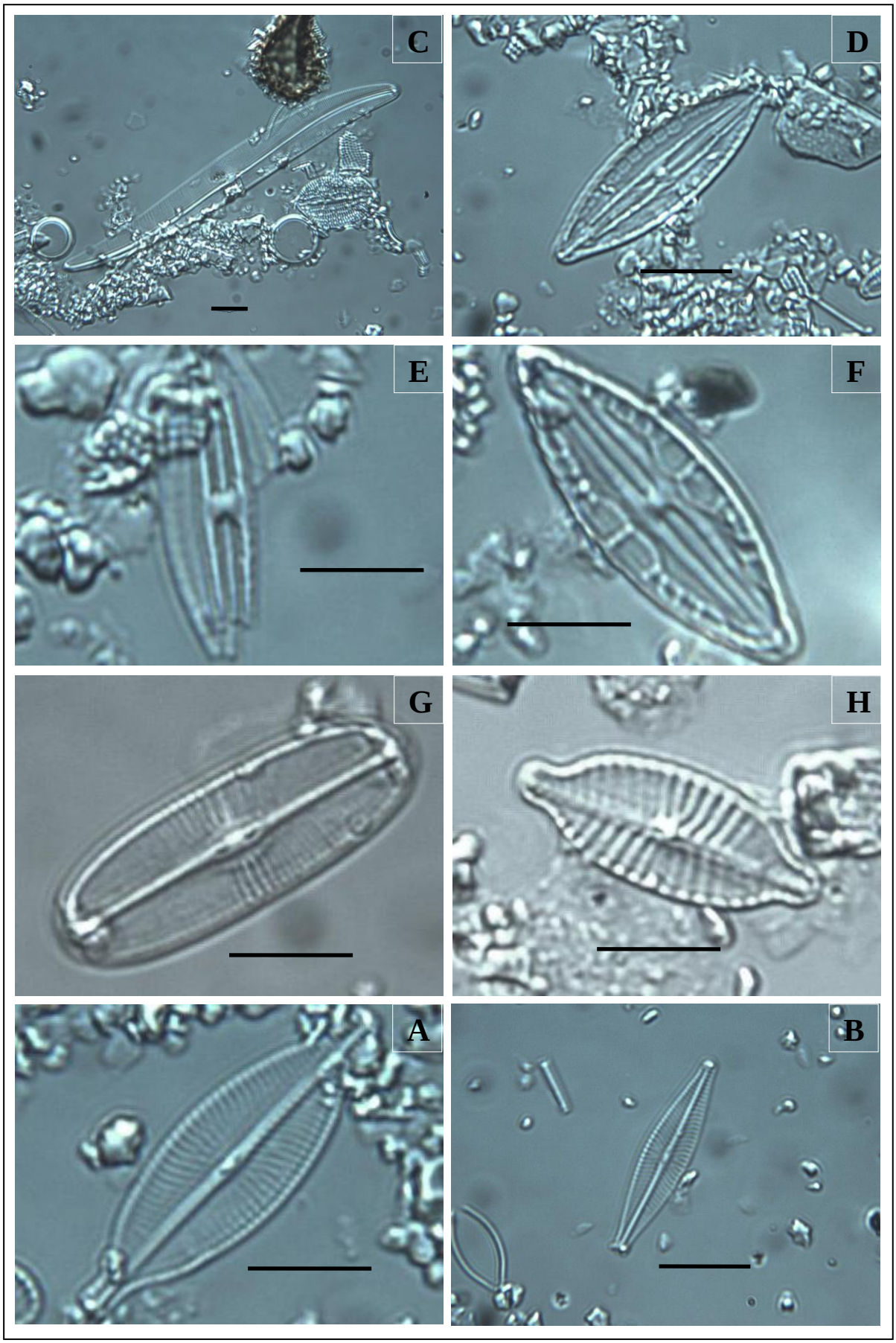

Plate 15

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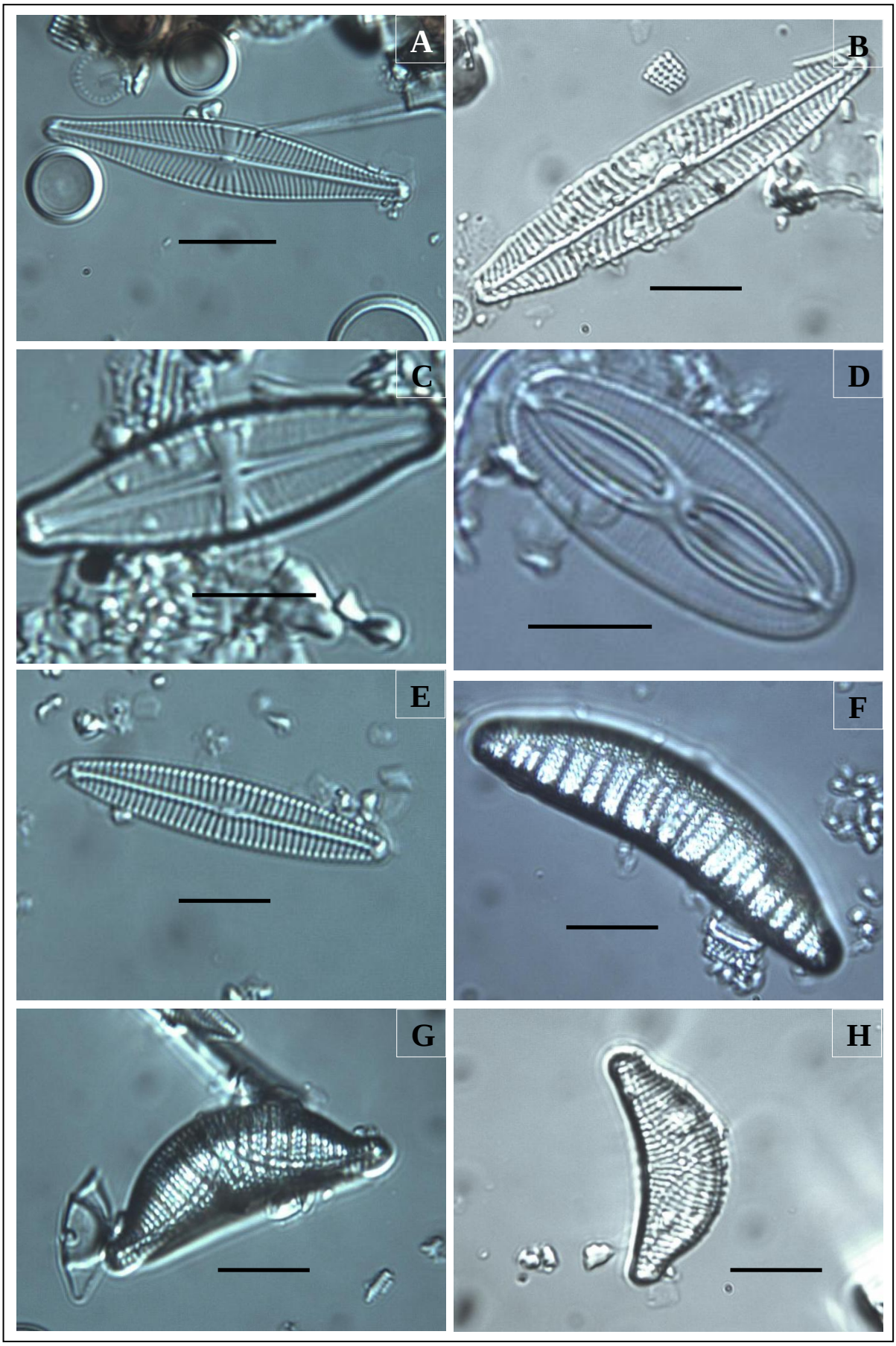

Plate 16

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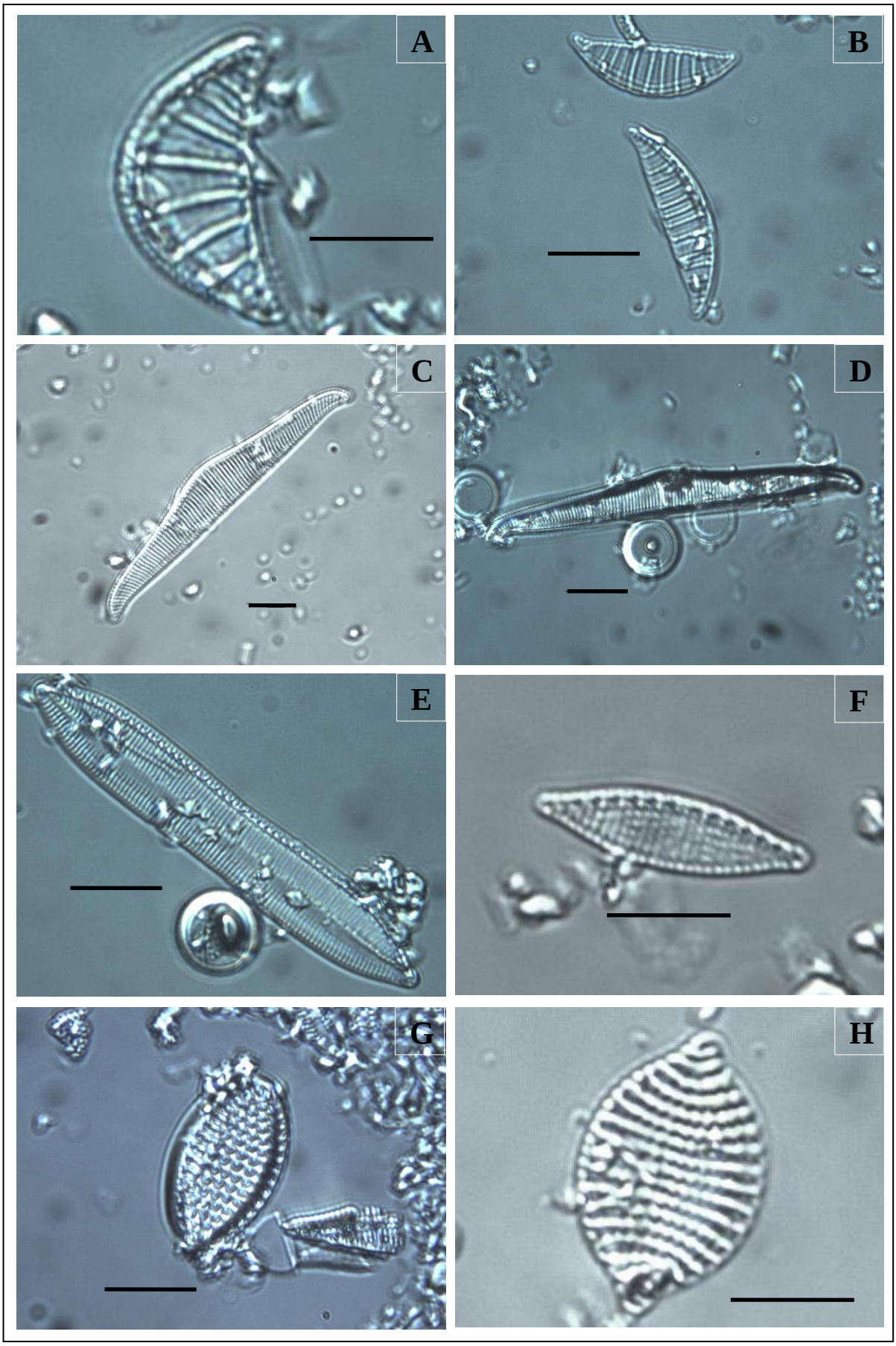

Plate 17

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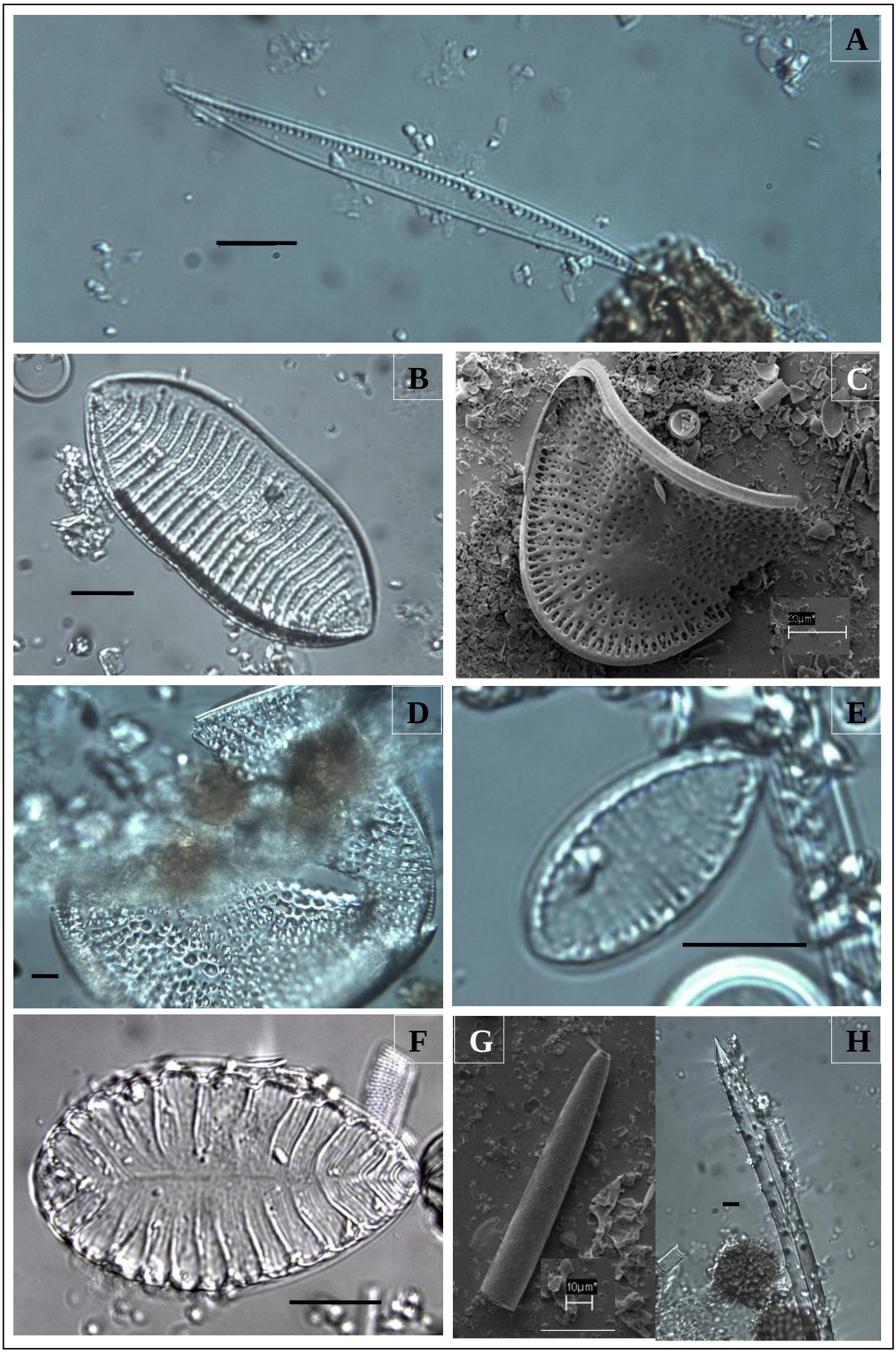

Plate 18

Scale = 10µm unless otherwise specified

Appendix IX Radiocarbon results

RAFTER
GNS SCIENCE

NZA	**33971**
R	32362/1
Job No	100847
Measured	17-Mar-10
TW No	2408
Issued	31-Mar-10

Accelerator Mass Spectrometry Result

Sample ID	WA09 51-52cm
Description	Sediment
Fraction Dated	plant material float at sp.gr. 1.30
Submitter	Stephen Kitto

* **Radiocarbon Age**	**7839 ± 80 BP**		$\delta^{13}C =$	-22.8 ‰	
** **Per cent modern =**	37.41 ± 0.38	$\delta^{14}C =$	-624.2 ± 3.8 ‰	$\Delta^{14}C =$	-625.9 ± 3.8 ‰

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS oxalic acid standard (HOxI) corrected for decay since 1950.

Age, $\Delta^{14}C$, $\delta^{14}C$ and absolute per cent modern are as defined by Stuiver Polach, Radiocarbon 19:355-363 (1977)

Sample Treatment Details

60.69g of dry, mostly grey (with small patches of pale brown) sediment with no obvious plant material present. Crumbled to fine lumps and mixed with deionised water before sieving wth150 micron mesh in a sartorius filter. The > 150 micron fraction was stored while the < 150 micron fraction was sieved at 10 microns. The <10 microns was discarded, and the > 10 microns was separated into mineral and plant material using sodium polytungstate at specific gravities 1.99 and 1.50. A further separation at s.g. 1.30 was applied to remove fine charcoal-like fragments present. The float at s.g. 1.30 contained only small plant fragments, pollen and palynomorphs and was used for C-14 dating.

Stored >1.50micron, precipitates at sp.gr.1.99 and sp.gr 1.50

Comments

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard.
For the present result the system error component is conservatively estimated as 0% (= ± 0 radiocarbon years).

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www.RafterRadiocarbon.co.nz

RAFTER RADIOCARBON LABORATORY

R32362/1

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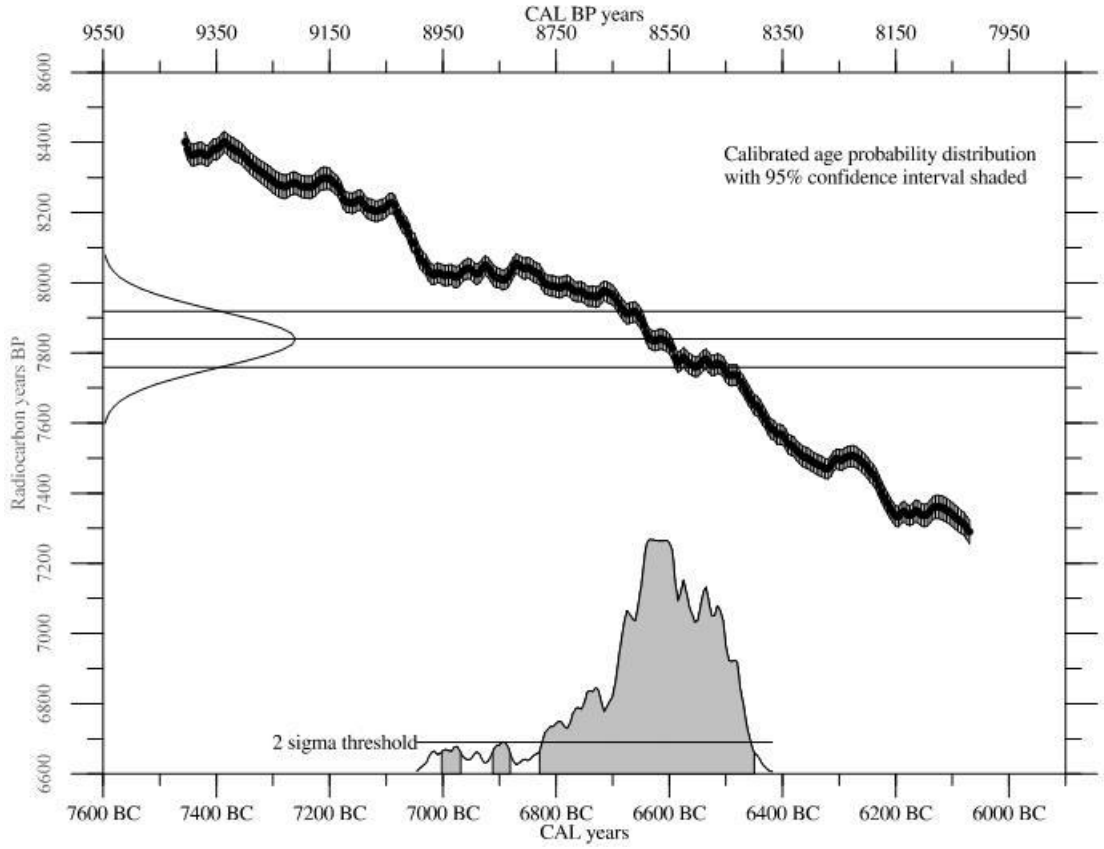
RADIOCARBON CALIBRATION REPORT

NZA 33971 CONVENTIONAL RADIOCARBON AGE 7839 ± 80 years BP

Southern Hemisphere Atmospheric data from McCormac et al (2004);
FG McCormac, AG Hogg, PG Blackwell, CE Buck, TFG Higham, and PJ Reimer (2004)
Radiocarbon 46, 1087-1092

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

68% confidence interval is	6689 BC to 6495 BC 8638 BP to 8444 BP (67.9% of area)
95% confidence interval is	7002 BC to 6968 BC 8951 BP to 8917 BP (1.6% of area)
plus	6912 BC to 6881 BC 8861 BP to 8830 BP (1.7% of area)
plus	6829 BC to 6450 BC 8778 BP to 8399 BP (91.5% of area)



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Accelerator Mass Spectrometry Result

NZA	**33952**
R	32362/1
Job No	101315
Measured	19-Mar-10
TW No	2409
Issued	31-Mar-10

Sample ID	WA09 51-52cm
Description	Sediment
Fraction Dated	plant material precipitate at sp.gr. 1.30
Submitter	Stephen Kitto

* **Radiocarbon Age**	**11533 ± 45 BP**		$\delta^{13}C$ =	-24.6 ‰
** **Per cent modern** =	23.62 ± 0.13	$\delta^{14}C$ =	-763.6 ± 1.3 ‰	$\Delta^{14}C$ =	-763.8 ± 1.3 ‰

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS oxalic acid standard (HOxI) corrected for decay since 1950.

Age, $\Delta^{14}C$, $\delta^{14}C$ and absolute per cent modern are as defined by Stuiver Polach, Radiocarbon 19:355-363 (1977)

Sample Treatment Details

60.69g of dry, mostly grey (with small patches of pale brown) sediment with no obvious plant material present. Crumbled to fine lumps and mixed with deionised water before sieving wth150 micron mesh in a sartorius filter. The > 150 micron fraction was stored while the < 150 micron fraction was sieved at 10 microns. The <10 microns was discarded, and the > 10 microns was separated into mineral and plant material using sodium polytungstate at specific gravities 1.99 and 1.50. A further separation at sp.gr 1.30 was applied to remove fine charcoal-like fragments present. The float at sp.gr. 1.30 contained only small plant fragments, pollen and palynomorphs and was considered best for C-14 dating. Unfortuately it was a very small fraction and the precipitate at sp.gr. 1.30 was also combusted separately as a backup sample.

Stored	>1.50micron, precipitates at specific gravities 1.99 and 1.50
Comments	Backup for job#100847

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard.
For the present result the system error component is conservatively estimated as 0% (= ± 0 radiocarbon years).

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Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter.
All liability whatsoever to any third party is excluded.

NZA	**33970**
R	32362/2
Job No	100848
Measured	17-Mar-10
TW No	2408
Issued	31-Mar-10

Sample ID	WA09 95-96cm
Description	Sediment
Fraction Dated	plant material float at sp.gr. 1.30
Submitter	Stephen Kitto

*** Radiocarbon Age**		**10257 ± 55 BP**		**$\delta^{13}C$ =**	-26 ‰
**** Per cent modern =**	27.69 ± 0.2	**$\delta^{14}C$ =**	-723.6 ± 2 ‰	**$\Delta^{14}C$ =**	-723.1 ± 2 ‰

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS oxalic acid standard (HOxI) corrected for decay since 1950.

Age, $\Delta^{14}C$, $\delta^{14}C$ and absolute per cent modern are as defined by Stuiver Polach, Radiocarbon 19:355-363 (1977)

Sample Treatment Details

60.91g of moist dark grey fine sediment with no obvious plant material present. Crumbled to fine lumps and mixed with deionised water before sieving wth150 micron mesh in a sartorius filter. The > 150 micron fraction was stored while the < 150 micron fraction was sieved at 10 microns. The <10 microns was discarded, and the > 10 microns was separated into mineral and plant material using sodium polytungstate at specific gravities 1.99 and 1.50. A further separation at sp.gr. 1.30 was applied to remove fine charcoal-like fragments present. The float at sp.gr. 1.30 contained only small plant fragments, pollen and palynomorphs and was used for C-14 dating.

Stored >1.50micron, precipitates at sp.gr. 1.99, 1.50, and 1.30

Comments

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard.
For the present result the system error component is conservatively estimated as 0% (= ± 0 radiocarbon years).

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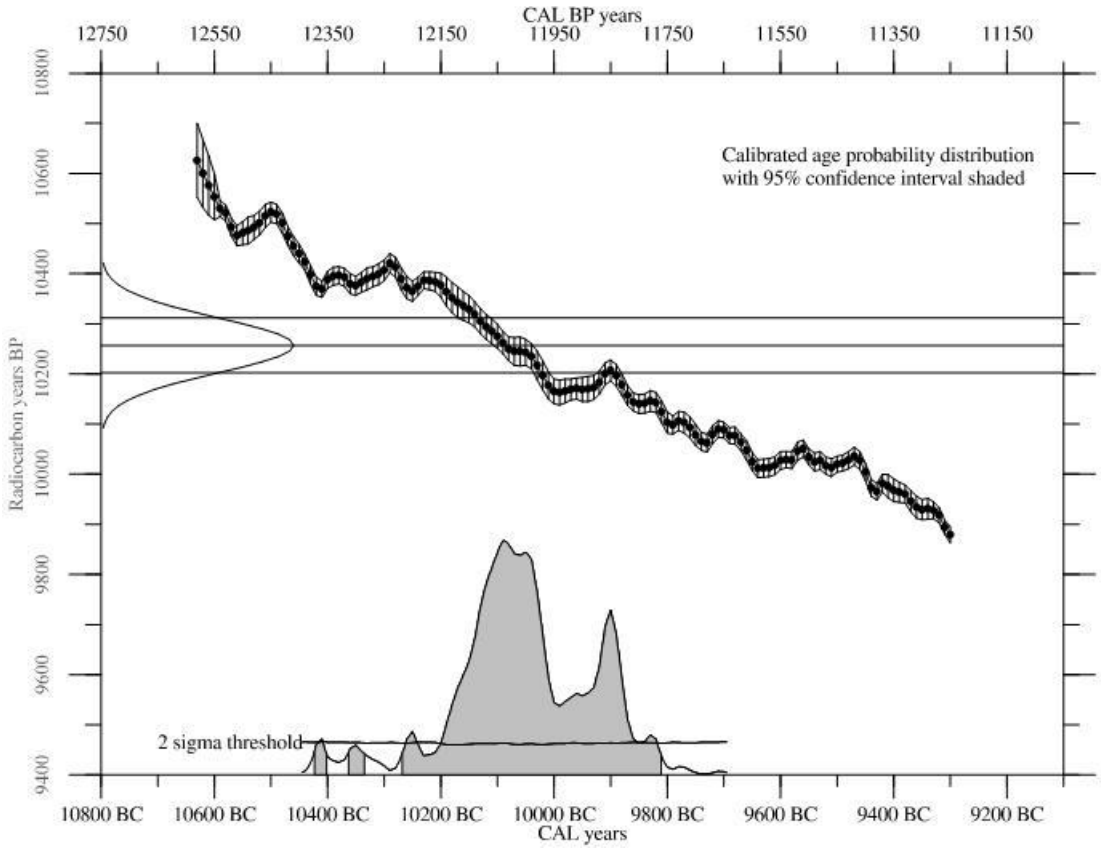
RADIOCARBON CALIBRATION REPORT

NZA 33970 CONVENTIONAL RADIOCARBON AGE 10257 ± 55 years BP

Atmospheric data from Reimer et al (2009);
PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, PG Blackwell,
C Bronk Ramsey, CE Buck, GS Burr, RL Edwards, M Friedrich, PM Grootes,
TP Guilderson, I Hajdas, TJ Heaton, AG Hogg, KA Hughen, KF Kaiser, B Kromer,
FG McCormac, SW Manning, RW Reimer, DA Richards, JR Southon, S Talamo,
CSM Turney, J van der Plicht, CE Weyhenmeyer (2009) Radiocarbon 51:1111-1150.

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

68% confidence interval is 10166 BC to 10008 BC	12115 BP to 11957 BP (55.5% of area)
plus 9927 BC to 9879 BC	11876 BP to 11828 BP (12.2% of area)
95% confidence interval is 10423 BC to 10402 BC	12372 BP to 12351 BP (1.2% of area)
plus 10363 BC to 10335 BC	12312 BP to 12284 BP (1.4% of area)
plus 10268 BC to 9811 BC	12217 BP to 11760 BP (92.2% of area)



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NZA	**33912**
R	32362/3
Job No	100849
Measured	09-Mar-10
TW No	2406
Issued	15-Mar-10

Accelerator Mass Spectrometry Result

Sample ID	WA09 171-172cm
Description	Sediment
Fraction Dated	plant material float at 1.50sg
Submitter	Stephen Kitto

* **Radiocarbon Age**		**10189 ± 50 BP**		$\delta^{13}C$ =	-26.8 ‰
** **Per cent modern** =	27.92 ± 0.18	$\delta^{14}C$ =	-721.8 ± 1.8 ‰	$\Delta^{14}C$ =	-720.8 ± 1.8 ‰

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS oxalic acid standard (HOxI) corrected for decay since 1950.

Age, $\Delta^{14}C$, $\delta^{14}C$ and absolute per cent modern are as defined by Stuiver Polach, Radiocarbon 19:355-363 (1977)

Sample Treatment Details

75.13g of moist dark grey fine sediment with no obvious plant material present. Crumbled to fine lumps and mixed with deionised water before sieving with150 micron mesh in a sartorius filter. The > 150 micron fraction was stored while the < 150 micron fraction was sieved at 6 microns. The < 6 microns was discarded, and the > 6 microns was separated into mineral and plant material using sodium polytungstate at specific gravities 1.99 and 1.50. The float at sg 1.50 contained smaller plant fragments than in 32362/1 and 2. Some dense plant material present, but no charcoal-like pieces seen.The float at 1.50sg was considered suitable for C-14 dating.

Stored >1.50micron, precipitates at 1.99sg and 1.50sg sg.

Comments

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard.
For the present result the system error component is conservatively estimated as 0% (= ± 0 radiocarbon years).

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RADIOCARBON CALIBRATION REPORT

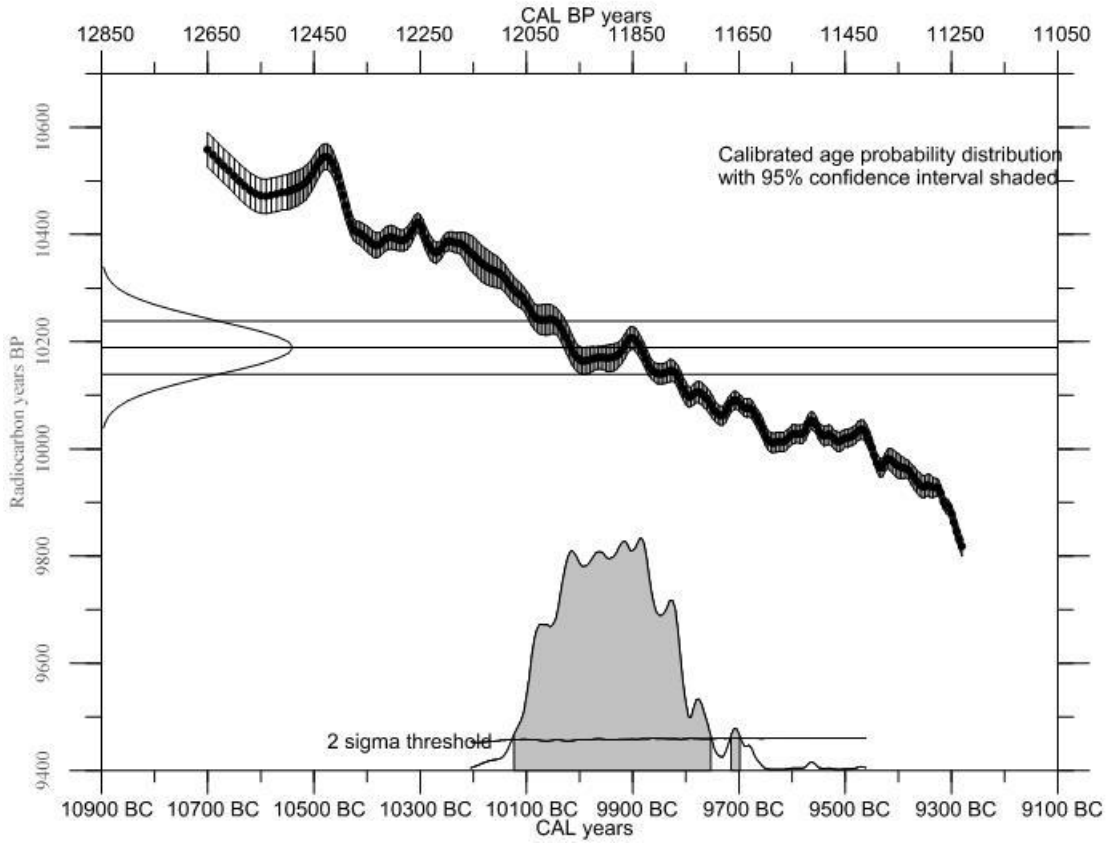
NZA 33912 CONVENTIONAL RADIOCARBON AGE 10189 – 50 years BP

Atmospheric data from Reimer et al (2004);

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell, CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich, TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey, RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor, J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46:1029-1058

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

68% confidence interval is 10041 BC to 9819 BC	11990 BP to 11768 BP (67.7% of area)
95% confidence interval is 10123 BC to 9753 BC	12072 BP to 11702 BP (93.9% of area)
plus 9715 BC to 9698 B11664 BP to 11647 BP	(1.1% of area)



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Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter.
All liability whatsoever to any third party is excluded.

NZA	**33828**
R	32362/4
Job No	100852
Measured	25-Feb-10
TW No	2404
Issued	04-Mar-10

Sample ID	WA09 207cm
Description	Plant material
Fraction Dated	treated plant material
Submitter	Stephen Kitto

* **Radiocarbon Age**		**6760 ± 40 BP**		$\delta^{13}C$ =	-27.7 ‰
** **Per cent modern** =	42.8 ± 0.22	$\delta^{14}C$ =	-574.4 ± 2.2 ‰	$\Delta^{14}C$ =	-572 ± 2.2 ‰

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS oxalic acid standard (HOxI) corrected for decay since 1950.

Age, $\Delta^{14}C$, $\delta^{14}C$ and absolute per cent modern are as defined by Stuiver Polach, Radiocarbon 19:355-363 (1977)

Sample Treatment Details

Sample consisted of fragments of woody plant material with grey silty sediment fines, brown-grey plant material. Microscopic exam revealed assorted woody plant material, mostly grey coloured twiggy fragments and a few seed pods; grey sediment coating on plant materials and the odd lump of sediment; blue synthetic fibres and a piece of white plastic. Sieved to remove much of the sediment. Treated portion of plant material with acid /alkali/ acid process. Dried in vacuum oven.

Stored untreated remainder

Comments

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard.
For the present result the system error component is conservatively estimated as 0% (= ± 0 radiocarbon years).

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RADIOCARBON CALIBRATION REPORT

NZA 33828 CONVENTIONAL RADIOCARBON AGE 6760 – 40 years BP

Southern Hemisphere Atmospheric data from McCormac et al (2004);
FG McCormac, AG Hogg, PG Blackwell, CE Buck, TFG Higham, and PJ Reimer (2004)
Radiocarbon 46, 1087-1092

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0, Offset: 0)

68% confidence interval is 5662 BC to 5610 7611 BP to 7559 BP (47.8% of area)
plus 5589 BC to 5563 B7538 BP to 7512 BP (20.6% of area)

95% confidence interval is 5708 BC to 5542 7657 BP to 7491 BP (94.8% of area)