RADIOCARBON CHRONOLOGY FOR DYNASTIC EGYPT AND THE TELL EL DAB^{C}A DEBATE: A REGIONAL HYPOTHESIS

By Graham Hagens[1]

1. Introduction

In light of the importance of Egyptian chronology for understanding the history of the Ancient Near East, a recent claim that sequence analysis is capable of significantly improving the accuracy of ^{14}C dating of dynastic material is of considerable interest. Bronk Ramsey *et al.* [2] utilized a Bayesian model incorporating historical information to evaluate 211 ^{14}C measurements of short lived samples dating from the 2nd to 21st Egyptian dynasties, a period of some 1500 years. In addition to concluding that the existing conventional chronology of that long period is reasonably secure, BR 2010 claim that the methodology reduces the error range of ^{14}C dating from ~5% to 2.5%, and that some dates near the beginning of the New Kingdom can be placed within the range of a single generation, close to a 0.5% standard deviation. With the decline in confidence in alternative dating techniques Bayesian enhanced ^{14}C sequence analysis would thus appear to be the only method capable of dating events during the second millennium BC to within a few decades.

It is argued here that this attempt to improve the accuracy of radiocarbon dating of Egyptian dynastic material suffers from several shortcomings which negatively impact the validity of the conclusions. This article explores three areas of concern which might impact the validity of this assessment. These are: (i) sample distribution, (ii) risk of circular reasoning and (iii) uncertain provenance. The first two will be treated briefly, because both are methodological issues capable of resolution by more extensive testing. The third concern will however be examined more closely because of evidence suggesting the existence of a systemic regional offset. It is further argued that significant differences detected during ^{14}C analyses of contemporary material from Tell el Dab^{c}a and Thebes may be indicative of a widespread regional radiometric anomaly. Moreover, it is suggested that anomalies in this dynastic study may also be related to a worldwide phenomenon of regional offsets attributable to local sources of ^{14}C depleted carbon dioxide. If confirmed this hypothesis could be of global significance affecting not only interpretation of ^{14}C dates from Egypt, but also a wide range of coastal radiometric data from both hemispheres.

2 Distribution, circular reasoning and provenance

2.1 Uneven distribution

The utility of the BR 20110 statistical algorithm is compromised by a very uneven distribution of the samples available for analysis. Close to a third of the total are clustered around two early 18th dynasty rulers Hatshepsut and Thutmosis III, while the majority consist of small data sets with concomitant high standard deviations. Consequently, the further the distance from the high data density 18th dynasty the more questionable is the validity of the model.

2.2 Circular reasoning

In order to resolve problems resulting from floating chronologies linked to questionable astronomical observations, BR 2010 utilizes a Bayesian model incorporating archaeo-historical regnal years. The authors caution that for this reason, none of the dates calculated by the model should be used to estimate reign lengths. This introduces a methodological problem in that many of the dates employed in the model derive from the very ancient astronomical observations which the authors hope to correct. This concern is of particular significance in the poorly represented upper and lower ends of the chronological spectrum. For example, conventional reign lengths from the Late

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[2] Bronk Ramsey *et al.* 2010, hereafter BR 2010.

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Table 1: Old Kingdom: Saqqara and Memphis.

Column	2	3	4	5	6	7	8	9	10
		Set		Sample	Historical	BR 2010	BR 2010	Cal-Hist	StDev t
Pharaoh	**Dyn**	**No.**	**Capital**	**provenance**	**Median, BC**	**model**	**Calibrated**	**Δ years**	**Δ/σ**
Djoser	3	7	Memphis	Saqqara	**2630**	2660±17	2756±85	126	1.5
Sneferu	4	2	Memphis	Meidum	**2758**	2616±18	2734±98	-24	-0.2
Djedkara	5	1	Memphis	Abusir	**2390**	2580±14	2403±52	13	0.3
Pepy I	6	1	Memphis	Saqqara	**2356**	2373±21	2518±38	162	4.3
							Averages	69	1.44±1.0

Table 2: Middle Kingdom, el-Lisht and Lahun.

		Set		Sample	Historical	BR 2010	BR 2010	Cal-Hist	StDev t
Pharaoh	**Dyn**	**No.**	**Capital**	**Provenance**	**Median**	**model**	**Calibrated**	**Δ years**	**Δ/σ**
Senusret I	12	1	el-Lisht	el-Lisht	**1938**	1955±10	1930±24	-8	-0.4
Senusret II	12	2	el-Lisht	Lahun	**1861**	1879±11	1910±20	49	2.5
Senusret III	12	10	el-Lisht	Lahun	**1854**	1872±12	1873±10	19	0.6
Amenemhat III	12	12	el-Lisht	Lahun	**1825**	1832±12	1915±13	90	6.9
							Averages	38	2.8±1.5

New Kingdom and Third Intermediate Periods utilized in the algorithm were influenced by astronomical evidence related to the accession of Ramesses II, combined with controversial estimates of the duration of the 21st dynasty.[3] In the case of the Old and Middle Kingdoms, the uncertainty is exacerbated by wide variances between different archaeo-historical dating models.

2.3 Uncertain provenance

None of the samples analyzed in BR 2010 was a recent discovery. All materials tested derived from collections placed in museums during the 19th and early 20th centuries. As a result the authors were forced to rely on information available from original reports and curators concerning the authenticity and provenance of the materials. In addition, close to 10 % of the total number analyses in BR 2010 were identified as outliers and not incorporated in the algorithm, raising concern that the body of data might suffer from a systemic error related to misattribution. Two other factors which may have increased uncertainty of the measurements involve the possibility that some items from burial contexts may have included older material such as heirlooms,[4] and perhaps more seriously the possible existence of regional anomalies.

3. Evidence of regional anomalies

Tables 1–4 present a re-analysis of ^{14}C dynastic data from BR 2010 and auxiliary sources comparing the results obtained from the BR 2010 algorithm and direct calculation using the published values. Columns 4, 5, 6 and 7 identify the capitals of the relevant dynasties and the provenance of the samples, historical medians,[5] and the BR 2010 modeled values, while Column 8 contains calibrated dates.[6] Column 9 shows the difference between the calibrated and historical dates (i.e. Δ Columns 8–6), while Column 10 shows the statistical confidence to test the null hypothesis that the calibrated ^{14}C date is identical with the conventional historical values.

During the Old Kingdom (Table 1) the pharaonic residences and burials were located at the apex of the Delta in the region of Memphis and

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[3] Hagens 1996.

[4] Hall 1986, 46.

[5] Conventional historical accession dates are median of higher and lower values from Shaw & Hornung (cf. BR 2010) & Wente & Van Siclen 1976; all dates BC.

[6] Source: BR 2010 Table S1, error range 1σ.

Table 3: Amarna and Thebes.

		Set		Sample	Historical	BR 2010	BR 2010	Cal-Hist	StDev t
Pharaoh	**Dyn**	**No.**	**Capital**	**Provenance**	**Median**	**model**	**Calibrated**	**Δ years**	**Δ/σ**
Mentuhotep II	11	9	Thebes	Deir el-Bahri	**2032**	2059±2	2004±20	-28	-1.4
Amenemhat I	12	4	Lisht	Thebes	**1962**	1992±1	1838±48	-124	-4.8
Thutmose IV	18	1	Thebes	Thebes	**1392**	1409±5	1363±37	-29	-0.8
Amenhotep III	18	2	Thebes	Thebes	**1388**	1399±6	1361±34	-27	-0.8
Amenhotep IV	18	12	Amarna	Amarna	**1351**	1360±5	1357±30	6	0.2
Tutankhamen	18	8	Thebes	Thebes	**1335**	1344±5	1404±69	69	8.6
							Averages	–1	-1.1±1.2

Table 4: Mixed provenance.

				Sample	Historical	BR 2010	BR 2010	Cal-Hist	StDev t
Pharaoh	**Dyn**	**No.**	**Capital**	**Provenance**	**Median**	**Model**	**Calibrated**	**Δ years**	**Δ/σ**
Hatshepsut	18	24	Thebes	Deir el-Bahri	**1488**	1483±5	1477±16	-11	-0.7
Thutmose III	18	33	Thebes	Deir el-Bahri	**1479**	1489±6	1489±16	10	0.6
Amenhotep II	18	1	Thebes	Thebes?	**1426**	1436±5	1453±29	27	0.9
Ramesses II	19	2	Pi-Ramesses	Thebes	**1279**	1287±5	1427±12	148	12.3
Ramesses I	19	7	Pi-Ramesses	N/a	**1294**	1303±5	1516±9	222	24.7
Merneptah	19	1	Memphis	KV	**1212**	1221±6	1381±41	169	4.1
Tausert	19	1	Memphis	Thebes	**1193**	1195±6	1196±54	3	0.1
Ramesses IV	20	3	Pi-Ramesses	Thebes	**1151**	1160±5	1251±30	100	3.3
Ramesses IX	20	1	Pi-Ramesses	Thebes	**1128**	1132±5	1033±32	-95	0.8
Smendes	21	1	Tanis	Deir el-Bahri	**1060**	1075±2	915±45	-145	-3.2
Amenemnisu	21	8	Tanis	Deir el-Bahri	**1046**	1049±5	1064±30	18	0.6
Psusennes I	21	1	Tanis	Deir el-Bahri	**1042**	1045±5	1225±67	183	2.7
Amenemope	21	2	Tanis	Deir el-Bahri	**996**	999±5	1024±30	28	0.9
								61	3.3±7.5

Saqqara. While the BR 2010 modeled dates of these four pharaohs are statistically indistinguishable from the historical values, direct calibration of the ^{14}C data reveals an average t value of 1.44, or 83 % confidence that the ^{14}C dates are older than the historical estimate.

During the twelfth dynasty the centre of political activity moved to el-Lisht and Lahun, near the Fayum depression a little south of the Delta. As shown in Table 2, while the BR 2010 model is indistinguishable from the historical estimate, direct calibration of the data reveals a high degree of confidence that the radiometric ages are lower than the archaeo-historical values.

All the pharaohs in Table 3 with the exception of Amenemhat I, were associated with Thebes or Amarna throughout their lives. Although Amenemhat moved his capital from Thebes to Itjtawy (most probably at Lisht) in the Fayum region during his reign, all the samples analyzed in this study originated in Upper Egypt. Re-calibration reveals ^{14}C dating of these Pharaohs to be indistinguishable from the archaeo-historical estimates.

The data in Table 4 derive from the 18th to 21st dynasties during which the Pharaohs ruled from Memphis, Pi-Ramesses and Tanis. Although the error range in this sample set defies statistical analysis, the two large blocks associated with Hatshepsut and Thutmose, are revealed to be statistically indistinguishable from the conventional dating. As discussed below, however, it is only in this case that we have clear and conflicting evidence from Tell el Dabᶜa of ^{14}C dating being significantly higher than that from upper Egypt.

While most of the kings of the Old Kingdom resided and were buried at locations close to the Delta, later burials in Upper Egypt came into prominence when some capitals were relocated in the Delta. It is suggested that these results combined with the archaeology of Tell el Dab^{c}a reveal a systemic geographical offset specifically related to environmental conditions within the Delta. If confirmed this hypothesis would have a number of significant consequences related to the dating of the Pharaohs of the 19–21st dynasties.

4. Tell el Dab^{c}a

Radiometric and archaeo-historical dating of material from Tell el Dab^{c}a, the historical Avaris, and the 18th dynasty Peru-nefer, have long been stubbornly at odds, with ^{14}C dating being consistently higher.[7] For some time the response from the radiocarbon community to this variance largely involved attempts to minimize its significance by criticizing the non-scientific aspects of archaeo-historical dating,[8] but only recently has identification of the magnitude of variance added urgency to finding a satisfactory solution to the problem. In 2012 ^{14}C analyses of 45 samples short lived material from archaeological strata associated with of dynasties 12 to 18, and thus overlapping with some of the BR 2010 timeframe were reported by Kutschera *et al.*[9] Their conclusion that the radiometric ages from Tell el Dab^{c}a are ~120 years older than the historical values broadly confirm earlier results of Bietak & Höflmayer[10] and evidence extracted from BR 2010, presented here. In Table 5, comparison of the pertinent offsets from Tables 1–2 above with those from Kutschera *et al.* (Table 1a) reveals the variances from Tell el Dab^{c}a to be ~3 times higher than those derived from BR 2010.

It is here argued that plants growing in proximity to Tell el Dab^{c}a like other deltaic sites may have experienced a unique $^{14}CO_2$ profile which may require the adoption of a regional offset. Thus, the differential between both the Kutschera *et al.* and BR 1060 offsets illustrated in Table 5 might be attributable to the fact that the Old Kingdom and 12th Dynasty Middle Kingdom capitals were located some ~ 120–160 km south of the heart of the Delta, as was Tell el Dab^{c}a itself. One other item supporting this hypothesis of a specifically deltaic anomaly, is an observation that material associated with Queen Hatshepsut discovered in Thebes yielded ^{14}C ages in close conformity with the historical chronology.[12]

Table 5: Conventional vs. ^{14}C dates[11].

		Tell el-	**Sample**	**Conventional**	**^{14}C, 2012**	**2012-Hist**	**^{14}C, BR 2010**	**2010-Hist**
Pharaoh	**Dyn**	**Dab^{c}a layer**	**Provenance**	**Dates, BC**	**Cal, BC (2σ)**	**Δ years (2σ)**	**Cal, BC (2σ)**	**Δ years (2σ)**
Djoser	3	n/a	Saqqara	**2630**			2756±170	126
Sneferu	4	n/a	Meidum	**2758**			2734±196	-24
Djedkara	5	n/a	Abusir	**2390**			2403±104	13
Pepy I	6	n/a	Saqqara	**2356**			2518±76	162
N/a	n/a	**N/2–3**	**Tell el Dab^{c}a**	**1970–1940**	**2135±110**	**180**		
Senusret I	12	n/a	el-Lisht	**1938**			1930±48	-8
N/a	n/a	**N/1**	**Tell el Dab^{c}a**	**1940–1920**	**2088±82**	**158**		
Senusret II	12	n/a	Lahun	**1861**			1910±40	49
Senusret III	12	n/a	Lahun	**1854**			1873±20	19
Amenemhat III	12	n/a	Lahun	**1825**			1915±26	90
N/a	12	H	**Tell el Dab^{c}a**	**1820–1790**	**1907±26**	**102**		
		G/1–4		**1790–1710**	**1844+/-73**	**94**		
		E/2		**1650–1620**	**1749±116**	**114**		
N/a	15	**D/3–E/1**		**1620–1560**	**1726+/-20**	**136**		
		D/2		**1560–1530**	**1695+/-62**	**150**		
N/a	18	**C/2–3**	**Tell el Dab^{c}a**	**1500–1410**	**1584+/-33**	**139**		
					Average	**134 ± 23**	**Average**	**53± 30**

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[7] Bietak, 2013.

[8] Manning 2007, 124–125.

[9] Kutschera *et al.* 2012.

[10] Bietak & Höflmayer 2007.

[11] Sources: Kutschera *et al.* 2012; BR 2010

[12] M. Bietak, personal communication.

This is not the first time the possibility of a regional Egyptian anomaly has been suggested. Bruins *et al.* have also speculated that a dual dating system might be required to resolve this dilemma.[13] Such a step would potentially present a significant threat to the core radiometric belief in the validity of a single uniform northern calibration curve.[14] Before pursuing this idea further however, it is necessary to examine the controversial topic of regional radiometric anomalies on the global scale.

5. Regional offsets review

Among the earliest evidence for the existence of regional ^{14}C offsets are two articles by Lerman *et al.*[15] which revealed southern hemispheric tree rings dating from AD 400 to 1950 to have significantly older ^{14}C ages than coeval wood from Europe. The authors speculated that the larger surface area and higher wind speeds of the southern oceans might effect a more efficient marine-atmospheric depleted $^{14}CO_2$ exchange than occurs in the mid-northern latitudes. Their further suggestion that such offsets might warrant a distinct southern calibration curve was later supported when comparison of 19th century wood from Europe and Cape Town revealed South African wood to be ~40 ^{14}C years older than coeval European rings.[16] Since then various efforts to define a southern hemispheric curve (SHCal) to complement the northern international curve (IntCal), have been pursued with mixed success.

Mathematical attempts to quantify this phenomenon include atmospheric transport models which predict latitudinal gradients in the atmospheric concentration of ^{14}C depleted maritime CO_2.[17] Among the most cited is the three-dimensional global circulation model of Braziunas *et al.* (hereafter "GCM"),[18] which describes atmospheric ^{14}C contours in response to oceanic boundary conditions. Its prediction of the existence of an atmospheric Δ^{14}C gradient that declines 1‰ (8 ^{14}C years)[19] per 10° of latitude to a maximum of 5‰ between 50° N and 50°S has found some support from empirical data from both hemispheres. For example, an estimate of the pre-industrial ^{14}C atmospheric signal in the Northern Hemisphere was found to have some similarity to that predicted by the GCM, while a North-South (N-S) "best guess" algorithm yielded an inter-hemispheric ^{14}C gradient within 10% of empirical values.[20] Consequently there is now general consensus that the observed pre-industrial latitudinal N-S ^{14}C gradation is to be attributed to the larger surface areas, higher wind speeds and lower $^{14}C/^{12}C$ ratios in the southern oceans

By contrast, no offsets capable of compromising the validity of IntCal in the mid-northern latitudes are admitted to exist. While numerous regional anomalies have been reported, there is general agreement that all are localized or ephemeral phenomena attributed variously to transient oceanic upwelling of "old" CO_2, seasonal growth retardation,[21] depleted ^{14}C volcanic emissions,[22] freshwater reservoir effects (FRE) related to the release of ^{14}C depleted CO_2 (detected during an arctic spring),[23] or atmospheric $\Delta^{14}CO_2$ fluctuations. [24] Theoretical rationales for these conclusions include arguments that in the mid-to-low northern latitudes, surface air-sea gas exchange is fast, and deep oceanic mixing slow enough to ensure that surface water remains in equilibrium with atmospheric CO_2.[25] Empirical data to support these arguments include failure to detect significant differences between the radiometric soft- and hardwood data sets from the North Western United States, Europe and Anatolia utilized in the construction of IntCal.[26] Consequently the assumption that all trees within the mid-northern latitudes have always sampled a spatially uniform $^{14}CO_2$ is now considered to be the cornerstone of contemporary radiocarbon dating methodology.[27] Such a

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[13] Bruins *et al.* 2009, 407.

[14] Manning *et al.* 2002

[15] Lerman *et al.* 1969, 1970

[16] Vogel *et al.* 1986, 1993

[17] Stuiver & Braziunas 1998.

[18] Braziunas *et al.*1995.

[19] "‰" refers to the concentration of ^{14}C in parts per thousand; although the decline of ^{14}C with time follows a logarithmic function, for much of the period under consideration here, 1‰ represents ~8 ^{14}C years.

[20] McCormac *et al.* 1998.

[21] Kromer *et al.* 2001; Dellinger *et al.* 2004; Dee *et al.* 2010.

[22] Bruns *et al.* 1980.

[23] Damon *et al.* 1992; 1996.

[24] Levin & Kromer 2004, 1262.

[25] Levin & Hesshaimer 2000, 72.

[26] Knox & McFadgen 2001, 98; Pearson *et al.* 1986; Manning 2002; Stuiver *et al.* 1998; Pearson & Stuiver 1986; Stuiver & Becker 1993; Damon *et al.*1989; McCormac *et al.* 1995.

[27] Kromer *et al.* 2001; Manning *et al.* 2002; Reimer *et al.* 2004, 1034.

Table 6: Regional offsets Northern Hemisphere.

	1	2	3	4	5	6	7	8
	Location Site 1	Coordinates Site 1	Site 1: km	Cal years AD/ (BC)	Location Site 2	Coordinates Site 2	Site 2: km	Δ^{14}C yrs Site 1–2
1	Olympic Pen.	124.1°W	~25	1861–1885	South. England	51.8°N, 2.6°W	~125	16±9
2	Olympic Pen.	47.8°N,124.1°W	~25	1861–1885	S. Catalina, AZ	32°N, 110.8°W	~400	12–51
3	Olympic Pen.	47.8°N,124.1°W	~25	1930–1954	S. Catalina, AZ	32.4°N, 110.8°W	~400	~24
4	Olympic Pen.	47.8°N,124.1°W	~25	1688–1710	Urals	~60°N	>500	18±4
5	Olympic Pen.	47.8°N,124.1°W	~25	1545–1615	High lat. Russia	~60°N	>500	26±6
6	Olympic Pen.	47.8°N,124.1°W	~25	1615–1715	High lat. Russia	~60°N	>500	~0
7	Nr.Coos Bay, OR	43.1°N, 123.7°W	~65	1470–1540	White Mts, CA	~37° N	~160	~0
8	Kodiac Is., AK	58.0°N ,153.0°W	~15	1885–1932	Olympic Pen.	47.8°N,124.1°W	~25	14±3
9	IntCal09	n/a	>100	1831–1841	Alaska, interior	64.9°N ,148°W	700	5±12
10	Trondheim	63.4°N, 10.4°E	~30	1894–1931	IntCal09	n/a	>100	25±5
11	Choukai, Japan	39.0°N, 140.0°E	~15	(797–477)	IntCal 04	n/a	>100	22±6
12	Nagano, Japan	36.7°N,138.2°E	~50	231–350	IntCal04/Kyoto	n/a	>100	14–37
13	Hakone-machi, Japan	35.2°N,139.1°E	~10	(240)–200	IntCal09	n/a	>100	21±4
14	Miyata-mura, Japan	35.8°N, 137.9°E	~110	330–630	IntCal09	n/a	>100	-13±5
15	Hotta-no-saka, Japan	39.5°N, 140.6°E	~80	660–900	IntCal09	n/a	>100	7±4
16	Ouban1, Japan	34.7°N, 132.5°E	n/a	820–436	IntCal04	n/a	>100	3–100

position is of course hardened by an acute awareness that loss of confidence in mid-northern latitude uniformity might necessitate the arduous task of developing a family of regional calibration curves throughout the Holocene.[28]

6. A dissipation hypothesis

It is argued here that the various debates on region-specific ^{14}C phenomena in both hemispheres fail to consider the rapidity with which riverine or maritime atmospheric conditions modulate once an air mass moves onto dry land. It is axiomatic that the IntCal assumption of a spatially uniform $^{14}CO_2$ atmosphere requires that the tree rings formed in locations where any $^{14}CO_2$ depleted air has completed dispersed into the general atmosphere.

Since wind borne dispersion is related to both topology and meteorology,[29] any evaluation of possible regional ^{14}C offsets should take into account the distance downwind from the sources of depleted CO_2 which existed when the tree was alive.

7. Testing the Hypothesis

This dissipation hypothesis will be tested by examining thirty seven examples of documented offsets other than those from Egypt, from the past two millennia. Tables 6 and 10 examine exemplars from the Northern and Southern hemispheres respectively, by comparing the Δ^{14}C differential (Column 8) between two sites (Columns 1 and 5), and estimated distances from the nearest open sea or ocean that the trees had originally grown (Columns 3 and 7).[30] In the convention employed here Site 1 is always older than Site 2, i.e. Δ^{14}C is always positive. The distances from the ocean attributed to the InCal exemplars are discussed in more detail below.

7.1 Northern Hemisphere

Table 6.1: Olympic Peninsula vs. Southern England

While a number of ^{14}C anomalies in the North Western United States (NWUS) have been reported, it has not been previously noted that these

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[28] McCormac *et al.*1995, 405; Stuiver & Braziunas 1998, 331.

[29] See for example: Okubo & Levin 1989, Shaw *et al.* 2006, Wanninkhof 1992.

[30] Sources: Google Earth, Google maps.

Table 7: Regionality of US dendrochronolgy.

Species	Years AD (BC)	Years	Location of NWUS trees	Km from ocean	Km-years
Douglas-fir	1820–1954	134	Olympic Pen. : 47.77°N,124.0°W	~25	3,350
Douglas-fir	1790–1819	29	Mt. Rainier Nat. Park: 46.75°N, 121.75°W	~180	5,220
Douglas-fir	1690–1719	29	Mt. Rainier Nat. Park: 46.75°N, 121.75°W	~180	5,220
Douglas-fir	1505–1935	430	Near Coos Bay, OR: 43.1°N, 123.7°W	~65	27,950
Douglas-fir	1510–1699	189	Near Coos Bay, OR: 43.1°N, 123.7°W	~65	12,285
Douglas-fir	1305–1505	200	Pierce City, WA: 47.0°N, 122.0°W	~170	34,000
Douglas-fir	945–1315	370	Shawinigan Lake, BC: 48.7°N, 123.7°W	~90	33,300
Sequoia	265–935	670	Sequoia Nat. Park, CA: 36.5°N, 118.5°W	~280	187,600
	(145)–265	410	Sequoia Nat. Park, CA: 36.5°N, 118.5°W	~280	114,800
	Total years	2343		Total km-years	419,425
				Average km	~179

NWUS exemplars have one feature in common: all the exemplars grew less than ~25 km from the Pacific coast in the Olympic Peninsula WA (hereafter "Olympic"). The first example presented here reveals that late 19th century AD tree rings from Olympic were 16±9 years older than coeval oak from Dean of Forest, Southern England.[31]

Table 6.2–6.3: Olympic vs.Santa Catalina

Comparison of 19th century AD Douglas fir from the Santa Catalina Mountains, Arizona, and coeval rings from Olympic revealed a time variable difference of 12–51 years.[32]

Table 6.4–6.6: Olympic vs. Northern Russia

Douglas fir rings from Olympic dated to AD1545–1615 were found to be 26±6 ^{14}C years older than coeval rings from high latitude Russia, and 18±4 years older than rings from the Urals between AD 1688–1710, but statistically identical to high latitude Russian rings between 1615–1715. These indicators of variations in the concentration of ^{14}C-depleted oceanic CO_2 have been attributed to enhanced oceanic upwelling, it being estimated that admixing of no more than 2,5 % of 10 % depleted ^{14}C from the deep ocean would have resulted in the observed phenomena.[33] Attempts have also been made to link the temporality of the offsets to fluctuations in solar activity associated with the contemporaneous Maunder climatic event (~AD 1645–1715).[34] In light of the large number of regional anomalies from the NWUS, some authors have suggested that a systemic, if temporal, Olympic-IntCal ^{14}C offset of ~11–22 years may be a reality.[35]

Table 6.7: Coastal Oregon vs. Californian interior.

There is little compelling evidence for regional offsets in the USA other than Olympic. For example, comparison of coeval softwood rings from the Californian interior and coastal Oregon between AD 1470–1540 revealed no significant ^{14}C differences either from each other or from the extensive European and Anatolian data used to construct IntCal.[36] These contradictions can be explained by considering the provenance of the American trees. Table 7 compares the temporal contribution of the NWUS trees utilized in the construction of IntCal covering the period 265 BC to AD 1954, with the distance from the ocean of the various sites.[37]

As illustrated, North American trees that grew in close proximity to the ocean made a very minor contribution to IntCal. The weighted average distance of the western US trees utilized was ~179 km, and only 134 of the 2343 years of data or 5.7 % (including 129 years overlap), derived from trees that grew in close proximity to the Pacific coast. By contrast rings that yielded ^{14}C data indistinguishable from IntCal, grew between 65 and 280 km from the ocean. A similar situation applies

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[31] Stuiver & Quay 1981.

[32] Stuiver & Quay 1981; Damon 1995a, 1995b; Damon *et al.*1989, 1999.

[33] Damon 1995b.

[34] Stuiver and Quay 1980; Knox & McFadgen 2004.

[35] Damon *et al.* 1989, 1999; McCormac *et al.* 2004; Damon 1995a; Damon *et al.* 1996; McCormac *et al.* 1995.

[36] Linick *et al.* 1986; Damon *et al.* 1989.

[37] Sources: Stuiver 1982; Stuiver & Quay 1980; Stuiver & Becker 1986: Table 2; Stuiver & Pearson 1986.

Table 8 Lerman offset analysis.

DATE	SITE	Δ^{14}C‰ Lerman	Δ^{14}C‰ IntCal09	Δ Lerman-IntCal09 ‰	Coordinates	Km from ocean
1445–1455	Büdingen	13.8±1.6	10.4±1.9	3.4±2.2	50.3°N, 10.2°E	450
1673–1691	Spessart	21.4±1.5	13.8±1.7	7.6±1.8	59°N, 9.5°E	600
1697–1700	Arizona	18.1±1.7	17.8±0.9	0.4±1.9	32.4°N, 110.8°W	500
1748–1753	Bayern C	6.8±2.5	4.4±0.2	2.4±2.7	49°N, 13°E	1000
1820–1840	Spessart	6.8±1.5	1.0±1.78	5.8±1.6	59°N, 9.5°E	600
1825–1835	Bayern C	9.1±1.5	1.9±1.1	7.2±1.6	49°N, 13°E	1000
1826–1840	Bayern H	8.8±1.4	0.8±1.6	8.0±1.4	49°N, 13°E	1000
1831–1838	Lycksele	6.3±1.5	1.1±1.4	5.2±1.5	64.6°N, 18.7°E	300
1830–1840	Colorado	5.1±1.6	0.6±1.6	4.5±1.6	37.3°N, 108.5°W	1300
1831–1841	Alaska	4.6±1.5	0.2±1.4	4.4±1.8	64.9°N, 147.9°W	700
1836–1843	Arizona,	1.6±1.7	-0.5±0.3	2.1±2.0	32.4°N, 110.8°W	500
1838–1843	Arizona,	2.3±0.5	-1.2±0.1	3.5±1.1	32.4°N, 110.8°W	500
1840–1846	India	5.4±1.5	-1.3±0.1	6.7±1.8	32°N, 72°E	1500
1858–1866	Bayern C	2.3±2.2	-4.2±0.5	6.5±2.4	49°N, 13°E	1000
1897–1904	Bayern C	-1.6±1.7	-3.2±0.7	1.6±1.9	49°N, 13°E	1000
1920–1930	Colorado	-9.8±1.8	-14.0±1.4	4.2±2.0	37.3°N, 108.5°W	1300
1920–1933	Arizona	-5.3±1.8	-14.6±1.4	9.3±2.0	32.4°N, 110.8°W	500
1926–1932	Bayern C	-10.2±1.8	-15.7±1.2	5.5±2.0	49°N, 13°E	1000
1926–1934	India	-6.5±16	-16.0±1.1	9.5±1.8	32°N, 72°E	1500
1930–1931	Lycksele	-11.6±1.5	-16.6±0.1	5.0±1.7	64.6°N, 18.7°E	300
1940	Arizona,	-14.3±1.8	-20.1±1.0	6.8±2.1	32.4°N, 110.8°W	500
1943–1951	Arizona,	-14.7±1.5	-20.3±1.0	6.0±1.8	32.4°N, 110.8°W	500
Average				5.3±0.4		

to the European and Anatolian contributions to IntCal. Thus, the South German oaks grew ~500–600 km from the ocean; [38] the Irish bog Oaks and English Oak rings formed between ~100[39] and ~150 km[40] downwind from the North Atlantic respectively, while the average distance of the Anatolian trees from the coastlines of the Black or Mediterranean seas was ~ 200 km.[41] It is argued here that the American IntCal ^{14}C data-sets are statistically indistinguishable from the European and Anatolian values because in both cases the data are dominated by wood which grew far enough from the ocean that any depleted maritime $^{14}CO_2$ was largely dissipated. The small contribution of ocean-proximal wood from Olympic to the overall data sets prohibits detection of oceanic influence in the northern hemisphere. We will now turn to evidence that regional offset in the Northern Hemisphere are not isolated events, and to a comprehensive collation of regional ^{14}C analyses found in Lerman *et al.*[42]

7.2 Lerman

In order to evaluate the Lerman corpus it is necessary to correct for a systematic bias, the result of utilization of different ^{14}C half lives. Comparison of Lerman data-sets from nine interior sites with IntCal09 in Table 8 below, reveals an average Δ^{14}C 5.3±0.4‰ higher (44±3 ^{14}C years younger) than IntCal09 values. This correction will be applied when utilizing these data.

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[38] Stuiver 1982; Stuiver & Becker 1986, Table 2; McCormac 1995, Fig. 4.

[39] 54.8°N, 6.3°W: Baillie *et al.* 1983.

[40] 53.2°N, 01.0°W: Pilcher *et al.* 1984.

[41] The Aegean Project utilized trees rings from Gordion, Kusakli and Porsuk/Ulukisla. Manning *et al.* 2002, 747.

[42] Lerman *et al.* 1970, Table 8: hereafter "Lerman."

Table 6.8–6.9: Alaska vs. Olympic & IntCal09

Stuiver & Braziunas detected a small, possibly time variable offset of 14±3 ^{14}C years when comparing contemporaneous data from Kodiac Island Alaska (58°N) and the Olympic Pen.(48° N) between AD1884–1932, with Alaska being older.[43] While this value may be taken as confirmation of the GCM prediction of a preindustrial offset of ~8 years as the result of the 10° latitudinal difference, it may be noted that both sites are located very close to the ocean. However, as shown in Table 8, Lerman reported an even more northerly (65°N) exemplar from the interior of Alaska with a $\Delta^{14}C$ of 4.6±1.5 years, which is indistinguishable from IntCal09. This would conform with the hypothesis that these northwestern offsets are the result of the trees growing in proximity to maritime air.

Table 6.10: Trondheim

Trondheim is the only northern site in Lerman located close to the ocean. According to the Braziunas GCM, at latitude 63.4°N Trondheim should have an average $\Delta^{14}C$ value ~10 years lower (older) than the ~40–50 ° latitude data sets that constitute IntCal09. However the Trondheim data (after correction) yield a value 26±5 years older than IntCal for the same period. This differential may be attributed to the close proximity of Trondheim to the North Sea

Table 6.11: Choukai, Japan

A Jindai cedar buried in clay at Mt. Choukai yielded 230 tree rings which when wiggle matched to three IntCal04 raw data sets revealed the rings to be ~ 22±6 ^{14}C years older than IntCal.[44] The authors' suggestion that this significant mid-northern latitude offset be attributed to intrusion of ^{14}C depleted southern hemispheric air during the summer monsoon,[45] is not unreasonable since Mt. Choukai is located no more than ~15 km from the west coast of Japan.

Table 6:12: Nagano, Japan

Imamura *et al.* reported comparative ^{14}C wiggle matching analyses of a wooden tray from Ujishigai (near Kyoto), with reference tree-rings of known age unearthed near Nagano and dated to AD 231–350. While dating the tray roughly conformed to IntCal04, the reference rings were found to be 14±7 ^{14}C years older than IntCal04, although the small number of rings in both samples precludes a high level of accuracy. However, when the ^{14}C ages of the artifact and reference sample are directly compared, the reference sample from Nagano appears to be 37±8 years older than those on the tray.[46] While the original provenance of the tree used to construct the tray is unknown, the cypress which yielded the reference sample grew ~50 km from the ocean.

Table 6:13–6.15: Hakone-machi, Miyata-mura & Hotta-no-saku, Japan

^{14}C analyses of unrelated tree-ring samples from several locations in Japan, representing an overall time span of 1100 years between 240 BC to AD 900, revealed that the Japanese calibration curve conforms fairly closely with IntCal04, with the exception of a relatively small offset during the early portion of the period.[47] The authors offered no explanation for this anomaly. It is suggested here that the earlier offset may be explained by considering the relative proximity of the three sites from the ocean.

As illustrated in Table 9 in which the data from the localities identified in that paper have been recalculated relative to IntCal09, a significant offset is revealed in the site close to the ocean, while the others conform reasonably well to IntCal09.

Table 6:16 Ouban 1, Japan

^{14}C dating of a wooden board with ~ 400 tree rings from the period 820–436 BC from the Ouban archaeological site close to Hiroshima, revealed close conformity with IntCal04 and the standard Japanese tree ring data set, the average difference being 3.5±3.6 years.[48] A few data points from around 680 BC were however up to ~100 years older than the IntCal standard. While the authors suggested that this offset could be indicative of a regional offset, further speculation is precluded by the uncertain provenance of the wood.

7.2 Southern Hemisphere

Table 10.1–10.3: Cape Town.

Two sets of analyses of coeval pine and oak rings from Cape Town (34°S) and the Netherlands over the period AD1835–1900 revealed an apparent $\Delta^{14}C$ variance of 37±7 and 41±5 years, with the

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[43] Stuiver & Braziunas 1998, 329.

[44] Takahashi *et al.* 2010, Suzuki *et al.* 2010.

[45] Suzuki *et al.* 2010, 1605.

[46] Imamura *et al.* 2007, data from Tables 2 and 3.

[47] Sakamoto *et al.* 2003, Tables 2–5.

[48] Ozaki *et al.* 2007.

Table 9

Location	Tree Ring Cal. Age	Km Inland	Offset, ^{14}C years
Hakone-machi	240 BC–AD 200	~10	20.9±3.5
Hotta-no-saku	AD 660–AD 900	~80	6.5±4.0
Miyata-mura	AD331–AD 630	~110	-13.0±4.8

Table 10 Regional offsets: Southern Hemisphere.

	1	2	3	4	5	6	7	8
	Location Site 1	Coordinates Site 1	Site 1: km	Cal years AD/(BC)	Location Site 2	Coordinates Site 2	Site 2: km	Δ^{14}C years Site 1–2
01	Cape Town	34°S, 18.3°E	~10	1840–1890	Norg	53° N,6.5°E	~80	37±7
02	Cape Town	34°S, 18.3°E	~10	1835–1900	Norg	53° N,6.5°E	~80	41±5
03	Cape Town	34°S, 18.3°E	~10	1900–1902	IntCal09	n/a	>100	49±7
04	Los Alerces F63	42.8°S, 72°W	~30	1100–1835	IntCal09	n/a	>100	57±8
05	Los Alerces II	42.6°S, 72.1°W	~60	1690–1952	IntCal09	n/a	>100	30±6
06	Huapi/Lanin	41°S, 71.8°W	~170	1826–1845	IntCal09	n/a	>100	32±6
07	San Pedro	27.0°S, 54.0°W	~500	1831–1839	IntCal09	n/a	>100	12±16
08	Southern Chile	54°S, 71°W	~20	1850–1952	Olympic Pen.	47.8°N,124.1°W	~25	21±5
09	Southern Chile	54°S, 71°W	~20	1670–1722	Olympic Pen.	47.8°N,124.1°W	~25	38±5
10	Magellan	54°S, 71.8°W	~50	1807–1845	IntCal09	n/a	>100	51±16
11	Tierra del Fuego	54.8°S, 62°W	~100	1835	IntCal09	n/a	>100	26±18
12	Tierra del Fuego	54.8°S, 62°W	~100	1690–1700	IntCal09	n/a	>100	67±16
13	Tasmania,Stanley R.	42°S, 145.3°E	~15	1895–1950	Olympic Pen.	47.8°N,124.1°W	~25	25±7
14	N. Zealand	~42°S, ~173°E	15–70	955–1845	Irish/English Oak	n/a	>100	40±13
15	N. Zealand, Pine	43.2°S,170.3°E	~15	955–1405	IntCal09	54.8°N, 6.3°W	>100	53±2.9
16	N. Zealand, Cedar	40°S, 176°E	~70	1405–1845	IntCal09	54.8°N, 6.3°W	>100	37±3
17	N. Zealand, Pine	43.2°S,170.3°E	~15	955–1845	N. Zealand, Cedar	40°S, 176°E	~70	17±4
18	N. Zealand, Kauri	36.0°S,173.8°E	~10	(200)–1000	Irish oak	54.8°N, 6.3°W	~100	44 ±17
19	N. Zealand, Matai	43.9°S,171.3°E	~80	1335–1745	IntCal09	n/a	~100	25±3
20	N. Zealand, Cedar	40.0°S, 176.0°E	70	1405–1745	N. Zealand, Matai	43.9°S,171.3°E	~80	11±5.9
21	N. Zealand, Cel.pine	38.6°S,175.6°E	~85	38BC–220	IntCal04	n/a	>100	12±37

Table 11: Patagonian offsets.

Location	Period, AD	Latitude	Coast	Km Inland	Offset, ^{14}C years
Los Alerces F63	1100–1835	42.8°S	East	~30	57±8
Los Alerces FII	1690–1952	42.6°S,	East	~60	30±6
Nahuel Huapi	1435–1838	41.0°S	West	~170	32±6
San Pedro	1831–1839	27.0° S	East	~500	12±16

southern wood being older.[49] Data derived from Cape pines of similar provenance reported by Lerman similarly reveal an offset relative to IntCal09 of 49±7 years. These South African trees all grew no more that 10–15 km from the Atlantic coast on two sides, being subject to high winds during the summer growing season

Table 10.4–10.7: Patagonia

Lerman contains four exemplars from Patagonia with which to test the hypothesis that southern

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[49] Vogel *et al.* 1986, 1993.

offsets reflect proximity to the ocean, rather than a response to GCM ^{14}C latitudinal gradients. The offsets and location of four sites from with different latitudes and distances from the east and west coasts of South America are shown in Table 11.

The eastern values reveal a reciprocal linearity supporting the hypothesis that these regional offsets are related to the distance from the ocean rather than latitude. The higher Nahuel Huapi offset could be related to its western location high in the high Andes, and to the contemporaneous climatically unstable Maunder Minimum.

Table 10.8–10.12: Southern Chile

Stuiver & Braziunas reported significant Δ^{14}C offsets between coeval rings from Olympic and southernmost Chile. Between AD 1670–1722 (i.e. close to the Maunder Minimum), Chilean ^{14}C dates were found to be 38±5 years older, but this offset diminished to 21±5 years older between AD 1850 and 1952. Noting that this difference is significantly greater than the 4 years predicted by the GCM, these authors also suggested that the differential could be attributed to temporal climatic changes in oceanic circulation.[50] Lerman also contains several sets of 19th century data from Magellan and Tierra del Fuego which yielded corrected values relative to IntCal09 of 51±16 and 26±18 years respectively. The smaller Tierra del Fuego offset could reflect the fact that this site is more than twice the distance from the southern coast as Magellan. Once again the Tierra del Fuego Δ^{14}C offset during the Maunder Minimum (1690–1700), 67±16 years, is considerably higher than observed during the 19th century.

Table 10.13–10.21: New Zealand and Tasmania

The largest body of data utilized to estimate the magnitude of the Southern Calibration Curve consists of several sets of data from five locations in New Zealand and Tasmania. The close similarity between these values has allowed researchers to extend SHCal to more than two millennia,[51] and provided evidence that quantification of this phenomenon may require clarification of some temporal variations. In spite of the wide range of the SHCal deviation from IntCal from ~20 to ~56 ^{14}C years, the possibility that SHCal may be no more than a regional southern hemispheric phenomenon is not generally considered.[52] Arguably, however, the most striking aspect of the New Zealand and Tasmanian data is that all the trees used to provide evidence of the hemispheric anomaly grew very close to the western costs of these three islands where they would have been exposed to the strong seasonal winds prevalent in those southern latitudes.

Table 10.13: Tasmania

The Tasmanian data all derive from Huon trees which grew ~15 km from the northwestern coast of that island. While earlier research revealed no evidence of ^{14}C offsets,[53] high precision analyses revealed a 19th century offset relative to Olympic of 25±7 ^{14}C years.[54] If corrected for the suggested systemic ~11–22 ^{14}C years Olympic-IntCal offset (above), this would yield a value of ~36–47 ^{14}C years. Similarly a set of ^{14}C measurements from Huon pine of the same provenance dating from 165BC to AD 1095, yielded an average offset relative to IntCal04 of 42±26 years.[55]

Table 10. 14–10.17: New Zealand Cedar and Silver Pine

A 900 year ^{14}C sequence derived from South Island Pines and North Island Cedars which grew between AD 955–1845, revealed an average offset relative to European oak of 40±13years, with some temporal variability. When examining the data from AD1405–1445 when the two sets overlapped, the authors found the South Island rings to be 9.4±7.6 ^{14}C years older than those from the north.[56] As illustrated in Table 10.17, a still larger N-S Island offset of 16.8±4.3 is obtained if the complete data sets are calculated relative to IntCal09.

An offset of this magnitude between sites in such close proximity is not predicted by the GCM. The locations of the trees relative to the ocean offers an explanation for the southern Pines, like the Kauris and Tasmanian Huons, were located ~15 km of the west coast of the island, while the Cedars grew near the centre of the North Island, ~70 km from both coasts.

Table 10.18: Tasmania vs. New Zealand Kauri and Silver Pine.

After comparing earlier Silver pine measurements[57] with ^{14}C analyses of North Island Kauri

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[50] Stuiver & Braziunas 1998, 331.

[51] Hall *et al. 2011.*

[52] Hogg *et al.* 2013.

[53] Barbetti *et al.* 1992; 1995.

[54] Stuiver & Braziunas 1998, 330.

[55] Zimmerman *et al.* 2010. Calculated after exclusion of an AD 775–855 anomaly.

[56] Hogg *et al.* 2002, 635.

[57] Hogg *et al.* 2002.

tree rings from the which grew between 200BC–AD 1000, Hogg *et al.* deduced that with the exception of AD 775–855, no location-dependent offsets between Tasmania and New Zealand exist, and estimated the mean hemispheric N-S offset between 195 BC to AD 1845 to be 44 ±17 years.[58] It is suggested here that this observation reflects the fact that the Tasmanian Huons, New Zealand Kauris and Pines were all located very close to the western coasts of their islands.

Table 10.19: South Island Matai

A single Matai tree which grew ~40 and ~110 km respectively from the east and west coasts of New Zealand's South Island between AD1335–1745 yielded an offset relative to IntCal89 of 24.7±3.3 years.[59] Once again the lower offset compared to the Kauri, Huon and Silver pine exemplars can be attributed to the greater distance from oceanic influence.

Table 10.20: North Island Cedar vs. South Island Matai

Comparison of the Matai and Cedar data during the period that the sets overlap (AD 1405–1745), revealed the Cedar to be ~18 years older than coeval Matai rings. The revised estimate that Matai-Cedar differential of 11.1±5.9 years in Table 10.20 was derived by calculating the Cedar and Matai offsets relative to IntCal09 (36.5±4.7 and 25.4±3.6 years respectively). In an argument similar to that made here, the authors speculated that this offset might reflect differences in oceanic conditions in the North and South Islands.[60] Arguably the variance could also be attributed to the relative distances of the Cedars and Matai from the ocean of ~70 and ~110 km respectively.

8. Regional offsets: summary

Of the various mechanisms invoked to explain regional ^{14}C offsets, the one most frequently cited attributes the phenomenon to the influence of the upwelling of ^{14}C depleted oceanic CO_2 exacerbated in the Southern Hemisphere by higher wind speeds and greater maritime surface area. Evidence presented here suggests however that the provenance of trees relative to the source of depleted ^{14}C, whether marine, fresh water, or volcanic, also makes an important contribution to such anomalies. In the Northern Hemisphere the limiting distance for detectable offset appears ~65 km downwind from the nearest coast, while in the Southern Hemisphere it may be closer to 100 km. This argument is supported by evidence that trees which grew within ~25 km of the Pacific and North Atlantic oceans in Washington, Alaska, Norway and Japan exhibit significant offsets (Table 6: 1–16), while the IntCal ^{14}C data-sets which derived from American, European and Anatolian wood which grew more than 100 km from the nearest coastline are statistically indistinguishable. Examination of a number of examples from the Southern Hemisphere (Table 10: 1–21), reveals that in contrast to the northern IntCal datasets, the SHCal offsets derive entirely from trees located in coastal locations in South Africa, New Zealand and Tasmania. While these coastal data all yield a significant, albeit temporally variable, N-S range between roughly 20 to 56 ^{14}C years. By contrast, such data as is available from the interior of the southern continents exhibit reduced or minimal offsets. There is indeed no compelling reason to believe that SHCal is anything more than a localized coastal anomaly.

None of the evidence presented here suggests that maritime-atmospheric models such as the Braziunas GCM that predict latitudinal ^{14}C gradients as a response to ocean surface and wind speed conditions are invalid. Nor is there any reason to dispute utilization of this GCM to rationalize the various coastal offsets reviewed here. However, the maritime basis of the GCM means that it is primarily applicable to ^{14}C dating of organic material growing in locations where dissipation of $^{14}CO_2$ depleted air has not yet occurred. Consequently, the current assumption that conformity with the GCM means that SHCal is also valid for trees located in the interior of southern landmasses cannot be sustained because the ^{14}C data used to validate that model all derive from trees which grew in close proximity to the same oceanic environment used to establish the GCM. The two sources of evidence are not independent.

Recognizing the coastal limitation of maritime ^{14}C offsets also provides an explanation for the systemic temporal variability which is a feature of many offset studies, and particularly evident in the extended Tasmanian and New Zealand data sets. With a $\Delta^{14}C$ value ranging from ~8–80 ^{14}C years,

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[58] Hogg *et al.* 2009, 2011.

[59] Sparks *et al.* 1995, Table 2.

[60] Knox & McFadgen 2001, 97.

and a possible ~130 years periodicity, these results have led some researchers to suggest that the very concept of a fixed N-S offset may be erroneous.[61] Climatic studies have demonstrated that climate is not globally uniform, and during times of rapid change regional the frequency and severity of coastal storms can be exacerbated.[62] As discussed above, the ^{14}C record suggests that local upwelling of depleted $^{14}CO_2$ is more intense before and after such events as the Maunder Minimum

9. Fresh water reservoir effects (FRE) and the Nile delta

Returning to the topic of Egyptian Dynastic dating: it is suggested here that the anomalously high ^{14}C ages associated with the Nile Delta can be attributed to a freshwater reservoir regional offset. Surface waters provide a potential pathway by which depleted $^{14}CO_2$ enters the atmosphere via sapropel, respiration of allochthonous organic matter, or as the result of a decline in the pH of dissolved inorganic carbon (DIC). The relationship between DIC and the Δ^{14}C in freshwater involves a number of factors such as substrate geology (particularly the presence of ^{14}C depleted carbonates), distance from the catchment area and alkalinity. [63] Under near neutral conditions groundwater DIC consists primarily of H_2CO_3 and CO_2 , the relative concentration being determined by the partial pressure of the CO_2 in the topsoil, ambient temperature as well as pH.[64] Consequently many fresh water systems exhibit much lower concentrations of labile ^{14}C than does the deep ocean. A recent radiometric study of acidic waterways associated with Scottish peatlands revealed systems supersaturated with CO_2, and one stream with a ^{14}C reservoir age of ~930 years.[65] High pH lakes and rivers however have the capacity to maintain much higher concentrations of depleted ^{14}C solutes derived from ancient alkaline earth carbonates or bicarbonates and bicarbonate-carbonate complexes. The alkalinity of such systems may also contribut to chemically enhanced $^{14}CO_2/^{12}CO_2$ exchange processes involving natural surfactants and aerosols.[66]

Two possible explanations for the anomalous ^{14}C ages in associated with the Nile Delta can thus be offered. The first could involve marine influence. The northern Dynastic capitals associated with Tell el Dabᶜa and Tanis were then located no more than 30 km from an estuary where the marine reservoir value is known to be unusually high. While recent measurements reveal the average reservoir age of the Mediterranean is no higher than ~458 years, shells collected closer to the Nile Delta at Port Saïd exhibit a value 633±40 years.[67] With the prevailing wind during the winter growing season being from the north, the concentration of depleted $^{14}CO_2$ could be enhanced by upwelling during seasonal storms, and during that season the Delta is also subjected to lingering off shore mists.[68] These locations would have been close enough to experience ^{14}C depleted CO_2 from the Mediterranean.

The second involves the possible influence of a localized FRE within the Delta floodplain itself, widespread settlement and development of which commenced ~1500 BC.[69] Sediment in Nile Delta has been ^{14}C dated to ~4000 years, while estimates of the surface water commonly exceed 2000 years BP. These high values can be attributed to very high concentration of alkaline earth carbonates in the waters of both the Blue and White Niles. The latter which originates in alkaline bedrock in central Africa exhibits consistently higher concentrations of ancient carbonates than the Blue, is of particular interest because winter crops were nourished by White Nile floods. Maximum DIC values occur pre-flood (March–May), with minima during Blue Nile floods (July–October), and depending on the season and degree of seepage and evaporation in the Sudd the pH ranges between 7.9 and 9.1. It is estimated that the concentration of extremely depleted inorganic carbon in the White Nile was ~3 times higher than that of sea water throughout the duration of the dynastic period.[70]

In fact ^{14}C analyses which were recently performed on crops harvested in the Nile Valley between AD 1702 and 1881, in an attempt to detect this phenomenon, and may actually have found it.

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[61] McCormac *et al.* 1998; Hogg *et al.* 2002, 650; McCormac et al. 2002, 2004.

[62] Lamb 1995.

[63] Krom et al. 2002.

[64] Geyh 2000, 99–107.

[65] Billet *et al.* 2006, 67.

[66] Wanninkhof 1992, 7377–7379.

[67] Siani 2000, 276; Reimer & McCormac 2002, 159.

[68] M. Bietak, personal communication.

[69] Geirnaert & Laeven 1992, 169.

[70] Williams 1969; Talling 1976; Dumont 1986, 64; Stanley & Hait 2000, 295.

These analysis yielded ^{14}C dates ~20 years higher than anticipated, a fixed offset which was utilized in the BR 2010 algorithm.[71] While an alternative explanation for the phenomenon was offered by those authors, FRE would appear to be a most reasonable explanation for this observation.

10. Conclusion

It is argued here that variances between ^{14}C and conventional dating of Egyptian dynastic material in BR 2010 are closely linked to the long standing controversy involving the chronology of ancient Tell el Dab^{c}a, and widespread evidence of regional ^{14}C offset observed in locations where the tree rings formed in proximity to ^{14}C depleted carbon dioxide. A review of the literature leads to the conclusion that contribution of marine ^{14}C depleted carbon dioxide can significantly influence the apparent age of trees within a distance of ~50 km from northern coastlines, while in the Southern Hemisphere it may extend to ~100 km.

It is also suggested that offsets detected in the radiometric dating of dynastic Egyptian material may be attributed to the existence of an anomalous ^{14}C environment unique to the Nile Delta. The existence of a high marine reservoir effect close to the Nile estuary and extremely ^{14}C depleted ground water in the Delta during the growing season of the materials may both have contributed to this phenomenon. A corollary to this argument for the existence of a regional anomaly, did exist is that concerns about the validity of ^{14}C dates of Egyptian artifacts could extend well beyond the samples described in BR 2010 and the results from Tell el Dab^{c}a if the original provenance of any organic material from ancient Egypt is unknown. This concern would for example not only apply to the interpretation of other radiometric data from the Old Kingdom,[72] but could include any item found in Egypt may been contaminated by deltaic ^{14}C depleted CO_2 to an unknown degree.

If confirmed, the hypothesis that regional offsets are largely restricted to sites in close proximity to ^{14}C depleted CO_2 would also have global chronological consequences. This is because application of a north-south (SHCal) offset might only be relevant for the ^{14}C dating of artifacts from southern coastlines while organic material originating from the interior of southern landmasses might conform closely to the northern IntCal. SHCal may thus prove to be no more than a regional coastal abnormality. As suggested elsewhere, the need may exist for a global family of calibration curves that take into account both spatial and temporal variations.[73] This hypothesis is also of potential relevance to the various disputes involving on the absolute dating of numerous archaeological sites in the Aegean and the Levant which are located within 50 kilometers of the Mediterranean coast.[74]

Fortunately these hypotheses are falsifiable. The existence of regional coastal offsets can be easily tested by comparing the ^{14}C ages of coeval rings from modern trees growing close to and distant from the shoreline in both hemispheres. In spite of enormous changes in conditions in since ancient times, trees still grow in the Nile Delta and in proximity to the Mediterranean Sea. Radiometric dating of living trees, and analyses of local short lived species growing in proximity to the oceans in both hemispheres would provide an opportunity to evaluate the need for regional calibration curves.

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[71] Dee *et al.* 2010.

[72] Dee *et al.* 2009.

[73] Knox & McFadgeon 2004, 995.

[74] The literature related to uncertainty in the dating of archaeological strata close to the Eastern Mediterranean is extensive. Examples include Hagens 2006; Manning 2006-2007; Bruins *et al.* 2011; Wiener 2012; Toffolo *et al.* 2014.

Bibliography

Baillie, M.G.L., Pilcher, J.R. & Pearson, G.W.

1983 Dendrochronology at Belfast as a background to high-precision calibration. *Radiocarbon* 25(2), 171–178.

Barbetti, M., Bird, T., Dolezal, G., Taylor, G., Francey, R., Cook, E. & Peterson, M.

1992 Radiocarbon variations from Tasmanian conifers: First results from late Pleistocene and Holocene logs. *Radiocarbon* 34(3), 806–817.

Barbetti, M., Bird, T., Dolezal, G., Taylor, G., Francey, R., Cook, E. & Peterson, M.

1995 Radiocarbon variations from Tasmanian conifers: Results from three Holocene logs. *Radiocarbon* 37(2), 361–369.

Bietak, M.

2013 *Antagonisms in Historical and Radiocarbon Chronology* , 76–109, in: A. J. Shortland & C. Bronk Ramsey (eds) *Radiocarbon and the Chronologies of Ancient Egypt.* Oxbow Books, Oxford.

Bietak, M. & Höflmayer, F.

2007 *Introduction: high and low chronology* , 13–27, in: M. Bietak M. & E. Czerny (eds) *The synchronization of Civilisations in the Eastern Mediterranean in the Second Millennium VC- III.* Vienna: Austrian Academy of Sciences.

Billet, M.F., Garnett ,M.H. & Hardie, S.M.L.

2006 A direct method to measure ^{14}C lost by evasion from surface waters, *Radiocarbon* 48(1), 61–68.

Braziunas, T.F., Fung I.E. & Stuiver, M.

1995 The preindustrial atmospheric ^{14}C latitudinal gradient as related to exchanges among atmospheric, oceanic, and terrestrial reservoirs, *Global Biogeochemical Cycles* 9, 565–584.

Bronk Ramsey, C., Dee, M.W., Rowland, J.M., Higham, T.F.G., Harris, S.A., Brock, F. , Quiles, A. & Wild, E.M., Marcuse S., & Shortland A.J.

2010 Radiocarbon-based chronology for Dynastic Egypt, *Science* 328, 1554–1557.

Bruins, H.J., Nijboer A.J. & van der Plicht, J.

2011 Iron Age Mediterranean chronology: a reply, *Radiocarbon* 53(1), 199–220.

Bruns, M., Levin, I., Munnich, K.O., Hubberten, H.W. & Fillipakis, S.

1980 Regional sources of volcanic carbon dioxide and their influence on ^{14}C content of present-day plant material, *Radiocarbon* 22(2), 532–536.

Damon, P.E.

1995a A note concerning "Location-dependent differences in the^{14}C content of wood" by McCormac *et al, Radiocarbon* 37(2), 829–830.

Damon, P.E.

1995b Note concerning "intercomparison of high-precision ^{14}C measurements at the University of Arizona and the Queen's University of Belfast radiocarbon laboratories" by Kalin *et al.* (1995) and the regional effect, *Radiocarbon* 37(3), 955–959.

Damon, P.E., Cheng, S. & Linick, T.W.

1989 Fine and hyperfine structure in the spectrum of secular variations of atmospheric ^{14}C, *Radiocarbon* 31(3), 704–718.

Damon, P.E., Burr, G., Cain, W.J. & Donahue, D.J.

1992 Anomalous 11-year $\Delta\ ^{14}$C cycle at high latitudes? *Radiocarbon* 34(2), 235–238.

Damon, P.E., Burr, G., Peristykh, A.N., Jacoby, G.C. & D'arrigo, R.D.

1996 Regional radiocarbon effect due to thawing of frozen earth, *Radiocarbon* 38(3), 597–602.

Damon, P.E., Eastoe, C.J. & Mikheeva, I.B.

1999 The Maunder Minimum: an interlaboratory comparison of Δ^{14}C from AD 1688 to AD 1710, *Radiocarbon* 41(1), 47–50.

Dee, M.W., Bronk Ramsey, C., Shortland, A.J., Higham, T.F.G. & Rowland, J.M.

2009 Reanalysis of the chronological discrepancies obtained by the Old and Middle Kingdom Monuments Project, *Radiocarbon* 51(3), 1061–1070.

Dee, M.W., Brock, F., Harris, S.A., Bronk Ramsey, C., Shortland, A.J., Higham, T.F.G. & Rowland, J.M.

2010 Investigating the likelihood of a reservoir offset in the radiocarbon record for ancient Egypt, *Journal of Archaeological Science* 37 (4), 687–693.

Dellinger, F., Kutschera, W., Nicolussi, K., Schiessling, P., Steier, P. & Wild, E.M.

2004 A ^{14}C calibration with AMS from 3500 to 3000 BC, derived from a new high-elevation stone-pine tree-ring chronology, *Radiocarbon* 46(2): 969–978.

Dumont, H.J.

1986 *The Nile River system,* 61–74, in, B.R. Davies & K.F. Walker (eds) *The Ecology of River Systems,* Dordrecht: W. Junk.

Geirnaert, W. & Laeven, M.P.

1992 Composition and history of ground water in the western Nile Delta, *Journal of Hydrology* 138 (1–2), 169–189.

Geyh, M.A.

2000 An overview of ^{14}C analysis in the study of groundwater, *Radiocarbon* 42(1), 99–114.

Hagens, G.

1996 A critical review of dead reckoning from the 21st dynasty. *Journal of the American Research Center in Egypt* 33, 153–163.

2006 Testing the limits: radiocarbon dating and the end of the Late Bronze Age. *Radiocarbon* 48(1), 83–100.

Hall, R.

1986 *Egyptian Textiles.* Aylesbury: Shire Egyptology.

Hogg, A.G., McCormac, F.G., Higham, T.F.G., Reimer, P.J., Baillie, M.G.L. & Palmer, J.G.

2002 High-precision radiocarbon measurements of contemporaneous tree-ring dated wood from the British Isles and New Zealand: AD 1850–950, *Radiocarbon* 44(3), 633–640.

Hogg, A., Palmer, J., Boswijk, G., Reimer, P.J. & Brown, D.

2009 Investigating the interhemispheric ^{14}C offset in the 1st millennium AD and assessment of laboratory bias and calibration errors. *Radiocarbon* 51(4), 1177–1186.

Hogg, A., Palmer, J., Boswijk, G. & Turney, C.

2011 High-precision radiocarbon measurements of tree-ring dated wood from New Zealand: 195 BC–AD 995. *Radiocarbon* 53(3), 529–542.

Hogg, A., Turney, C., Palmer, J., Cook, E. & Buckley, B.

2013 Is there any evidence for regional atmospheric ^{14}C offsets in the Southern Hemisphere? *Radiocarbon* 55(2), 1–6.

Imamura, M., Ozaki, H., Mitsutani, T., Niu, E. & Itoh, S.

2007 Radiocarbon wiggle-matching of Japanese historical materials with a possible systematic age offset. *Radiocarbon* 49(2), 331–337.

Knox F.B. & McFadgen, B.G.

2001 Least-squares fitting smooth curves to decadal radiocarbon data from AD 1145 to 1945. *Radiocarbon* 43(1), 87–118.

2004 Radiocarbon/tree-ring calibration, solar activity, and upwelling of ocean water. *Radiocarbon* 46(2), 987–95.

Krom, M.D., Stanley, J.D., Cliff, R.A. & Woodward, J.C.

2002 Nile River sediment fluctuations over the past 7000 years and their key role in sapropel development. *Geology* 30, 71–74.

Kromer, B., Manning, S.W., Kuniholm, P.I., Newton M.W., Spurk, M. & Levin I.

2001 Regional $^{14}CO_2$ offsets in the troposphere: magnitude, mechanisms, and consequences. *Science* 294, 2529–2532.

Kutschera, W., Bietak, M., Wild, E.M., Bronk Ramsey, C., Dee, M., Golser, R., Kopetzky, K., Stadler, P., Steier, P., Thanheiser, U. & Weninger, F.

2012 The chronology of Tell El-Daba: a crucial meeting point of ^{14}C dating, archaeology and Egyptology in the 2nd millennium BC. *Radiocarbon* 54 (3–4), 407–422.

Lamb, H.H.

1995 *Climate, History and the Modern World, 2nd Edn.* New York: Routledge.

Lerman, J.C., Mook, W.G., Vogel, J.C. & de Waard, H.

1969 Carbon-14 in Patagonian tree rings. *Science* 165, 1123–1124.

Lerman, J.C., Mook, W.G. & Vogel, J.C.

1970 *C14 in tree rings from different localities*, 275–301, in Olsson I.U. (ed) *Radiocarbon variations and Absolute Chronology.* New York: Wiley.

Levin, I. & Hesshaimer, V.

2000 Radiocarbon – a unique tracer of global carbon cycle dynamics. *Radiocarbon* 42(1), 69–80.

Levin, I. & Kromer, B.

2004 The tropospheric $^{14}CO_2$ level in mid-latitudes of the Northern Hemisphere (1959–2003). *Radiocarbon* 46 (3), 1261–1272.

Linick, T.W., Long, A., Damon, P.E. & Ferguson, C.W.

1986 High-precision radiocarbon dating of bristlecone pine from 6554–5350 BC. *Radiocarbon* 28(2B), 943–953.

Manning ,S.W.

2006–2007 Why radiocarbon dating 1200 BCE is difficult: a sidelight on dating the end of the Late Bronze Age and the contrarian contribution. *Scripta Mediterranea* 27–28, 53–80.

2007 *Clarifying the 'high v. 'low' Aegean/Cypriot chronology for the mid Second Millennium BC: assessing the evidence, interpretive frameworks, and current state of the debate*, 101–138, in Bietak M. and Czerny E. (eds) *The Synchronization of Civilizations in the Eastern Mediterranean in the Second Millennium B.C. W*ien: Österreichische Akademie der Wissenschaften:

Manning, S.W., Barbetti, M., Kromer, B., Kuniholm, P.I., Levin, I., Newton, M.W. & Reimer, P.J.

2002 No systematic early bias to Mediterranean ^{14}C ages: radiocarbon measurements from tree-ring and air samples provide tight limits to age offsets. *Radiocarbon* 44(3), 739–754 .

McCormac, F.G., Baillie, M.G.L., Pilcher, J.R. & Kalin, R.M.

1995 Location-dependent differences in the ^{14}C content of wood. *Radiocarbon* 37(2), 395–407.

McCormac, F.G., Hogg, A.G. , Higham, T.F.G., Lynch-Stieglitz, J., Broecker W.S., Baillie, M.G.L., Palmer, J., Xiong.L., Pilcher, J.R. & Brown, D. & Hoper S.T.

1998 Temporal variation in the interhemispheric ^{14}C offset. *Geophysical Research Letters* 25(9), 1321.

McCormac, F.G., Reimer, P.J., Hogg, A.G., Higham, T.F.G., Baillie, M.G.L., Palmer, J. & Stuiver, M.

2002 Calibration of the radiocarbon time scale for the Southern Hemisphere: AD 1850–950. *Radiocarbon* 44(3), 641–651.

McCormac, F.G., Hogg, A.G., Blackwell, P.G., Buck, C.E., Higham, T.F.G. & Reimer, P.J.

2004 SHCAL04 Southern Hemisphere calibration, 0–11.0 cal KYR BP. *Radiocarbon.* 46(3), 1087–1092

Okubo, A. & Levin, S.A.

1989 A theoretical framework for data analysis of wind dispersal of seeds and pollen. *Ecology* 70 (2), 329–338.

Ozaki, H., Imamura, M., Matsuzaki H. & Mitsutani T.

2007 Radiocarbon in the 9th to 5th century BC tree-ring samples from the Ouban 1 Archaeological Site, Hiroshima, Japan. *Radiocarbon* 49(2), 473–479

Pilcher, J.R., Baillie, M.G.L., Schmidt, B. & Becker, B.

1984 A 7,272-year tree-ring chronology for western Europe. *Nature* 312, 150–152.

Reimer, P.J. & McCormac, F.G.

2002 Marine radiocarbon reservoir corrections for the Mediterranean and Aegean Seas. *Radiocarbon* 44(1), 159–166.

Reimer, P.J. *et al.*

2004 Intcal04 terrestrial radiocarbon age calibration 0–26 KYR BP. *Radiocarbon* 46(3), 1029–1058.

Sakamoto, M., Imamura, M., van der Plicht, J. & Mitsutani, T. & Sahara, M.

2003 Radiocarbon calibration for Japanese wood samples. *Radiocarbon* 45(1), 81–89.

Shaw, M.W., Harwood, T.D., Wilkinson, M.J. & Elliot, L.

2006 Assembling spatially explicit landscape models of pollen and spore dispersal by wind for risk assessment. *Proceedings Biological Science.* 273 (1594), 1705–1713.

Siani, G., Paterne, M., Arnold, M., Bard, E., Métivier, B., Tisnerat, N. & Bassinot, F.

2000 Radiocarbon reservoir ages in the Mediterranean Sea. *Radiocarbon* 42(2), 271–280.

Sparks, R.J., Melhuish, W.H., McKee, J.W.A., Ogden, J., Palmer, J.G. & Molloy, B.P.J.

1995 ^{14}C calibration in the Southern Hemisphere and the date of the last Taupo eruption: evidence from tree-ring sequences. *Radiocarbon* 37(2), 155–163.

Stanley, D.J. & Hait, A.K.

2000 Deltas, radiocarbon dating, and measurements of sediment storage and subsidence. *Geology* 28(4), 295–298.

Stuiver, M.

1982 A high-precision calibration of the AD radiocarbon time scale. *Radiocarbon* 24(1), 1–26**.**

Stuiver, M. & Quay, P.D.

1980 Changes in atmospheric carbon-14 attributed to a variable sun. *Science* 207: 11–19.

1981 Atmospheric ^{14}C changes resulting from fossil fuel CO_2 release and cosmic ray variability. *Earth and Planetary Science Letters* 53: 349–362.

Stuiver, M. & Becker, B.

1986 High-precision decadal calibration of the radiocarbon time scale, AD 1950–2500 BC. *Radiocarbon* 28(2B), 863–910.

1993 High-precision decadal calibration of the radiocarbon time scale, AD 1950–6000 BC. *Radiocarbon* 35(1), 35–65.

Stuiver, M. & Braziunas, T.F.

1998 Anthropogenic and solar components of hemispheric ^{14}C. *Geophysical Research Letters* 25 (3), 329–332.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J. & Spurk, M.

1998 INTCAL98 radiocarbon age calibration 24,000–0 cal BP. *Radiocarbon* 40(3), 1041–1083.

Suzuki, K., Sakurai, H., Takahashi, Y., Sato, T., Gunji, S., Tokanai, F., Matsuzaki, H. & Tsuchiya, Y.

2010 Precise comparison of ^{14}C ages from Choukai Jindai cedar with IntCal 04 raw data. *Radiocarbon* 52 (4), 1599–1609.

Takahashi, Y., Sakurai, H., Suzuki, K., Sato, T., Gunji, S., Tokanai, F., Matsuzaki, H. & Sunohara, Y.

2010 Comparison of ^{14}C ages between LSC and AMS measurements of Choukai Jindai cedar tree rings at 2600 cal BP. *Radiocarbon* 52 (2–3), 895–900.

Talling, J.F.

1976 *Water Characteristics,* 356–384, in Rzoska J (ed.) *The Nile: Biology of an Ancient River.* The Hague: W. Junk.

Toffolo, M.B., Arie E., Martin M.A.S., Boaretto E. & Finkelstein I.

2014 Absolute chronology of Megiddo, Israel, in the Late Bronze and Iron Ages: high-resolution radiocarbon dating. *Radiocarbon* 56(1), 221–244.

Vogel, J.C., Fuls A. & Visser E.

1986 Radiocarbon fluctuations during the third millennium BC. *Radiocarbon* 28(2B), 935–938.

Vogel, J.C., Fuls A., Visser E. & Becker, B.

1993 Pretoria calibration curve for short-lived samples 1930–3350 BC. *Radiocarbon* 35(1), 73–85.

Wanninkhof, R.

1992 Relationship between wind speed and gas exchange over the ocean. *Journal of Geophysical Research* 97(C5), 7373–7382.

Wente, E. F. & van Siclen, C.C. III.

1976 *A Chronology of the New Kingdom* 217–261, in Johnson J.H. and E.F.Wente (eds) *Studies in Honor of George R. Hughes*, Studies in Ancient Oriental Civilization, Chicago: Oriental Institute.

Wiener, M.H.

2012 Problems in the measurement, calibration, analysis, and communication of radiocarbon dates (with special reference to the prehistory of the Aegean world). *Radiocarbon* 54 (3–4), 423–434.

Williams, M.A.J.

1969 The Nile in the Sudan. *Geographical Journal* 135(3), 489–490.

Zimmerman, S., Guilderson, T., Buckley, B. & Cook, E.

2010 Extension of the Southern Hemisphere atmospheric radiocarbon curve, 2120–850 years BP: results from Tasmanian Huon pine. *Radiocarbon* 52(2–3), 887–94.