Radiocarbon, Vol 56, Nr 2, 2014, p 655–665 DOI: 10.2458/56.16958

ESTE, PADOVA, ITALY: DATING THE IRON AGE WATERFRONT

John Meadows[1,2] • Nicoletta Martinelli[3] • Marie-Josée Nadeau[2] • Elodia Bianchin Citton[4]

ABSTRACT. Two floating tree-ring chronologies were developed from oak timbers recovered during salvage excavations of a pre-Roman wharf in Este, a prominent center of the Veneti people, who lived in northeastern Italy during the Iron Age. Wiggle-match radiocarbon dating shows that one chronology spans the 10th and 9th centuries cal BC, and that the waterfront was probably built ~800 cal BC. The second chronology apparently spans most of the 7th century cal BC, and is associated with a phase of construction about 2 centuries after the first. One of the samples gave what appeared to be anomalous ^{14}C results that may best be explained as evidence of a short-term fluctuation in atmospheric ^{14}C level, which can be seen in short-lived samples but is not apparent in the decadal or bidecadal calibration data. Both chronologies cover periods for which there are no other tree-ring chronologies in this region, and could become key to refining the local Iron Age chronology.

INTRODUCTION

In the course of archaeological excavations conducted in 2004 in the town center of Este, one of the capitals of the ancient Veneti peoples, in advance of the replacement of the sewerage network, an area of structures was discovered with remains of an ancient road and a timber dock (Ruta Serafini and Salerno 2006). The dock consisted of a series of imposing lines of posts, with large timbers in a reasonable state of preservation (Figures 1–2). The waterfront was attributed to the Iron Age and its first phase assigned to no later than the 5th century BC, on the basis of pottery sherds from the lowest layer of the adjacent road, parallel to the waterfront.

Dendrochronological analyses, carried out on 23 samples, produced two site chronologies, both for oak (*Quercus* sp. Sec. *robur*), which provide important starting points for the absolute dating of other Iron Age wooden structures in this region. The first site chronology, *910q*, which spans 207 yr, is composed of four timbers from structures US 48 and US 51 (Figure 3a). The second, *911q*, is derived from four elements of structures US 51A and US 51B, and spans 94 yr (Figure 3b).

The two chronologies do not cross-match each other, or against absolutely dated reference chronologies or undated site mean curves. There are oak local chronologies in this part of Italy from earlier and later periods, i.e. for the final part of Late Bronze Age (Bianchin Citton and Martinelli 2005) and for the early Roman period (N Martinelli, unpublished data), but the Este dock is the first Iron Age site in this region from which a dendrochronological sequence suitable for dating has been obtained.

The floating chronologies were expected to fall on the Hallstatt calibration plateau in the 1st millennium cal BC. In 2011, ^{14}C samples were taken at the beginning and end of each chronology, in the hope that one of the samples might fall on a steep section of the calibration curve, either before 750 cal BC or after 400 cal BC, and thus give a relatively precise absolute date range for that chronology.

RADIOCARBON DATING

After careful inspection under a microscope and manual removal of any visible contaminants, such as rootlets, the samples were pretreated by acid-alkali-acid (AAA) cleaning with diluted HCl and

1. Zentrum für Baltische und Skandinavische Archäologie, Schloss Gottorf, 24837 Schleswig, Germany. Corresponding author. Email: jmeadows@leibniz.uni-kiel.de.
2. Leibniz-Labor für Altersbestimmung und Isotopenforschung, Christian-Albrechts-Universität zu Kiel, Max-Eyth-Str. 11–13, 24118 Kiel, Germany.
3. Dendrodata s.a.s., via Cesiolo 18, Verona 37126, Italy.
4. Soprintendenza per i Beni Archeologici del Veneto, via Aquileia 7, Padova 35139, Italy.

Proceedings of the Radiocarbon and Archaeology 7th International Symposium
Ghent, Belgium, April 2013 | Edited by Mark Van Strydonck, Philippe Crombé, and Guy De Mulder

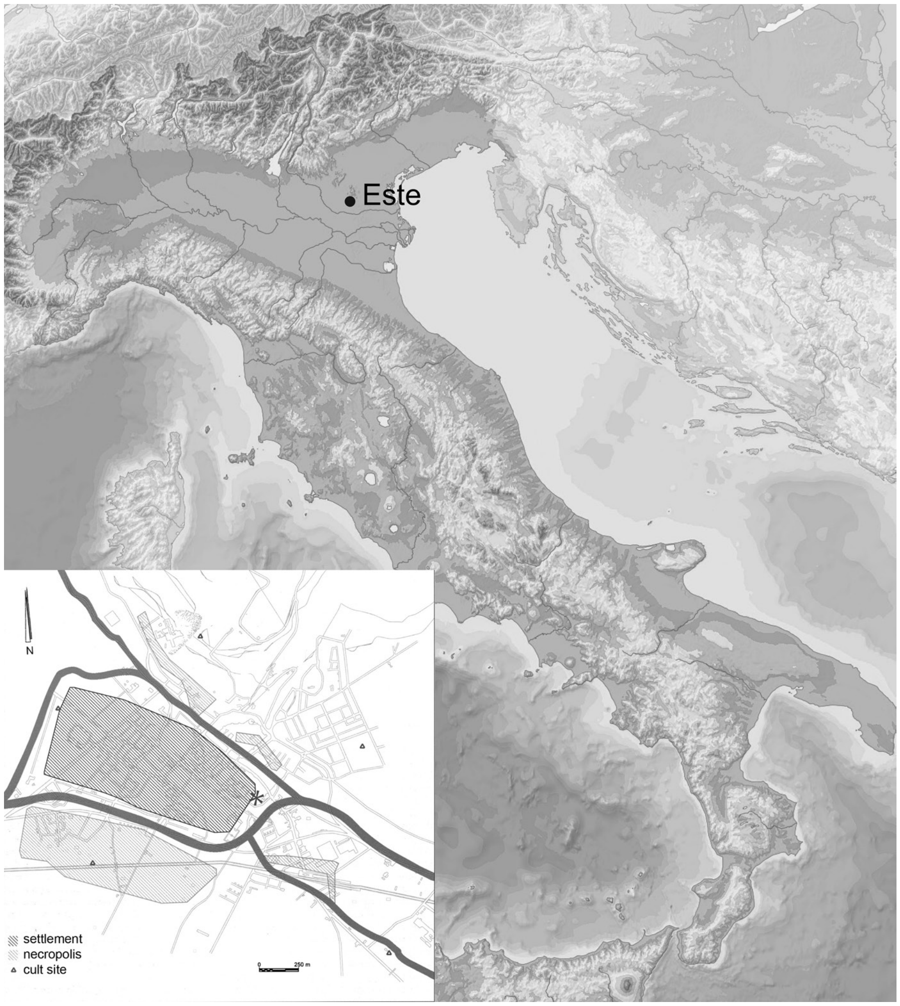

Figure 1 Map of Italy, showing Este. Inset: location of Campo Sportivo (*); former river channels and the extent of known Iron-Age archaeological remains are superimposed on the modern town center.

NaOH, to remove soil carbonates and humic acids, and combusted to CO_2 following methods described by Grootes et al. (2004). Following Nadeau et al. (1998), the CO_2 was converted to graphite targets, which were measured by accelerator mass spectrometry (AMS) at the Leibniz-Labor, Kiel. The measured ^{14}C concentrations were corrected for isotopic fractionation using $\delta^{13}C$ values measured simultaneously in the AMS system, and converted to conventional ^{14}C ages (Stuiver and Polach 1977; Table 1). Because two of the results were unexpectedly early, and one was unexpectedly recent, a second set of samples of exactly the same tree rings was prepared and measured in 2013, following the same protocols as in 2011. With one exception (see below), the 2013 results are statistically consistent with those obtained in 2011 (Table 1), and the weighted mean of each pair of results is therefore regarded as the best estimate of each sample's ^{14}C age (Ward and Wilson 1978). Their calibration (Table 1) provides an independent estimate of the calendar date of each sample.

Figure 2 The Iron Age waterfront under excavation (Dedalo snc). The horizontal timbers belong to US 48 and US 51, and include components of chronology *910q*. The partly exposed double alignment of vertical posts in the center (structures US 51A and US 51B) includes timbers in chronology *911q*. The triple alignment of posts above (US 52A–C) has not been dated.

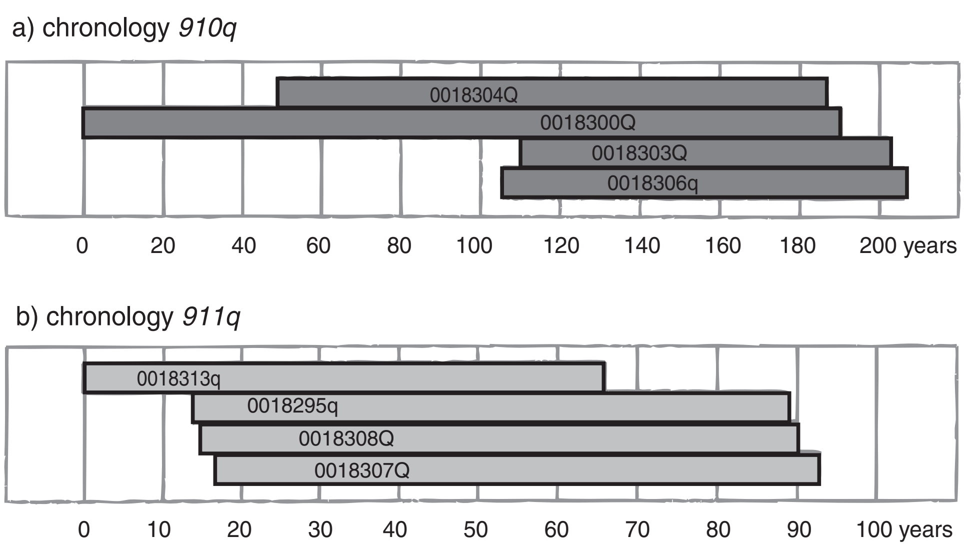

Figure 3 Cross-matching positions of tree-ring sequences in the floating chronologies, *910q* and *911q*

Table 1 ^{14}C results, Este Campo Sportivo. The calibrated date ranges for the weighted mean ^{14}C ages were calculated in OxCal v 4.2.1 (Bronk Ramsey 2009) using the probability method (Stuiver and Reimer 1993) and the IntCal13 calibration curve (Reimer et al. 2013), without taking into account the known calendar-age differences between samples.

Sample reference	Material dated	Lab nr	AMS $\delta^{13}C$ (‰)	Corrected ^{14}C concentration ($F^{14}C$)	Conventional ^{14}C age (BP)	Calibrated date range (95% probability)
Chronology *910q*						
ESTE 1, years 1–5	US 48/6, *Quercus* sp.	KIA-44436	−27.19 ± 0.13	0.7058 ± 0.0025	2799 ± 28	1110–930 cal BC (95.4%)
			−26.06 ± 0.33	0.6970 ± 0.0023	2900 ± 26	
			weighted mean ($T = 6.8$)*		2853 ± 20	
ESTE 2, years 202–207	US 51/6, *Quercus* sp.	KIA-44437	−25.79 ± 0.16	0.7185 ± 0.0023	2656 ± 26	830–795 cal BC (95.4%)
			−23.30 ± 0.24	0.7207 ± 0.0022	2631 ± 25	
			weighted mean ($T = 0.5$)*		2643 ± 19	
Chronology *911q*						
ESTE 3, years 1–5	US 51B/27, *Quercus* sp.	KIA-44438	−28.20 ± 0.10	0.7418 ± 0.0027	2400 ± 29	540–400 cal BC (95.4%)
			−25.99 ± 0.16	0.7420 ± 0.0023	2397 ± 25	
			weighted mean ($T = 0.0$)*		2398 ± 19	
ESTE 4, years 86–94	US 51A/10, *Quercus* sp.	KIA-44439	−24.45 ± 0.14	0.7298 ± 0.0022	2530 ± 24	780–730 cal BC (21.0%)
			−24.67 ± 0.20	0.7354 ± 0.0026	2469 ± 29	695–655 cal BC (16.0%)
			weighted mean ($T = 2.5$)*		2506 ± 19	650–540 cal BC (58.4%)

*Critical values, $\nu = 1$: $T'(5\%) = 3.8$, $T'(1\%) = 6.0$ (Ward and Wilson 1978).

WIGGLE-MATCHING

Dendrochronological cross-matching indicated that the midpoint of sample ESTE 1 (KIA-44436) is 201.5 yr older than the midpoint of sample ESTE 2 (KIA-44437), as ESTE 1 corresponds to the years 1–5 and ESTE 2 represents years 202–207 of the site master chronology *910q*. Sample ESTE 3 (KIA-44438) is 87 yr older than sample ESTE 4 (KIA-44439), as these samples represent years 1–5 and 86–94, respectively, of the 94-ring site master chronology *911q*. The wiggle-matching algorithm *D_Sequence* (Bronk Ramsey et al. 2001) in OxCal v 4.2.1 (Bronk Ramsey 2009) was used to calculate the most probable calendar dates for all four samples, consistent with their known age differences and the probability distributions of the calibrated dates (Figure 4).

The weighted mean ^{14}C ages for ESTE 1 and ESTE 2 are consistent with the relative dates of the samples, as indicated by the good agreement indices for individual samples (A > 60; Figure 4a) and for the combination (A_{comb} = 140.8, well over the critical value for two dates, A_n = 50.0; Bronk Ramsey et al. 2001). Although the 2011 and 2013 ^{14}C ages for ESTE 1 are not statistically consistent (following Ward and Wilson 1978), their weighted mean is clearly a better estimate of the real

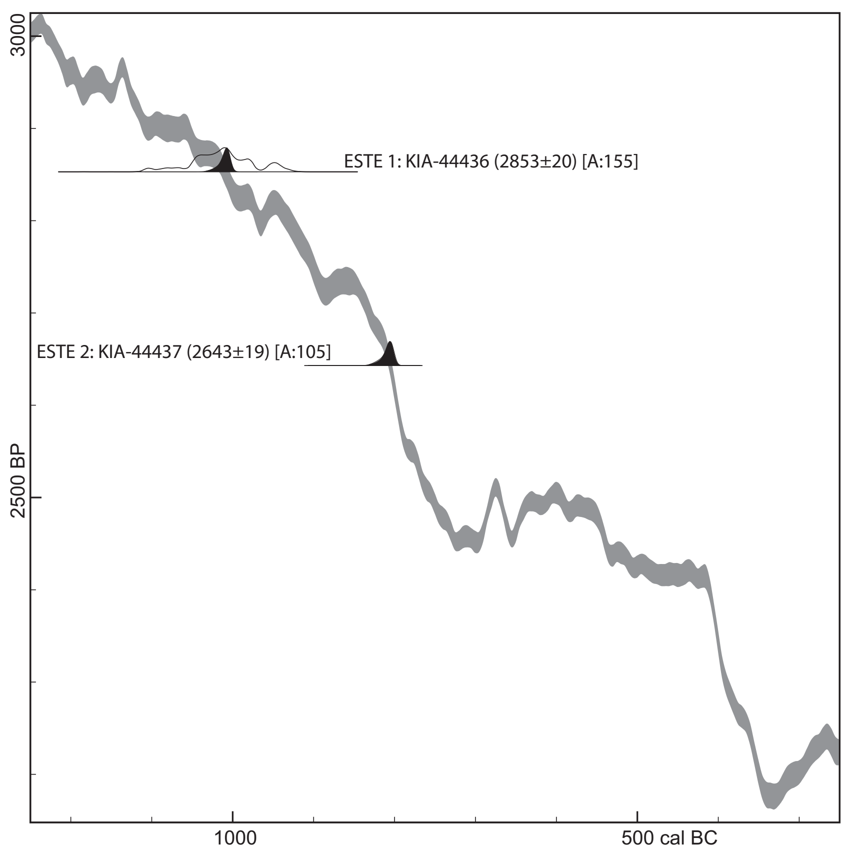

Figure 4a Wiggle-matching of the ^{14}C samples from Este master chronology *910q* in OxCal v 4.2.1 (Bronk Ramsey 2009). The distribution in outline is the simple calibration of each ^{14}C result by the probability method (Stuiver and Reimer 1993), using the IntCal13 calibration curve (Reimer et al. 2013). The solid distribution represents the probable date of each sample, given that the midpoint of ESTE 1 is known to be 201.5 yr older than the midpoint of ESTE 2 (note that the solid distribution exactly overlies the outline distribution for ESTE 2). This wiggle-match has good overall agreement (A_{comb} = 140.8, A_n = 50.0; Bronk Ramsey et al. 2001).

^{14}C age of this sample than either of the individual ^{14}C ages, which each fit poorly (A < 60) when wiggle-matched against either of the ^{14}C ages for ESTE 2, or their weighted mean. The ESTE 2 sample falls on a particularly steep section of the calibration curve, and its two ^{14}C ages are extremely similar, so our estimated date of the final ring of chronology *910q* is barely affected by the ESTE 1 results. The model shown in Figure 4a estimates that year 207 of chronology *910q* dates to within the range *825–795 cal BC (95% probability*).

The *911q* weighted mean ^{14}C ages fit the IntCal13 calibration curve (Reimer et al. 2013) quite poorly at the best wiggle-matching position (Figure 4b) (A_{comb} = 14.9, A_n = 50.0). Calibration with the IntCal98 calibration curve (Stuiver et al. 1998) yields only a marginal improvement (A_{comb} = 31.8, A_n = 50.0). A similar unsatisfactory fit (A_{comb} = 31.4) may be obtained by arbitrarily omitting the 2011 result for ESTE 4, but the 2011 and 2013 ^{14}C ages for this sample are not significantly different (T = 2.5, T'(5%) = 3.8, ν = 1; Ward and Wilson 1978) and the two ^{14}C ages for ESTE 3 are practically identical. Notwithstanding the poor overall fit, the model shown in Figure 4b estimates that year 94 of chronology *911q* dates to within the ranges *640–595 cal BC (85% probability*) or *570–555 cal BC (10% probability*).

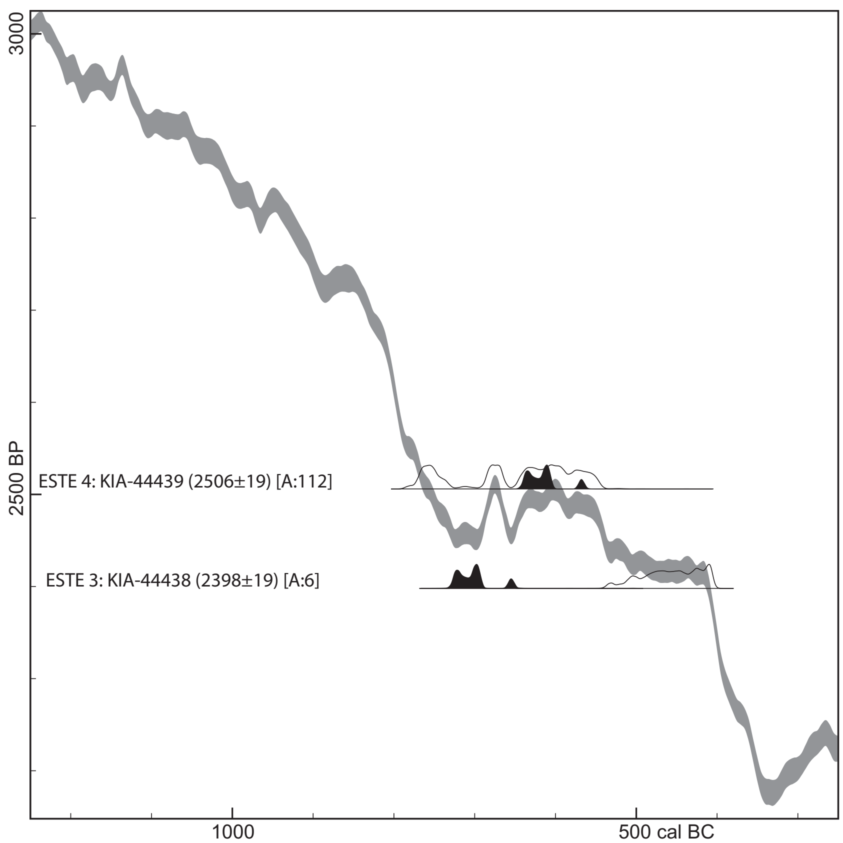

Figure 4b Wiggle-matching of the ^{14}C samples from Este master chronology *911q* in OxCal v 4.2.1 (Bronk Ramsey 2009). The distribution in outline is the simple calibration of each ^{14}C result by the probability method (Stuiver and Reimer 1993), using the IntCal13 calibration curve (Reimer et al. 2013). The solid distribution represents the probable date of each sample, given that ESTE 3 is 87 yr older than ESTE 4. This wiggle-match has poor overall agreement (A_{comb} = 14.9, A_n = 50.0; Bronk Ramsey et al. 2001).

DISCUSSION

As no sapwood survived, we cannot calculate precise felling dates for the horizontal planks in US 48 and vertical posts in US 51. Following Corona (1974), at least 11 sapwood rings must be added to the *terminus ante quem non* given by the final year of floating chronology *910q*. These structures therefore could date to the first half of the 8th century cal BC. A possible heartwood-sapwood transition on timber 51A/10 puts the felling date of this timber between 10 and 20 yr after the final year of chronology *911q*, dating the felling of post US 51A/10 and the construction of the parallel lines of posts closer to the river channel to the late 7th/early 6th century cal BC.

Our results suggest that the dock, piling, and caissons had a long history. The older chronology is particularly important, as it confirms that the foundation of the Venetic center of Este had occurred by the end of the 9th or the early 8th century cal BC, in a period which is currently known primarily from burials rather than settlement archaeology (Tosi 1992; Ruta Serafini 2002). Este already had developed a waterfront and traces of a road at this date. The more recent chronology demonstrates the continued use of a previously unknown waterfront well into the Iron Age, a period for which there is abundant evidence that Este was an urban center. Moreover, the result suggests that the road surfacing was probably associated with this more recent waterfront.

The importance of the two site chronologies, as reference chronologies for the absolute dating of other early-middle Iron Age contexts in northeast Italy, must be emphasized. The tree-ring chronologies begin at the turn of the 1st millennium. Wiggle-matching proves that they do not overlap in time but are separated by a brief interval, which may be bridged if additional structures are discovered. Both chronologies fall into a gap for which there are currently (almost certainly) no other floating tree-ring chronologies in this region, for any species. Moreover, *911q* dates to the first half of the so-called Hallstatt calibration plateau, where ^{14}C dates from short-lived samples are of limited use. The results therefore highlight the site's importance in refining the chronology of the Iron Age, particularly as oak was the main source of construction timber in northern Italy until the Roman period.

The discrepancy between the 2011 and 2013 ^{14}C ages for ESTE 1 can only be due to chance variation, as, given the ^{14}C age of ESTE 2, the true ^{14}C age of this sample must be ~2850 BP, within the 2σ range of each of the individual measurements (Table 1; Figure 4a). It is the similarity of the 2011 and 2013 ^{14}C ages for ESTE 3 that is puzzling; they suggest that the true ^{14}C age of this sample is really ~2400 BP, well below the calibration curve in the period before 500 cal BC (Figure 4b). If ESTE 3 really dates to after 500 cal BC, however, the ^{14}C ages for ESTE 4 are much too high, as this sample should be 87 yr later than ESTE 3.

One explanation for this situation could be a spurious dendrochronological cross-match, as the two samples were from different timbers. The cross-matching between timbers in chronology *911q* is convincing, both statistically and visually, but it is conceivable that the two dated timbers are not contemporaneous (e.g. due to reuse or replacement). It is highly improbable that such similar growth patterns over the course of an apparent overlap of more than 50 yr (Figure 5) would appear in two timbers that were not contemporaneous, but it is not impossible. If the cross-matching between timbers is disregarded, however, post US 51B/27 was probably not felled before the 4th century cal BC, as the timber included 67 heartwood rings, with no evidence of the heartwood-sapwood transition, after its earliest surviving growth rings, which were dated by ESTE 3 (Table 1). This would mean that this timber was felled more than a century after post US 51A/10, dated by ESTE 4 (Table 1), and ~400 yr after the timbers in chronology *910q*. Given the excavators' interpretation that the timber alignments were functionally associated with each other, these intervals appear excessive.

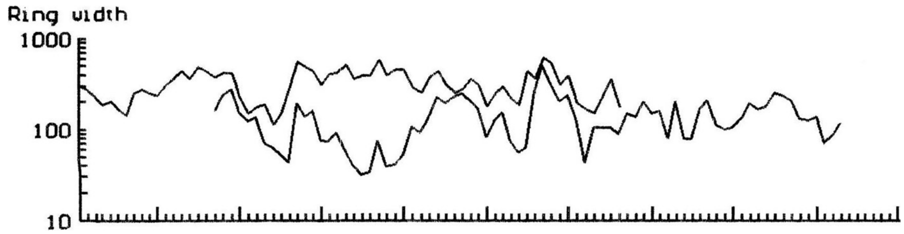

Figure 5 Cross-matching positions of ring-width sequences for US 51B/27 (top) and US 51A/10 (below), the two dated components of *911q*. The satisfactory visual cross-match is confirmed by the following statistical parameters, calculated using the TSAP® software (Rinntech 2003): CDI = 28, TVBP = 5.3, TVH = 2.8, GL% = 76, probability 99.9.

A second possibility is that the atmospheric ^{14}C level was more variable than indicated by existing calibration curves. The ^{14}C age of ESTE 3 is almost compatible with some of the raw data in IntCal13, which represent the average ^{14}C ages of blocks containing 10 or 20 annual rings (Figure 6). As only two or three contiguous annual rings in the middle of ESTE 3 were actually dated, a brief spike in atmospheric ^{14}C could be visible in this sample and not in the IntCal raw data. Such an explanation implies that elsewhere in the Northern Hemisphere, short-lived samples of the same date as ESTE 3 would also give anomalously low ^{14}C ages, but it is rare that short-lived wiggle-matched samples are measured. One exception is a wiggle-match of five 2–3 tree-ring samples in a floating chronology from Arzhan, Tuva region, Russia (Heußner and Sljusarenko 2010), which spans the same period as the Este floating chronologies, and which includes a ^{14}C age similar to that of ESTE 3 from a sample that must date to ~700 cal BC. The sample appears to be an outlier when the wiggle-match is fitted to IntCal13 and IntCal98.

Ozaki et al. (2007) measured ^{14}C ages in homogenized 5-yr blocks of dendrochronologically dated Japanese cypress (*Chamaecyparis obtuse*) spanning the years 820–450 cal BC, to investigate the possibility of a regional offset between Japanese trees and the consensus international calibration data for the Northern Hemisphere, which are based on trees growing at similar latitudes in Europe and North America; no such offset was found. If the Ozaki et al. data are used as a calibration curve, our ^{14}C ages for ESTE 3 no longer appear anomalous, yet the best wiggle-match position is almost identical to that given by IntCal13 (Figure 7). The Japanese data also provide a much better fit for the Arzhan wiggle-match, without significantly altering its estimated date.

The Este results suggest that some Japanese calibration data may be applicable in Europe. Ozaki et al. (2007) reported an insignificant offset (3.5 ± 3.6 ^{14}C yr) between dendrodated Japanese wood and IntCal in the period 820–436 BC. By contrast, Suzuki et al. (2010), who measured 165 wiggle-match-dated single-year samples spread over a similar period, argued that an influx of Southern Hemisphere air during the East Asian monsoon was responsible for a 16.4 ± 3.3 ^{14}C yr offset between their results and IntCal data. This explanation should also apply to the Ozaki et al. data, however. Recent papers by Tani et al. (2013) and Nakamura et al. (2013) show that the issue has not been resolved, but even if there were a systematic offset between Europe and Japan, significant ^{14}C production events should appear at the same calendar dates (Miyake et al. 2012; Usoskin et al. 2013).

It therefore appears that the poor fit between the *911q* ^{14}C ages and IntCal98/IntCal13 is more likely to be due to the use of short-lived (2–3 tree ring) samples than to a spurious dendrochronological cross-match. The statistical smoothing inherent in the random walk model used to construct calibra-

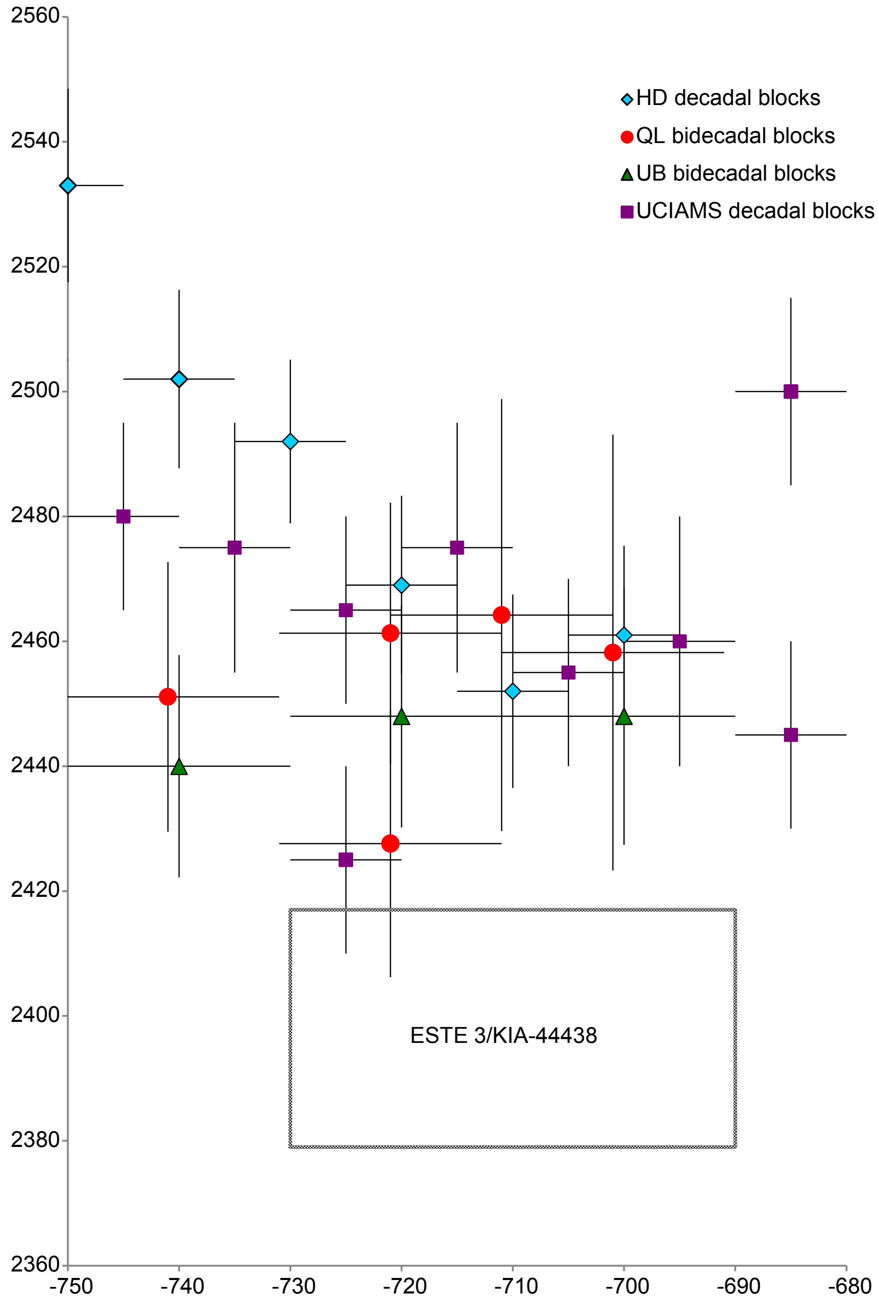

Figure 6 Raw data included in IntCal13 (Reimer et al. 2013; http://www.radiocarbon.org/IntCal13.htm). Horizontal axis: calendar date (negative values mean cal BC); *x* error bars on points correspond to the actual dates of the tree rings in each sample. Vertical axis: conventional ^{14}C ages BP; *y* error bars are 1σ errors in ^{14}C ages. The box represents the 1σ range for KIA-44438's ^{14}C age and its probable calendar age (*730–690 cal BC, 85% probability*, Figure 4b model).

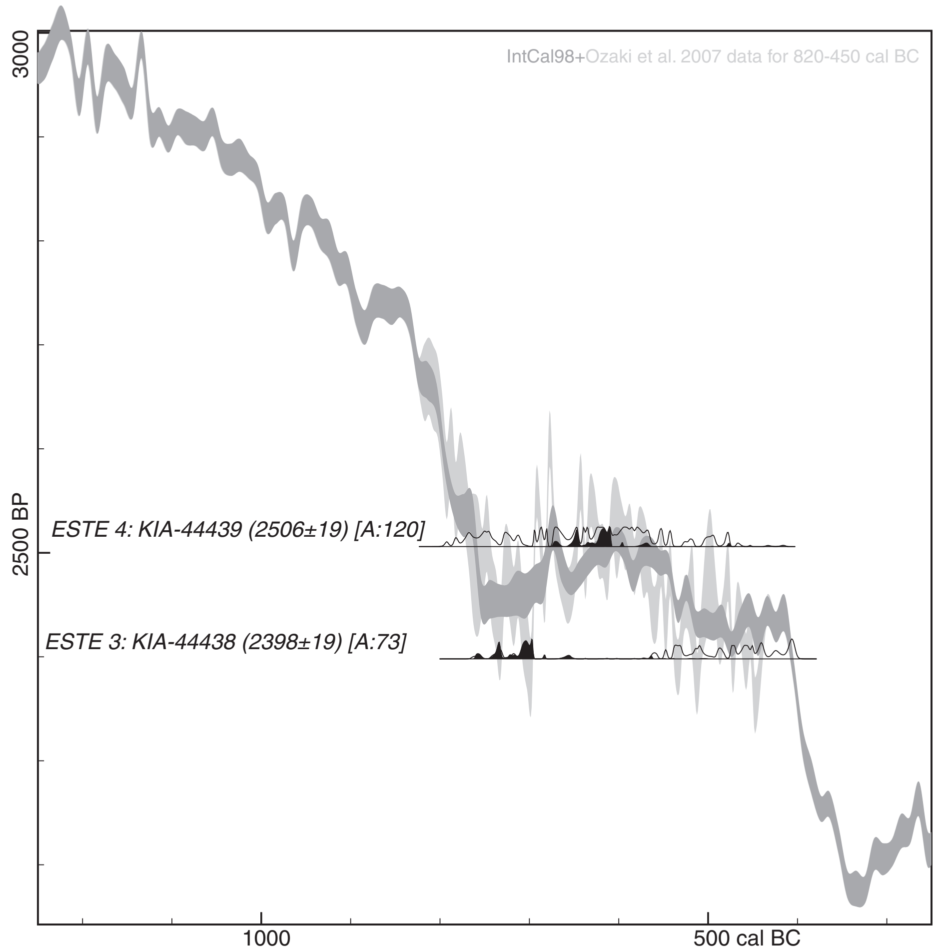

Figure 7 Wiggle-matching of the ^{14}C samples from the Este master chronology *911q* in OxCal v 4.2.1 (Bronk Ramsey 2009). The distribution in outline is the simple calibration of each ^{14}C result by the probability method (Stuiver and Reimer 1993), using a hybrid calibration curve in which decadal and bidecadal data in the IntCal98 curve (Stuiver et al. 1998; dark gray) are replaced by the 5-yr blocks dated by Ozaki et al. (2007; pale gray). The solid distribution represents the probable date of each sample, given that ESTE 3 is 87 yr older than ESTE 4. This wiggle-match has good overall agreement (A_{comb} = 90.7, A_n = 50.0; Bronk Ramsey et al. 2001).

tion curves since 2004 (Buck and Blackwell 2004) is not as significant as the fact that the raw ^{14}C data in both IntCal98 and IntCal13 are from decadal or bidecadal samples, which mask any short-term fluctuations in atmospheric ^{14}C levels.

CONCLUSION

The value of the Este sequences as reference chronologies must be emphasized. Both chronologies date to periods for which there are no other floating tree-ring chronologies in this region, and *911q* dates to the Hallstatt calibration plateau, where ^{14}C dates from short-lived samples are of limited use. The results highlight the site's importance in refining the Iron Age chronology of northeastern Italy. Our results also demonstrate some of the difficulties inherent in the interpretation of ^{14}C ages from short-lived samples, particularly in periods in which atmospheric ^{14}C levels fluctuated sharply, given the decadal or bidecadal resolution of most calibration data.

ACKNOWLEDGMENTS

Research at Este was financed by the Ministero dell'Economia e Ministero per i Beni le Attività Culturali, through ARCUS SpA, its body supporting advancement of art, culture and performance. We would like to thank Dr Karl-Uwe Heußner of the German Archaeological Institute for discussing the Arzhan wiggle-match with us.

REFERENCES

Bianchin Citton E, Martinelli N. 2005. Cronologia relativa e assoluta di alcuni contesti veneti dell'età del Bronzo recente, finale e degli inizi dell'età del Ferro. Nota preliminare. Atti dell'Incontro di studio "Oriente e Occidente: metodi e discipline a confronto. Riflessioni sulla cronologia dell'età del Ferro italiana." "*Mediterranea,*" *Quaderni annuali dell'Istituto di Studi sulle civiltà italiche e del mediterraneo antico del Consiglio Nazionale delle Ricerche* I (2004):239–53.

Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–60.

Bronk Ramsey C, van der Plicht J, Weninger B. 2001. 'Wiggle matching' radiocarbon dates. *Radiocarbon* 43(2A):381–9.

Buck CE, Blackwell PG. 2004. Formal statistical models for estimating radiocarbon calibration curves. *Radiocarbon* 46(3):1093–102.

Corona E. 1974. Ricostruzione dell'alburno in legnami sommersi. *Geoarcheologia* 1/2:19–22.

Grootes PM, Nadeau M-J, Rieck A. 2004. ^{14}C-AMS at the Leibniz-Labor: radiometric dating and isotope research. *Nuclear Instruments and Methods in Physics Research B* 223–224:55–61.

Heußner K-U, Sljusarenko I. 2010. Die dendrochronologie. In: Cugunov KV, Parzinger H, Nagler A, editors. *Der skythenzeitliche Fürstenkurgan Arzan 2 in Tuva*. Mainz, Archäologie in Eurasien 26:178–82.

Miyake F, Nagaya K, Masuda K, Nakamura T. 2012. A signature of cosmic-ray increase in AD 774–775 from tree rings in Japan. *Nature* 486(7402):240–2.

Nadeau M-J, Grootes PM, Schleicher M, Hasselberg P, Rieck A, Bitterling M. 1998. Sample throughput and data quality at the Leibniz-Labor AMS facility. *Radiocarbon* 40(1):239–45.

Nakamura T, Masuda K, Miyake F, Nagaya K, Yoshimitsu T. 2013. Radiocarbon ages of annual rings from Japanese wood: evident age offset based on IntCal09. *Radiocarbon* 55(3–4):763–70.

Ozaki H, Imamura M, Matsuzaki H, Mitsutani T. 2007. Radiocarbon in 9th to 5th century BC tree-ring samples from the Ouban 1 archaeological site, Hiroshima, Japan. *Radiocarbon* 49(2):473–9.

Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hoffmann DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55(4):1869–87.

Rinntech. 2003. *TSAP-Win™. Time series analysis and presentation for dendrochronology and related applications. Version 0.59 for Microsoft Windows 98, 2000, XP. User Reference*. Heidelberg: Rinntech.

Ruta Serafini A, editor. 2002. *Este preromana: una città e i suoi santuari*. Treviso: Canova. 342 p.

Ruta Serafini A, Salerno R, editors. 2006. Este: la strada e l'approdo fluviale dell'età del ferro di via Principe Umberto. *Quaderni di Archeologia del Veneto* XXII:26–32.

Stuiver M, Polach HA. 1977. Discussion: reporting of ^{14}C data. *Radiocarbon* 19(3):355–63.

Stuiver M, Reimer PJ. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35(1):215–30.

Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac G, van der Plicht J, Spurk M. 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40(3):1041–83.

Suzuki K, Sakurai H, Takahashi Y, Sato T, Gunji S, Tokanai F, Matsuzaki H, Sunohara Y. 2010. Precise comparison between ^{14}C ages from Choukai Jindai cedar with IntCal04 raw data. *Radiocarbon* 52(4):1599–609.

Tani S, Kitagawa H, Hong W, Park J, Sung K, Park G. 2013. Age determination of the Kawagodaira volcanic eruption in Japan by ^{14}C wiggle-matching. *Radiocarbon* 55(3–4):748–52.

Tosi G, editor. 1992. *Este antica dalla preistoria all'età romana*. Este: Zielo. 441 p.

Usoskin IG, Kromer B, Ludlow F, Beer J, Friedrich M, Kovaltsov GA, Solanki SK, Wacker L. 2013. The AD775 cosmic event revisited: the Sun is to blame. *Astronomy & Astrophysics* 552: L3.

Ward GK, Wilson SR. 1978. Procedures for comparing and combining radiocarbon age determinations: a critique. *Archaeometry* 20(1):19–31.