^{14}C WIGGLE-MATCH DATING IN HIGH-RESOLUTION SEA-LEVEL RESEARCH

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ABSTRACT. Comparison of two sets of marsh-accumulation records from each of three Connecticut (USA) salt marshes, one based on individually calibrated dates and the other on wiggle-match dating of the same series of dates, shows that wiggle-match dating results in more precise and objective reconstructions of longer-term (10^2–10^3 yr) changes in accumulation rate. On (sub-)century time scales, wiggle-match dating can reveal steps in the calibrated marsh-accumulation envelope as artefacts of the calibration curve, but may also leave real short-term changes in accumulation rate undetected. Wiggle-matches are non-unique, being dependent on the number, quality and distribution of radiocarbon dates in a sequence, how a series of dates is subdivided into groups (representing intervals of uniform accumulation rate), and what is considered a “best match”. Samples from the studied salt-marsh deposits required no correction for reservoir effects prior to calibration.

INTRODUCTION

High-resolution records of relative sea-level (RSL) variations covering the past several thousand years have been extracted from peaty salt-marsh deposits along the western and eastern seaboards of North America. A primary objective of studies from the USA Atlantic coast is the investigation of the relationship between sea-level and climate-ocean changes (e.g. Varekamp et al. 1992; Nydick et al. 1995; van de Plassche et al. 1998a, 1998b; Varekamp and Thomas 1998; Gehrels 1999; van de Plassche 2000). Records of local RSL change can be established by examining intra-core variations in marsh-paleoecological indicators, such as vascular plants, diatoms and foraminifera, which possess quantified vertical relationships to tidal parameters. The accelerator mass spectrometry radiocarbon (AMS ^{14}C) dating of plant macro-fossils provides ages for individual horizons within the core, and interpolation between these points yields an age-depth relationship (marsh-accumulation history) which can be used to place the inferred RSL variations into a temporal context (Varekamp et al. 1992; van de Plassche et al. 1998a). Ultimately, the precision and accuracy of the accumulation history will, in part, determine the resolution at which sea-level variations can be meaningfully investigated.

Variations in atmospheric ^{14}C activity and the statistical nature of radioactive decay mean that calendar dates converted from individual ^{14}C dates are associated with uncertainties of variable magnitude. The precision of a chronology is particularly affected where it coincides with periods when the ^{14}C calibration curve exhibits “plateaus” (e.g. the “Hallstatt Plateau” ca. 2450 BP), and resulting calendar-age uncertainties may extend up to 400 years. These characteristics introduce considerable scatter in age-depth diagrams which complicate the construction of reliable accumulation curves.

A strict consideration of age errors as advocated by Shennan (1986), would frequently require the assignment of a single, linear interpolation through an entire set of dates. Such an approach is undesirable in the context of high-resolution studies since this single value may mask shorter period rate changes, and is likely to be a gross over-simplification where variations in stratigraphy are present. Attempts have been made to improve chronologies by constructing an error envelope, and within it a 'best fit' working curve, based on an evaluation of the reliability of individual age-depth data by reference to other age-depth data from the same core and to changes in vegetation communities and inferred depositional conditions (e.g. van de Plassche 2000). However, this approach contains sub-

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jective judgements and tends to give added weight to dates with small uncertainties, corresponding to steep sections of the ^{14}C calibration curve.

In this paper, we explore the potential application of AMS ^{14}C wiggle-match dating (WMD) as a tool to improve the precision of salt-marsh peat-based chronologies developed in sea-level research. This technique, previously used to refine accumulation histories from raised peat bogs, utilizes the variations (wiggles) present in the ^{14}C calibration curve to more precisely determine the ages of a sequence of ^{14}C dates (van Geel and Mook 1989; Kilian et al. 1995). We present three sets of age-depth data from different salt-marshes in Connecticut, USA. For each marsh, accumulation histories are constructed based, firstly, on individually calibrated dates, and secondly, by wiggle-matching the same data. These results are compared and the implications for construction of records at millennial and (sub-)centennial time scales are discussed.

STUDY AREAS AND METHODS

We obtained a sequence of twenty or more ^{14}C dated marsh-surface indicators sampled at vertical intervals of about 10 cm from cores of salt-marsh peat collected in Pattagansett River marsh (PRM), Hammock River marsh (HRM), and East River marsh (ERM), Connecticut (Figure 1). These marsh-surface indicators (e.g. sub-surface stems, corms, and rhizomes) possess a quantified relationship to a former marsh surface, estimated on the basis of numerous observations, both in the field and in cores, of the modern depth ranges of sub-surface plant parts (van de Plassche et al. 1998a). The vertical uncertainty of each paleomarsh-surface estimate includes an error for depth measurement relative to the modern marsh surface (Tables 1–3).

In HRM and PRM, core-site selection was based on prior stratigraphic mapping, and carried out to avoid sampling at locations with known erosive hiatuses in the record. In ERM, we revisited the core GK site studied by Nydick et al. (1995); here the record contains three stratigraphic hiatuses not apparent in the original data. In PRM, we retrieved one continuous vibracore (10 cm diameter) with 100% recovery (i.e. no compaction). In the other two marshes, we used a 1-m-long auger with a diameter of 6 cm to collect one or two sets of overlapping cores located 10–25 cm apart. These cores, which were stratigraphically matched prior to sampling, can contain some (1–5 cm) deformation due to stretching of the lower end of the core.

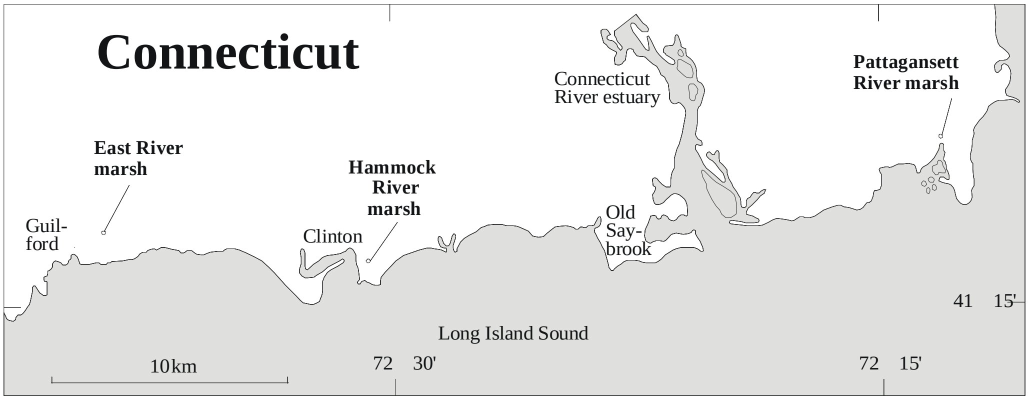

Figure 1 Location of the three study sites

Table 1 Radiocarbon data from Pattagansett River Marsh

Lab code (PRM-)	Date nr	Paleomarsh surface (m)		^{14}C dates		δ^{13}C ‰	Calibrated calendar age (cal AD/BC) Method A	Wiggle-matched age (cal AD/BC)	Wiggle-match group
		Depth	Error	Age (BP)	1 σ				
28	1	2.21	0.03	1702	32	−14.3	260–280 292–297 322–402 AD	248 AD	A
27	2	2.33	0.03	1813	34	−14.1	133–243 AD	252 AD	A
26	3	2.45	0.03	1909	38	−14.2	34–36 62–129 AD	156 AD	A
25	4	2.57	0.03	1909	33	−14.1	67–129 AD	60 AD	A
24	5	2.69	0.03	2004	37	−14.0	44 cal BC–30 cal AD 39–51	36 BC	A
23	6	2.81	0.03	2083	43	−14.0	169–43 6–4 BC	132 BC	A
22	7	2.93	0.03	2189	39	−14.4	357–285 258–243 234–197 191–175 BC	228 BC	A
21	8	3.05	0.03	2156	33	−14.1	347–320 227–223 205–167 BC	324 BC	A
20	9	3.27	0.03	2215	35	−14.9	363–330 325–268 263–202 BC	358 BC	B
19	10	3.29	0.03	2481	45	−14.2	764–515 486–485 463–450 439–428 421–414 BC	415 BC	B
17	11	3.35	0.03	2457	42	−14.6	761–679 669–612 594–476 474–410 BC	587 BC	B
18	12	3.41	0.03	2503	36	−14.4	782–756 703–540 526–525 BC	759 BC	B
16	13	3.62	0.05	2731	35	−14.7	904–829 BC	915 BC	C
15	14	3.75	0.03	2908	39	−14.5	1207–1202 1190–1179 1156–1142 1130–1011 BC	1036 BC	C
14	15	3.87	0.03	2940	38	−14.0	1256–1239 1213–1196 1194–1137 1134–1106 1104–1050 BC	1148 BC	C
13	16	3.99	0.03	2997	43	−14.8	1367–1362 1313–1208 1202–1190 1179–1156 1142–1130 BC	1260 BC	C
12	17	4.11	0.03	3093	39	−14.1	1410–1369 1360–1347 1344–1316 BC	1372 BC	C
11	18	4.23	0.03	3141	43	−13.7	1439–1391 1329–1323 BC	1482 BC	C
10	19	4.35	0.03	3312	40	−13.8	1680–1670 1658–1652 1637–1522 BC	1596 BC	C
09	20	4.47	0.03	3378	45	−14.8	1738–1708 1694–1619 BC	1708 BC	C
08	21	4.59	0.03	3527	41	−14.9	1916–1860 1844–1806 1804–1772 BC	1820 BC	C
07	22	4.71	0.03	3620	42	−14.6	2031–1986 1985–1918 BC	1932 BC	C
06	23	4.83	0.03	3684	37	−14.9	2137–2076 2074–2025 1995–1981 BC	2044 BC	C
05	24	4.95	0.03	3818	41	−14.3	2306–2199 2156–2154 BC	2155 BC	C
04	25	5.07	0.03	3772	43	−14.7	2281–2251 2231–2219 2209–2138 BC	2267 BC	C
02	26	5.25	0.03	3916	39	−14.5	2467–2397 2384–2344 BC	2434 BC	C
01	27	5.43	0.03	4150	50	−15.4	2876–2656 2654–2621 2607–2602 BC	2602 BC	C

AMS ^{14}C dating was conducted at the R J Van de Graaff Laboratory, Utrecht. The dated samples consisted of rhizomes or sub-surface stems of *Distichlis spicata*, *Scirpus robustus*, *Spartina alterniflora*, *Spartina patens*, and *Triglochin maritima*. A binocular microscope was used to check each sample for presence of younger rootlets. The ^{14}C ages were calibrated using the Washington Calibration Program (CALIB rev. 4.1.2) (Stuiver and Reimer 1993).

AMS ^{14}C Wiggle-Match Dating

The ^{14}C calibration curve relating ^{14}C ages (Y-axis) to calendar dates (X-axis), exhibits numerous "wiggles" caused by varying atmospheric ^{14}C activity. These variations may mean that the calibration of an individual ^{14}C date results in multiple calendar ages. If a suite of ^{14}C dates from a core is available, however, the uniqueness of parts of the calibration curve can be exploited to more reliably determine calendar age. The position of an individual date within a suite of dates is related to its neighbors via the accumulation rate of the sedimentary sequence. A suite of ^{14}C ages can therefore be mapped onto the calibration curve by performing a linear "stretch" along the X-axis which, in effect, serves to select the most appropriate accumulation rate for the sedimentary sequence. This fit-

Table 2 Radiocarbon data from Hammock River Marsh

		Palaeomarsh surface (m)		^{14}C dates					
Lab code (HRM-)	Date nr	Depth	Error	Age (BP)	1 σ	δ^{13}C‰	Calibrated calendar age (cal AD/BC) Method A	Wiggle-matched age (cal AD/BC)	Wiggle-match group
132	1	1.59	0.04	1471	36	–28.5	544–549 558–640 AD	544 AD	A
135	2	1.62	0.04	1709	35	–14.4	259–283 288–299 320–396 AD	529 AD	A
138	3	1.73	0.04	1628	37	–13.3	400–434 AD	444 AD	A
137	4	1.80	0.05	1694	37	–14.2	261–279 293–296 323–411 AD	389 AD	A
139	5	1.90	0.06	1809	35	–13.6	133–244 310–315 AD	315 AD	A
140	6	2.00	0.04	1769	35	–13.9	236–261 278–261 330–336 AD	241 AD	B
141	7	2.06	0.04	1877	43	–13.9	78–181 188–215 AD	200 AD	B
142	8	2.16	0.04	1929	41	–13.9	28–41 50–93 97–127 AD	105 AD	B
143	9	2.22	0.04	2014	37	–14.5	46 cal BC–27 cal AD 42–48 AD	43 AD	B
144	10	2.29	0.03	2091	37	–14.3	169–46 BC	23 BC	B
145	11	2.45	0.04	2151	45	–14.4	348–317 227–220 205–150 132–116 BC	175 BC	C
146	12	2.51	0.04	2217	38	–14.5	375–366 364–325 324–266 263–201 BC	235 BC	C
147	13	2.56	0.03	2197	39	–14.8	358–272 259–197 187–179 BC	297 BC	C
148	14	2.64	0.03	2308	34	–14.7	398–380 BC	386 BC	C
149	15	2.74	0.05	2400	39	–15.3	516–456 453–435 432–400 BC	492 BC	C
151	16	2.80	0.03	2513	39	–14.7	786–756 694–655 652–541 BC	564 BC	C
152	17	2.94	0.06	2468	39	–15.4	761–676 671–607 599–481 466–446 442–411 BC	714 BC	C
153	18	3.01	0.03	2584	42	–25.8	801–776 BC	798 BC	C
154	19	3.07	0.04	2780	40	–14.1	994–994 972–954 942–894 875–842 BC	859 BC	C
155	20	3.20	0.05	2888	43	–16.4	1186–1181 1144–1144 1127–999 BC	1004 BC	C

ting process may be achieved via the Cal25 computer program (van der Plicht 1993), and its use in dating raised peat-bog deposits has been documented (e.g. van Geel and Mook 1989; Kilian et al. 1995). This method assumes that the accumulation rate has remained constant throughout the formation of the dated sequence. It is also possible to "Y-shift" the data which can be used to account for reservoir effects, etc.

In this paper, we apply the WMD approach to suites of AMS ^{14}C dates derived from salt-marsh peat cores. As mentioned above, a strict consideration of age errors would require the use of a constant accumulation rate throughout the sedimentary sequence. Consequently, we start by WMD the entire suite of dates to produce a single accumulation rate. However, unlike a simple linear interpolation, the WMD derived age takes into account the variability within the ^{14}C calibration curve. Where the rate of accumulation differs from this general trend, the data points progressively "drift" away from the calibration curve. When this occurs, the suite of dates can be sub-divided into sections of uniform accumulation rate, and wiggle-matched separately, thereby improving their fit to the calibration curve and refining the age estimates. This is most reliably achieved when supported by lithostratigraphic and biostratigraphic evidence of changing depositional conditions. Where sub-division of the data is required, "tie dates" are used to link the suites together and ensure that the overall sequence of dates is maintained.

Wiggle-match dating was performed using the Groningen Radiocarbon Calibration Program (Cal25) (van der Plicht 1993). Details of the ^{14}C dates and the WMD results are presented in Tables 1–3. Whilst the Cal25 program does not return errors for the WMD ages, the non-unique solutions of WMD, particularly if "Y-shifts" in the data are invoked, means that uncertainties are inevitably

Table 3 Radiocarbon data from East River Marsh

Lab code (ERM-)	Date nr	Palaeomarsh surface (m)		^{14}C dates			Calibrated calendar age (cal AD) Method A	Wiggle-matched age (cal AD)	Wiggle-match group
		Depth	Error	Age (BP)	1 σ	δ^{13}C‰			
1	1	0.21	0.03	222	28	−26.4	1650–1668 1782–1796	1870	A
2	2	0.32	0.03	69	32	−25.9	1709–1718 1823–1826 1885–1912 1949–1953	1817	A
3	3	0.4	0.03	179	25	−12.9	1667–1681 1735–1783 1793–1806 1933–1947	1779	A
4	4	0.44	0.03	145	43	−12.2	1671–1708 1719–1779 1798–1822 1827–1885 1912–1944 1945–1950	1761	A
5	5	0.5	0.03	126	25	−11.7	1681–1709 1718–1734 1806–1823 1826–1885 1912–1932 1947–1950	1732	A
6	6	0.61	0.03	124	37	−10.9	1678–1742 1750–1757 1804–1892 1907–1936 1946–1951	1680	A
19	7	0.725	0.065	621	36	−13.9	1299–1331 1341–1374 1376–1397	1393	B
7	8	0.79	0.03	615	43	−13.5	1299–1334 1336–1400	1329	B
7	9	0.79	0.03	579	29	−13.7	1323–1350 1390–1407	1329	B
8	10	0.89	0.03	624	24	−12.0	1301–1327 1345–1372	1232	B
9	11	1.015	0.065	934	34	−14.3	1028–1160	1109	B
20	12	1.14	0.04	1006	42	−13.1	997–1032	987	B
21	13	1.24	0.04	1184	36	−13.8	779–893	889	B
22	14	1.35	0.04	1196	38	−13.9	777–891	782	B
10	15	1.37	0.07	1289	32	−14.4	678–728 738–773	762	B
11	16	1.42	0.05	1315	27	−13.7	664–692 701–712 752–761	713	B
12	17	1.53	0.03	1272	26	−14.0	688–776	606	B
13	18	1.67	0.03	1602	27	−14.4	420–442 448–468 481–494 496–530	461	C
14	19	1.76	0.03	1733	25	−14.3	256–303 317–343 372–377	369	C
15	20	1.84	0.03	1770	34	−13.8	236–261 279–294 295–324 335–335	287	C
16	21	1.87	0.03	1783	30	−14.5	224–258 283–288 300–320	256	C
17	22	1.94	0.04	1798	29	−14.5	185–185 216–245 305–316	184	C
18	23	2.04	0.04	1901	23	−15.0	76–128	82	C

associated with the results. Kilian et al. (1995) used an error based on sample-sediment thickness, but note that it is "…only part of the (undeterminable) error". Here, we demonstrate this uncertainty by assigning an arbitrary value of 50 years. The sequences presented here possess, on average, one ^{14}C date per 80 calendar years or so.

RESULTS

Accumulation Records Derived From Individually Calibrated Dates

Individually calibrated ^{14}C dates are shown for each of the three marshes in Figures 2A, 3A, and 4A (grey error boxes), in association with the lithostratigraphy of each core. All three diagrams demonstrate the problems associated with deriving precise, high-resolution marsh-accumulation curves from dates calibrated in isolation. Even with such a high frequency of ^{14}C dates (samples every ca. 10 cm, or ca. 80 calendar years), a wide range of possible scenarios may be invoked depending upon the degree to which data are (over)interpreted. For example, a straight line can be drawn through the data for PRM (Figure 2A) suggesting a uniform rate of accumulation. Alternatively, if deviations in single ^{14}C dates are considered significant, it is possible to create a record exhibiting numerous accelerations in accumulation, such as at 2225 cal BC, 1350 cal BC, and 100 cal AD.

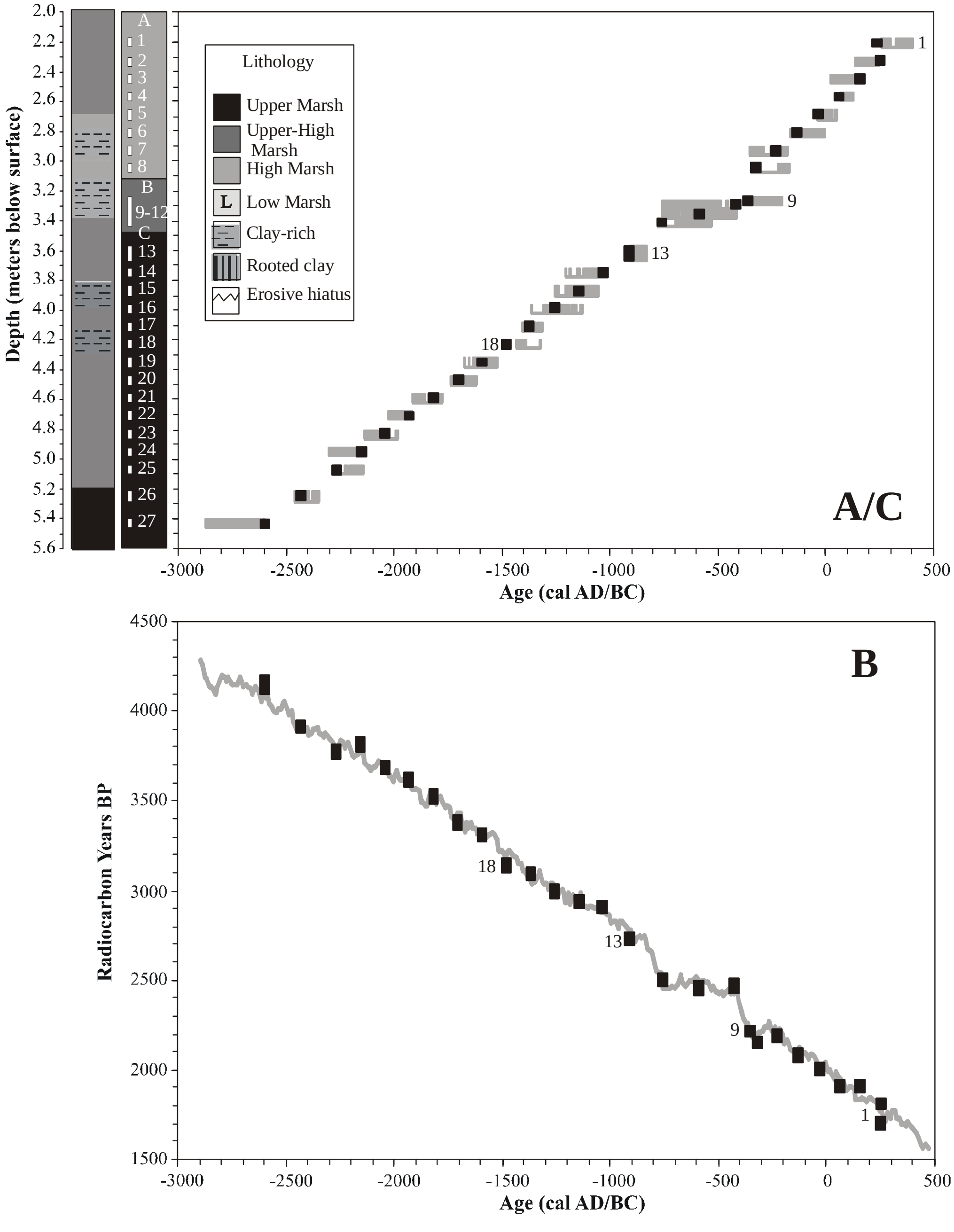

Figure 2 Pattagansett River marsh. A. Stratigraphic column and accompanying, individually calibrated, AMS ^{14}C dates (grey error boxes); B. Wiggle-matched dates plotted against the ^{14}C calibration curve; C. Wiggle-matched sub-groups (second column on left) and wiggle-matched dates (black error boxes); Dates 13 and 9 are "tie dates" between sub-groups.

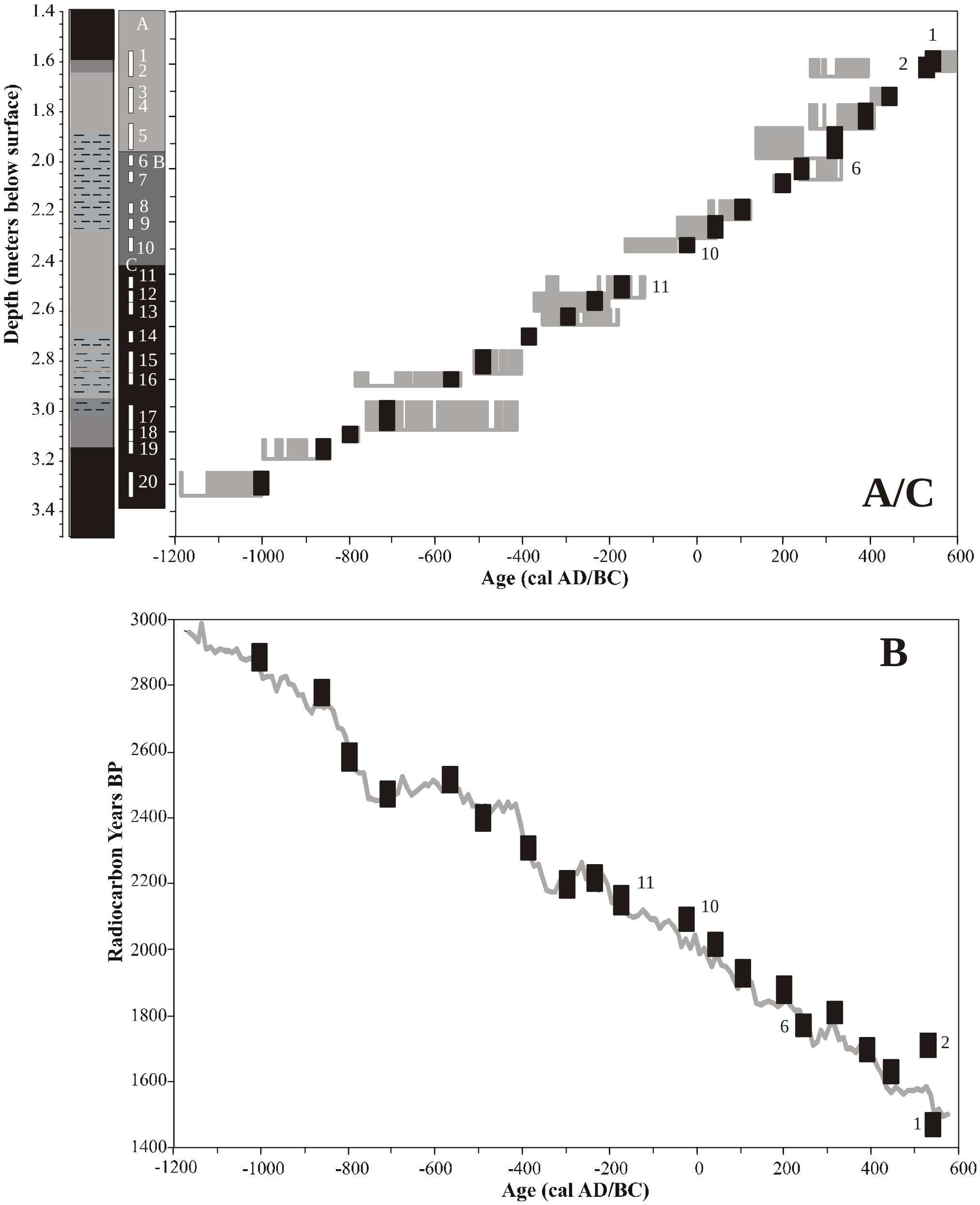

Figure 3 Hammock River marsh. A. Stratigraphic column and accompanying, individually calibrated, AMS ^{14}C dates (grey error boxes); B. Wiggle-matched dates plotted against the ^{14}C calibration curve; C. Wiggle-matched sub-groups (second column on left) and wiggle-matched dates (black error boxes); Dates 11 and 6 are “tie dates” between sub-groups.

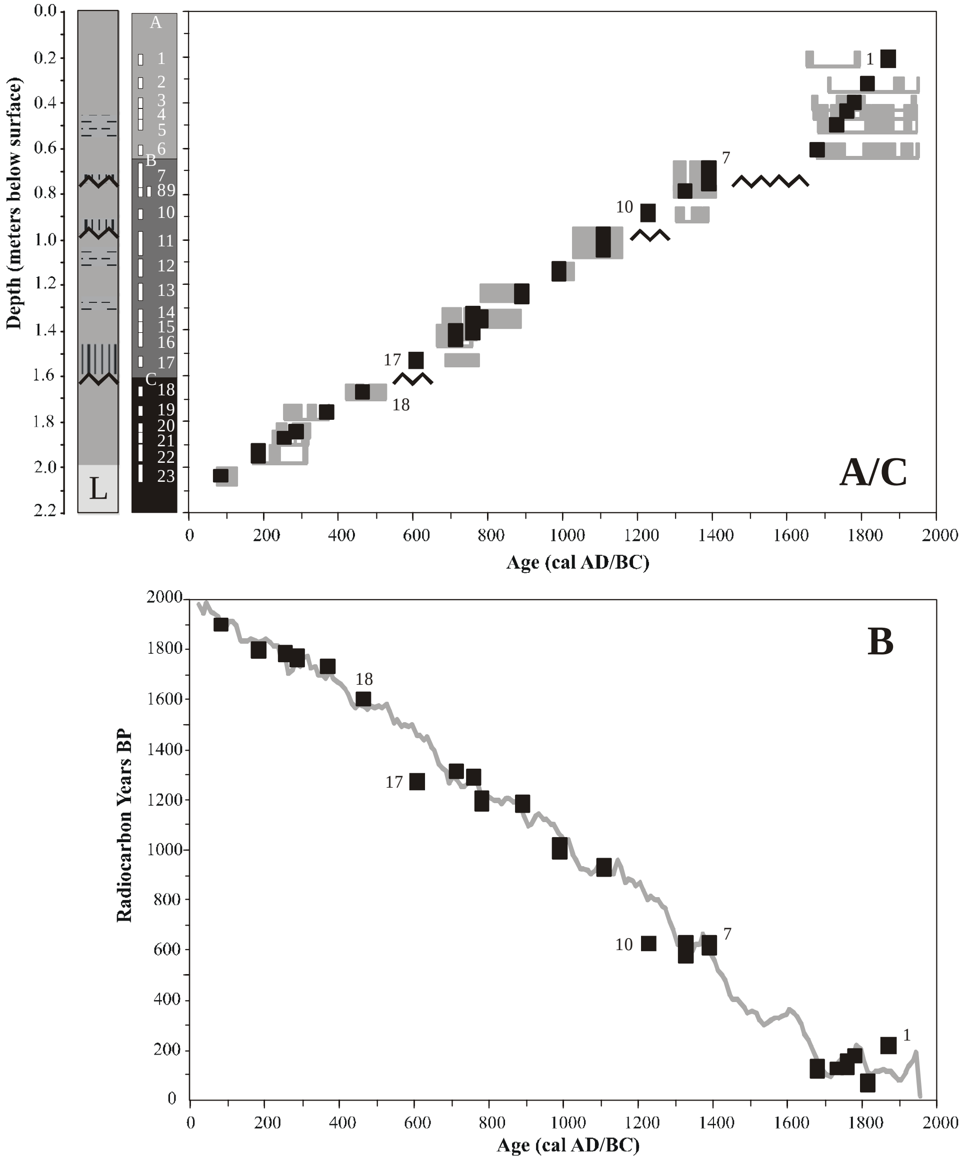

Figure 4 East River marsh. A. Stratigraphic column and accompanying, individually calibrated AMS ^{14}C dates (grey error boxes); B. Wiggle-matched dates plotted against the ^{14}C calibration curve; C. Wiggle-matched subgroups (second column on left) and wiggle-matched dates (black error boxes).

The records from PRM (Figure 2A) and HRM (Figure 3A) also demonstrate the influence of features such as the "Hallstatt Plateau" between 750 and 400 cal BC where it is impossible to draw reliable conclusions on accumulation rate during this period. Unless supporting evidence for changes in depositional environment are provided by stratigraphic analysis, there is little alternative but to use a single, generalized accumulation rate for the entire period of study.

The record from ERM (Figure 4A) demonstrates how lithological information can influence the interpretation of the accumulation record. The stratigraphic record from ERM exhibits three hiatuses which are evident as an absence of ^{14}C dates between the intervals 525–650 cal AD, 1150–1300 cal AD and 1400–1650 cal AD. The two deeper hiatuses are related to the presence of rooted clay beds, 5–15 cm thick, with sharp lower boundaries. Unlike the histories of PRM and HRM, these abrupt changes in lithostratigraphy suggest brief periods of altered sedimentary conditions, and the individually calibrated ^{14}C data indicate these may have been associated with temporary increases in accumulation rate following erosion (Figure 4A). It is certainly plausible that the clay and clayey peat immediately overlying the hiatus was deposited at a higher rate than the average rate of vertical marsh-peat growth. The upper hiatus (1450–1650 cal AD) is also associated with a thin (a few cm) rooted clay layer and marks the abrupt transition from the accumulation of peat with a low clay content. The variation in atmospheric ^{14}C during the past 400 years creates a confusing pattern of change in the accumulation curve above this hiatus, but the data appear to indicate it may also be associated with an increased rate.

Accumulation Records Derived from Wiggle-Match Dating

Figures 2B, 3B, and 4B show the wiggle-matched dates for each study site plotted onto the ^{14}C calibration curve. Figures 2C, 3C, and 4C (black error boxes) show the accumulation record derived from these dates, how the total suite of dates were divided into sub-sets for individual WMD (A, B, and C; second column on left), and how these WMD age-depth plots compare with the individually calibrated calendar ages.

The sequence from PRM (Figures 2B, 2C) was divided into three sub-sets and produces a good wiggle-match result. The earliest portion of the sequence could not reliably be sub-divided any further due to lack of distinct features in the calibration curve. The WMD age for Date 18 is an outlier, and plots around 50 years too old. The presence of the "Hallstatt Plateau" permitted a more precise subdivision of the data between 800–400 cal BC and distinguished a period of reduced accumulation rate.

The sequence from HRM (Figures 3B, 3C) was divided into three sub-sets and produces a good wiggle-match result. The WMD age for Date 10 is an outlier and plots approximately 20 years too young. Date 10 is included in sub-group B, which corresponds to a section of the core with an increased clay content, but the date itself is actually situated just below this clay enrichment. It is probable that the erroneous WMD age of Date 10 indicates a change in accumulation rate occurred at this time. It should be noted that, whilst the HRM record also encompasses the period of the "Hallstatt Plateau", no change in accumulation rate is apparent in the data. In the upper part of the sequence, the WMD age for Date 2 plots around 130 years too young. This discrepancy is most reasonably explained as a problem with the original date since this displays an age inversion with respect to Date 3.

The sequence from ERM (Figures 4B, 4C) was also divided into three sub-sets, although the WMD procedure was slightly different from the previous two marshes owing to the presence of hiatuses in the record. The periods of non-deposition meant that using tie dates to link the sub-sets of age data together would introduce considerable errors in the matches, and consequently the separate sections were wiggle-matched in isolation. The resulting WMD record possesses the most outliers of all the sites. Date 17 and Date 10, which plot about 80 and 70 years too old respectively, are associated with the two lower hiatuses. As mentioned previously, it is possible that these periods were associated with enhanced rates of accumulation, and this would account for the erroneous ages of the wiggle-matched dates. At the top of the sequence, the complicated pattern of change associated with the last 400 years, coupled with the absence of a tie date resulting from the erosive hiatus, means that this portion of the record is difficult to wiggle-match. The chosen WMD produces an erroneously young age for Date 1 (ca. 70 years), although the position of Date 1 relative to the other five ^{14}C ages may indicate that it is contaminated.

DISCUSSION

The results demonstrate that WMD can be applied successfully to salt-marsh peat sequences and can increase the precision of reconstructed accumulation histories. These advantages are most evident when comparing the two accumulation records for each marsh presented in Figures 2A/C, 3A/C, and 4A/C. The WMD technique is most successful where pronounced variations in the ^{14}C calibration curve are present since more "wiggles" permit more precise and reliable matches. Conversely, individually calibrated ^{14}C dates are at their least precise during "plateau" intervals. A further advantage is that the WMD histories are readily testable by the collection of more ^{14}C dates, particularly in areas where changes in accumulation rate are inferred. Increasing the number of dates during periods such as the "Hallstatt Plateau" will allow the timing of the changes to be more precisely and accurately matched. This is also in direct contrast to the use of individually calibrated dates, where the collection of more data frequently serves to increase the observed scatter and complicate the reconstruction of accumulation histories.

On a century time scale, the WMD distinguishes a step in the PRM accumulation record between 750 and 300 cal BC (Figure 2C), and suggests a higher rate of vertical marsh growth in ERM during the past 400 years, but straightens out all other short-term variations in the rate of marsh accumulation. The linearity inherent within the WMD approach means that, at these shorter time scales, brief changes in accumulation rate may be masked. Evidence for this is seen in the WMD accumulation records, particularly where WMD ages plot as outliers. The most outliers occur in the ERM record, and it is reasonable to suggest that this is because the sequence contains a greater number of short-term changes in accumulation rate associated with the hiatuses. The more uniform, higher marsh sediments of PRM and HRM, exhibit less evidence of such brief "pulses" in accumulation, and are better suited to the WMD approach. Nevertheless, as HRM Date 10 demonstrates, independent lithologic or biostratigraphic evidence remains an important element to be considered when interpreting the data. Once again, the advantage of the WMD histories is that they are testable. The existence of outliers "flags" regions of the accumulation curve that require more investigation, and the collection of additional stratigraphic data (or dates) should serve to resolve whether a real, short-term change in accumulation rate occurred, or whether the ^{14}C date is in error. Stratigraphic hiatus, for instance, can be difficult to detect. Careful re-inspection of the study site in PRM may reveal indications or evidence of a stratigraphic hiatus between Date 19 and outlier Date 18 and between Dates 10 and 9. In the latter case, the WMD will result in a PRM accumulation record without a step between 750 and 300 cal BC.

Despite the advantages described above, it is important to realize that the results of WMD are influenced by the number, frequency and distribution of available dates, the characteristics of the corresponding portion of the ^{14}C calibration curve, and the (arbitrary) error assigned to the WMD ages. Whilst the computerized process indicates which WMD scenarios display the "best fit", it does not determine the way in which the data are manipulated (axis shifted, sub-divided etc.). For example, the introduction of Y-shifts in the data, to describe features such as the reservoir effect noted in ombrogenous bogs by Kilian et al. (1995), will alter the final WMD accumulation curve. Figure 3B shows that Dates 3–10 from HRM plot along the upper limits of the calibration curve (toward the younger end of the acceptable age range). It would be possible to invoke a Y-shift in the data to achieve a statistically "better" fit, but it is questionable whether this would result in a more accurate accumulation curve. Clearly, invoking multiple and varying sized Y-shifts in the data is not justified. Here, we have kept manipulation of the data to a minimum and no Y-shifts in the data have been attempted. Whilst it is possible that a reservoir effect is present in our salt-marsh sequences, it is not necessary to invoke one in order to produce the wiggle-matches presented above.

The construction of reliable, high-resolution sea-level records requires precise age and elevation data. Whilst it is possible to sample sediment every 1–2 cm for paleoecological data, technical and financial limitations commonly prevent the age of each sample from being estimated by ^{14}C dating. Even if this were possible, the uncertainties inherent to radiometric dating would result in overlapping dates and require some interpretation. Interpolation of data is fundamental to the production of unique age-depth relationships. The WMD approach presented here is a useful tool for facilitating more precise and reliable quantification of these relationships.

CONCLUSIONS

1. Wiggle-match dating of AMS ^{14}C age estimates from salt-marsh peat samples offers a more precise and objective way of constructing long-term (century to millennium scale) accumulation histories than the interpolation of individually calibrated dates.
2. On (sub-)century time scales, wiggle-match dating will detect real short-term increases in accumulation rate only if the quality, quantity and distribution of the dates are optimal.
3. Chronologies derived from WMD may be tested and refined by the collection of additional dates from parts of the record that exhibit poor agreement with the calibration curve.
4. The results of WMD are not unique and it is important to consider supporting evidence from lithostratigraphic and biostratigraphic data when interpreting the accumulation records.
5. No reservoir effect was invoked to obtain the wiggle-matches presented.

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