Gunbower Forest Wetlands – Paleoecological History

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Summary

This project identified and enumerated the fossilised remains of pollen, charcoal, diatom algae and crustaceans (cladocera) archived in the sediments of three Gunbower Forest wetlands. The following conclusions are made based on the known ecology and taphonomy of the specimens recorded:

1. **The sediment sequence from Black Swamp extends back to, and possibly beyond, the boundary of European settlement;**

2. **The sediment sequences from Green Swamp and Little Reedy Lagoon appear to extend only as far as the onset of river regulation (c 1940 CE);**

3. **The relatively short nature of the records suggests that, during indigenous times, these wetlands were dry so frequently (3-7 times/decade) that no net sediment accumulation occurred;**

4. **The fragmentary nature of the diatom fossils in the lower sediments suggests that, even after regular inundation, the wetlands were shallow or existed as mudflats;**

5. **The three wetlands were originally clear water systems with some submerged aquatic plants. From c 1960 CE these wetlands transitioned into turbid system dominated by phytoplankton and floating plants;**

6. **The water quality transitioned from clear, fresh, oligotrophic, slightly acid to circum-neutral water to turbid, fresh, eutrophic, neutral to alkaline water;**

7. **The modern sedimentation rates are in the order of 3-5 mm/yr which is low relative to other wetlands along the Murray River floodplain;**

8. **The charcoal record increases in the middle and upper sections. While this may reflect increased post-European burning it may reflect increased transport of charcoal into the wetlands. Irrespective, the concentrations of charcoal are low relative to those documented from wetlands in other Australian biomes.**

Introduction

The Gunbower Forest hosts wetlands that are deemed of international significance under the Ramsar Convention, and the area is listed as an icon site under the Living Murray Program. The floodplain wetlands are targets for wetland restoration and the government has invested in infrastructure to provide environmental flows to the wetlands with a view to ensuring that their ecological character and biological diversity are maintained and enhanced.

The site had been subjected to human use for millennia, with abundant evidence for intensive Aboriginal occupation that includes earth mounds, clay balls and widespread canoe trees. Under conditions when floodplain lakes are full, the slack water conditions allow for the accumulation of sediments. Preservation of wetland sediments present an archive of evidence for biological and sedimentological changes through time within and around the wetlands. Recovering and analysing this evidence, the paleoecological approach, along with the analysis of archaeological and enthohistoric material provides a powerful insight in to how these wetlands have responded to changes in human occupation and other factors, such as climate. This data allows us to better understand the contemporary condition of these significant wetlands, as well as the interactions between floodplain environments and people. This project reports on analyses of microfossil remains from sediment cores extracted from key Gunbower wetlands that were used to reconstruct local and regional water quality, vegetation and fire history.

Methodology

Five wetlands were selected for sediment coring which was completed on the 18th and 19th October, 2017. At each site, the sediment was probed at multiple locations to ascertain the location with the longest sediment sequence – usually in the mid-point of each wetland. A d-section coring device was used to extract sediment (after Jowsey 1966) in 50 cm contiguous segments. Coring continued until the nose of the corer met with resistance, thus, halting progress. The wetlands and length of sediment extracted are:

- Black Swamp (84 cm)
- Green Swamp (86 cm)
- Little Gunbower Lagoon (40 cm)
- Little Reedy Lagoon (45 cm)
- Reedy Lagoon (21 cm)

Replicate cores were taken to ensure sufficient sediment was available for multiple analyses. All 50 cm segments were wrapped and stored in an *Engel* field fridge and stored at ~ 4^{o}C in the core store at Federation University. Subsamples (0.5 – 1 cc) of sediment were extracted at ~ 5 cm increments for preparation for charcoal, pollen and diatom analysis. In addition several samples of 1 cc were extracted for cladoceran analysis.

Diatoms were isolated from the sediment by treating all samples with warm H_2O_2 and HCl to disperse clays and digest organic matter. The remaining suspension was washed, dried onto coverslips and mounted on slides using the high diffractive index mountant NAPHRAX. Up to 200 diatom valves were identified using Krammer & Lange-Bartalot (1986-1991) and counted from each slide made from the sediment from the cores from Green Swamp, Black Swamp and Little Reedy Lagoon. Where diatoms were sparse at least three transects were traversed and all entire valves counted.

Pollen was isolated from all 0.5 cc samples taken at 5 cm intervals in cores from Green Swamp, Black Swamp and Little Reedy Lagoon using standard methods (Faegri and Iversen 1989). A minimum of 300 terrestrial pollen grains were identified per sample and percentages were determined using a sum that comprised terrestrial pollen types only. Aquatic and spore pollen percentages were calculated from a supersum including all pollen and spores. Macroscopic charcoal was processed at 1 cm continuous intervals for the entire length of each sedimentary sequence according to standard protocols (Whitlock and Larsen 2001). A sample volume of 1.25 cc was placed in store-bought bleach for at least seven days then sieved through 250 μm and 125 μm mesh and enumerated under a dissecting microscope at 10 to 20X magnification. Charcoal concentration was calculated from the summed macroscopic charcoal counts.

For cladocceran analysis about 3g of wet sediment was treated with warm 10% KOH and 10% HCL to disperse the matrix. Samples were sieved and rinsed through a 63 μm sieve and stained with safranin. Individual cladocerans were counted and concentrations determined using an exotic pollen spike (*Lycopodium* spp.) (*sensu* Faegri & Iversen, 1989). A total of 100 cladoceran individuals were identified at 100–400x magnification based on Frey (1991) and Shiel & Dickson (1995).All data were assembled in excel and entered into C2 (Juggins 2003) for the creation of stratigraphic diagrams. Diatom and pollen principle component analyses (PCA) were performed in R (R Development Core Team, 2014) using the rioja package (Juggins, 2016). Ordinations were performed separately on all pollen and diatom taxa, that had an abundance above 1% and occurred in at least two samples, with Hellinger transformation.

Results

The pollen record provides evidence for change in both aquatic and regional terrestrial vegetation. The first arrival of exotic pollen (e.g. *Pinus*) provides evidence for the post-European phase. The macroscopic charcoal record provides proxy evidence for local fire activity, while microscopic charcoal provides information on regional fire activity and for more localised burning of fine fuels, such as grasses. The diatom record provides evidence of changing water quality including pH, nutrient status, turbidity and light regime and changing habitat as growth substrate and changes in cladocerans reveal changing faunal habitat availability over time. Where patterns of change in diatom records align, correlation with records from wetlands elsewhere in the Basin can assist in the establishment of core chronologies.

Black Swamp

The pollen and charcoal data from Black Swamp is displayed as Figure 2 and the diatom data is displayed in Figure 3. Pollen from *Eucalyptus* is abundant and sustained throughout the record, while *Allocasuarina* increases to maximum at 40 cm and then declines to the surface. *Pinus* pollen appears first in the record at 20 cm. Of the herb flora Asteraceae (daisy) declines above 40 cm. Apiaceae reaches maximum between 60-47 cm but is uncommon elsewhere whereas Scrophulariaceae increases rapidly at 35 cm and these numbers are sustained to the surface. *Polygonum* is relatively abundant at the base but declines to absence by 30 cm. Of the aquatic taxa *Myriophyllum* (milfoil) is the most common but has relatively low representation above 30 cm, (and below 60 cm). *Azolla* increases above 45 cm and *Lemna* (duckweed), and an unknown bryophyte, increase from ~ 15 cm as does *Botryococcus* algae. The incidence of charcoal decreases from 65 cm and increases above 15 cm.

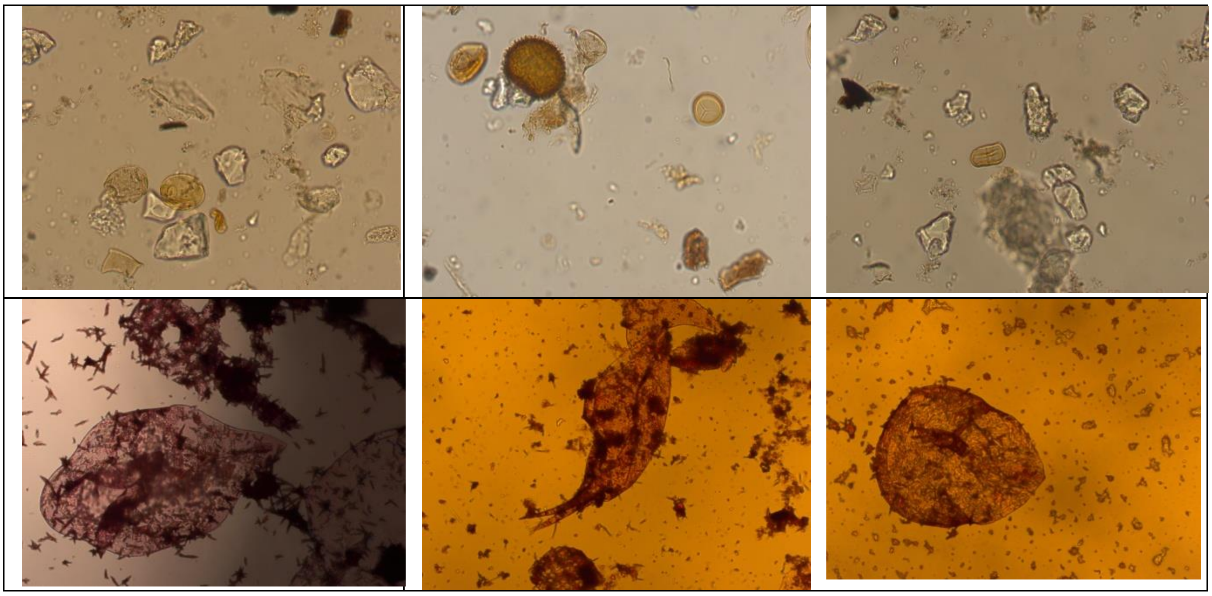

Figure 1. Microphotographs of pollen and spores (top row) and cladoceran head capsules (bottom row) (photos by Kristen Beck and Giri Kattel).

The diatom flora from 83-35 cm is dominated by benthic types (*Craticula cuspidata*, *Eunotia serpentina*, *Stauroneis phoenicenteron*), with many valves broken, with limited numbers of plankton (mostly *Aulacoseira italica*). The benthic taxa decline to the surface and, from 55 cm, are replaced in sequence by *Cyclotella meneghiniana*, *Diadesmis confervaceae*, *Fragilaria capucina gracilis*, *Sellaphora pupula*, *Lemnicola hungarica*, *Nitzschia* spp. (incl. *N. palea*) and *Cyclotella pseudostelligera*. *Ulnaria ulna* is present throughout but declines to the surface. Above 30 cm the *Aulacoseira* spp. increase and *A. granulata* (incl. var. *angustissima*) and *A. alpigena* co-dominate. Generally, above 30 cm benthic taxa are less abundant and are replaced by aerophilous and planktonic forms.

Green Swamp

The pollen and charcoal record from Green Swamp is provided as Figure 4 while the diatom record is shown in Figure 5.

Eucalyptus is the most abundant pollen throughout the record while Poaceae (grasses) is also common. *Allocasuarina* declines from 30 cm to the surface while Chenopodiaceae (saltbush) increases towards 10 cm. Exotic pollen are evident from 80 cm to the surface. *Lemna* and an unknown bryophyte increase from 15 cm and 20 cm respectively while numbers of *Typha* and *Triglochin* are greatest from 20 cm. Other than a small peak at 80 cm the abundance of charcoal is low throughout.

The basal sediments are dominated again by broken fragments of benthic taxa including *Craticula cuspidata*, *Eunotia serpentina*, *Pinnularia viridis* and *Stauroneis phoenicenteron*. Here epiphytes (*Gomphonema parvulum*) and aerophilous forms (*Diadesmis confervaceae*, *Sellaphora pupula*) are common at the base, as are *Fragilaria capucina gracilis* and *Ulnaria ulna*. Plankton are rare until 60 cm above which they dominate, with *Aulacoseira alpigena*, and then *A. granulata*, reaching maximum values at 60 cm and 40 cm respectively. *Cyclotella meneghiniana* increases from 80 cm peaking between 15-10 cm.

Little Reedy Lagoon

The pollen and charcoal record from Little Reedy Lagoon is provided as Figure 6 while the diatom record is shown as Figure 7.

Again *Eucalpyptus* and Poaceae dominate the pollen record. Exotic taxa (*Pinus*, Asteraceae Liguliflorae) are evident from the base. Many other types are sustained throughout the record. *Lemna* and an unknown bryophyte increase from 15 cm while *Azolla* declines from 20 cm. The abundance of charcoal gradually increases towards the surface.

The basal samples are again dominated by fragmented valves of benthic forms such as *Craticula cuspidata*, *Eunotia serpentina*, *Pinnularia viridis* and *Stauroneis phoenicenteron*, but also the aerophilous taxa *Diadesmis confervaceae* and *Sellaphora pupula,* as well as the facultative planktonic *Fragilaria capucina gracilis* and *Ulnaria ulna*. Of the plankton *Aulacoseira* spp. increase from 35 cm while *Cyclotella meneghiniana* is common throughout and *C. pseudostelligera* increases from 15 cm. The epiphyte *Gomphonema parvulum* increases from 17 cm as does the eutraphentic *Nitzschia palea*. Benthic taxa represent ~ 40% of valves from 45 – 17 cm above which plankton dominates reaching 80 % at 17 cm.

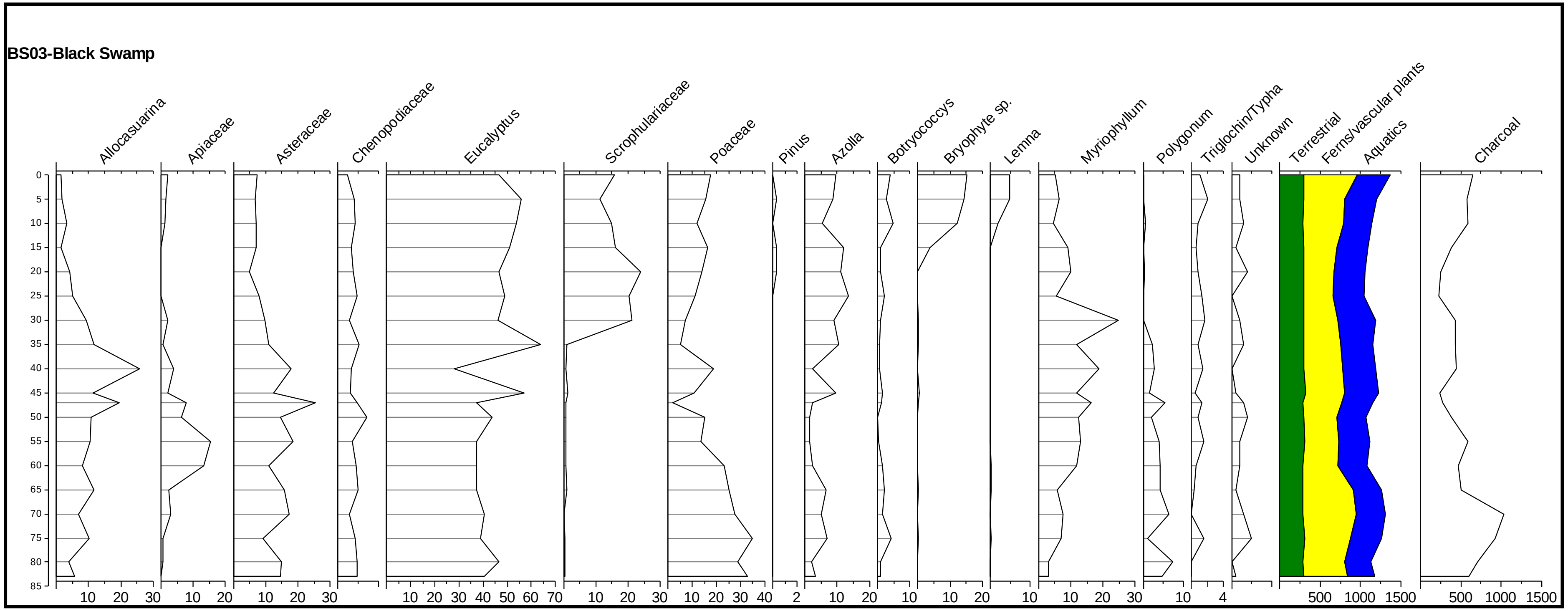

Figure 2. The pollen record from core BS03 from Black Swamp.

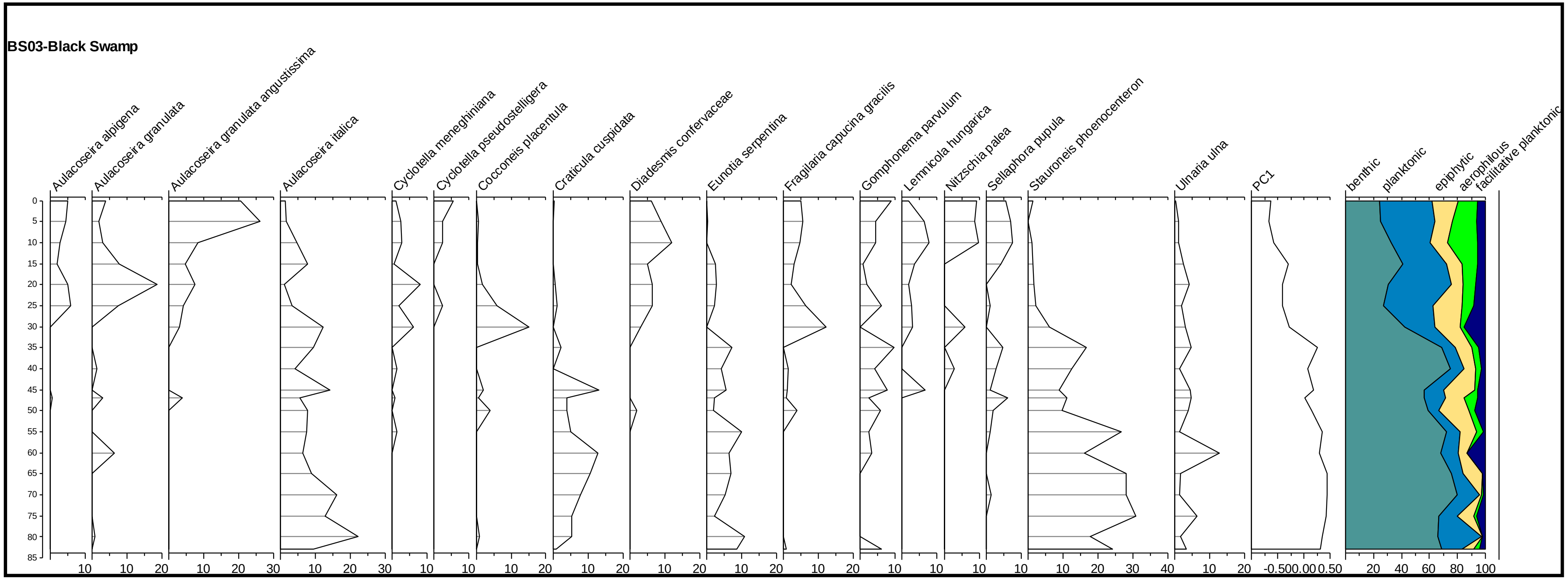

Figure 3. The diatom record from core BS03 from Black Swamp.

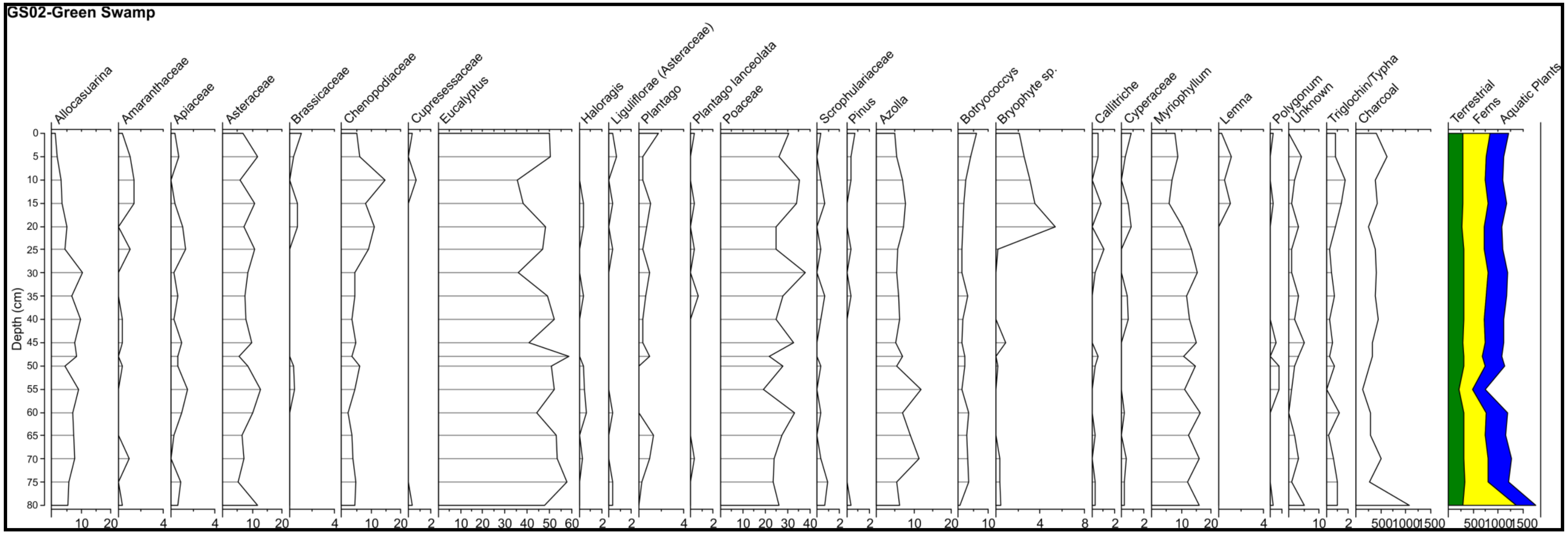

Figure 4. The pollen record from core GS03 from Green Swamp.

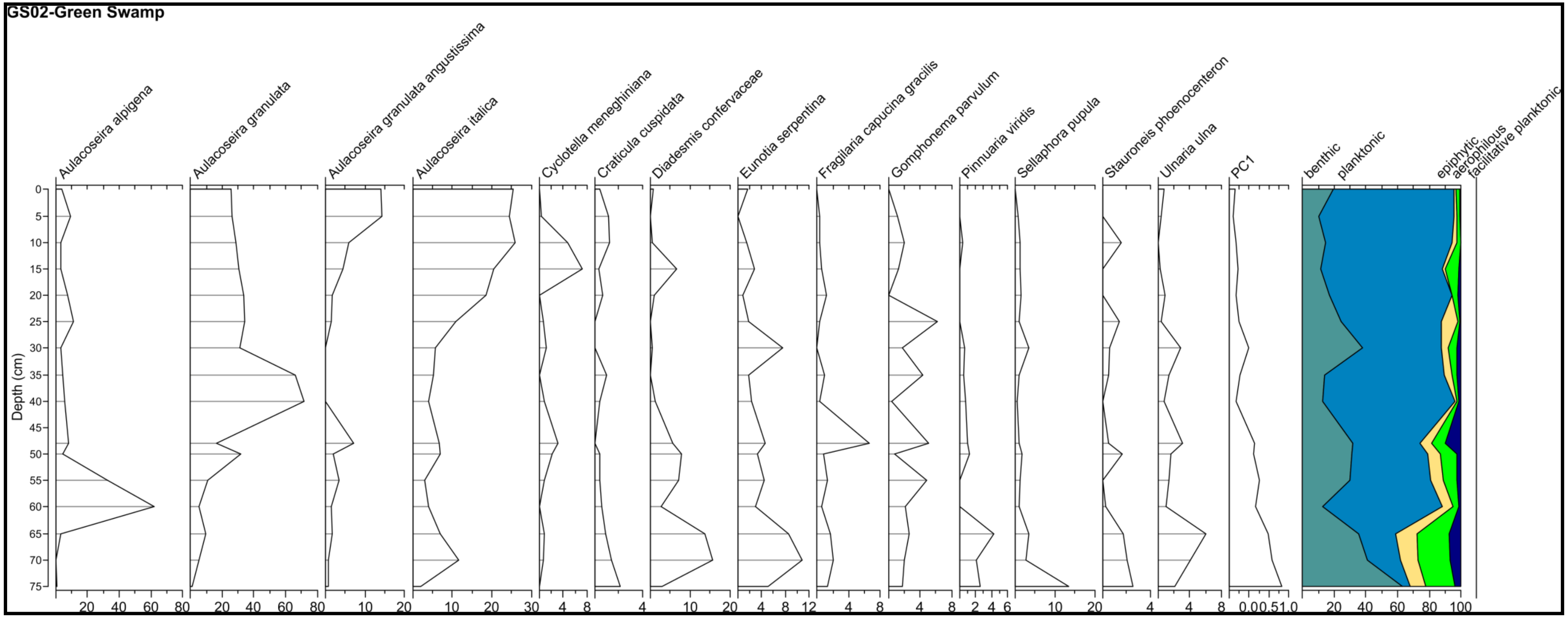

Figure 5. The diatom record from core GS02 from Green Swamp.

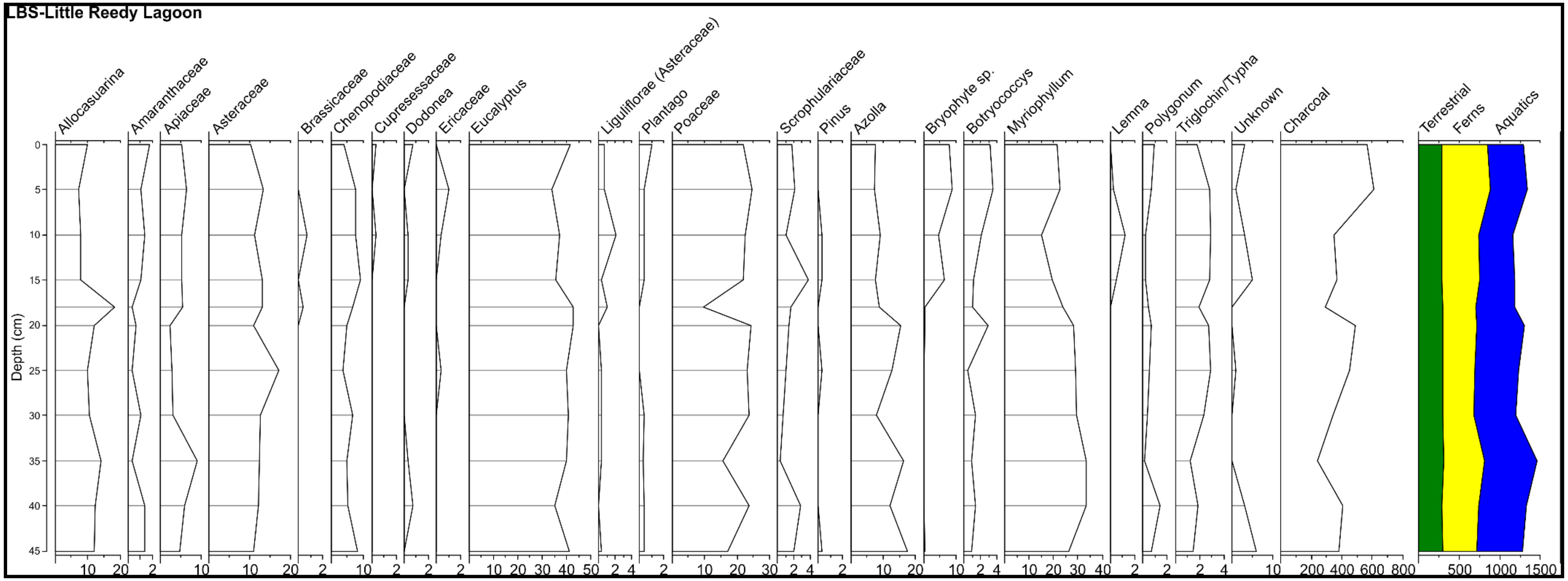

Figure 6. The pollen record from core LRS01 from Little Reedy Lagoon.

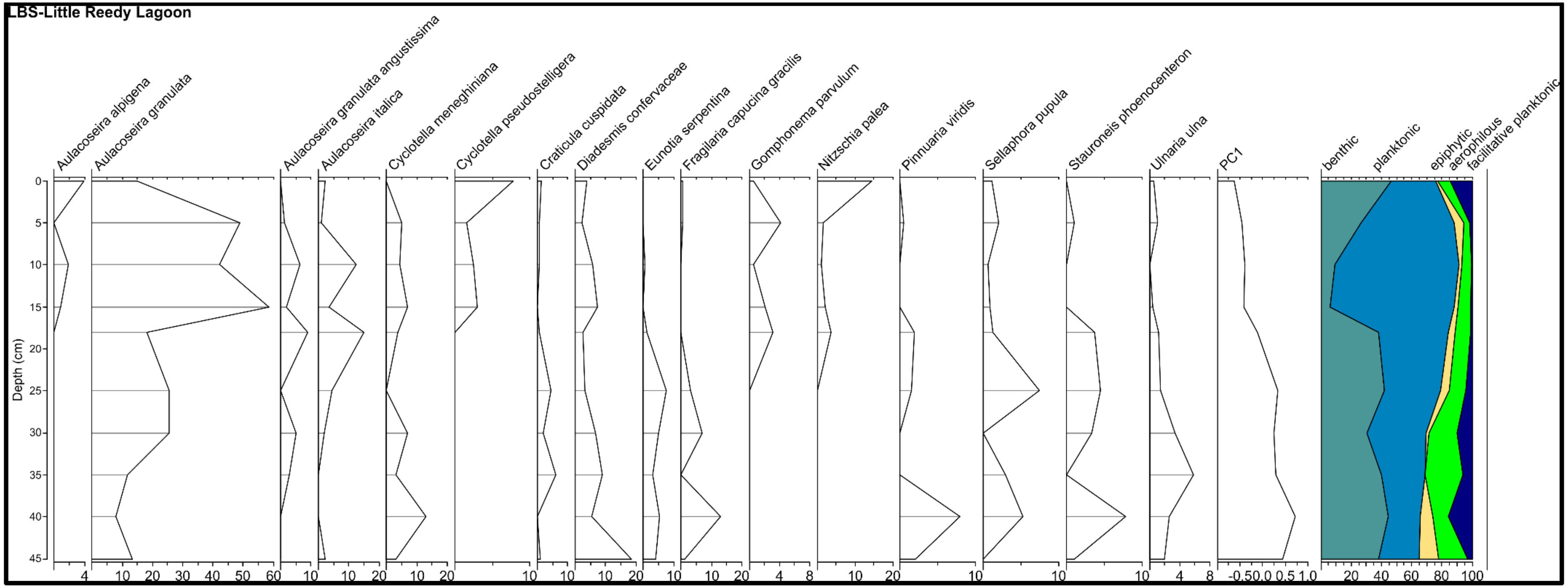

Figure 7. The diatom record from core LRS01 from Little Reedy Lagoon.

Discussion

Core Chronology

Radiometric dating approaches present particular challenges in riverine situations with relatively high proportions of lead entering the system from fluvial, rather than atmospheric sources. Even so, there are several published records that have provided age-depth curves for floodplain lake sediment sequences. Consistent patterns of change in chemical and biological remains allow for a regional pattern to be established, particularly if the river channel is a likely source of these indicators. For example, *Aulacoseira alpigena* has been shown to arrive in Murray River wetland records soon after river regulation (Fluin et al. 2010) and so early increases in this taxon provide a temporal tie-point around 1940 CE (e.g. Gell et al. 2017). The other non-radiometric approach to dating is the identification of the point of first arrival of exotic pollen, particularly that of wind dispersed *Pinus*. Owing to spatial variability in the development of landscapes around south-east Australia it is likely that, in some cores, there are many decades of post-European sediment accumulation that are without *Pinus* (e.g. Bickford et al. 2008). So, while the presence of pine pollen definitively identifies post-European sediment, the first arrival does not necessarily equate to ~ 1840 CE.

The Black Swamp sediments show pine arriving at 20 cm and *A. alpigena* increasing at 25 cm. Further, the increase in *Diadesmis confervaceae*, at 30 cm, may reflect increased erosional input and so mark early catchment disturbance. So, this circumstantial evidence suggests that 30 cm may equate to 1920 CE, and by extrapolation, the basal sediments extend into pre-European times. The absence of the nutrient indicator *Cyclotella meneghiniana* below 55 cm supports the thesis that the basal layers represent a low impact period.

Pine and thistle (Asteraceae *Liguliflorae*) pollen was detected at the base of the Green Swamp core and the introduced plantain (*Plantago lanceolata*) was recognised at 70 cm. A peak in *A. alpigena* is evident at 60 cm, again preceded by a peak in *D. confervaceae*. Further, *C. meneghiniana* was recorded from 70 cm. These features combine to suggest that this record covers a period of high disturbance and so may extend only as far as the early 20th century.

Pine and thistle pollen are also recorded at the base of the Little Reedy Lagoon record, yet *A. alpigena* was first recorded at 15 cm. Nutrient (*C. meneghiniana*) and disturbance (*D. confervaceae*) indicators are present to the base however suggesting, by correlation with the other records, that the Little Reedy Lagoon record extends to the early-mid 20th century.

Sediment Accumulation

The analysis of these three sites brings the total number of wetlands analysed across the Southern Basin to 55 (see Gell & Reid, 2014). As in the case of Little Reedy Lagoon, several of these wetlands had sediment sequences no longer than 40 cm while sequences as long as 1450 cm were extracted from a wetland near Wellington (SA) (Gell et al., 2005a) and 460 cm from a site downstream of Wentworth (Gell et al., 2005b). Only eight wetlands sediment records extend into Indigenous time and the typical sediment rate ranged between 0.5-3 mm/yr. Most wetlands experienced net sediment accumulation only after the time since widespread river regulation (post 1922). The sedimentation rates in these sites, and that in the upper sections of the longer records, were typically 10-50 mm/yr.

Of the Gunbower wetlands, as no sequence exceeded 90 cm, the lower of these post-regulation rates leads to the conclusion that these wetlands did not experience net sediment accumulation until after regulation. However, the absence of exotic pollen and prevalence of clear water, benthic diatoms to 40 cm in the Black Swamp core, suggests the record extends beyond regulation and possibly into times before European settlement. So, it is likely that these wetlands were not permanently wet at the contact period in the case of Black Swamp, and perhaps not until regulation in the case of Green Swamp and Little Reedy Lagoon. This suggests that the pre-European/pre-regulation condition included frequent phases where the wetlands were dry and the accumulated sediment was lost. The diatom valves preserved in the lower sections of each core were mostly broken suggesting, at most, very shallow water. While throughflows cannot be excluded as a possible agent of sediment removal the sediment-water interface is usually buffered from the effects of flows when wetlands are full as evident in steady radiometric decay models derived from multiple wetlands across the system.

So, these preferred chronologies described above suggest that the average sedimentation rates at these sites range from 4 mm/yr (Black Swamp) to 8 mm/yr (Green Swamp). These rates are likely to have been lower early, and increased through time. Nevertheless, they are considerably lower than those recorded from wetlands situated closer to the main river channel including in the Perricoota Forest nearby (Gell et al., 2017).

Vegetation

The pollen records from the three wetlands reveal the persistence of *Eucalyptus* cover across the forest. They do record the regional decline in *Allocasuarina*, that is recognised widely across south-east Australia, however, these records suggest a later decline in this region compared to western Victoria. Of the aquatic vegetation, submerged plants (e.g. water milfoil) declined and floating (*Azolla*, duckweed) and emergent (*Typha*) vegetation increased following regulation.

Fire

In the Black Swamp core charcoal levels increased in the middle sections. This may suggest increased burning although it may also suggest increasing transport of charcoal with eroded sediment. Irrespective, the levels of charcoal counted are very low relative to sequences cored elsewhere in forested parts of Australia suggesting that natural and anthropogenic fire was infrequent or there was much less fuel to burn to become sedimentary charcoal.

Diatom-inferred water quality

The basal sediment of the three wetlands were dominated by large, benthic (bottom) species suggesting high water transparency. Epiphytic species are common suggesting the widespread presence of aquatic plants. Species from several genera (*Eunotia*, *Pinnularia*) reflected circumneutral to acid water conditions suggesting organic acids influenced the chemistry of the waters. The organic acids are likely derived from the local leaching of humic material from the floodplain and these are balanced by the relatively neutral waters from the channels. The assemblage is a mix of river plankton and wetland species and where the river flows in rarely the local wetland species dominate the mixture that are preserved in the sediments. As the proportion of river plankton is generally low in the basal sediments it is inferred that there was only minor connectivity with the main channels at this time.

The aerophilous form, *Diadesmis confervacea*, which colonises mud surfaces and can be transported on eroded sediment, increases mid way through the Black Swamp cores attesting to increased sediment flux. The increases in plankton in the upper sections of each core attests to either increasing connectivity with the rivers or reduced water clarity (or both). In all cores eutrophic indicators (*Cyclotella* spp., *Nitzschia* spp.) increased in the upper sediments suggesting unprecedented nutrient concentrations in recent (~ 10-20) years.

Wetland Change

A summary of the evidence collated from Black Swamp, Green Swamp and Little Reedy Lagoon is provided as Figures 8-10.

The PCA curves for Black Swamp reveal an ongoing transition with the main shift occurring between 45-30 cm. This is characterised by a shift from benthic to planktonic diatoms and cladocerans and increases in a bryophyte, but also *Lemna* sp. and *Azolla* sp. (Figure 2). The abundance of epiphytes (*Cocconeis*, *Gomphonema*) are generally low suggesting aquatic plants were not abundant yet increases in *Lemnicola hungarica*, an epiphyte on floating plants, support evidence for increases in *Azolla* and *Lemna*. This record likely extends further than those for Green Swamp or Little Reedy Lagoon and so the timing of the main transition is likely post-regulation.

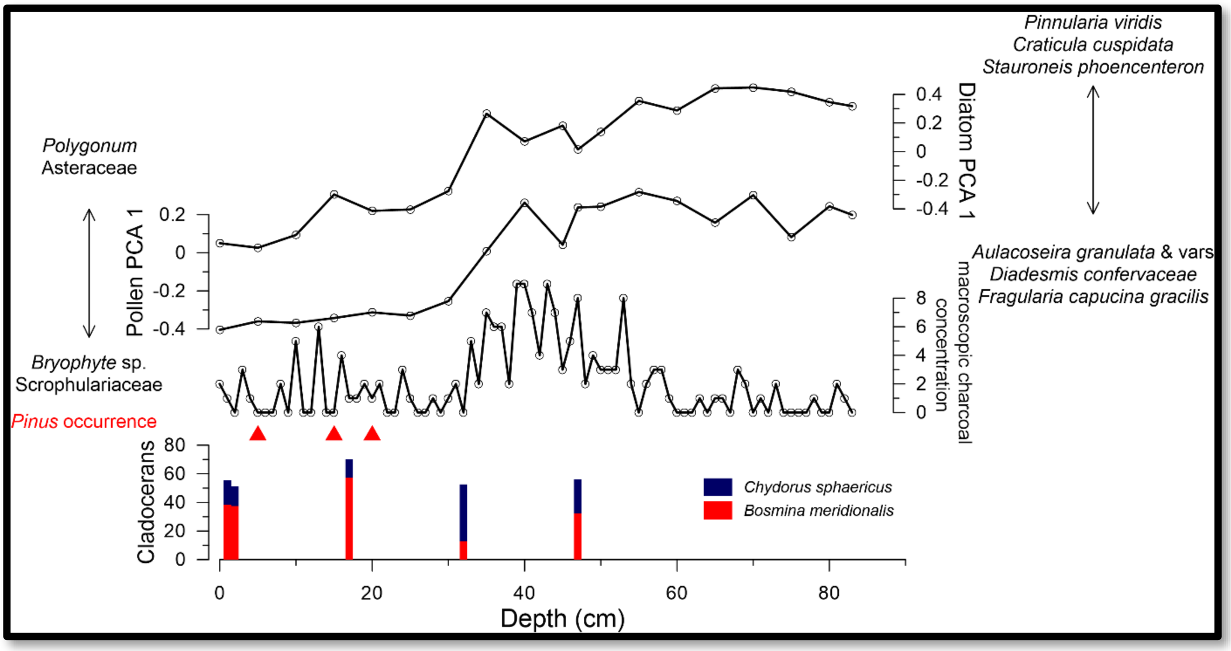

Figure 8. A summary diagram from core BS03 from Black Swamp.

The PCA curves from Green Swamp show a largely continuous trend that represents a shift from benthic diatom taxa to aerophilous and the increase in a bryophyte at the expense of *Myriophyllum*. The main transition in the pollen is after 20 cm, which coincides with a charcoal peak, after which planktonic cladocerans increase markedly.

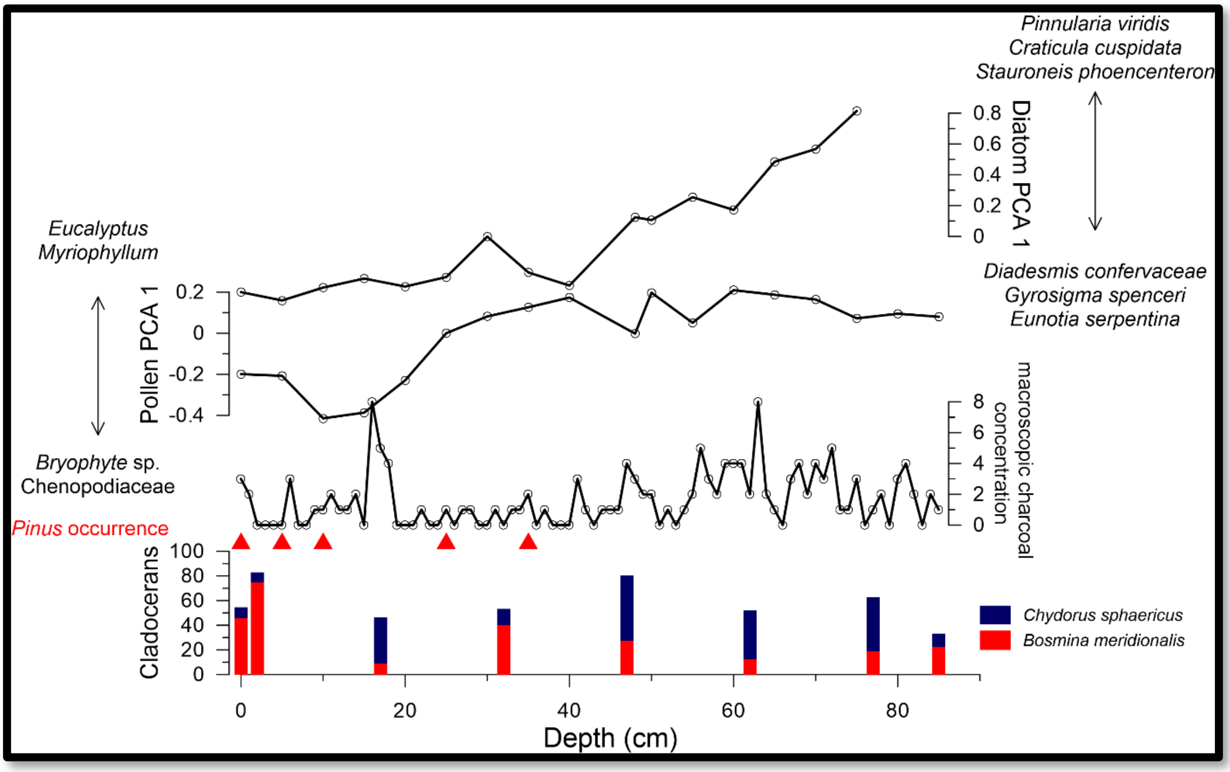

Figure 9. A summary diagram from core GS02 from Green Swamp.

The PCA for the shorter Little Reedy Lagoon core also shows a transition with a stepped change after 20 cm. Here benthic and epiphytic diatoms give way to plankton and eutraphentic taxa while a bryophyte and *Lemna* increase at the expense of *Myriophyllum* and *Azolla*. Charcoal is variable but relatively high above 20 cm.

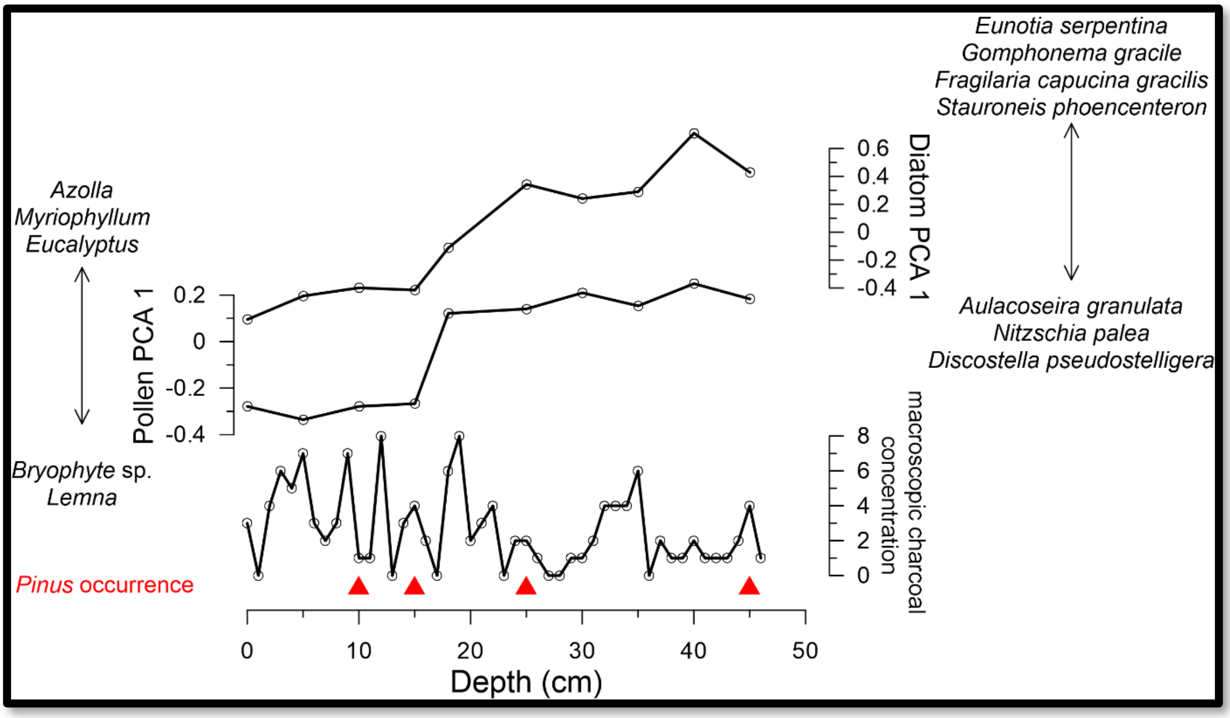

Figure 10. A summary diagram from core LR01 from Little Reedy Lagoon.

At the outset, the wetlands of the Gunbower Forest appear to have been dry sufficiently often for no net sediment to have accumulated i.e. all deposited sediment was lost. The Black Swamp record suggests that it became more frequently inundated from a time before, or soon after, European settlement. This suggests that the hydroecological state of the wetlands in the past was more variable than today. Gradually, and particularly after regulation, more lagoonal conditions were established that allowed for the incoming sediments to settle and be free from mechanisms that may displace them. Even so, the fragmented nature of the diatom valves preserved in the basal sediments of all three cores suggest that inundation was irregular, but sufficient to resist deflation or erosion of deposited sediments.

In the early phase of increased incidence of inundation, the water quality was clear, fresh, oligotrophic, circumneutral and slightly acidic and aquatic plants were common. Either sedimentation rates increased, or the aquatic plants only declined slowly under the new regime. Nevertheless, submerged plants declined and floating and emergent types increased. There was insufficient light for benthic diatoms to persist and phytoplankton assumed the role as the dominant algae. Similarly, there has been a decline in crustacean (cladoceran) diversity and the main shift has been from littoral chydorids to pelagic bosminids. While these ecological transitions occurred under lower sedimentation rates than occurred elsewhere, the influx of sediment has been sufficient to impact the algal and microcrustacean assemblages.

Recent eutrophic conditions may have arisen through increased nutrient loads with more permanent water inputs, internal recycling of nutrients from the accumulated sediments, or evaporative concentration of nutrients during the 'Big Dry'.

The records from these three separate sites are very consistent suggesting the sites are connected and are responding to regional forces of change rather than evolving independently. The long term nature of the wetlands appears to have been intermittent or seasonal wetlands that regularly dried yet carried stands of aquatic plants. The water was clear, oligotrophic, slightly acid and fresh. Since regulation this has transitioned into permanent standing waters that are alkaline (perhaps episodically acid), eutrophic, turbid and fresh with a limited submerged plant cover. The timing and nature of these changes are largely consistent with those recorded from a high proportion of wetlands across the southern Murray-Darling Basin suggesting regional scale drivers of change (Gell & Reid, 2014, 2016).

Further Work

While such sites pose challenges for the establishment of robust chronologies, the identification of the timing of these changes would benefit from the application of ^{210}Pb and ^{137}Cs dating. Such a chronology may also benefit from analysis of aDNA that may identify the first point of arrival of exotic fauna such as sheep, carp and mosquito fish.

Understanding of the impact of water quality and habitat changes identified here, on the nature of the aquatic food webs, would be strengthened through analysis of carbon and nitrogen isotopes and algal pigments.

Acknowledgements

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Appendix 1. Diatom species and their ecological preferences (see Sonnemann et al., 2000).

Aulacoseira spp.	River plankton that may also occur in deeper lakes
Aulacoseira alpigena	River plankton that appears in fossil records after regulation (syn. *A subborealis; A. pusilla).*
Cyclotella meneghiniana	Planktonic form with high salt tolerance; a nitrogen heterotroph and nutrient indicator
Cyclotella pseudostelligera	Small planktonic form tolerant of elevated nutrients
Craticula cuspidata	large benthic diatom (syn. *Navicula cuspidata*)
Diadesmis confervaceae	aerophilous form that grows on mudflats; may be washed in with sediment
Eunotia serpentina	benthic species evident in the basal sediments of many River Murray records
Fragilaria capucina gracilis	inhabits a variety of habitats including the plankton
Gomphonema parvulum	an epiphyte that tolerates elevated nutrients

Lemnicola hungarica	an epiphyte that inhabits the roots of floating plants e.g. lemna. (syn. *Achnanthes hungarica*)
Nitzschia palea	a periphytic diatom that is an indicator of nutrient enrichment
Pinnularia viridis	large benthic form that max exist in acidic waters
Sellaphora pupula	an aerophilous form
Stauroneis phoenicenteron	a large benthic diatom
Ulnaria ulna	A common diatom that inhabits a range of habitats (syn. *Synedra ulna*)