PROGRESS REPORT FOR 10044 P

PROJECT TITLE
Ecological and limnological history of the Ashburton Lakes region, South Island, New Zealand

INVESTIGATOR(S)

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Specialist Committee:
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SCIENTIFIC OBJECTIVES
The aim of this work is to reconstruct the former natural vegetation cover of an inland basin in the Canterbury foothills, New Zealand and to investigate human and other environmental impacts on lake systems in this area of outstanding heritage and natural values.

PROGRESS REPORT and RESEARCH OUTCOMES (In addition to a discussion of your research results please indicate the value of any other funding generated by AINSE support for this project and the resulting benefits, if any, to the Australian community):

Summary:
This report summarizes the results from a paleoecological study of three lakes in the Hakatere Conservation Park centred on the Ashburton Lakes/ Ō Tū Wharekai. These lakes are located in the mid Canterbury high country (>600m altitude) on the eastern side of the Southern Alps in the South Island (Figure 1). Multiple proxies (pollen, charcoal, chironomids, and macrofossils) were used to reconstruct the evolution of the lakes and their catchments including their response to Holocene climate change and human disturbance. Thirty-six $^{210}$Pb and six radiocarbon dates provided by the ANSTO facilities were used to provide age control for the proxy records.

The longest record of pre-human conditions in the lake and its catchment came from the Lake Emma percussion core, which extends back to possibly 12,000 calendar years before present (cal yrs BP). This record provides information on vegetation changes and fire history from a key area in New Zealand. This area is located at the northern end of the “beech gap” an area of the South Island largely devoid of Nothofagus forest. This is also an area susceptible to El Niño Southern Oscillation (ENSO) related droughts. The current paradigm among paleoecologists is that natural fires prior to human arrival in New Zealand were generally small scale fires with a long time period between fires at any locality. Some paleoecologists have claimed that these fires were “ecologically insignificant”. The Lake Emma record shows an increase in fire frequency in the late Holocene and the pollen record may be interpreted to indicate a change in vegetation structure in response to increased drought/fire frequency. The ecological significance of natural fires may also extend into the lakes themselves where local fires may have temporarily increased the productivity of the lakes.

With the present age control we cannot pinpoint without speculation the presence of both Polynesian (Maori) and European disturbance events in the Ashburton Lakes records. The most recent macroscopic charcoal deposit pre-dates 1858 AD and may relate to European forest clearance. The most recent charcoal peak is associated with a loss of native vegetation in the lake catchment and a spike in lake-water conductivity and productivity. Lake water chemistry and productivity appears to have recovered, perhaps only decades after forest clearance, but changes in catchment hydrology and the introduction of exotic aquatic weeds has prevented at least lake Clearwater (the deepest lake) from returning to pre-human conditions. There is a possibility that a macroscopic charcoal horizon pre-dating the most recent disturbance event is related to local Polynesian deforestation. This event was more minor than the inferred European forest clearance but did have a major effect on the ecology of the lake. A few more strategically placed radiocarbon dates would serve to strengthen an already very informative and interesting story from this study.
Coring was completed in early November 2009. In total, eight cores that provided usable results were extracted from the targeted lakes; the Maori Lakes, Lake Emma and Lake Clearwater (Figure 1). Four types of cores were taken – percussion, gravity, hammer, and D-section cores. Percussion cores were taken from Maori Lakes, Lake Emma and Lake Clearwater, along with gravity cores to sample the top sediment. These were taken within 50 cm to 1 m of one another to allow comparison correlation and comparison between cores. The percussion cores were taken from as close to the centre of the lakes as possible to get an accurate record of the sedimentation history and to minimise wind effects. Centre lake samples are also more representative of the conditions in the entire lake as there is no bias towards littoral macrofossils and pollen. D-cores were taken from the swamp that edges Maori Lake, and one of the Spider Lake swamps. A boat hired from the University of Canterbury was used to core the lakes.

Two cores were recovered from Lake Clearwater, a percussion core and a gravity core (CWPC and CWGC). These cores were taken from the eastern end of the lake where the water was 3 meters deep. The percussion core was 40 cm in length, and the gravity core 40 cm (check). The two cores were taken within 1 m of one another to acquire the most complete record. This process was repeated for Lake Emma, with a percussion core (LEPC) and a gravity core (LEG) extracted from the close to the centre of the lake. At Maori Lakes three cores were taken, a percussion and a gravity core in the centre of the lake, and a D-section core from the swamp that borders the southern end of the lake.

Pollen preparation and counting:

Sediment was processed for pollen following a process adapted from van der Kaars et al. (2001) method. Samples were deflocculated in 10% tetra-sodiumpyrophosphate solution over a moderate heat, and one lycopodium tablet added to each sample for pollen and charcoal concentration.
calculations. Sediments were passed through a 150 µm sieve to remove larger particles, and then washed through an 80 µm mesh with distilled water to remove clays. The sediment was then rinsed and centrifuged twice and rinsed with 10 ml distilled water. Following this, heavy liquid (sodium-polytungstate) of 1.9 SG was used to separate organics. The sample was centrifuged at 2500 rpm for 30 minutes with the heavy liquid, and the floating particles decanted. This was again rinsed twice, and then centrifuged with 10 ml of glacial acetic acid to remove any traces of water. Nine ml of acetic anhydride and 1 ml sulphuric acid were added to perform acetolysis. Acetolysed pollen grains are cleared and give excellent topographic information since the outer pollen wall consists exclusively of sporopollenin (Hesse and Waha 1989). The remaining material was rinsed twice with 10 ml of distilled water and washed into 1 ml tubes with ethanol, for storage until counting. Slides were made up immediately prior to counting. A drop of glycerine was placed onto a glass microscope slide, topped with a cover slip and sealed. Counting was performed at 40x magnification using a Leica CME microscope. Publications by Pocknall (1981a,b,c), Large and Braggins (1991), Moar (1993), and Moar and Wilmshurst (2003) aided identification of palynomorphs. A target of 300 dryland pollen grains was attempted for each slide. This was not possible for some levels within the core due to various factors discussed later in the text.

- Charcoal counting:

The relative abundance of charcoal particles within each depth sampled in the cores can be used to infer fire history for the area. Charcoal concentrations were estimated by counting the number of charcoal particles through three transects of each microscope slide. Charcoal was counted on the same slides as pollen, and only charcoal above 10 microns in size was included. Within these transects lycopodium spores were counted, and the charcoal abundance was then calculated using the formula: 18583 (average number of lycopodium spores per tablet)/no. of lycopodium counted * no. of charcoal particles counted. No precise record of the relative sizes of charcoal within the samples was taken, although note was made of slides which contained particularly large amounts of macroscopic charcoal. Charcoal values are presented on pollen diagrams as the number of charcoal fragments per cm³.

- Loss on ignition:

Loss on ignition (LOI) is carried out to determine the organic content of sediment. Samples of around 1 cm³ were taken from the cores, sampled at the same intervals as pollen. The samples were first weighed, and then dried for 24 hours in a low-temperature oven at 100⁰ C. The samples were then re-weighed, and placed in a muffle-furnace at 450⁰C for 12 hours, and again weighed.

- Chironomids:

Sediment samples were processed for chironomids following a modified version of the method outlined in Walker (2001). Samples were weighed, deflocculated in hot 10% KOH and washed through a 90 µm mesh with copious amounts of distilled water. Samples were then transferred to a Bogorov counting tray and examined for chironomid head-capsules under a dissection microscope at 50X magnification. 100 head-capsules were extracted where possible and a minimum sample size of 50 was set for inclusion into stratigraphic plots and temperature reconstructions (Heiri and Lotter, 2001; Quinlan and Smol, 2001). Chironomid head-capsules were mounted on glass slides in a drop of Euparal® and covered with a glass coverslip. Chironomids were identified using a transmission light microscope with the aid of publications by Schakau (1993), Boubee (1983), Forsyth (1971), Winterbourne et al. (2000), and identification guides by Boothroyd (1994, 2002, 2004). The division of the genus *Chironomus* was based on unpublished morphological and karyotypic data from Jon Martin and Don Forsyth. Chironomid counts were displayed as relative abundances of the total head-capsule sum for each horizon using PSIMPOLL (Bennett, 2005). Division of the chironomid stratigraphy into zones was based on cluster analysis using the CONISS function available in PSIMPOLL.

Other common fossils and charcoal fragments were also identified and enumerated in the lake sediment residue during chironomid extraction.

Exploratory analysis of down-core trajectories for the fossil chironomid samples and chlorophyll a and lake water conductivity reconstructions used the published New Zealand chironomid training set (Woodward and Shulmeister, 2006) with some modifications. This training set was developed for the construction of transfer-functions for temperature (February mean) and lake production (chlorophyll a).
Twelve additional lakes were added to this dataset from archived material from lakes sampled in 2002/2003 for a diatom training set developed by Reid (2005) (seven lakes) and data from additional fieldwork during the summer of 2006/2007. A sub-set of the resulting 58 lakes in this training set was used to develop models for lake productivity and chemistry and to explore changes in the fossil assemblages through time. All alpine/sub-alpine lakes were removed from the 58 lake dataset resulting in a 40 lake dataset. Multiple constrained ordinations in CANOCO version 4.5 (ter Braak and Šmilauer, 2002) were used to confirm which environmental variables had the strongest influence on New Zealand chironomid distribution and select possible variables for reconstruction. Models were evaluated and applied to the fossil data in the computer program C2 (Juggins, 2003)

- Chronology:

14C Radiocarbon Dating

Initially, six samples were taken for AMS 14C radiocarbon dating. These were extracted from the base of percussion cores from Lake Emma (25 cm), Lake Clearwater (36 cm), and Maori Lakes (53 cm), and the base of the D-cores from Spider Lakes (28 cm) and Maori Lakes (2.29 m). An additional sample was taken from the Maori Lakes D-core at 1.52 m to determine sedimentation rates for this core. Of the samples, 5 were plant fragments such as rootlets or stems and woody material. The sixth sample was one cm³ of sediment. For the sediment sample, bulk pollen was measured rather than bulk organic carbon content. All of the samples were oven dried for 48 hours at 50°C, before being sent to ANSTO for analysis. The Maori Lakes D-core samples were run on the STAR accelerator, while the remaining samples were run on the ANTARES accelerator. This was due to the very small size of the plant fragments submitted.

210Pb Dating

For 210Pb dating of the gravity cores, 36 samples were taken from Lake Emma, Lake Clearwater and Maori Lakes. These were taken at approximately 3-4 cm intervals through the entire length of the cores to give a clear picture of the age of the recent sediments. The samples were then oven-dried for between 24 and 48 hours at 50°C, and ground to a powder before being sent to ANSTO. A further 10 samples were taken from the top of the Maori Lakes percussion core, after it was determined through pollen analysis that this core likely overlapped with the gravity core.

Environmental interpretations

Overview:

The variation in lake morphology (e.g. size and depth), catchment to lake size ratio, and sedimentation rate, each lake is capable of providing information on the evolution of the Ashburton Lakes region in slightly different ways. The morphology of each lake influenced our ability to generate a good 210Pb age model. The shallow lakes (Emma and Maori) were affected by sediment mixing, probably by wind disturbance. Lake Emma was most badly affected due to its large fetch and shallow depth. The 210Pb data (Table 5 and Figures 5A, B, and C) indicates sediment mixing to a depth of about 20cm. The sediment mixing does not prevent this record from providing excellent insights into the effects of human impact on Lake Emma and its catchment. The Lake Emma cores also provided perhaps the longest pre-human impact record (Figures 6 and 7), and based on the pollen stratigraphy, we may have a record from lake Emma that extends back possibly to the end of the Last Glacial/Interglacial Transition (LGIT) 12,000 calendar years BP. This estimate is based on the arrival of Podocarpus pollen in sites from similar altitudes further north in the foothills of the Southern Alps.

Sediment mixing in The Maori Lakes gravity core appears to extend down to only 9cm depth and it was therefore possible to construct an age/depth model (Table 3, Figures 3A, B, and C). The gravity core provides the highest resolution record of European activities in the vicinity of one of the Ashburton lakes since approximately 1900 AD. Each 1 cm thick sample from the Maori Lake therefore represents about 2 years of deposition. Lake Clearwater is the deepest of the Ashburton Lakes, with a maximum water depth of 18m. The 210Pb decay profile is therefore not affected by sediment mixing. The sedimentation rate in Lake Clearwater is much lower than in the Maori Lakes and the gravity core represents perhaps over a thousand years of deposition.

In the following section we will provide a more detailed discussion of the results from the Lake Clearwater gravity core, the Lake Clearwater percussion core and the Lake Emma Percussion core.
Combined, these cores provide us with a record of pre-human vegetation change from the beginning of the Holocene and provide insight into the effects of anthropogenic deforestation and low to medium intensity agriculture in the lake catchments. As the age constraint stands at the moment, it is difficult to attribute landscape disturbance recorded in the pollen record to Maori deforestation and a few more strategically placed radiocarbon dates would improve our ability to distinguish a possible Maori disturbance signal in these records.

Environmental interpretations part 1: Catchment evolution during the Holocene

The Lake Emma percussion core – pre-human vegetation in the Ashburton Lakes area

- Vegetation response to early Holocene climate change:

The pollen and charcoal record from the Lake Emma percussion core (Figure 6) provides a record of vegetation change and fire frequency dating back to possibly 12,000 calendar years BP (hereafter cal BP). This prediction for the basal date is based on a comparison of sites of similar altitude in Canterbury in the foothills of the Southern Alps. Pollen from *Podocarpus* appears in the record published by McGlone et al. (2004) from Kettlehole Bog (85 km NE from the Ashburton Lakes) 12,000 cal BP and increases rapidly about 11,500 cal BP.

The pollen stratigraphy records the transition from shrubland dominated by *Phyllocladus* (Celery Pine), *Coprosma* (a small leaved shrub) and *Halocarpus* (Bog Pine) (Zone LEPC-1) to *Podocarpus* forest with a *Podocarpus* "climax" sometime before 4000 cal BP (Zone LEPC-2/LEPC-3 transition). *Podocarpus* continues to dominate the pollen sum to the top of the core, but *Nothofagus* fuscaspora-type pollen appears at the beginning of Zone LEPC-3. The charcoal concentration is very low but increasing in Zone LEPC-1. From the base of Zone LEPC-2 there is a constant background level of charcoal with one peak at the Zone LEPC-2/3 transition a trough mid Zone LEPC-3 and a peak at the top of the core.

The transition from *Halocarpus/Phyllocladus/Coprosma* shrubland to *Podocarpus* broadleaf forest most likely represents an increase in mean annual temperature. *Phyllocladus alpinus* is a common component of sub alpine forest and scrub in this area between 1000m and 1200m asl (Speight et al. 1911, Burrows 1986) and is frost tolerant to -18°C (Sakai et al. 1981). Leathwick (1995) determined that *P. alpinus* has a mean annual (MAT) temperature optimum of between 6 and 7°C. The MAT in the Ashburton Lakes basin is approximately 8.5 - 9°C based on climate normals from the Godley Peaks climate station near Lake Tekapo (43°51'54.00"S, 170°28'19.20"E). Therefore the MAT in the Ashburton Lakes area was between 1.5-3°C cooler than the present MAT in Zone LEPC-1.

The *Podocarpus* pollen was not separated into the three main identifiable *Podocarpus* types: *Podocarpus hallii, Prumnopitys taxifolia and Prumnopitys ferruginea*. Both *P. taxifolia* and *P. ferriginea* have MAT optima of ~ 10 °C, while *P. hallii* has a temperature optima of 8.5 °C. It is likely that some if not all of the *Podocarpus* pollen in Zone LEPC-1 belongs to *P. hallii* with *P. taxifolia* and *P. ferriginea* arriving in Zone LEPC-2. The MAT in late Zone LEPC-2 and LE-PC-3 would most likely at least 10 °C as *Dacrycarpus dacrydoides* and *Dacrydium cupressinum* both have MAT optima of 11-12°C.

- The east coast "beech gap":

*Podocarpus* type pollen remained dominant throughout the percussion core record above 30cm depth. *Nothofagus* fuscaspora type pollen appears in low abundances in Zone LEPC-3 and increases to 10% of the dryland pollen sum at the top of the percussion core. The Ashburton Lakes sit within the diffuse northern margin of an approximately 100 km wide “beech gap”, an area of the South Island largely devoid of any *Nothofagus* species. This “beech gap” is complete on the western side of the Southern Alps, but there are scattered stands of *Nothofagus menziesii* within the gap on the eastern side (McGlone 1985). Large swaths of the landscape 30 km north of the study sites are cloaked in *Nothofagus soandri* var. *cliffortiodes* forest. South of this, there are scattered stands of *N. s. var. cliffortiodes*, with the most southerly major stand being 20km south-west of the study sites. There are no significant stands of *Nothofagus* in the Ashburton Lakes valley itself.

The pollen record from many other localities outside the “beech gap” in the South Island indicate the replacement of Podocarpaceae forest with *Nothofagus* forest between 8000 and 7000 cal yr BP (e.g. McGlone et al. 2004). McGlone et al. (2004) interpret this change as indicative of a climatic change (a cooling) that favoured the survival of *Nothofagus* forest over Podocarpaceae forest.
There has been considerable debate surrounding the reasons for the absence of *Nothofagus* within the “beech gap”. One school of thought (the “glacial refugia hypothesis”) proposes that the current *Nothofagus* distribution is a snapshot of a continuous expansion of *Nothofagus* from glacial refugia triggered by favourable climatic conditions after 8000 cal yr BP (Wardle 1963 and Burrows 1965). A climate cooling after 8000 cal yr BP meant that *Nothofagus* could out-compete and replace the Podocarpaceae forest that dominated during the warmer climate of the mid-Holocene. Within the premises of this hypothesis we should see a continuous expansion of *Nothofagus* into the “beech gap”. If *Nothofagus* was slowly colonising the “beech gap” we should see a continuous increase in *Nothofagus* after it appears in the pollen record (Zone LEPC-3, Fig. 6). Instead we see a rise to about 10% sometime after 4000 cal BP and a stabilisation. *Nothofagus* pollen is typically well to over represented in the pollen record (McPhail & McQueen 1983) and an abundance of 10% is more likely to represent long-distance transport rather than *Nothofagus* forest close to the sample site. Evidence from this study suggests that certain environmental conditions have prevented *Nothofagus* from expanding into the “beech gap” in this area which has also been suggested by McGlone (1985).

- Pre-human fire regimes:

The current paradigm among paleoecologists is that natural fires prior to human arrival in New Zealand were generally small scale fires with a long time period between fires at any locality (Ogden et al. 1998; McGlone 2001; McWethy et al. 2010). The continuous presence of microscopic charcoal (mainly < 50μm in diameter) in many pollen records from the South Island is taken to represent the continuous background fall-out of charcoal sourced from small lightning ignited fires (McGlone 2001). McWethy et al. (2010) suggest that with few exceptions, the presumed small low frequency fires in New Zealand prior to human arrival were ecologically insignificant. This paradigm was recently challenged by Pugh & Shulmeister (2010) who proposed that increased fire frequency during late Holocene at Stace’s Tarn opened up the Phyllocladus woodland present at the site and may have encouraged the arrival of Beech (*Nothofagus*) in the area.

Definitive evidence for fire at a site is provided by macroscopic charcoal, usually preserved in visible layers in bog and lake sediments or paleosols. Pugh & Shulmeister (2010) summarise the macroscopic charcoal data for this area. The broad trend appears to agree with Ogden et al.’s (1998) observation on the frequency of fires in New Zealand prior to human arrival. Extensive forest fires in New Zealand occurred every few centuries, but fires at any one place appear to be roughly a millennium or two apart.

We have a microscopic and macroscopic charcoal record derived from this study. A few more strategically placed radiocarbon dates would enable us to better constrain the timing of microscopic and macroscopic charcoal in these records. At this stage we have a definitive date on a macroscopic charcoal layer from the Maori Lakes site, but placing dates on the other events would be speculative and based on correlations between pollen zones in these and other local records.

We can say for sure that local fire events become more common in the late Holocene and this fits with the accepted wisdom that there was a late Holocene pre-human increase in burning in New Zealand, perhaps associated with intensified ENSO circulation (McGlone et al., 1992). Shulmeister & Pugh (2010) speculated that increased fire during the late Holocene lead to an opening up of the local *Phyllocladus* shrubland which is represented by an increase in Poaceae pollen. There is a slight increase in Poaceae pollen at roughly 5000 cal BP in the lake Emma percussion core record. Considering the under-representation of *Chionochloa* pollen in pollen records, this site increase at this site could also represent an opening up of the local forest.

**The Lake Clearwater gravity core – human disturbance in the Ashburton Lakes area**

The generally accepted date for widespread environmental impact following Polynesian settlement in New Zealand is ~ 1280 AD (McWethy et al. 2010). In the Lake Clearwater Gravity core there is one substantial microscopic charcoal peak at 14cm (Figure 8) and two macroscopic charcoal peaks, one at 36cm and one at 14 cm (Figure 8). Until we achieve better age control on these records, we can explain the pollen and charcoal data with two possible scenarios.

1) The macroscopic and microscopic charcoal layer at 14cm could represent European deforestation ca. 1840 AD and there is an accelerated period of deposition (due to erosion) between the charcoal peaks and the lowest 210Pb date (1858 +/- 2 AD). The lower macroscopic charcoal peak at 36cm could represent Polynesian burning and forest clearance ca. 1280 AD. We do see low levels of *Pteridium esculentum* pollen associated with this macroscopic charcoal peak, but no obvious response in the
pollen record until 25cm where there is an increase in grass pollen and Podocarpus pollen begins a slight decline. The lower macroscopic charcoal layer is associated with a change in lake biota (see Figure 10 and discussion in the following section) but there is no obvious decrease in the LOI (Figure 11).

2) The second possible scenario (although unlikely) is that the macroscopic and microscopic charcoal layer at 14cm could represent Polynesian deforestation at ~ 1280 AD. This would mean that there would have to have a reduced sedimentation rate below the first $^{210}$Pb date and above the charcoal peak (1cm ~ 58 years), with the average sedimentation rate during the European period (pollen zone CWGC-2b) being ~ 1cm per 18 years.

Environmental interpretations part 2: In-lake natural variability and response to human impact:
The Lake Emma percussion core – pre-human natural variability

Based on the pollen evidence and radiocarbon dating, the percussion core represents the response of lake biota to changing climate, landscape and vegetation development in the last 12,000 years. This basal age estimate is based on the transitions in the pollen record and the presence of chironomid taxa that prefer warm conditions (e.g. Cladoplema curtivalva) in the basal sediments. We therefore have a good record of pre-human impact variability in Lake Emma in the percussion core.

The dominant chironomid taxon throughout the pre-human impact record (Corynocera spp.) is abundant in shallow clear, oligotrophic - mesotrophic lakes and the littoral zone of oligotrophic-mesotrophic clear deeper lakes (Woodward and Shulmeister 2006). The changes in the fossil record in the percussion core can be roughly divided into two main phases that correspond to the Montane Forest Pollen Zone (the bottom 20cm of the core) and the sediment deposited after this time in the percussion core.

- Montane Forest Zone (LEPC-1) 45 cm to the base:
Lake Emma is an oligotrophic lake with sparse macrophytes for most of this zone. At the bottom of this zone Lake Emma is a very shallow oligotrophic lake, with abundant Isoetes. Isoetes is found at a maximum depth of 4.5m in South Island oligotrophic lakes (Clayton et al., 1979). A sharp increase in the abundance of Chironomus spp. and Macropelopini head-capsules and a decline in the abundance of Isoetes indicate an increase in lake depth. Chironomus spp. is a common chironomid larval type from the profundal (deep water) zone of New Zealand lakes (Woodward & Shulmeister 2006). There is no evidence for what caused the increase in lake level, but could be related to a change in moisture balance (precipitation-evaporation) in this area.

Top of the Percussion core to the Montane Forest Zone (0 cm to 45cm): An increase in charophyte oospores is indicative of an increased macrophyte standing crop. This could be a response to increased temperatures and longer growing season (reduced length of ice cover). The chironomids indicate relatively stable lake conditions during this period and the abundance of Corynocera is indicative of continued oligotrophic-mesotrophic conditions. There is a more diverse chironomid assemblage, perhaps due to the increased habitat area provided by the increased macrophyte biomass. A decline in Corynocera spp., an increase in Chironomus spp., and the appearance of a testate amoeba taxon (Centropyxis spp.) typical of “stressed environments” (Patterson et al. 2002) is mostly likely the result of a disturbance event in the lake catchment (fire). It is not conclusive that this represents the start of human impact in the Lake Emma catchment.

The Lake Clearwater gravity core –the effect of human disturbance on Lake Clearwater

In the Lake Clearwater record there is evidence from the macroscopic charcoal and pollen for three (or possibly two if there is overlap between cores) disturbance events in the Lake Clearwater catchment prior to 1858 AD. It seems most likely that the macroscopic charcoal peak in the percussion core (Figure 9) is a pre-human impact naturally occurring fire because the fire occurs before the increase in Nothofagus pollen in the pollen record (Figure 9). If this is the case we have the first evidence for significant impacts of natural fire on the aquatic ecosystem of New Zealand lakes. Chironomid-based reconstructions indicate increased lake productivity and lake-water conductivity associated with fire events in the lake catchment (Figure 11). There is also a major increase in charophyte (algal) oospores and an increase in the abundance of head-capsules belonging to Naonella kimihia. The increase in charophyte oospores indicates an increase in macrophytes production in Lake Clearwater, probably in response to increased lake productivity. An increase in lake productivity is also indicated by the increase in chironomid-based chlorophyll a reconstructions (Figure 11). Schakau (1990)
speculated that an increase in *N. kimihia* (then called Orthocladiinae sp. IX) abundance in a record from Lake Grasmere was a signal for an increase in lake productivity and possibly macrophytes biomass. The increase *N. kimihia* in Grassmere record was associated with pollen and charcoal evidence for Polynesian burning in the lake catchment.

It is quite likely that the larger charcoal peak in the lake Clearwater gravity core corresponds to European forest clearance. There is a large microscopic charcoal peak at the base of the Maori Lakes gravity core (Figure 12) that is 5cm below a 210Pb date of 1904 AD. This period of land clearance had the greatest impact on the limnology and ecology of Lake Clearwater. The chironomid-based reconstructions (Figure 11) indicate a major increase in lake-water conductivity and lake productivity at the time of deforestation and a subsequent recovery. It therefore appears that the influx of nutrients associated with deforestation and catchment destabilisation had a greater effect on the lake productivity of Lake Clearwater than the subsequent low intensity European agriculture in this area. Other impacts on Lake Clearwater possibly result from the long term effects of a major vegetation change in the lake catchment and the introduction of exotic macrophytes species – particularly *Elodea canadensis* (Canadian Pondweed).

A change in vegetation cover in the lake catchment could reduce the response time of the inflowing stream network with possible lowered interception of overland and subsurface water flow by grassland as opposed to the previous forest cover. *Elodea* was first introduced to Christchurch, New Zealand early in the 20th century (Mason, 1975). Direct competition between *Elodea* and native macrophytes (e.g. charophytes) could have prevented a recovery in native macrophytes communities. Charophyte communities could have been adversely affected by sediment and nutrient influx. Eutrophication could have favoured the invasion of *Elodea* which can tolerate eutrophic conditions.

**Literature cited:**


DATA (Please summarise the data collected within this Award. You may use tables, graphs or diagrams)
[please fill in your research outcomes here]

- Chronology

Tables and figures in this section provide a summary of all the radiocarbon and $^{210}$Pb dates provided by ANSTO for the purposes of this project. Radiocarbon dates are presented in Table 1. Raw $^{14}$C dates were adjusted for the Southern Hemisphere offset of 56 +/- 24 years (McCormack et al., 2004). Calibrations were performed using CALIB REV 5.1 Beta in conjunction with the IntCal04 calibration curve (Reimer et al., 2004).

### $^{14}$C Radiocarbon Dating

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<td>2260 +/-110</td>
<td>Maori Lakes Percussion core 52-53 cm</td>
</tr>
</tbody>
</table>

* δ $^{13}$C estimated for this sample. Measured data not available.

### $^{210}$Pb Dating

The results of $^{210}$Pb dating from the Lake Clearwater gravity core (CW-GC1), Maori Lakes gravity core (ML-GC2), Maori Lakes percussion core (ML-PC) and the Lake Emma gravity core (LE-GC1) are presented in Tables 2, 3, 4, and 5 and Figures 2, 3, 4, and 5.

Lake Clearwater gravity core: Unsupported $^{210}$Pb activities in the CW-GC1 core exhibit an overall decreasing profile with increasing depth (Table 2, Figure 2A, B, and C). Unsupported $^{210}$Pb activities between 2 and 8 cm were used to calculate the CIC and CRS model sediment ages and mass accumulation rates (see Table 2). Below 8 cm, unsupported $^{210}$Pb activities are background level, therefore were not used in the dating calculations.

Maori Lakes gravity core: Unsupported $^{210}$Pb activities in the ML-GC2 core exhibit an overall decreasing profile with increasing depth (see Figure 3C). Unsupported $^{210}$Pb activities between 9 and 39 cm were used to calculate the CIC model sediment ages and the mass accumulation rate. For the
CRS model, all the unsupported $^{210}$Pb data in the core were used to calculate sediment ages and mass accumulation rates (see Table 3).

Lake Emma gravity core: Unsupported $^{210}$Pb activities in the top 20 cm, and between 27 and 40 cm, of LE-GC1 core exhibit two separate mixed sediment layers (see Figure 5C). Due to the mixing of sediment in the core, the $^{210}$Pb dating method cannot be used to determine the chronology of this core.

Maori Lakes percussion core: Unsupported $^{210}$Pb activities in core ML-PC are very low (less than 10 Bq/kg) and do not exhibit a decay profile with increasing depth (see Figure 4C). Therefore, this core is not suitable for $^{210}$Pb dating.
### Table 8: MAJOR LAKES PERCUSSION CORE ML-PF

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth (cm)</th>
<th>Dry Bulk Density (g/cm³)</th>
<th>Cumulative Dry Mass (g/m²)</th>
<th>Total Pb-210 (dpm/g)</th>
<th>Supported Pb-210 (dpm/g)</th>
<th>Unsupported Pb-210 (dpm/g)</th>
<th>Corrected to reference date 1981-90 (dpm/g)</th>
<th>C14 Ages (year)</th>
<th>Calculated C14 Ages (year)</th>
<th>C14 model Mass Accumulation Rates (g/m² yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U4956</td>
<td>0.0 - 1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>10.2</td>
<td>1.1</td>
<td>11.0</td>
<td>11.9 ± 1.1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>U4957</td>
<td>1.0 - 2.0</td>
<td>1.0</td>
<td>2.0</td>
<td>17.0</td>
<td>2.0</td>
<td>19.0</td>
<td>17.6 ± 1.6</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U4959</td>
<td>2.0 - 3.0</td>
<td>1.0</td>
<td>3.0</td>
<td>25.0</td>
<td>3.0</td>
<td>28.0</td>
<td>25.0 ± 2.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
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<td>U5000</td>
<td>3.0 - 4.0</td>
<td>1.0</td>
<td>4.0</td>
<td>35.0</td>
<td>4.0</td>
<td>39.0</td>
<td>35.0 ± 3.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U5001</td>
<td>4.0 - 5.0</td>
<td>1.0</td>
<td>5.0</td>
<td>55.0</td>
<td>5.0</td>
<td>60.0</td>
<td>55.0 ± 5.0</td>
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<td>N/A</td>
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<td>U5002</td>
<td>5.0 - 6.0</td>
<td>1.0</td>
<td>6.0</td>
<td>65.0</td>
<td>6.0</td>
<td>71.0</td>
<td>65.0 ± 6.0</td>
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<tr>
<td>U5003</td>
<td>6.0 - 7.0</td>
<td>1.0</td>
<td>7.0</td>
<td>75.0</td>
<td>7.0</td>
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<td>85.0</td>
<td>8.0</td>
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<td>N/A</td>
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<tr>
<td>U5005</td>
<td>8.0 - 9.0</td>
<td>1.0</td>
<td>9.0</td>
<td>95.0</td>
<td>9.0</td>
<td>104.0</td>
<td>95.0 ± 9.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Figure 4A

![Image](image-url)

### Figure 4B

![Image](image-url)

### Figure 4C

![Image](image-url)

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### Table 9: LAKE EMMA GRAVITY CORE LC-D1

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth (cm)</th>
<th>Dry Bulk Density (g/cm³)</th>
<th>Cumulative Dry Mass (g/m²)</th>
<th>Total Pb-210 (dpm/g)</th>
<th>Supported Pb-210 (dpm/g)</th>
<th>Unsupported Pb-210 (dpm/g)</th>
<th>Corrected to reference date 1981-90 (dpm/g)</th>
<th>C14 Ages (year)</th>
<th>Calculated C14 Ages (year)</th>
<th>C14 model Mass Accumulation Rates (g/m² yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U107</td>
<td>0.0 - 1.0</td>
<td>0.95</td>
<td>0.9 ± 0.1</td>
<td>17.0</td>
<td>1.0</td>
<td>18.0</td>
<td>18.0 ± 1.0</td>
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<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U108</td>
<td>1.0 - 2.0</td>
<td>1.05</td>
<td>1.0 ± 0.1</td>
<td>17.0</td>
<td>1.0</td>
<td>18.0</td>
<td>18.0 ± 1.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U109</td>
<td>2.0 - 3.0</td>
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<td>25.0</td>
<td>2.0</td>
<td>27.0</td>
<td>27.0 ± 2.0</td>
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<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>U110</td>
<td>3.0 - 4.0</td>
<td>4.1</td>
<td>4.1 ± 0.1</td>
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<td>4.1</td>
<td>39.0</td>
<td>39.0 ± 4.1</td>
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<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U111</td>
<td>4.0 - 5.0</td>
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<td>65.0</td>
<td>7.0</td>
<td>72.0</td>
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<td>N/A</td>
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<td>U112</td>
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<td>3.0</td>
<td>3.0 ± 0.1</td>
<td>75.0</td>
<td>3.0</td>
<td>78.0</td>
<td>78.0 ± 7.8</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>U113</td>
<td>6.0 - 7.0</td>
<td>8.0</td>
<td>8.0 ± 0.1</td>
<td>85.0</td>
<td>8.0</td>
<td>93.0</td>
<td>93.0 ± 8.8</td>
<td>N/A</td>
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<tr>
<td>U114</td>
<td>7.0 - 8.0</td>
<td>10.0</td>
<td>10.0 ± 0.1</td>
<td>95.0</td>
<td>10.0</td>
<td>105.0</td>
<td>105.0 ± 10.0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Figure 5A

![Image](image-url)

### Figure 5B

![Image](image-url)

### Figure 5C

![Image](image-url)
Figure 6: Lake Emma percussion core pollen and charcoal stratigraphy. Pollen is presented as a percentage of the total dryland pollen sum, while charcoal is presented as a concentration per cm$^3$ of sediment.

Figure 7: Chironomids and macrofossils from the Lake Emma gravity and percussion core. Chironomids are represented as a percentage of the total head-capule count while other macrofossils are represented as individuals per cm$^3$ of sediment.
Figure 8: Pollen and charcoal stratigraphy from the Lake Clearwater gravity core (CW-GC1). Pollen and charcoal is represented as a percentage of the total dryland pollen count.

Figure 9: Pollen and charcoal stratigraphy from the Lake Clearwater percussion core (CW-PC). Pollen and charcoal is represented as a percentage of the total dryland pollen count.
Figure 10: Chironomid and macrofossil stratigraphy from A: the Lake Clearwater gravity core (CW-GC1), and B: the Lake Clearwater percussion core (CW-PC). Chironomid counts are shown as a percentage of the total number of head-capsules counted. The abundances of other macrofossils and charcoal fragments are also shown as a percentage of the total number of chironomid head-capsules.

Figure 11: Organic content (loss on ignition), chironomid based lake water conductivity and productivity (Chla) compared to the chironomid zones, pollen zones and charcoal abundances from CW-GC1 and CW-PC.
Figure 12: Pollen and charcoal stratigraphy from the Maori Lakes gravity core (MLGC-2). Pollen and charcoal is represented as a percentage of the total dryland pollen count.

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After signing this report please fax this page with your signature for our files

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<thead>
<tr>
<th>Proj: 10P044</th>
<th>Date:</th>
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</thead>
</table>

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2 papers are in early draft form from this work. One will deal with the long-term vegetation history around the basin and will include Geraldine Jacobsen as an author. The second will look at changes in the lakes focussing mainly on human impacts in historical time and Atun Zadawski will be a co-author on this paper.

PhD STUDENTS For each student involved with the project, please indicate the date or anticipated date of conferment of a PhD or other award, and give the title of the thesis.

MPhil Thesis – Anita Staniland - Reconstructing the vegetation history of O Tu Wharekai, Ashburton basin wetlands and lakes, Canterbury - submission is imminent