**Supplementary material for:**

**The application of pollen radiocarbon dating and Bayesian age-depth modelling for developing robust geochronological frameworks of wetland archives**

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**Lake Werri Berri**

Timeline

Description automatically generatedA 5.46m deep sediment core, WB1, was extracted from the dry bed of Lake Werri Berri in 2019. The core was extracted using a 7m aluminium tube connected to a vibracorer deployed from a 3m quadrupod. Extraction of porous sediment using a vibracore can result in substantial compaction. The WB1 sediment core from Lake Werri Berri was adjusted for compaction by determining the difference between the penetration of the aluminium tube and sediment retrieved. Nine depth locations within the upper 3m of the WB1 sediment sequence were sub-sampled for radiocarbon dating.

**Figure S1.** Photograph of the Lake Werri Berri cores. First three core sections are approximately 1.5 m in length, fourth core is approximately 1 m in length. The depth locations (reported as depth after correction for compaction during coring) of the radiocarbon samples reported in this study. Photographs of material picked for dating are included for depths 159.5, 269.6 and 284.5 cm.

**Welsby Lagoon**

Two wetland sediment cores, WEL15-1 to 12.78m depth and WEL15-2 to 12.72m depth, were extracted from the Welsby Lagoon basin in 2015 (Cadd et al. 2018, Lewis et al. 2020). The stratigraphy of both cores was similar, with limited visual sedimentological changes apparent in the dark brown to black organic rich peat in either core.

The dominant pollen type throughout the periods of the core that underwent radiocarbon dating is Casuarinaceae (Cadd et al., 2018). Casuarinaceae can be a dominant arboreal and shrub species across a range of Australian climate regions. Casuarinaceae species produce an abundance of pollen (Mariani et al., 2021) that reaches values great than 60% of the terrestrial pollen percentages in the Welsby Lagoon sediment sequence between 50 ka and present (Cadd et al., 2018).

Single Grain Optically Stimulated Luminescence (OSL) dating was performed on 21 samples from both sediment core sequences. Twenty radiocarbon ages were determined from a variety of organic components from WEL15-2 using standard ABA preparation techniques. For further information on OSL dating and original radiocarbon dating see Lewis et al. 2020. An additional 21 depth locations from WEL15-2 were sub-sampled for radiocarbon analysis from the lacustrine phase of the Welsby Lagoon sediment sequence from 564 – 721cm.

**Radiocarbon dating**

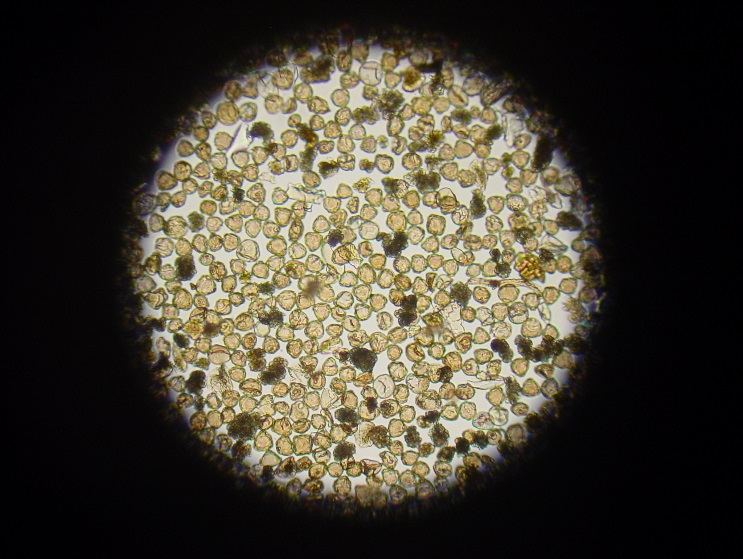
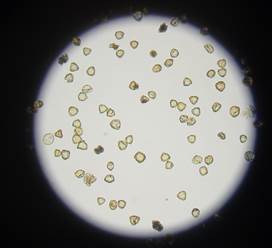
**Chronos 14-C Carbon Cycling Facility**

A total of 56 14C samples were pre-treated, graphitised, and measured at the Chronos 14-C Carbon Cycling Facility at the University of New South Wales. Graphite targets contained ~1000 µg of carbon, except for Werri Berri SPAC targets, which ranged from 137-338 µg C.

All sieves used during 14C sample preparation were sonicated for 5 minutes in each of dilute Hydrochloric acid followed by concentrated Nitric Acid and finally Milli-Q water prior to use.

**Rafter Radiocarbon**

Wet sediment samples were sieved through a 90µm sieve prior to progressive density separation at 1.8s.g., 1.4s.g. and 1.3.s.g. The pollen-rich float was then sieved at 48µm before undergoing three nitric acid treatments. Samples were then sieved at 15µm, with material about the sieve retained. Finally, density separation at 1.17s.g. was performed with the >1.17s.g. Casuarina pollen-rich float retained for dating (Supplementary Figure 1). Resulting casuarina pollen residue was heated in 0.5 M HCl, followed by two 0.1 M NaOH washes before a final 0.5 M HCl treatment. Following pre-treatment, carbon dioxide was generated by sealed tube combustion. Carbon dioxide (941 µg C) was converted to graphite by reduction with hydrogen over an iron catalyst.



**Figure S2:** Sample WEL 15-2 526cm (41116/2) processed at Rafter Radiocarbon prior to graphitisation. Casuarina pollen percentage estimated to be ~90% by count; mass estimation of ~80-85%.

**ANSTO**

All samples were pre-treated using standard ABA treatment. An initial 2 M HCl (60oC,1 hr) is followed by repeated 0.5 -1.0 % NaOH washes (60oC, 1hr) until the wash solution is clear, followed by a 2 M HCl treatment. Pre-treated samples were then combusted *in vacuo* to CO2 in a sealed tube with CuO and Ag wire at 900oC. The CO2 was converted to graphite using the H2/Fe method (Hua et al., 2001) prior to measurement at the Centre for Accelerator Science (Fink et al. 2004). Samples OZY151 and OZY152 were measured on the VEGA 1 MV and samples OZY153 and OZY154 were measured on the ANTARES 10MV accelerator (Fink et al., 2004).

**Age Depth modelling**

*rbacon* settings

**Werri Berri**

Bacon("WerriBerri", d.by=1, thick=5, rotate.axes=TRUE, title="", model.only=TRUE, d.lab="Depth (cm)", yr.lab="Age (cal. yr BP)", ssize=8000, rev.yr=TRUE)

**Welsby Lagoon**

Bacon("WelsbyLagoon", d.by=1, thick=15, rotate.axes=TRUE, title="", remember=FALSE, boundary = 500, model.only=TRUE, d.lab="Depth (cm)", yr.lab="Age (cal. yr BP)", ssize=8000, rev.yr=TRUE)

*Undatable* settings

**Werri Berri**

Undatable run on 2021-06-01 17:21:42. nsim=100000 bootpc=50 xfactor=0.1 combine=Yes

**Welsby Lagoon**

Undatable run on 2021-05-17 14:26:02. nsim=100000 bootpc=75 xfactor=0.1 combine=Yes

*OxCal*

‘P\_Sequence’ uses a Poisson process and assumes that the underlying deposition is random, with fluctuations in the deposition rate (defined through a k value). In this study, the k value was set to be variable, with a k range (log10) that allows it to vary over a factor of 100 greater and lower than the value given (1). This allows the model to find the k value that is best suited for the data. The interpolation was set to 1, which means output is provided once per cm.

The ‘General’ outlier model draws outliers from a Student’s t-distribution with 5 degrees of freedom to account for extreme outliers, and sets the scale of offset to range widely, between 100 to 104 years.

**Werri Berri**

Options()

{Curve="shcal20.14c";

BCAD=FALSE;};

Plot()

{Outlier\_Model("General", T(5), U(0,4), "t");

P\_Sequence(" ", 1, 1, U(-2,2))

{Boundary("Bottom");

R\_Date("Plant Remains 1", 9560, 35)

{

Outlier();

color="red";

z=284.5;

};

R\_Date("Charcoal 1", 12245, 45)

{

Outlier("General", 0.01);

color="black";

z=269.5;

};

Combine("200")

{

R\_Date("Pollen 200", 10036, 18);

Outlier("General", 0.05);

R\_Date("Humic 200", 9975, 19);

Outlier("General", 0.05);

R\_Date("Bulk Sediment 200", 10213, 20);

Outlier();

R\_Date("SPAC 200", 8567, 34)

{

Outlier();

color="red";

};

z=247.5;

};

Combine("160")

{

R\_Date("Pollen 160", 7898, 16);

Outlier("General", 0.05);

R\_Date("Pollen rpt 160", 7908, 16);

Outlier("General", 0.05);

R\_Date("Humic 160", 7867, 16);

Outlier("General", 0.05);

R\_Date("Bulk Sediment 160", 7859, 16);

Outlier("General", 0.05);

R\_Date("SPAC 160", 6852, 36)

{

Outlier();

color="red";

};

z=197.9;

};

R\_Date("Plant Remains 2", 1510, 35)

{

Outlier();

color="red";

z=159.5;

};

Combine("100")

{

R\_Date("Pollen 100", 4369, 13);

Outlier("General", 0.05);

R\_Date("Humic 100", 4344, 13);

Outlier("General", 0.05);

R\_Date("Bulk Sediment 100", 4330, 13);

Outlier("General", 0.05);

R\_Date("SPAC 100", 4417, 25);

Outlier("General", 0.1);

z=123.7;

};

Combine("90")

{

R\_Date("Pollen 90", 3665, 12);

Outlier("General", 0.05);

R\_Date("Humic 90", 3618, 13);

Outlier("General", 0.05);

R\_Date("Humic rpt 90", 3634, 12);

Outlier("General", 0.05);

R\_Date("Bulk Sediment 90", 3584, 13);

Outlier("General", 0.05);

R\_Date("SPAC 90", 3641, 24);

Outlier("General", 0.05);

z=111.3;

};

R\_Date("Plant Remains + charcoal", 3385, 40)

{

Outlier("General", 0.05);

color="green";

z=107.6;

};

Date("Sampled", 2018)

{

z=1;

};

Boundary("Top");

};

};

**Welsby Lagoon**

Options()

{

Curve="shcal20.14c";

BCAD=FALSE;

PlusMinus=FALSE;

Ensembles=500;

};

Plot()

{

Outlier\_Model("General",T(5),U(0,4),"t");

Curve("SHCal20","shcal20.14c");

P\_Sequence("Welsby Lagoon Lacustrine",1,1,U(-2,2))

{

Boundary("Lacustrine Phase Start")

{

z=1230;

};

Date("OSL1213", N(2016-78500, 8600))

{

Outlier("General", 0.05);

color="purple";

z=1213;

};

Date("OSL1210", N(2016-79500, 6500))

{

Outlier("General", 0.05);

color="purple";

z=1210;

};

Date("OSL1180", N(2016-79600, 6800))

{

Outlier("General", 0.05);

color="purple";

z=1180;

};

Date("OSL1119", N(2016-73800, 7700))

{

Outlier("General", 0.05);

color="purple";

z=1119;

};

Date("OSL1047", N(2016-70700, 8000))

{

Outlier("General", 0.05);

color="purple";

z=1047;

};

Date("OSL980", N(2016-79100, 9600))

{

Outlier("General", 0.05);

color="purple";

z=980;

};

Date("OSL892", N(2016-55700, 6000))

{

Outlier("General", 0.05);

color="purple";

z=892;

};

Date("OSL880", N(2016-62400, 7900))

{

Outlier("General", 0.05);

color="purple";

z=880;

};

Date("OSL815", N(2016-55800, 5900))

{

Outlier("General", 0.05);

color="purple";

z=815;

};

Date("OSL775", N(2016-59900, 6500))

{

Outlier("General", 0.05);

color="purple";

z=775;

};

R\_Date("Pollen 721", 44825, 1726)

{

Outlier("General", 0.05);

color="blue";

z=721;

};

Date("OSL710", N(2016-50500, 5500))

{

Outlier("General", 0.05);

color="purple";

z=711;

};

R\_Date("Pollen 710", 44018, 1565)

{

Outlier("General", 0.05);

color="blue";

z=710;

};

R\_Date("Pollen 704", 42474, 1291)

{

Outlier("General", 0.05);

color="blue";

z=704;

};

R\_Date("Pollen 699", 45311, 1838)

{

Outlier("General", 0.05);

color="blue";

z=699;

};

R\_Date("Pollen 693", 41828, 1192)

{

Outlier("General", 0.05);

color="blue";

z=693;

};

R\_Date("Pollen 685", 40145, 967)

{

Outlier("General", 0.05);

color="blue";

z=685;

};

Date("OSL680", N(2016-46200, 5100))

{

Outlier("General", 0.05);

color="purple";

z=680;

};

R\_Date("Pollen 679", 37717, 717)

{

Outlier("General", 0.05);

color="blue";

z=679;

};

R\_Date("Pollen 669", 37903, 733)

{

Outlier("General", 0.05);

color="blue";

z=669;

};

R\_Date("Pollen 654", 37123, 667)

{

Outlier("General", 0.05);

color="blue";

z=654;

};

Combine("639")

{

R\_Date("Pollen 639", 33973, 454);

Outlier("General", 0.05);

R\_Date("Humic 639", 33437, 381);

Outlier("General", 0.05);

R\_Date("Plant Remains 639", 22680, 105)

{

Outlier();

color="red";

};

z=639;

color="blue";

};

R\_Date("Pollen 633", 32963, 401)

{

Outlier("General", 0.05);

color="blue";

z=633;

};

Combine("621")

{

R\_Date("Pollen 621", 33411, 426);

Outlier("General", 0.05);

R\_Date("Humic 621", 32920, 360);

Outlier("General", 0.05);

R\_Date("Plant Remains 621", 27412, 182)

{

color="red";

Outlier();

};

z=621;

};

R\_Date("Pollen 620", 33397, 422)

{

Outlier("General", 0.05);

color="blue";

z=620;

};

R\_Date("Pollen 613", 31779, 348)

{

Outlier("General", 0.05);

color="blue";

z=613;

};

Date("OSL610", N(2016-46400, 5200))

{

Outlier("General", 0.05);

color="purple";

z=610;

};

Combine("602")

{

R\_Date("Pollen 602", 29429, 260);

Outlier("General", 0.05);

R\_Date("Humic 602", 28877, 219);

Outlier("General", 0.05);

R\_Date("Plant Remains 602", 26178, 159)

{

color="red";

Outlier();

};

z=602;

};

R\_Date("Pollen 598", 29129, 251)

{

Outlier("General", 0.05);

color="blue";

z=598;

};

Combine("597")

{

R\_Date("Pollen 597", 28949, 246);

Outlier("General", 0.05);

R\_Date("Pollen 597.2", 28614, 62);

Outlier("General", 0.05);

z=597;

color="blue";

};

Combine("589")

{

R\_Date("Pollen 589", 26979, 194);

Outlier("General", 0.05);

R\_Date("Pollen 589.2", 26929, 56);

Outlier("General", 0.05);

R\_Date("Humic 589", 27102, 56);

Outlier("General", 0.05);

R\_Date("Plant Remains 589", 24218, 125)

{

color="red";

Outlier();

};

z=589;

};

Combine("583.5")

{

R\_Date("Pollen 583.5", 27529, 206);

Outlier("General", 0.05);

R\_Date("Humic 583.5", 26206, 159)

{

color="red";

Outlier();

};

R\_Date("Plant Remains 583.5", 22792, 106)

{

color="red";

Outlier();

};

z=583.5;

};

Date("OSL580", N(2015-44700, 5400))

{

Outlier("General", 0.05);

color="purple";

z=580;

};

Combine("570")

{

R\_Date("Pollen 570", 12078, 35)

{

color="red";

Outlier();

};

R\_Date("Pollen 570.2", 11911, 22)

{

color="red";

Outlier();

};

R\_Date("Charcoal 570", 8798, 24)

{

color="red";

Outlier();

};

R\_Date("Humic 570", 16275, 51)

{

color="red";

Outlier();

};

R\_Date("Plant Remains 570",7322, 20)

{

color="red";

Outlier();

};

z=570;

};

Combine("564")

{

R\_Date("Pollen 564", 8975, 26)

{

color="red";

Outlier();

};

R\_Date("Plant Remains 564", 8235, 20)

{

color="red";

Outlier();

};

z=564;

};

Date("OSL543", N(2015-37600, 4300))

{

Outlier("General", 0.05);

color="purple";

z=543;

};

R\_Date("Plant Remains 540", 13828, 53)

{

Outlier();

color="red";

z=540;

};

R\_Date("Plants Residuals 530", 13025, 69)

{

Outlier();

color="red";

z=530;

};

R\_Date("Pollen-Casuarina", 21380, 133)

{

Outlier("General", 0.05);

color="blue";

z=526;

};

Date("OSL510", N(2016-43700, 5400))

{

Outlier("General", 0.05);

color="purple";

z=510;

};

Boundary("Swamp Phase")

{

z=500;

};

R\_Date("Charcoal 490", 17308, 67)

{

Outlier();

color="red";

z=490;

};

R\_Date("Plant Residuals 490", 15581, 80)

{

Outlier();

color="red";

z=490;

};

R\_Date("Wood 480", 17453, 67)

{

Outlier("General", 0.05);

Delta\_R("uniform",U(0,100));

color="grey";

z=480;

};

R\_Date("Plant Residuals 480", 16089, 82)

{

Outlier();

color="red";

z=480;

};

R\_Date("Bark 460", 17538, 55)

{

Outlier("General", 0.05);

color="grey";

z=460;

};

R\_Date("Plant Remains 460", 17359, 69)

{

Outlier();

color="red";

z=460;

};

R\_Date("Bark 440", 17646, 91)

{

Outlier("General", 0.05);

color="grey";

z=440;

};

R\_Date("Seed 430", 16887, 78)

{

Outlier("General", 0.05);

color="grey";

z=430;

};

Date("OSL380", N(2015-18600, 4100))

{

Outlier("General", 0.05);

color="purple";

z=380;

};

Combine("360")

{

R\_Date("Bark 360", 9602, 54);

Outlier("General", 0.05);

R\_Date("Seeds 360", 9553, 64);

Outlier("General", 0.05);

z=360;

color="grey";

};

R\_Date("Charcoal 310", 9653, 64)

{

Outlier();

color="red";

z=310;

};

R\_Date("Plant Residuals 260", 1197, 37)

{

Outlier();

color="red";

z=260;

};

R\_Date("Bark/Plant remains 230", 6456, 70)

{

Outlier();

color="red";

z=230;

};

R\_Date("Charcoal 100", 2259, 63)

{

Outlier();

color="red";

z=100;

};

R\_Date("Plant Remains100", 940, 21)

{

Outlier();

color="red";

z=100;

};

R\_Date("Plant Residuals80", 1392, 34)

{

Outlier();

color="red";

z=80;

};

R\_Date("Leaf Fragments80", 1260, 64)

{

Outlier("General", 0.05);

color="grey";

z=80;

};

Date("Sampled", 2016)

{

z=1;

};

Boundary("Swamp Phase End");

};

};