La Trobe Archaeology Research Partnerships

BIG SWAMP PALEOENVIRONMENTAL STUDY

Prepared by Peter Gell, Matthew Meredith-Williams, Georgia Stannard, Tracy Martens, Emmy Frost and Rebekah Kurpiel

Date: 19 July 2023

ENQUIRIES
Rebekah Kurpiel
Tracy Martens
La Trobe University
Victoria 3086

E r.kurpiel@latrobe.edu.au
T +61 3 9479 1385
E t.martens@latrobe.edu.au
T +61 3 9479 1531

Table of contents

Contents

EXECUTIVE SUMMARY

La Trobe Archaeology Research Partnerships (La Trobe University) was engaged by Eco Logical Australia Pty Ltd to undertake a paleoenvironmental study at Big Swamp, on Boundary Creek, south of Colac, in southern Victoria (Figure 1). Eco Logical Australia Pty Ltd have been engaged by Barwon Water to establish the paleoenvironmental conditions of the Swamp and potential anthropogenic impacts. The report includes data from two cores (BS1 and BS2) collected from locations with potential for deep sediment sequences (Figure 2). The cores were sampled at predetermined intervals, and samples were subjected to palynological, charcoal and diatom analysis. Core BS2 was included in the report primarily to demonstrate the variable conditions within the swamp. Only core BS1 provided adequate preservation of all three proxies for detailed analysis.

Three radiocarbon dates were obtained from core BS1, at 32-33 cm, producing a date of 487-542 CAL BP, 49-50 cm producing a date of 957-1,062 CAL BP and 199-200 cm, producing a date of 11,157-10,730 CAL BP. Deposition modelling indicates an accumulation rate of roughly 2,000 years per meter in core BS1, between the upper two dates. However, if continual deposition had occurred at this rate from the basal age of 11,157-10,730 CAL BP, the core would have a depth of over 6.5 m. Given that the basal age was obtained from a depth of only 2 m, it is likely that a hiatus or hiatuses have occurred somewhere between the two dates. Further research, including more radiocarbon dates and sediment analysis, would be required to elucidate the timing of the hiatus or hiatuses.

Pollen counts from core BS1 are dominated by tree and sedge species (predominantly eucalypts and Myrtaceae, Cyperaceae (sedge)). The pollen and diatom records indicate that European/Australian colonisation has significantly impacted the catchment, however, the swamp appears to have retained much of its character with established forest and sedges still dominant in the local landscape. Analysis indicates six notable fluctuations in relative abundance of trees and grasses over time with the earliest samples also producing evidence of shrubs, indicating a mixed woodland environment.

The diatom record indicates that acidic conditions have prevailed at Big Swamp for over a millennia. The main changes noted in the character of the swamp may be the result of increased sediment input from land clearing higher in the catchment area (both higher run-off and increased sediment load), and hydrological changes from the establishment of dams upstream. Limited numbers of planktonic species suggests that Big Swamp has never sustained deep waters and few aerophilous species suggest that the site has not dried appreciably in the past. The decline in benthic diatom species supports the idea that the swamp has probably experienced sedimentation, reducing the presence of deeper pools. The rise in *Pinnularia obscura* in between 140 and 85 cm may reflect recent changing conditions, but insufficient data is available regarding the relative preferences of the acidophilous species to infer a change in acidity. The most likely cause of the diatom shifts recorded are small increases in nutrient and sediment loads resulting from vegetation clearing and farming in the upper catchment.

Charcoal analysis indicates variable burning patterns with higher intensity burning events evident throughout the core in the top 50 cm, prior to 957-1,000 CAL BP. The frequency and intensity of burning events decreases between 50 cm and 100 cm depth. Much of this record is probably from fires outside the local catchment. Large firing events are evident at approximately 120 cm and 200 cm depth (11,157-10,730 CAL BP), with increased charcoal accumulation persisting for several centimetres in this interval. Charcoal analysis indicates that between ~1,000 CAL BP and European/Australian colonisation, Big Swamp experienced an increase in fire frequency/intensity that does not appear to have significantly impacted vegetation, however, the diatom record does show a slight increase in disturbance indicators during this interval. Further research could be undertaken to understand the paleoenvironment of Big Swamp in additional detail, however, these data provide a useful indication of how conditions at the swamp have changed over time.

PROJECT BACKGROUND AND AIMS

This project aims to contribute to an understanding of the past environments at Big Swamp and surrounding regions through the analysis of pollen (reconstructing past vegetation), diatoms (reconstructing the conditions of past waterways), and charcoal particulates (to reconstruct past burning within the landscape).

Barwon Water have indicated that the information generated by this project is intended to be used to inform ongoing land management strategies for this important place, in addition to understanding past environmental conditions.

Big Swamp is a vegetated swamp located on private property within the Otway Forest Park to the south of Colac (Figure 1). Modern vegetation cover is dominated by Tea Tree (*Leptospermum continentale*). As a result, the waters are tannic and influenced by organic acids. Whilst the swamp and immediate upstream channel are situated within woodland, much of the upstream channel runs through farmland, with multiple dams within the catchment area.

PALEOENVIRONMENTAL CONTEXT

Paleoenvironmental reconstruction is a process that uses a range of different methods to build a picture of what a place, landscape or time period looked like. This includes the physical geography of a place, its plants and animals, climate, and the intersection of each of these components. Past landscapes are reconstructed using proxies; data that represent things that can no longer be observed. Biological, chemical, and geological traces of the past can be observed in the present and, using modern equivalents of those same traces in the present, can be used to interpret past landscapes. Additionally, the geomorphology of sediments – how sediments have changed through time based on their interaction with the surrounding landscape and climate – can provide information about weather patterns, wind intensity and surface water movement.

To understand the paleoenvironmental conditions at Big Swamp and meet the aims of the project, a combination of palynology (pollen analysis), diatom and charcoal analyses has been used. Palynology involves using the proportions of different types of pollen preserved within sediments to determine the composition of local vegetation and climate. Diatom analysis provides information about the characteristics of waterways, including water quality, salinity, and acidity. Charcoal analysis provides information about past fire histories (paleofire reconstructions). Fire is a key ecological process which has played an active role in shaping local environments for millions of years. There are two sources of ignition within any landscape – natural ignition through lightning and anthropogenic ignition by people.

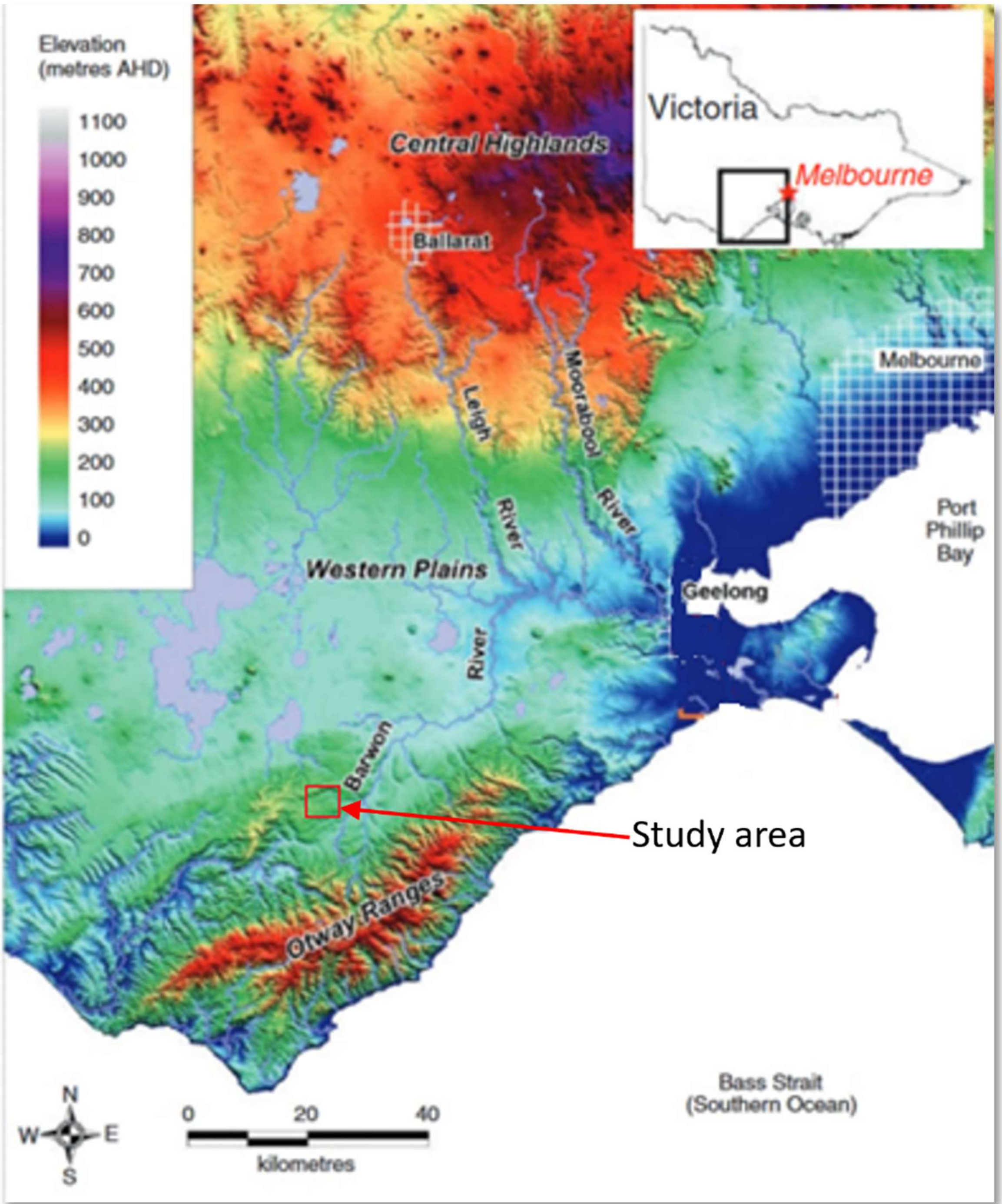


Figure 1 Location of study area showing relative elevation and catchments (modified from Reeves et al., 2016, p. 838).

Resolution and scale

There are significant challenges associated with trying to meld the records of past landscapes and people; one of the most significant is that of temporal scale. Paleoenvironmental records form at a relatively low resolution, gradually laid down over many hundreds to thousands of years. In contrast, the activities undertaken by people represent a discrete moment in time, such as using a hearth to cook a meal, knapping a core to make stone tools, or removing the bark from a tree. Some archaeological places, such as coastal shell middens, might be returned to multiple times, therefore building up a record representing a longer overall time frame, but still made up of a series of snapshots. It is important to be mindful of these differences in temporal scale when attempting to relate past records of environmental change to land management practices occurring within those landscapes; the scale at which people are making management decisions may not necessarily be reflected in the scale of the environmental record.

Environmental records such as pollen and charcoal are derived from a large catchment area (with materials transported to the study area by the actions of wind and water) and thus are more likely to represent broader patterns of landscape change than those taking place at a discrete local level. This is significant when aiming to reconstruct local landscape management strategies by Aboriginal communities in the past, as the record that is preserved in a fluvial system, such as the study area, is probably derived from many kilometres upstream, as well as from the surrounding landscape.

METHOD

Approach to selecting the coring location

Coring locations were selected using information provided by Barwon Water, primarily the LiDAR imagery, which indicated that both locations were inundation areas (Figure 2 & Figure 3). This provided information on the central axis of the creek that was likely to be a depocenter or base of much of the system. This is a preferred coring location because of the relatively high likelihood it will contain deeper sequences of sediment for analysis.

Fieldwork

The sites (BS1 and BS2) were cored using a Russian or d-section coring device (Jowsey, 1964) which allows the operator to take contiguous 50 cm half-cylinder sections until the corer nose reaches a hard base. Extracted core segments were photographed and wrapped in clingfilm, then transported to refrigerated storage at La Trobe University (see Appendix B for personnel involved in coring and sampling).

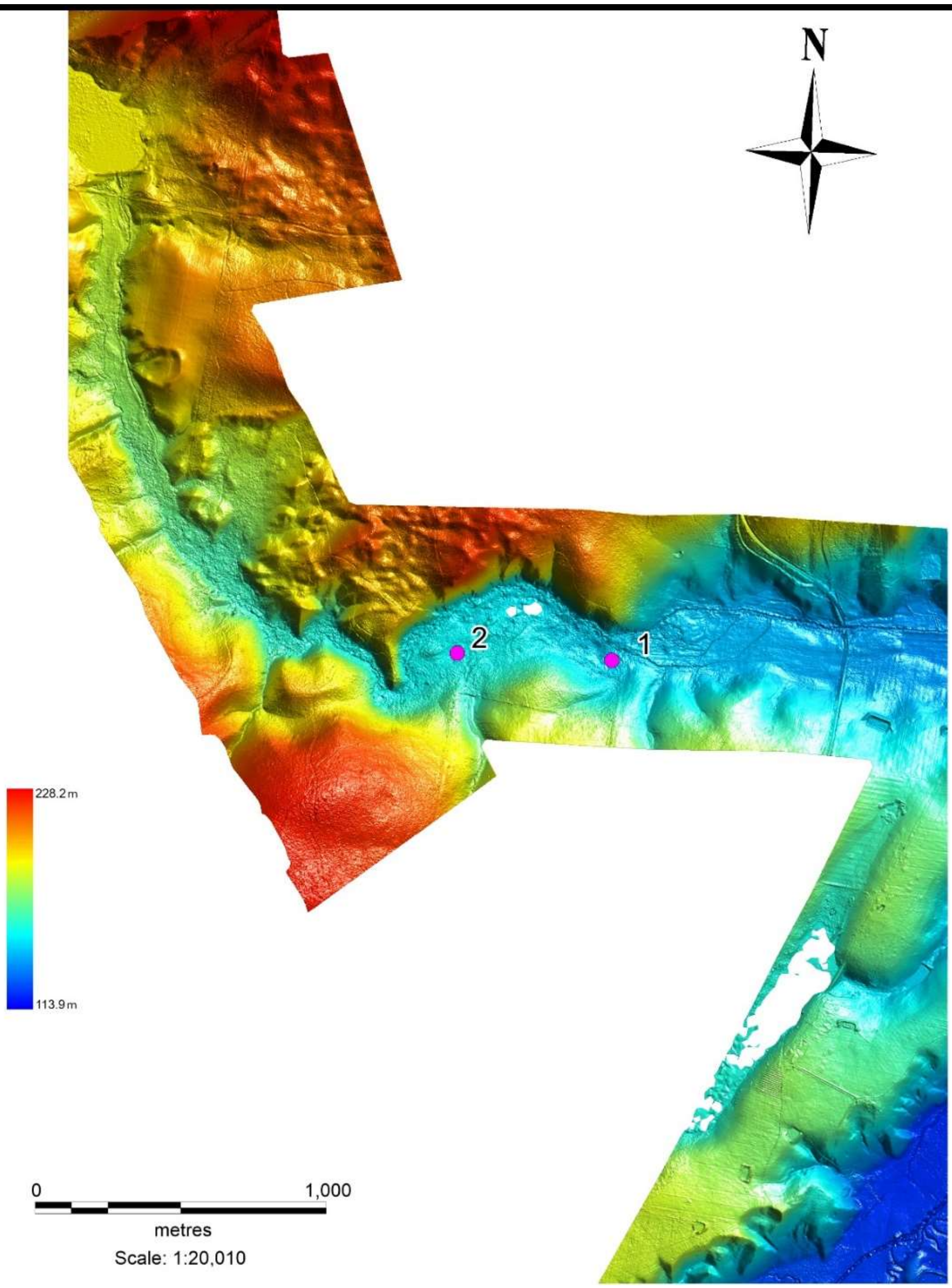


Figure 2: Coring locations BS1 (1) and BS2 (2), marked by pink dots.

Figure 3: Location of BS1 core.

Core sampling

Sampling of the core BS1 and BS2 (Figure 4) was completed on October 10, 2022, in the archaeology laboratory at La Trobe University. The core BS1 was sampled every 2 cm for the upper 20 cm then every 5 cm from 20 cm to 100 cm, followed by every 20 cm to the base (200 cm). Core BS2 was sampled every 15-20 cm to the base (180 cm). Each sampled section was bagged and labelled individually. Cutting tools were cleaned between samples. Subsamples of each 1 cm section were taken for each of the three analytical methods; three sets of approximately 1.5 cm^3 of sediment were bagged individually for diatom, pollen, and charcoal analyses.

Figure 4: Composite image of core BS1: 0-100 cm (top) 100-200 cm (bottom)

Dating

Radiocarbon dating was used to date the core. Bulk sediment samples were sent for analysis at the Chronos Radiocarbon cycle facility at the University of New South Wales (Table 1; Appendix B). Sediment samples were prepared using Acid-Base-Acid protocol. Pre-treated samples were then converted to CO_2 by reaction with 85% H_3PO_4 and flushed through a water trap (phosphorus pentoxide) into the AGE3 system with helium gas. The CO_2 was concentrated in a zeolite trap, which was heated to 420°C to release pure CO_2 into the graphitisation reactor tube. The sample was then reduced to graphite at 580°C with hydrogen on iron powder.

Palynology

The pollen extraction protocol follows the Cambridge University/UCL pollen preparation protocol (Gosling et al., n.d.).

Diatoms

Core BS1 was considered the most likely to provide a paleoecological record and so it was subsampled at fine increments in the upper levels, and coarser increments below 1 meter core depth. Core BS2 was sampled coarsely to assess its potential for preserving fossil paleoindicators. Diatom samples were prepared following standard techniques (Battarbee et al., 2001) employing hydrochloric acid and hydrogen peroxide digestion.

Diatoms were identified by reference to standard texts (Krammer & Lange-Bertalot, 1986-95) and Foged as well as Sonneman et al. (1999). At least 100 valves were counted from each BS1 core sample except in levels at 3 cm and 75 cm where at least 6 slides transects were traversed. Where no fragments were visible in the first transect it was considered that all diatoms had dissolved, and no further scanning was undertaken. Identifications and counts were made on a Zeiss Axiolab microscope using 1000 x magnification under phase contrast.

Charcoal analysis

Charcoal analysis was performed on 1.5 cm^3 samples following the method described by Whitlock and Larsen (2002, p. 85). Samples were wet-screened through both a 125µm and 250µm mesh sieves and charcoal particles were counted under a stereomicroscope at 40x magnification; these size fractions are suitable to reconstruct watershed-scale fires (Whitlock and Larsen, 2002).

Data analysis

Pollen zones were calculated using Bray–Curtis dissimilarity indices, followed by the Constrained Incremental Sums of Squares using the R packages Vegan (Oksanen et al. 2020) and Rioja (Juggins 2020); the *vegdist* and *chclust* functions were employed, following the approach by Grimm (1987).

The R package RBacon (Blaauw and Christen, 2011) was used to create an age-depth model for the core; this uses the three dates, the depth of the core, and changes in the pollen/charcoal/diatom record to model.

RESULTS

Of the two recovered cores only core BS1 contained suitable preservation conditions for all proxies necessary for analysis. BS2 exhibited low proxy concentration rates, which is probably a result of its location near the head of the swamp where local geomorphology appears to have allowed periodic drying. Periodic drying is conducive to the decomposition of the diatoms. Diatoms are best preserved in a stable anaerobic environment; where conditions fluctuate, they will oxidise and decay. Owing to the poor perseveration of diatoms in BS2, in addition to time and budgetary constraints, this core was not analysed in detail. However, the difference in preservation between the two cores is noted as an indication of differences in conditions within the swamp.

Dating

Three bulk sediment samples were collected from core BS1 at depths of 32-33 cm, 49-50 cm, and 199-200 cm for radiocarbon dating (Table 1). Ages were calibrated using the SHCal20 calibration (Appendix B).

Table 1: Radiocarbon analysis from core Big Swamp 1 (BS1).

UNSW Laboratory code	Depth	Sample type	Age (14C yr BP)	Age Error ±	Calibrated Age Range BP to 2 sigma	Additional Calibrated 2 sigma ranges
UNSW-2208	32-33 cm	Bulk Sediment	500	30	487-542 CAL BP (95.4%)	478-471 CAL BP (1.5%)
UNSW-2209	49-50 cm	Bulk Sediment	1150	30	957-1062 CAL BP (93.3%)	935-942 CAL BP (2.1%)
UNSW-2210	199-200 cm	Bulk Sediment	9620	50	11157-10730 CAL BP (95.4%)	N/A

Pollen

Forty sediment samples were processed from the two cores: 30 from BS1 and 10 from BS2. Twenty of the samples from BS1 contained enough pollen grains to meet the threshold for statistical significance (>300 grains). Just six samples from core BS2 met the threshold to be included in statistical analysis (Moore et al. 1991). However, owing to poor diatom preservation, time, and budgetary constraints, it was not included in this analysis (pollen counts from BS2 are presented in Appendix D).

The top 5 cm of BS1 was compressed or otherwise not present for sampling, which is not uncommon in sediment coring. Apart from BS1 11-12 cm, the remaining samples from the upper portion of BS1 (above 10 cm) did not contain adequate amounts of pollen and had to be excluded from the below analysis. When it became clear that the upper 20 cm of BS1 was not yielding statistically significant pollen grain counts, the samples were surveyed for potentially higher density pollen yields and an additional sample was processed (BS1 12-13 cm). This process yielded an additional sample of statistical significance to represent the upper section of the core.

Low pollen concentrations in many slides mean that there was not enough pollen to count. It is also possible that some of the samples with very low counts were affected by the extraction process which requires dozens of delicate pouring and separating procedures.

In the samples where pollen was abundant, concentrations were very high. This is typical of swamp environments, where anaerobic conditions are perfect for organic and pollen preservation. Analysis of the pollen data (Figure 5) has been undertaken, with pollen representing 10% or more of the assemblage shown in the diagrams. The main characteristics of the pollen diagram for BS1 are abundant tree pollen (predominantly eucalypts and Myrtaceae) throughout the core, with Cyperaceae (sedge) also abundant, reflecting the nature of swamp, being surrounded by a stand of trees, with abundant sedges in and around the swamp. However, it is also possible to see changes within this composition.

The pollen concentrations change through time, and this has been divided into zones using Bray–Curtis dissimilarity indices, followed by the Constrained Incremental Sums of Squares. Six zones were identified using this method (N.B. not all samples were processed – therefore it is possible that changes in the core in between processed samples are not represented):

1. 12-14 cm – continued tree cover nearby, with a significant increase in both Poaceae (grass) and Cyperacea (sedge). This has the highest concentration of grass in the core, and most likely represents nearby clearing of land. The increase in sedge could be linked to the clearing, however, it could also represent the re-establishment of swamp conditions after a possible previous drying phase in the swamp.
2. 17-25 cm – an increase in tree cover and significant decline in Cyperaceae, indicating an increase in local tree cover and decline in aquatics. This could indicate a drying phase in the swamp, although not in the wider environment as there is an increase in tree pollen, which suggests good moisture availability. However, the diatom and charcoal records do not indicate either drying or absence of swamp but do indicate changing conditions such as possible disturbance. These changing conditions may have resulted in reduced sedge growth, or at the very least reduced sedge pollen into this area of the swamp.
3. 35-96 cm – a period of relative stability in the swamp, with abundant tree and sedge pollen. Low levels of grass pollen indicate either grasses around the periphery of the swamp, and/or small communities within the surrounding trees.
4. 121-122 cm – a sharp decline in trees and increase in sedges indicates that the swamp had expanded in this period, perhaps also indicating increased seasonality of rainfall.
5. 140-161 cm – conditions like zone 3.
6. 198-199 cm – an abundance of shrub and reduction in tree species suggests a more mixed woodland surrounding the swamp, but the absence of grass suggests that the lower story was dominated by shrubs rather than being an open woodland.

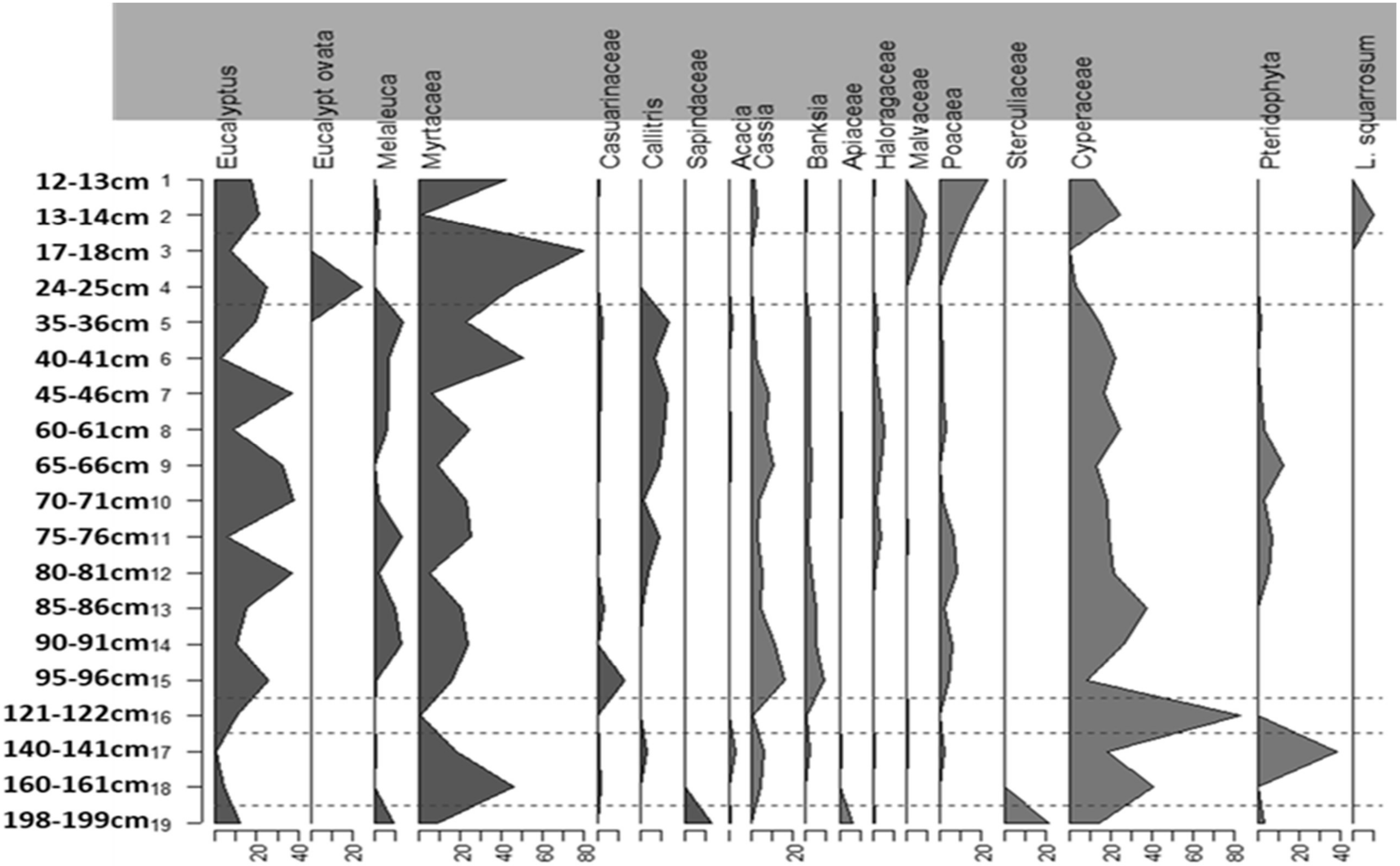


Figure 5: Pollen stratigraphic diagram from core BS1.

Diatoms

Diatoms were preserved in all subsamples of core BS1 down to and including 95 cm, although in a few samples fossil diatom concentration was low. No diatoms were preserved from 100 cm to 180 cm other than at 140 cm. Most diatom remains were fragments challenging clear identification to species. The slides at 100, 120, 160 and 180 cm yielded no fragments and so diatoms appear to have been completely dissolved. Of the six slides examined from core BS2 two linked cells were observed and one small fragment suggesting that post depositional valve dissolution was also at play, but throughout that core.

A total of 3667 valves were identified and counted across the 34 BS1 samples in which diatoms were preserved (Appendix C). The most common diatom genera identified were *Eunotia*, *Nitzschia*, and *Pinnularia* while *Frustulia*, and *Stauroneis* were also common. The most common (> 100 valves) of the 88 species recorded were *Eunotia paludosa*, *Frustulia rhomboides*, *Nitzschia capitellata*, *Pinnularia microstauron*, *Pinnularia obscura*, *Pinnularia subcapitata*, *Pinnularia viridis* and *Stauroneis obtusa*. All samples were dominated by acidophilous species. There was a gradual transition from large benthic species at the base to smaller forms and diatoms indicative of disturbance towards the top. The diatom stratigraphy is provided as Figure 6 and is described below. Zones are determined (by eye) based on sustained changes in the flora.

Zone BS1a (140-85 cm)

Four of the samples in this zone were devoid of diatoms. There were no fragments visible suggesting that water conditions were dissolving the silica valves before they were deposited. The remaining four samples were dominated by *Eunotia paludosa*, *Pinnularia microstauron*, *Pinnularia subcapitata* and *Pinnularia viridis* while there were high numbers of *Stauroneis obtusa* and to a lesser extent *Stauroneis phoenicenteron*.

Zone BS1b (80-18 cm)

These samples were dominated by *Eunotia paludosa*, *Pinnularia microstauron*, *Pinnularia subcapitata* while *Encyonopsis amphicephala*, *Pinnularia viridis* and *Stauroneis obtusa* were well represented. *Nitzschia capitella* began to increase from 40 cm.

Zone BS1c (17-2 cm)

These samples were dominated by *Eunotia paludosa*, *Nitzschia capitellata*, *Pinnularia obscura* and *Pinnularia subcapitata*. *Frustulia rhomboides* declined from 10 cm and was absent above 8 cm.

The depth of sediments of cores BS1 and BS2 suggest that the site has been a swamp for at least a thousand years. The absence of preserved diatoms in BS2, and below 1 meter in BS1, suggest that the early prevailing conditions dissolved the diatom silica, and it is possible that fragmentation was also brought on by water movement. The greater number of small forms towards the top of BS1 may reflect this increasing preservation leaving mostly the larger, more silicified forms towards the base. The recent conditions were more conducive to valve preservation, albeit mostly as fragments, possibly due to higher productivity and sedimentation rates.

Broadly, the diatom assemblage reflects persistent acidic-circumneutral conditions. The prevalence of large forms in the lower sediments (95-20 cm) suggest benthic conditions were conducive to diatom growth (or reflects differential preservation). This would be likely under clear water, low nutrient conditions with lower sediment inputs. The transition from large (*P. viridis, P. microstauron*) to small (*P. obscura*) Pinnularia species may be attributable to smaller particle size as there is little contrast in their preferred water quality. This is supported by the increase in Nitzschia species from << 5% to more than 40% above 40 cm. The genus is common is disturbed situations and, while not a eutrophic indicator, *N. capitellata* is considered to reflect human impact. This rise in disturbance indicators is also reflected in the decline in the sensitive *Frustulia rhomboides* above 10 cm.

The presence of diatoms down to 95 cm suggests the existence of conditions suitable for diatom preservation for a long time. Many factors may contribute to diatom dissolution including drying and water movement that may break the valves making them more vulnerable to dissolution. Swamps adjoining streams may be variously subject to drying and water movement, arising from climate variability or merely the migration of the main channel across the wetland.

The diatom record indicates that acidic conditions have prevailed at Big Swamp for some time and there is no evidence that recent water management has exacerbated water acidity. There were only single counts of planktonic species suggesting that Big Swamp has never sustained deep waters. Also, there were few aerophilous species or indicators of saline waters suggesting that the site has not dried appreciably in the past. The most likely cause of the diatom shifts recorded are small increases in nutrient and sediment loads on account of the settlement, clearance, and farming of the upper catchment.

Charcoal analysis

Charcoal particles are an indicator of fire occurrence, with macroscopic particles >125 μm considered indicative of catchment-scale fires and microscopic particles representing broader-scale burning patterns (Black et al., 2006; Burrows et al., 2014; Stevenson et al., 2015; Whitlock and Larsen, 2002). Local firing events are typically identified by particle concentrations greater than 50 particles per cm^3 in dry forest environments but have been found to be highly variable in wet marshland (Graves et al., 2019; Whitlock and Larsen, 2002). In marshlands, the continuous input of external riverine source material from surrounding catchments means that the presence of macro-charcoal is not necessarily a direct indicator of local fire events (Carcaillet et al., 2001; Clark and Royall, 1996); nor is the absence of charcoal necessarily an indicator of an absence of cultural burning.

Fire indicators (charcoal) show a long sequence of intense burning both locally and within the broader landscape (here local is within approximately 5 km of the coring site) (Figure 1). The charcoal record is well preserved throughout core BS1 and no issues were identified impacting the quality or representativeness of the paleofire record.

The top 50 cm of the core showed variable burning patterns with higher intensity burning evident throughout the core at this depth (Figure 7). The frequency and intensity of burning events decreases between 50 cm and 100 cm depth. Much of this record is from fires outside the local catchment, represented in the finer charcoal caught in the 125 μm sieve.

Large firing events are evident at approximately 120 cm and 200 cm depth, with increased charcoal accumulation persisting for several centimetres of the core. The degradation of larger macro charcoal (>1 cm^3) fragments present at around 200 cm depth is likely to have contributed to the very high count of smaller charcoal particles at this depth; the high counts of charcoal in both the 125 μm and 250 μm fractions however remain significant.

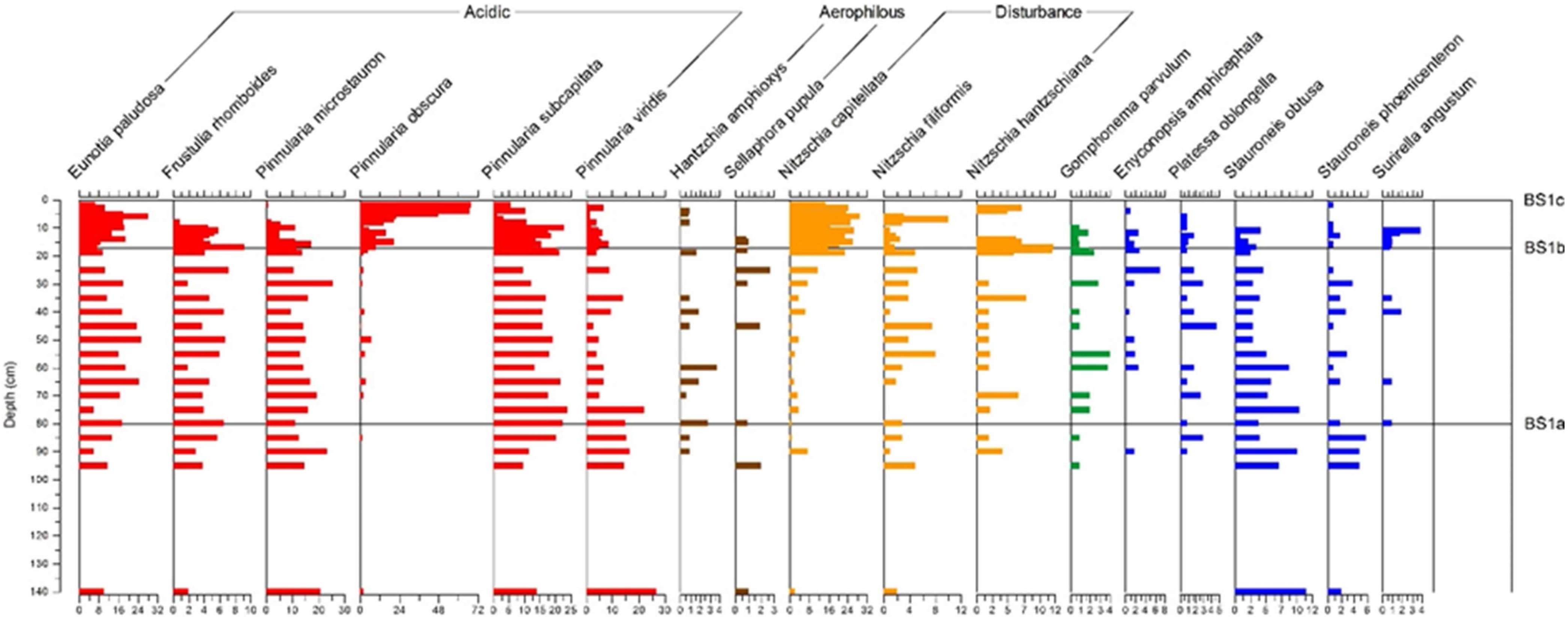


Figure 6: Stratigraphic diatom diagram of the more common species from core BS1 (Epiphytic – green; Benthic – blue)

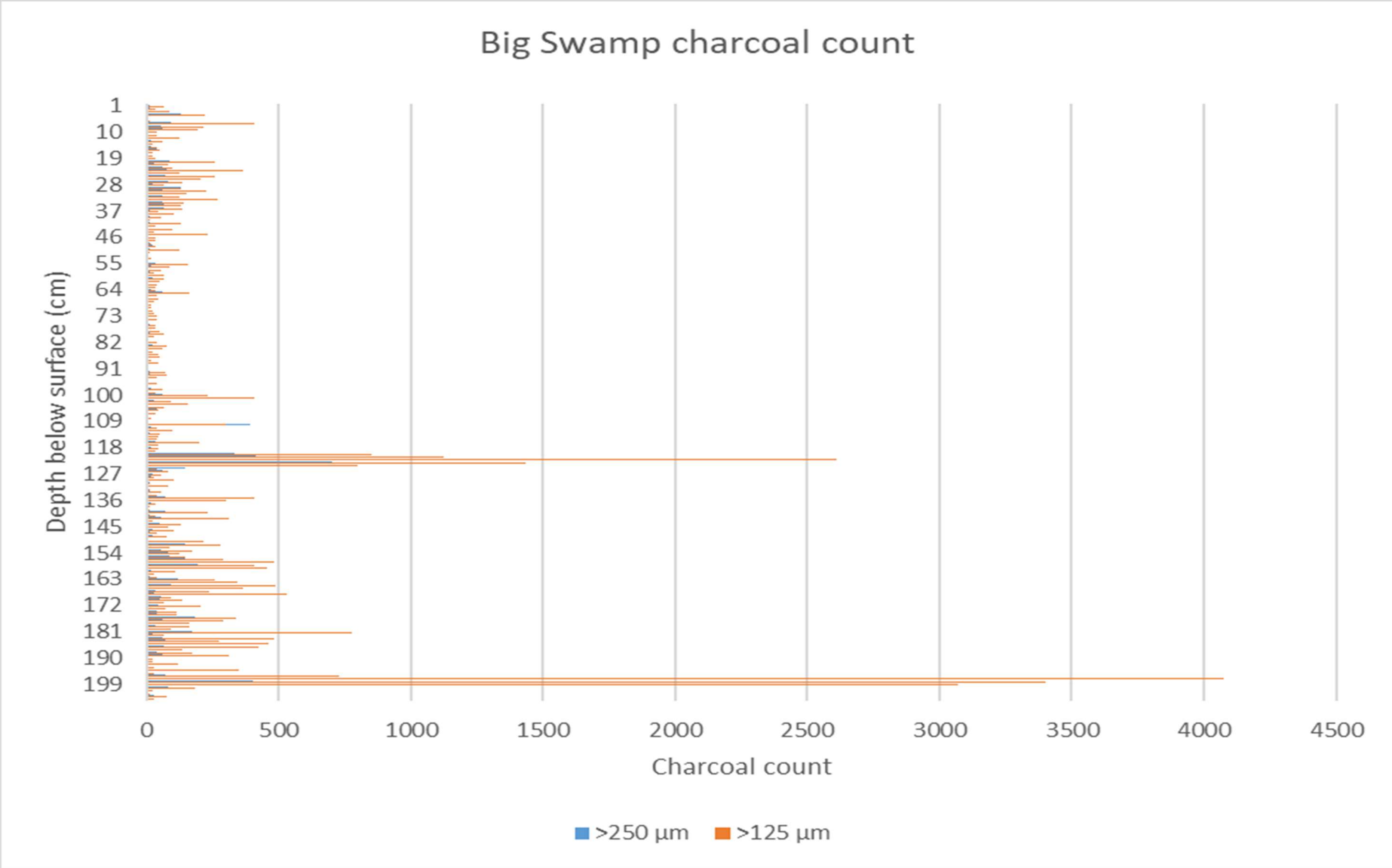


Figure 7: Charcoal particles within the BS1 core.

Deposition Modelling

It is clear that there is a hiatus somewhere in the record, since the first two dates suggest an accumulation rate of roughly 1,000 years per 50 cm (or 2000 years per meter). Continual deposition at this rate would have seen the basal age of 11,157-10,730 CAL BP at a hypothetical depth of over 6.5 m; given that this age was taken at 2 m depth it suggests a hiatus somewhere between the two dates. The sediment visually appears consistent down the core with no clear visual change; further analysis such as particle size analysis (discontinuous change in sediment particle size might point to the hiatus location), XRF/XRD (for elemental composition), or magnetic susceptibility could all potentially help identify the location(s) of the hiatus. However, the three environmental proxies employed in this study can also be used to infer where the hiatus may be located.

The most probable location for the hiatus is at approximately 1 m, where all three records indicate an abrupt change in conditions: no diatoms are preserved below this depth; the pollen record shows a shift in vegetation, and the charcoal record suggests a change in fire frequency. Whilst the location of the hiatus may differ, or there may be multiple hiatus present, only further dating and/or sediment analysis would be able to determine this. This is beyond the remit of the current project, therefore the use of the three proxies for the best current determination of the location of the hiatus will be used.

Figure 8 shows the output of the RBacon deposition model, which assumes a single hiatus at 1 m, and a constant rate of accumulation, calculated from the two radiocarbon dates at the top of the core. These assumptions can only be tested through further dating and sediment analysis.

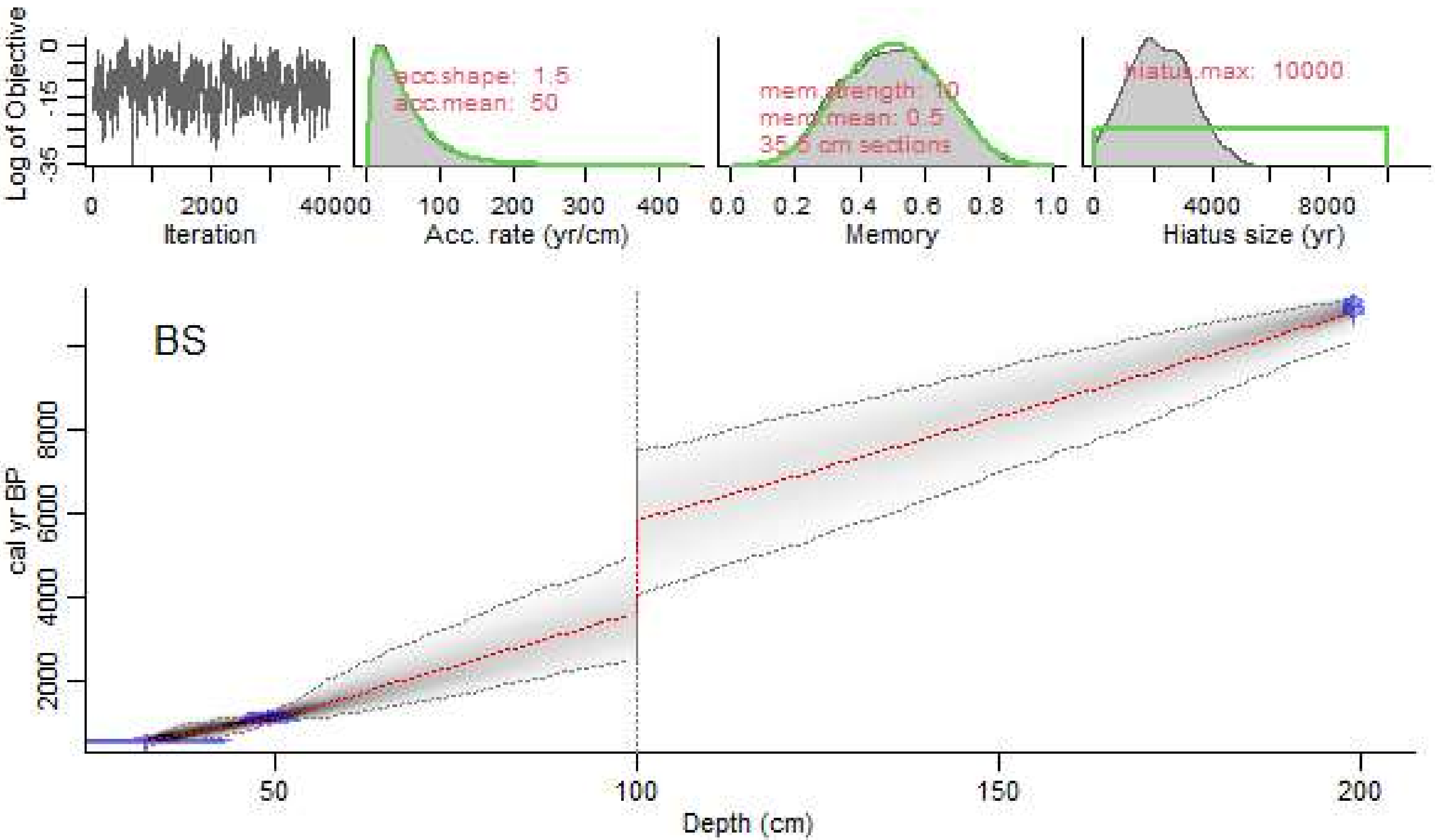


Figure 8: Modelled accumulation rate with modelled hiatus at 1m; N.B. model assumes only 1 hiatus, and constant accumulation rate either side of hiatus. Radiocarbon dates are shown in purple on the main accumulation curve (grey area delineated by dotted line is 95% confidence interval). Top left panel (Log of Objective/Iteration) shows 'fit' for each iteration of the model; centre left panel shows accumulation rate (sedimentation time), showing a mean accumulation rate of 50 years per cm; centre right panel (memory) shows how much accumulation rates can change from one depth to the other; given that we only have three dates the model has a near straight line interrupted only by the hiatus; right panel shows the likely length of the hiatus.

DISCUSSION

Land clearing associated with European/Australian colonisation

All records indicate an increase in disturbance in the upper 20 cm of the core, with dating indicating that this is within the past 500 years. The pollen and diatom records indicate that this can be further divided into two periods, probably relating to pre- and post-European/Australian colonisation, however, further dating would be needed to confirm this. The pollen record shows change through this period (reduced input of sedge pollen input; increase in tree pollen); before the upper-most sections indicate increase in grasses that is suggestive of clearing – possibly coincident with European/Australian colonisation of the area, or of subsequent establishment of agriculture. This aligns with the diatom record which shows disturbance from 20 cm (i.e., starting before 500 years ago). Historically, cultural burning was used in particular locations for the purpose of managing movement through the landscape and promoting food resources. It is likely that there was more regular burning in grassy and open woodland communities than in closed forests (Lindenmayer and Bowd 2022). The charcoal record suggests an increase in burning in the top 50 cm of the core; much of this could possibly represent cultural burning within the catchment. The final 10-15 cm probably represents post-European/Australian colonisation clearing as it coincides with increases in both grass pollen and diatom disturbance indicators. The dating and inferred accumulation rates would therefore suggest that these disturbance events relate to European/Australian activity on the landscape.

This landscape activity is represented by an increase in grass pollen in the record and increased disturbance indicators in the diatoms. Both are suggestive of land clearing and potential establishment of agriculture in the area and/or upstream. The continued presence of arboreal pollen does suggest that deforestation was not all encompassing and the area surrounding the swamp retained a population of trees during the period studied.

Whilst the diatoms indicate that pH remained relatively stable with slightly acidic water conditions, the significant reduction of benthic species at the top of the core suggests one of two possibilities: first, that increased sedimentation from land clearance filled the swamp and removed benthic conditions. Second, that the location the core was taken from is an area where benthic conditions no longer exist, but that they do exist elsewhere in the swamp. Alternatively – it is possible that the whole swamp was not explored, and accessibility to areas conducive to coring played a key role in site selection. However, as can be seen in Figure 3, the modern swamp is now covered with vegetation, and it is likely that areas that had deeper water have experienced sedimentation. This would be supported by the disturbance indicators.

Traditional Landscape: Pre-European/Australian colonisation

The significant disturbance signalled by the diatoms comes in at around 20 cm; this can largely be assumed to be the indicator of European/Australian induced landscape, therefore the environmental indicators in the depths below this should be indicative of the pre-European/Australian landscape. The diatom record at these depths (~20 – 100 cm) shows an established swamp with low sedimentation rates, specifically this contained clear water that allowed benthic forms to flourish, with organic matter in the swamp contributing to a more acidic water environment. The low sedimentation rates are supported both by the pollen, which shows established tree cover with sedges in the swamp, and the fire history which shows relatively low rates of burning. Higher fire frequencies and/or intensities could have contributed to higher accumulation rates due to impact on sediment-binding vegetation. An increase in fire intensity and/or frequency could have removed or damaged vegetation, resulting in higher sediment influx into the swamp. This ties in with the relatively low abundance of grasses shown in the pollen record, suggesting that an open forest did not exist, though grass was likely present either in small openings, or around the periphery of the swamp. The more established vegetation could have helped to bind the soil and minimise erosion of sediment into the swamp.

An interesting point to note is a trend of increased fire frequency/intensity is recorded in the time prior to the arrival of Europeans in the top 50 cm of the core, relating to the past 1,000 years. This is mirrored by a minor increase in the diatom disturbance indicators through this depth. However, this burning does not seem to significantly impact the pollen record with an increase in grass pollen. Early European/Australian colonisers were known to regularly use fire to *open up* country for grazing and other types of farming. This and direct clearing are likely to be reflected in the recent rise in grasses (Poaceae). Typically, large fires would drive an increase in grass and pioneer plants such as Acacia. There is little change in these groups until the upper 20 cm suggesting little disturbance through regular fire before European/Australian colonisation (Lindenmayer and Bowd 2022).

The dating suggests that “disturbance” was also occurring pre-European/Australian colonisation – however, the nature of this is clearly differentiated with the evidence of post-European/Australian colonisation grass pollen. The pre-European/Australian colonisation disturbance possibly relates to fire in the landscape (whether Traditional, natural, or a combination) which was mobilising sediments in the catchment and impacting both diatom communities and pollen composition. However, further work would be needed to explore this in detail – such as looking at sediment particle size (to determine sediment inputs into the swamp); loss on ignition (to explore the concentration of sediment input); elemental composition (to detect any changes through time); etc.

A hiatus in sedimentation in the core BS1

The dating indicates that there is a major hiatus in sedimentation in the sequence, with a significant discrepancy between the top and bottom of the core. The most likely location of this is at 1 m depth, where diatom, pollen, and charcoal signatures all indicate an abrupt change. However, it is possible that more than one hiatus exists, and there may have been multiple episodes of sedimentation and erosion within the intervening period.

Further dating is required to characterise the hiatus, and the extent to which the early/late Holocene is represented in the core. This could be complemented with particle size analysis, loss on ignition, elemental analysis, and other methods to better understand both the nature of the hiatus, and the deep time history of this swamp.

The large crater lakes to the west of Big Swamp attest to recent drying through the last two centuries (Jones et al. 2001). The recent fire events (which are not evident in the charcoal record) may be the result of a much greater number of potential ignition sources, the drier climate, increased fuel from regular deliberate burning in association with recent fire suppression (e.g., Gell et al., 1993).

Earlier landscape change

Further down the core, there are some interesting patterns. The peaks of charcoal at 195 cm and 120 cm may pre-date the expansion of eucalypt forest across western Victoria (~ 7,000 years ago; D'Costa et al., 1989) and so may have burned scrub or grassy communities. The pollen record shows low numbers of Eucalyptus at these levels. Further, they may pre-date the increases in human use of the western region until the climate improved in the mid-Holocene (~ 5-6,000 years ago) and so they may reflect natural ignition under a drier climate, in different vegetation communities to today. The Otway region has a humid climate today and effective moisture was even higher (~ 40%) through the mid-Holocene (Gell et al., 2013). So, for much of the record the site, and perhaps also the region, it may have been too wet to burn, except during brief drier periods.

The fire peaks at 120 cm and 200 cm also correspond to changes in vegetation communities, with notable shifts between Cyperaceae and Myrtaceae species. Whilst for most of the core the established swamp appears to be a stable environment, the big charcoal event at around 120 cm depth also corresponds to a significant drop in tree pollen and increase in sedges – suggesting that the event was large enough to either suppress pollen production in the trees or kill them completely. An increase in ferns (Pteridophyta) likely represents the rapid colonisation of the newly open forest floor with ferns, which would explain the absence of grasses and other colonisers.

The dates for the core were unexpected. Generally, for Victoria, an accumulation rate for aquatic environments is around 1 meter per 1,000 years; however, the rates encountered in the Big Swamp core are double this for the top half of the core. This probably reflects the local catchment conditions, with higher sediment availability upstream. An alternative hypothesis could be that a higher fire incidence has resulted in greater sediment mobility upstream. The dates obtained for core BS1 highlight that even short sequences can preserve windows into the deep time of this landscape, which are vital for better understanding long term changes in the landscape, the recent impacts of European/Australian colonisation, and the long connection to Country of First Nations people.

CONCLUSIONS

This project aimed to contribute to understanding the past environment at Big Swamp and its surrounds through the analysis of pollen (reconstructing past vegetation), diatoms (reconstructing the conditions of past waterways), and charcoal particulates (to reconstruct past burning within the landscape). This multiproxy approach to reconstructing the past environment of Big Swamp has contributed the following key points:

- Prior to European/Australian colonisation Big Swamp was a stable environment for at least the past 1,000 years, being a swampy environment surrounded by established forest. An increase in fire frequency/intensity during this period does not seem to have significantly impacted the vegetation, however, the diatom record does show a slight increase in disturbance indicators.
- European/Australian colonisation has significantly impacted the catchment, in particular this is visible in the diatoms and pollen. However, the swamp appears to have retained much of its character with established forest and sedge still dominant features in the local landscape. The main changes are likely to have been increased sediment input from land clearing higher in the catchment area (both higher run-off and increased sediment load), and further impact on the hydrology from the establishment of dams upstream. The decline in benthic diatom species also supports the idea that the swamp has probably experienced sedimentation, reducing the presence of deeper pools.
- The long-term stability of the swamp has been punctuated by fire – there are two instances of large-scale fires, dated to more than 1,000 years ago BP, interrupting the vegetation communities, in one case particularly severely with the reduction of forest cover.

- The presence of early-Holocene sediments and accompanying environmental record was unexpected but offers the opportunity to consider the deep time history of the swamp and its catchment.
- The diatom record is dominated by acid tolerant species throughout. While there are changes in the upper 20 cm the record does not suggest a recent increase in acidity. The diatom record shows that acidic conditions have prevailed over millennia. The rise in *Pinnularia obscura* in zone BS1c may reflect changing conditions recently, but insufficient is known of the relative preferences of the acidophilous species to infer a change in acidity.

This study has presented an insight into the past environment of Big Swamp and associated changes as indicated by pollen, diatoms, and charcoal. Whilst significant events and changes are evidenced within the sequence, the past 1,000 years prior to European/Australian colonisation appears to have been relatively stable. European/Australian activity has resulted in greater disturbance, sedimentation, and reduction in deeper water within the swamp; however, the surrounding vegetation is largely representative of pre-European/Australian colonisation conditions. Further research is needed to better resolve the nature of these; however, these data provide a useful indication of how conditions at the swamp have changed over time.

REFERENCES

Allam, L., 2020. Right fire for right future: how cultural burning can protect Australia from catastrophic blazes. *The Guardian*, 19 January. Available at: https://www.theguardian.com/australia-news/2020/jan/19/right-fire-for-right-future-how-cultural-burning-can-protect-australia-from-catastrophic-blazes

Battarbee, R.W., Jones, V.J., Flower, R.J., Cameron, Bennion, H., Carvalho, L., Juggins, S. 2002.Diatoms, in: *Tracking Environmental Change Using Lake Sediments: Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Springer Science & Business Media, pp. 155–202.

Blaauw M, Christen JA. 2011. "Flexible paleoclimate age-depth models using an autoregressive gamma process." *Bayesian Analysis*, 6(3), 457 – 474. doi:10.1214/11-BA618

Black, M.P., Mooney, S.D., Martin, H.A. 2006. A 43,000-year vegetation and fire history from Lake Baraba, New South Wales, Australia. *Quaternary Science Reviews* 25, 3003–3016.

Bliege Bird, R., Bird, D.W., Codding, B.F., Parker, C.H., Jones, J.H. 2008. The "fire stick farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. *Proceedings of the National Academy of Sciences* 105, 14796–14801. https://doi.org/10.1073/pnas.0804757105

Bliege Bird, R., Bird, D.W., Fernandez, L.E., Taylor, N., Taylor, W., Nimmo, D. 2018. Aboriginal burning promotes fine-scale pyrodiversity and native predators in Australia's Western Desert. *Biological Conservation* 219, 110–118. https://doi.org/10.1016/j.biocon.2018.01.008

Bowman, D.M.J.S. 1998. The impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140, 385–410. https://doi.org/10.1111/j.1469-8137.1998.00289.x

Bowman, D.M.J.S., Walsh, A., Prior, L.D. 2004. Landscape analysis of Aboriginal fire management in Central Arnhem Land, north Australia. *Journal of Biogeography* 31, 207–223. https://doi.org/10.1046/j.0305-0270.2003.00997.x

Burrows, M.A., Fenner, J., Haberle, S.G. 2014. Humification in northeast Australia: Dating millennial and centennial scale climate variability in the late Holocene. *The Holocene* 24, 1707–1718.

Carcaillet, C., Bouvier, M., Fréchette, B., Larouche, A.C., Richard, P.J. 2001. Comparison of pollen- slide and sieving methods in lacustrine charcoal analyses for local and regional fire history. *The Holocene* 11, 467–476.

Clark, J.S., Royall, P.D. 1996. Local and regional sediment charcoal evidence for fire regimes in presettlement north-eastern North America. *Journal of Ecology* 84(3), 365–382.

Clark, S.S., McLoughlin, L.C. 1986. Historical and biological evidence for fire regimes in the Sydney region prior to the arrival of Europeans: implications for future bushland management. *Australian Geographer* 17, 101–112. https://doi.org/10.1080/00049188608702909

Dahlhaus, P., Billows, C., Carey, S., Gwyther, J., Nathan, E. 2007. Lake Connewarre Values Project: Literature Review. Corangamite Catchment Management Authority, Colac, Victoria.
Department of Jobs, Precincts and Regions. 2021. GeoVic [WWW Document]. Earth Resources. URL https://earthresources.vic.gov.au/geology-exploration/maps-reports-data/geovic (accessed 3.30.22).

D'Costa, D. M., Edney, P., Kershaw, A.P., De Deckker, P. 1989. Late quaternary Palaeoecology of Tower Hill, Victoria, Australia. *Journal of Biogeography* 16, 461–482

Fletcher, M.-S., Hall, T., Alexandra, A.N. 2020. The loss of an indigenous constructed landscape following British invasion of Australia: An insight into the deep human imprint on the Australian landscape. *Ambio*. https://doi.org/10.1007/s13280-020-01339-3

Foged, N., 1978. Diatoms in eastern Australia. *Bibliotheca phycologica* 41, 1–243.

Freeman, D., Williamson, B., Weir, J. 2021. Cultural burning and public sector practice in the Australian Capital Territory. *Australian Geographer*, 52(2), 111–129.

Gell, P., Mills, K., Grundell, R. 2013. A legacy of climate and catchment change: the real challenge for wetland management. *Hydrobiologia* 708, 133–144. https://doi.org/10.1007/s10750-012- 1163-4

Gell, P.A., Stuart, I-M. & Smith, J.D. 1993. The response of vegetation to changing fire regimes and human activity in the Delegate River catchment, East Gippsland, Victoria. *The Holocene* 3(2), 150-160.

Gosling, W., Lawson, I., Roucoux, K., Boreham, S. n.d. *Fossil Pollen Preparation Protocol*, (V. 1-1). ed. Cambridge University, Cambridge, U.K.

Gott, B. 2005. Aboriginal fire management in south-eastern Australia: aims and frequency: Aboriginal fire management. *Journal of Biogeography* 32, 1203–1208. https://doi.org/10.1111/j.1365-2699.2004.01233.x

Graves, B.P., Ralph, T.J., Hesse, P.P., Westaway, K.E., Kobayashi, T., Gadd, P.S., Mazumder, D. 2019. Macro-charcoal accumulation in floodplain wetlands: problems and prospects for reconstruction of fire regimes and environmental conditions, *PLoS ONE,* 14(10), 1-33. https://doi.org/10.1371/journal.pone.0224011

Grimm, E.C. 1987: CONISS:aFORTRAN77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares, *Computers & Geosciences*,13,13–35.

https://doi.org/10.1371/journal.pone.0224011

Moore P. D. Webb J. A., Collinson M. E. 1991. *Pollen analysis* (2nd ed.). Blackwell Science.

Hallam, S.J. 1975. Fire and Hearth. Australian Institute of Aboriginal Studies, Canberra, ACT.

Holdgate, G., Norvick, M., 2017. Geological evolution of the Holocene Yarra Delta and its relationship with Port Phillip Bay. *Australian Journal of Earth Sciences* 64, 301–318.

Jones, R. N., McMahon, T.A., Bowler, J. 2001. Modelling historical lake levels and recent climate change at three closed lakes, Western Victoria, Australia (c. 1840–1990). *Journal of Hydrology* 246, 159–180.

Juggins,S. 2020. Rioja: Analysis of Quaternary Science Data, https://cran.r-project.org/package=rioja, R Package Version 0.9-26.

Krammer, K., Lange-Bertalot, H. 1991a. Susswasserflora von Mitteleuropa. Bacillariophyceae Teil iii: Centrales, Fragilariaceae, Eunotiaceae. Gustav Fischer Verlag, Stuttgart.

Krammer, K., Lange-Bertalot, H. 1991b. Susswasserflora von Mitteleuropa. Bacillariophyceae Teil iv: Achnanthaceae. Gustav Fischer Verlag. Gustav Fischer Verlag, Stuttgart.

Krammer, K., Lange-Bertalot, H. 1988. Susswasserflora von Mitteleuropa. Bacillariophyceae Teil ii: Bacillariaceae, Epithemiaceae, Surirellaceae. Gustav Fischer Verlag, Stuttgart.

Krammer, K., Lange-Bertalot, H. 1986. Susswasserflora von Mitteleuropa. Bacillariophyceae, Teil i: Naviculaceae. Gustav Fischer Verlag, Stuttgart.

Li, L., Gallagher, S., Finlayson, B. 2000. Foraminiferal response to Holocene environmental changes of a tidal estuary in Victoria, southeastern Australia. *Marine Micropaleontology* 38, 229–246. https://doi.org/10.1016/S0377-8398(00)00004-9

Lindenmayer D., Dowd E. 2022. Cultural burning, cultural misappropriation, over-simplification of land management complexity, and ecological illiteracy. *Ecological Management & Restoration* 23(3), 205-208. http:// doi/full/10.1111/emr.12564

McKemey, M., Patterson, M.L. 2019. Aboriginal Cultural Revival through the Reintroduction of Cultural Burning and Development of a Fire & Seasons Calendar, in south-eastern Australia, in: *6th International Fire Behaviour and Fuels Conference. International Association of Wildland Fire*, Sydney, Australia.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H. 2020. Vegan: Community Ecology Package, https://CRAN.R-project.org/package=vegan,r590 package version 2.7.

Reeves, J.M., Gell, P.A., Reichman, S.M., Trewarn, A.J., Zawadzki, A. 2016. Industrial past, urban future: using palaeo-studies to determine the industrial legacy of the Barwon Estuary, Victoria, Australia. Marine and Freshwater Research. 67, 837. https://doi.org/10.1071/MF15344

Skiba, R. 2020. Usage of Cool Burning as a Contributor to Bushfire Mitigation. Natural Resources 11, 307–316.

Sloss, C.R., Murray-Wallace, C.V., Jones, B.G. 2007. Holocene sea-level change on the southeast coast of Australia: a review. The Holocene 17, 999–1014. https://doi.org/10.1177/0959683607082415
Stevenson, J., Brockwell, S., Rowe, C., Proske, U., Shiner, J. 2015. The palaeo-environmental history of Big Willum Swamp, Weipa: An environmental context for the archaeological record.
Australian Archaeology 80, 17–31.
Stuiver, M., Polach, H.A. 1977 Discussion: Reporting of 14C Data. Radiocarbon (19):355-363.
Trauernicht, C., Brook, B.W., Murphy, B.P., Williamson, G.J., Bowman, D.M.J.S. 2015. Local and global pyrogeographic evidence that indigenous fire management creates pyrodiversity. *Ecology and Evolution* 5, 1908–1918. https://doi.org/10.1002/ece3.1494
Turney, C., Becerra-Valdivia, L., Sookdeo, A., Thomas, Z.A., Palmer, J., Haines, H.A., Cadd, H., Wacker, L.,
Baker, A., Andersen, M.S., Jacobsen, G., Meredith, K., Chinu, K., Bollhalder, S., Marjo, C. 2021. Radiocarbon Protocols and First Intercomparison Results from the Chronos 14Carbon-Cycle Facility, University of New South Wales, Sydney, Australia. *Radiocarbon* (63), 1003-1023, doi: 10.1017/RDC.2021.23
Ward, D.J., Lamont, B.B., Burrows, C.L. 2001. Grasstrees reveal contrasting fire regimes in eucalypt forest before and after European settlement of southwestern Australia. *Forest Ecology and Management* 150, 323–329. https://doi.org/10.1016/S0378-1127(00)00584-3
Whitlock, C., Larsen, C. 2002. Charcoal as a Fire Proxy, in: Smol, J.P., Birks, H.J.B., Last, W.M., Bradley, R.S., Alverson, K. (Eds.), *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, pp. 75–97. https://doi.org/10.1007/0-306-47668- 1_5

APPENDIX A Research personnel

Professor Peter Gell (Diatoma) has a Bachelor of Science (Hons), Master of Environmental Science and PhD from Monash University. Peter is a paleoecologist who examines change in the condition of wetlands over culturally relevant timelines. He specialises in the use of diatoms as indicators of present, and past, river and lake condition, particularly in coastal systems and across Australia's Murray Darling Basin. He has published research on both the Indigenous, and post-European fire regimes of our forest estate and climate variability and change over millennial timescales. Drawing on more than 35 years of experience, Peter managed the diatom analysis for the project.

Dr Matthew Meredith-Williams (La Trobe University) has a Bachelor of Science (with Honours) (University of Leeds), Masters in quaternary science (Cambridge University) and PhD in archaeology (University of York). Matthew is an archaeologist specialising in the emergence and dispersal of Pleistocene hominins and associated human-environmental interactions. This research builds on skills developed over the past twenty years in both the commercial and academic sectors, in landscape and environmental archaeology, and geoarchaeology. Matthew manages the Ancient Environments Lab (which specializes in palynology) at La Trobe University. With more than 20 years of experience, Matthew managed the pollen analysis for this project.

Dr Georgia Stannard (La Trobe University) has a Bachelor of Science, Bachelor of Arts (Hons) and Master of archaeological science from the Australian National University and a PhD in archaeology from La Trobe University. Georgia is an active researcher in the field of cold climate archaeology in Australia, is particularly interested in human adaptation and the intersection of landscapes, ecology, and people. Georgia is a registered Heritage Advisor under Section 189 of the *Aboriginal Heritage Act 2006* and has 15 years of experience in charcoal analysis. Georgia managed the paleofire analysis for this project.

Dr Tracy Martens (La Trobe University) has a Bachelor of Arts (Hons) in archaeology from the University of Saskatchewan (Canada), A Master of archaeological Science and a PhD in archaeology from the Australian National University. Tracy is a registered Heritage Advisor under Section 189 of the *Aboriginal Heritage Act 2006* and draws on over 10 years of experience in the study and management of cultural heritage. Tracy project managed this study and contributed to the collection of the core, preparation of core samples for analysis and conducting palynological laboratory protocols.

Emmy Frost (La Trobe University) has a Bachelor of Arts (Hons) in archaeology from La Trobe University and worked as a research assistant on this project.

Dr Rebekah Kurpiel (La Trobe University) has a Bachelor of Arts/Bachelor of Science degree (Hons) in archaeology and a PhD in archaeology from La Trobe University. Rebekah is a registered Heritage Advisor under Section 189 of the *Aboriginal Heritage Act 2006* and draws on over 15 years of experience in the study and management of Aboriginal cultural heritage, primarily in the State of Victoria. Rebekah contributed to project design and management.

APPENDIX B Radiocarbon dates

Chronos Radiocarbon Facility

UNSW SYDNEY

14 June 2023

Dr. Tracy Martens
La Trobe University – Archaeological Science
Melbourne Victoria 3086

Dear Tracy,

Please find below the results of the samples sent for radiocarbon analysis. All samples have been assigned a unique UNSW Laboratory Code, which should be referenced for publications. Should you have any queries about the pre-treatment and analysis methods please do not hesitate to get in touch.

Table 1: Chronos Radiocarbon Analysis - P143 - Paleoenvironmental Reconstruction of Big Swamp, Otway State Forest.

UNSW Laboratory Code	Sample Label	Pre-treatment Code	Date ^{14}C yr BP [a,b,c]	Date ± ^{14}C yr BP	$F^{14}C$	$F^{14}C$ ±
UNSW-2208	BSI 32-33	PS	500	30	0.939384	0.003268
UNSW-2209	BSI 49-50	PS	1150	30	0.866645	0.003086
UNSW-2210	BSI 199-200	PS	9620	50	0.301951	0.001833

Table 1 indicates the chemical pre-treatment method used for samples and associated matrix matched backgrounds and standards. Additional details of the chemical pre-treatment and duration can be found in Turney et al., 2021, full reference below.

[a] There are several assumptions implicit in the citation of a conventional radiocarbon age (date), for example the Libby half-life for ^{14}C of 5568 years was used; 'before present' (BP) refers to 1950 for the reference year zero; and that 0.95 NBS Oxalic Acid provided the modern reference standard. Radiocarbon years BP (^{14}C yr BP) are the units to express the date.

[b] Modern is defined as 95% of the ^{14}C activity for NBS Oxalic Acid standard (NIST 4990C), samples where $F^{14}C$ are greater than Modern (>0.95 $F^{14}C$) values are not reported, and dates are reported as > Modern.

[c] Date values are rounded according to the convention of Stuiver & Polach (1977).

Pre-treatment Code PS:

Pre-treatment Code PS denotes an Acid-Base-Acid protocol for sediments and peat.

For publication of these data, the following conventions for the reporting of ^{14}C determinations apply:

- The laboratory measurement should be reported as a conventional ^{14}C age and the units to express the date are in ^{14}C yr BP or a fractionation-corrected fraction modern ($F^{14}C$), with the corresponding UNSW laboratory code.

- Quoted errors are 1 standard deviation due to counting statistics multiplied by an experimentally determined Laboratory Error Multiplier.

- The sample material dated, and the pre-treatment methods applied, should be reported. Please reference our current facility paper (Turney et al., 2021) as this describes in detail the analytical methods required for chemical pre-treatment and AMS analysis.

- Where data are calibrated, the calibration curve used should be reported.

Thank you for choosing the Chronos Radiocarbon Facility to process your radiocarbon samples.

With best wishes,

Dr Tim Barrows, Director (Research) t.barrows@unsw.edu.au

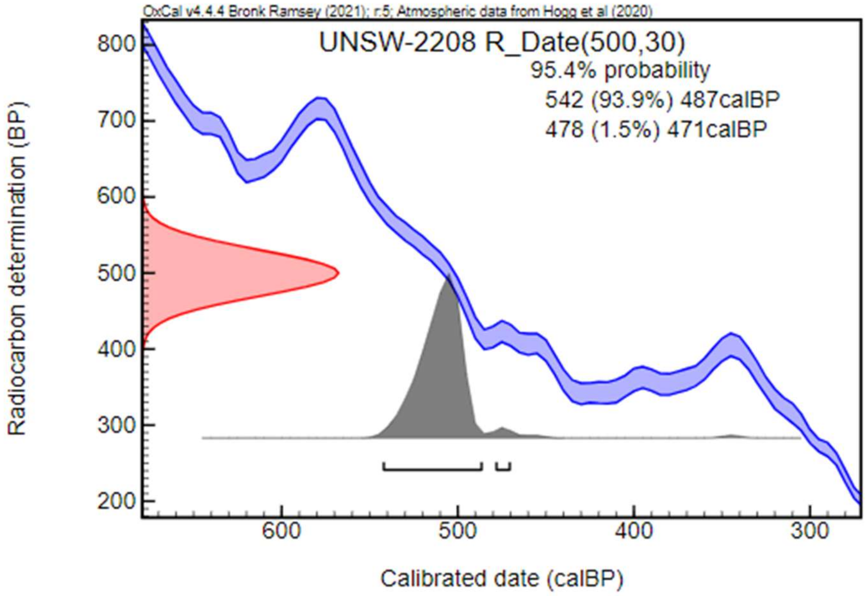
Juee Vohra, Technical Officer j.vohra@unsw.edu.au
Dr William T Hiscock, Technical Officer w.hiscock@unsw.edu.au
Dr Christopher E Marjo, Director (Operations) c.marjo@unsw.edu.au

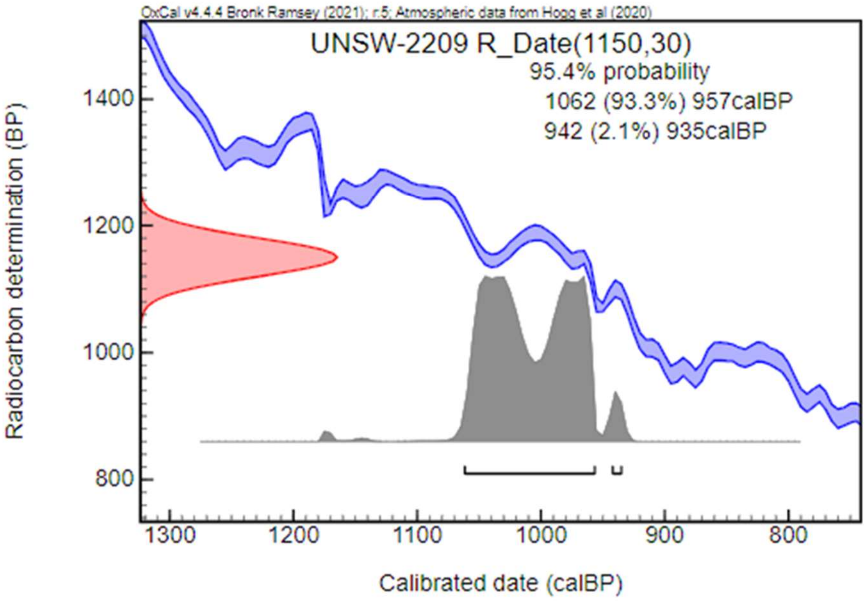
P143 – AMS10032023_T

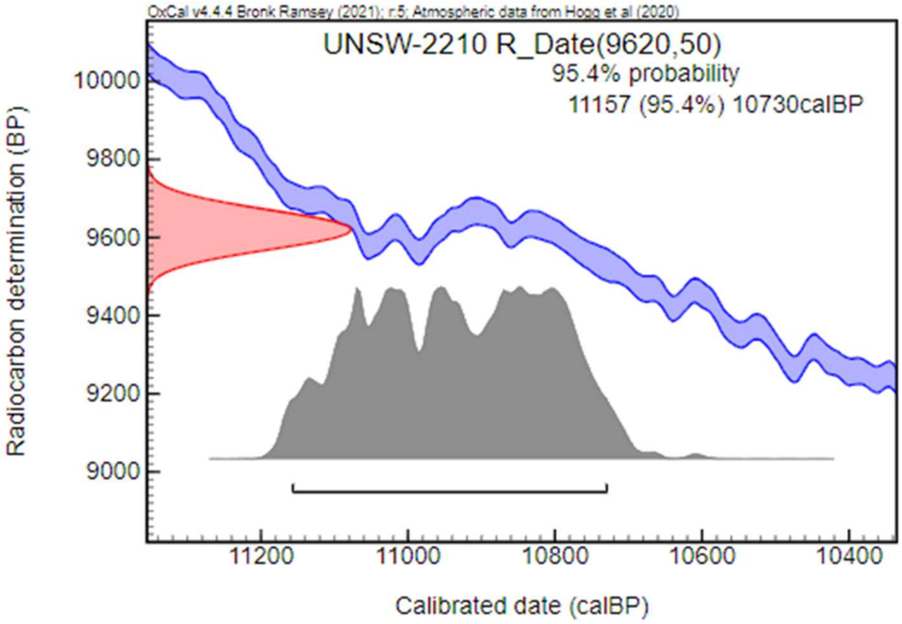
Reference:

Stuiver, M. and Polach, H.A. (1977) Discussion: Reporting of ^{14}C Data. Radiocarbon (19):355-363.

Turney, C., Becerra-Valdivia, L., Sookdeo, A., Thomas, Z.A., Palmer, J., Haines, H.A., Cadd, H., Wacker, L., Baker, A., Andersen, M.S., Jacobsen, G., Meredith, K., Chinu, K., Bollhalder, S., & Marjo, C. (2021). Radiocarbon Protocols and First Intercomparison Results from the Chronos ^{14}Carbon-Cycle Facility, University of New South Wales, Sydney, Australia. Radiocarbon (63): 1003-1023, doi: 10.1017/RDC.2021.23.


OxCal v4.4.4 Bronk Ramsey (2021); r:5; Atmospheric data from Hogg et al (2020)
UNSW-2208 R_Date(500,30)
95.4% probability
542 (93.9%) 487calBP
478 (1.5%) 471calBP
Radiocarbon determination (BP)
Calibrated date (calBP)


OxCal v4.4.4 Bronk Ramsey (2021); r:5; Atmospheric data from Hogg et al (2020)
UNSW-2209 R_Date(1150,30)
95.4% probability
1062 (93.3%) 957calBP
942 (2.1%) 935calBP
Radiocarbon determination (BP)
Calibrated date (calBP)


OxCal v4.4.4 Bronk Ramsey (2021); r:5; Atmospheric data from Hogg et al (2020)
UNSW-2210 R_Date(9620,50)
95.4% probability
11157 (95.4%) 10730calBP
Radiocarbon determination (BP)
10000
9800
9600
9400
9200
9000
11200
11000
10800
10600
10400
Calibrated date (calBP)

APPENDIX C Diatom data Core BS1

Species \ Depth(cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Achnanthidium minutissimum		1			2		1					2						2				1				1				1								
Achnanthidium plonensis					1																																	
Amphora libyca																														1								
Amphora ovalis																											1											
Asterionella formosa												2																										
Aulacoseira ambigua																																1						
Brachysira vitrea																				1																		
Caloneis bacillum										1									2	1													1					
Caloneis molaris																														2	2	1	3					
Caloneis sp 1																					2																	
Caloneis silicula																												3										
Cyclotella meneghiniana		1																																				
Diatoma tenuis						1						2																										
Encyonema mesiana																					2																	

Species \ Depth(cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Encyonema minuta			1						2											2			1			3		1			2	3	2			2		
Encyonema silesiaca																															2					2		
Encyonopsis amphicephala			1								3		1		2	1	3		8	2		1		2	2	3						2						
Encyonopsis microcephala																																1						
Eolimna minima					2																																	
Eunotia bilunaris					3	5					2	1	3	1		1		2	2				1					1										
Eunotia diodon								1		3		1	1						1			1																
Eunotia formica															4		1		1							2												
Eunotia minor	2			1		1							2										1		2				1	1		1						
Eunotia paludosa	7	3	9	21	60	21	19	24	20	13	15	7	22	9	7	9	5	12	12	19	12	19	25	26	16	20	26	26	3	19	14	6	12			10		
Eunotia pectinalis											2																	1										
Eunotia praerupta										2																	2											
Fallacia monoculata								2																														
Fragilaria capucina									1			1																										
Fragilaria gracilis				2																							2											
Frustulia rhomboides							1	2	5	6	6	5	4	4	5	11	4	5	8	2	5	7	4	7	6	2	5	6	2	7	6	3	4			2		

Species \ Depth(cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Gomphonema acuminatum																							1					2					1					
Gomphonema parvulum									1		2		1		1		2	3		3		1	1		4	4		3	1		1		1					
Hantzschia amphioxys			1	1			1											2			1	2	1			4	2	1		3	1	1					
Luticola mutica			1				4																														
Luticola nivalis																													1									
Mayamaea atomus					1	1						1					1		1																		
Melosira nummularia									2																												
Navicula absoluta						6	3																														
Navicula angusta																				3			1			1		1									
Navicula contenta				2	1		2	2		1	1		1				2		4	2		1	1	2		1		5		1	1					1		
Navicula menisculus																								1													
Navicula minuscula				2																																	
Navicula recens																	1	1													2						
Navicula sp. 1										3	1	4	3	1		4	7		1		1	3	2	3	2	2		3									
Navicula tenelloides						1		1						1																							
Navicula veneta					1														1			2															

Species \ Depth(cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Neidium ampliatum										1							2				1				2	1	1					1	2					
Nitzschia capitellata	16	7	6	27	62	30	26	26	18	27	13	25	23	26	21	19	16	28	13	8	4	7	1	4	2	1	2	5	2	1	1	8				2		
Nitzschia dissipata						2																																
Nitzschia filiformis					7	12	3			1	1	2	3	1		2		6	6	4	4	1	8	4	8	3	2			3	3	1	5			2		
Nitzschia frustulum								1	2	1	1	1																										
Nitzschia hantzschiana		2	5										7	7	3	14	12	7		2	8	2	2	2	2	2		10	1		2	4						
Nitzschia inconspicua											2																											
Nitzschia palea													1			1																						
Nitzschia perminuta					2	4	2	7	4		2								2			2							2									
Nitzschia vasta								4	4	2																												
Pinnularia borealis					3	1	4																		1					1		1						
Punnularia divergentissima																				2	4	1	2		2	3		2		1						1		
Pinnularia gibba					1			5	3	3	6	9	5	4	3	1				1	2	4	5	1	2	4				1			2					
Pinnularia intermedia				2	11		4	4	4	1		1	1	2		1				1					1													
Pinnularia interrupta						1				2			1																									

Species \ Depth(cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Pinnularia maior																					1		1															
Pinnularia microstauron	1						2	1	12		6	4	6	11	18	14	10	17	12	27	17	10	15	16	13	15	18	30	8	12	13	24	15			21		
Pinnularia obscura	72	13	70	56	47	25	15	14	2	6	18	10	6	21	10	11	5	2	2	1		3	1	7	3		4	3			1					2		
Pinnularia subcapitata	6		11		3	4	11	6	25	14	20	20	16	1	16	16	21	26	11	13	18	17	17	20	18	14	23	27	12	24	21	12	10			14		
Pinnularia subrostrata																														2								
Pinnularia viridis	1	2		2	3	1	4	2	2	5	7	3	6	6	9	6	2	5	10		15	10	3	5	4	7	7	8	11	16	16	17	15			27		
Placoneis elginensis																1			2										1				2					
Planothidium grana					2	2																																
Planothidium lanceolatum																					1				1													
Platessa oblongella					2	1	1		1			2	1	1		1	1		2	3	1	2	5			2	1	4		1	3	1						
Rhopalodia gibba																1																						
Rhopalodia operculata															1			1										1		1	1		9					
Sellaphora pupula													1	1			1		3	1			2							1			2			1		
Sellaphora seminulum																	1																					
Stauroneis anceps																	4																					

Depth(cm) / Species	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120	140	160	180
Stauroneis kriegerii											1												1					2			1		2					
Stauroneis legumen							1																			1												
Stauroneis obtusa								1		4	1	1		2	1	4	2	3	5	3	4	3	3	3	5	9	6	8	5	4	4	10	7			11		
Stauroneis phoenicenteron	1								1		1	2			1				1	4	2	3	1		3	1	2			2	6	5	5			2		
Stauroneis producta										1																												
Surirella angusta								1		4	2	1	1	1	1	1					1	2					1			1								
Surirella bifrons																									1													
Surirella ovalis																												1										
Tryblionella angustata								2																														
Tryblionella debilis																			2																			
Tryblionella levidensis																						2																
Ulnaria ulna								1		1		1					1										1			1	1		2					
Total	106	29	105	116	214	119	104	107	109	102	113	108	116	100	103	119	104	122	112	105	106	107	106	103	100	106	106	154	50	107	104	103	102	0	0	100	0	0

APPENDIX D Pollen Data

Pollen Data Core BS1

Species / Depth cm	12-13	13-14	17-18	24-25	35-36	40-41	45-46	60-61	65-66	70-71	75-76	80-81	85-86	90-91	95-96	121-122	140-141	160-161	198-199
Eucalyptus	55	63	20	80	60	8	115	28	98	113	17	115	45	32	80	34	2	15	36
Melaleuca		7			40	19	20	18		7	39	7	28	39	2		2		27
Myrtacaea	136	4	210	144	70	153	20	74	27	68	75	17	62	72	50	2	55	151	28
Casuarinaceae	4	2			9	5	5	3	4	2	3	1	10	2	41		4	6	8
Callitris					41	21	41	34	27	3	28	11	1				8		4
Pinus			0														5		
Myoporaceae		4			1		1			3	3	1	3	1	7	2	2		
Sapindaceae											1								
Acacia	1				5	1	1	3	4	2	1	1	1	1	2		10	2	
Cassia	5	9			5	6	26	20	33	12	8	16	13	33	49	3	18	14	40
Caesalpiniaceae	2																		4
Hakea/Grevillea																			
Banksia	2	1			5	7	7	6	9	7	4	8	14	14	27	1	5		5
Proteaceae																			
Gyrostemon acaea																			
Pittosporaceae																			
Exocarpus																			
Santalum																			
Chenopodiaceae								1	1			2	1	1			2		
Epacridaceae														1					
Rhamnaceae												1		3					
Zygophyllaceae				1															2
Asteraceae		2	1		1			1	2			1			1		2		1
Apiaceae					1	1	1	3	3	4	1	1	1	1			3		3

Depth cm / Species	12-13	13-14	17-18	24-25	35-36	40-41	45-46	60-61	65-66	70-71	75-76	80-81	85-86	90-91	95-96	121-122	140-141	160-161	198-199
Fabacaea												9							
Haloragaceae	2	1			7	2	9	16	11	6	13	4	1		1		2		20
Malvaceae		27	16								2					3	2		
Rubiaceae					5	3	2		3	1					3				2
Plantaginaceae						1								2				5	
Poacaea	74	42	17	1	3	5	4	9	1	5	20	26	7	19	13	1	7		5
Scrophulariaceae								1											
Sterculiaceae																			
Violaceae											3	3				3			
Cyperaceae	41	74		11	45	67	53	75	41	56	59	68	114	79	28	267	58	135	68
Cyatheaceae											1								
Pteridophyta					5	2	5	10	38	11	22	19					117		47
Undifferentiated (Whole Grains)		8	77	26	5	6	11	12	5	3	2	6	37	25	30		4		11
Undifferentiated (partial or torn grains)	112	35	11	19	4	18	20	6	16	20	11	22	30	40	67	17	28	55	11
Lycopodium	73	54	12	0	14	9	18	6	16	9	40	34	35	55	77	1	15	185	19
Angophora costata																			
Caryophyllaceae																			
Cupressaceae																			
Eucalpt amygdalina		14																	
Eucalpt globulus				1															
Kunza ambigua																			
L. laevigatum																			
L. lanigerm																			
L. squarrosum		31																	
Eucalypt diversifolia																			
Eucalypt ovata				78															

Depth cm / Species	12-13	13-14	17-18	24-25	35-36	40-41	45-46	60-61	65-66	70-71	75-76	80-81	85-86	90-91	95-96	121-122	140-141	160-161	198-199
Eucalypt viminalis																			
Solanaceae																			
Papaveraceae																			
Eucalyptus s-type		13														3			
Melaleuca Symphomyrtus															3				
Eucalyptus p-type		6														3			
Melaleuca sp.																			
Eucalypt Calytrix tetragona																			
Total Sum	**507**	**397**	**364**	**316**	**326**	**334**	**359**	**326**	**339**	**332**	**353**	**373**	**403**	**420**	**481**	**340**	**351**	**568**	**341**
Total Identifiable Pollen	**322**	**300**	**310**	**361**	**303**	**301**	**310**	**302**	**302**	**300**	**300**	**311**	**301**	**300**	**307**	**322**	**304**	**328**	**300**

Pollen Data Core BS2

Species \ Depth (cm)		39-40	59-60	79-80	101-102	122-123	179-180
Eucalyptus		46	24	12	10	7	28
Melaleuca			43	16	3	5	1
Myrtacaea		119	57	101	22	39	10
Casuarinaceae		11	8	5		4	7
Callitris			9	2			
Pinus			7	12	222	12	
Myoporaceae							5
Sapindaceae							
Acacia	Trees and tall shrubs		1	1			
Cassia		6	11	5	1		4
Caesalpiniaceae							
Hakea/Grevillea							
Banksia		1	6	2	2	8	
Proteaceae			4				
Gyrostemon acaea							
Pittosporaceae							
Exocarpus							
Santalum							
Chenopodiaceae				2		2	
Epacridaceae	Low Shrubs				1		
Rhamnaceae							
Zygophyllaceae			3		13		
Asteraceae			2	4		5	
Apiaceae			1	10			
Fabacaea							
Haloragaceae		1	6	8			3
Malvaceae					1	6	6
Rubiaceae	Herbs and Grasses			2			
Plantaginaceae							
Poacaea		83	3	28	2	6	20
Scrophulariaceae							
Sterculiaceae							
Violaceae			1				1
Cyperaceae		92	104	82	34	208	200
Cyatheaceae	Aquatics						
Pteridophyta			10	8			
Undifferentiated (Whole Grains)			2	3	34	21	
Undifferentiated (partial or torn grains)			9	15	52	9	27
Lycopodium		136	21	11	18	16	
Angophora costata							
Caryophyllaceae							
Cupressaceae							

Eucalpt amygdalina							9
Eucalpt globulus							
Kunza ambigua							
L. laevigatum							
L. lanigerm							
L. squarrosum							4
Eucalypt diversifolia							
Eucalypt ovata							
Eucalypt viminalis							
Solanaceae							
Papaveraceae							
Eucalyptus s-type							4
Melaleuca Symphomyrtus							
Eucalyptus p-type							1
Melaleuca sp.							
Eucalypt Calytrix tetragona							
Total Sum		495	332	329	415	366	330
Total Identifiable Pollen		359	300	300	311	320	303