IRON AGE CHRONOLOGY IN ISRAEL: RESULTS FROM MODELING WITH A TRAPEZOIDAL BAYESIAN FRAMEWORK

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ABSTRACT. Bayesian methods have been widely used to address the Iron Age chronological debate in Israel, which has implications for the entire eastern Mediterranean Iron Age chronology. However, a consensus has not been reached. This is largely because radiocarbon dates of materials in this period lie on an oscillation in the calibration curve. This study focuses on the modeling of ^{14}C dates from the Iron I and Iron II periods, discusses the underlying assumptions and limitations of existing Bayesian chronologies, and proposes the use of a more appropriate model that allows for the phase transitions not being instantaneous. The new trapezoidal model sheds light on the probable duration of the transitions between the Iron Age phases.

INTRODUCTION

The debate and discussion concerning Iron Age I, IIA, and IIB in Israel has been very active since 1995 and has yielded substantial literature. The time period of this debate is limited on the upper side by the end of the Egyptian control over Canaan ~1140/1130 and on the lower side by the Assyrian conquests in Israel and Judah between 732 and 701, both well dated by Egyptian and Assyrian historical records and correlated with archaeological contexts. All agree concerning the important implications of this debate on the absolute chronology of the archaeological phases in the Levant, Cyprus, and Greece, as well as the interpretation of the archaeological data in relation to biblical history. The period is divided by most archaeologists into 4 phases, though the terminology varies among scholars. Table 1 shows suggested divisions and dates of the Iron Age in Israel according to 3 different paradigms. Inner divisions of each of these subperiods are not taken into consideration in the present study.

Table 1 Chronological division of the Iron Age I–IIB in Israel and suggested dates in BCE according to 3 paradigms.

Conventional Chronology[a]	Low Chronology[b]	Modified Conventional Chronology[c]
900–732/700 Iron IIB	~780–732/701 Iron IIB	830–732/701 Iron IIB
1000–900/925 Iron IIA	920/900~800/780 Iron IIA	~980–830 Iron IIA
1150–1000 Iron IB	1130~920/900 Iron I	1140/30~980 Iron IB
1200–1140/30 Iron IA	1200–1140/30 Late Bronze III	1200–1140/30 Iron IA

[a]Compiled after Stern (2003:1529), Mazar (1990:30).
[b]Compiled from Finkelstein (2005), Finkelstein and Piasetzky (2006) and previous papers, Sharon et al. (2005).
[c]After Mazar (2005).

During the 1990s, scholars saw the potential of radiocarbon dating in helping to solve the Iron Age chronology debate. Dozens of sites from this period were excavated, and a good number of them

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yielded samples for ^{14}C dating. Hundreds of samples were measured during the last 2 decades, mostly in 2 large-scale projects: the Iron Age Dating Project (first phase published in Sharon et al. 2007, second phase not yet published), and a large number of dates from a stratigraphic sequence at Tel Rehov in the Beth Shean Valley (Mazar et al. 2005). Additional isolated dates were measured before these large projects, e.g. Lachish and Dor (Gilboa and Sharon 2003). Over 80 dates from Khirbet en-Nahas in southern Jordan belong to the same period, but are not included in this study due to the isolation and uniqueness of this site, though in general terms they support the Modified Chronology for the Iron IIA period that includes both the 10th and 9th centuries BCE in this timeframe (Levy et al. 2008). Following the publications, synthesis was attempted using Bayesian models (see below).

Although similar (but not identical) databases were utilized, some serious differences between the results of the various studies were presented. Our goal in this paper is to present a new statistical approach to the subject of modeling the transition between phases of the Iron Age I–IIB. This study employs the idea that transition of a period is not abrupt and can take a period of time, drawing inferences on the start and end of the transition between phases.

The present study is based on 420 dates measured on samples from 26 sites. The detailed list of samples and references to the original publications are presented in Table S1 in the online supplement to this paper. The contexts of each sample and its attribution to one of the subperiods of the Iron Age were discussed in the original publications (mainly Sharon et al. 2007; for Tel Rehov see Mazar et al. 2005; for Khirbet Qeiyafa see Garfinkel et al. 2012) as well as in subsidiary papers (Mazar and Bronk Ramsey 2008, 2010; Finkelstein and Piasetzky 2006, 2009, 2010a,b). Thus, we avoid a detailed discussion of contexts in this paper, except previously unpublished dates from Tel Rehov and a few additional comments to be found in the online supplement. Only short-lived samples (consisting of mostly seeds) were used, while charcoal, reworked wood samples, and samples with uncertain contexts were excluded. Table 3 specifies the sites included in this study, their relative stratigraphy, and the number of dates used from each stratum or phase in each site.

Despite more than 400 ^{14}C determinations of short-lived samples available from this period, their interpretation is still especially difficult because the ^{14}C calibration curve for this period is very unhelpful. Oscillations in the calibration curve mean that calibration yields very imprecise dates. A ^{14}C date in this period rarely gives a calibrated age range (95.4% probability) of less than a century.

MODELING

Bayesian modeling can help improve precision and accuracy of ^{14}C dates. Since the introduction of the method (Buck et al. 1991), scholars have been using this approach to analyze multiple measurements on samples from different periods to try to recover the underlying Iron Age chronology. Relative information is combined with absolute dates to draw inference on the dates of transitions between the various phases of this period. ^{14}C dates are attributed to individual Iron Age phases and grouped together using the uniform phase prior (Buck et al. 1992). Examples can be seen in Boaretto et al. (2005), Bruins et al. (2005), Sharon et al. (2007), Mazar and Bronk Ramsey (2008), and Finkelstein and Piasetzky (2010a,b), where the authors use it to model multiple dates from different sites across the region. The modeling in these papers used 2 generic frameworks: Contiguous phase models and Sequential phase models.

Contiguous Phase Models

Boaretto et al. (2005), Sharon et al. (2007), Mazar and Bronk Ramsey (2008), and Finkelstein and Piasetzky (2010b) performed analyses on the date of the Iron I/II transition using ^{14}C dates from different sites. The authors built multiple phase models, assuming that the change from Iron I to Iron II is synchronous across the region. The Iron I phase is constrained to be before the Iron II phase, sharing a model parameter to the one used to infer the date of the Iron I/II transition.

Sequential Phase Models

Finkelstein and Piasetzky built comprehensive age models using a Bayesian framework to draw conclusions on the dates of Iron I and Iron II subphase transitions using all of the ^{14}C ages available for that period. The authors published results of 2 models: Finkelstein and Piasetzky (2010a) analyzed the ^{14}C ages using 7 sequential uniform phases; and Finkelstein and Piasetzky (2010b) modeled only Late Iron I and the Early Iron IIA of those 7 phases. Both of these studies used the same Bayesian framework.

Results from both studies show that this transition date, analyzed using this framework, put the Iron I/IIA transition in the second half of the 10th century BCE. All of the existing models used the uniform phase prior (Buck et al. 1992), assuming that the temporal constraints of each of the Iron Age phases are abrupt events. But is the abrupt uniform phase prior the correct prior for modeling the Iron Age transitions? Does it appropriately and sufficiently represent the underlying assumptions? The uniform phase prior is the appropriate prior to use if archaeological evidence indicates abrupt events, for example, destruction layers, which are observed in some of the Iron Age sites across the Levant. An example of modeling a destruction layer is demonstrated in Mazar and Bronk Ramsey (2008), where the authors questioned the sensitivity of using the uniform phase prior to model dates from across the region and did a single-site investigation using information from Megiddo. This is an appropriate prior to use because occupation of the site terminated abruptly, as suggested by the destruction layer of Stratum VIA. The Iron Age transition across the region can be non-abrupt, since it is largely based on gradual changes in pottery assemblages. Modeling non-abrupt phase transitions with an abrupt model gives estimates for the middle of transitions (Lee and Bronk Ramsey 2012).

A New Bayesian Model

The Iron Age cultural phases have been separated into 4 phases in the order Iron IA (or Late Bronze III), Iron IB, Iron IIA, and Iron IIB. Most of the samples included in the model were measured by the Iron Age Dating Project (Phase I) published by Sharon et al. (2007). Most of the dates from Tel Rehov were published by Mazar et al. (2005). Additional dates included in the model come from Khirbet Qeiyafa (Garfinkel and Kang 2011), Atar Haro‘ah (Boaretto et al. 2010), and a few additional sites. See Finkelstein and Piasetzky (2010a) for a compilation of dates from this period. Dates listed in Table 2 are also included in the model in this study.[4] The full data set can be found in the online supplement. Most of the samples were prepared and measured in 4 different laboratories: Groningen, Oxford, Rehovot, and Tucson. Some of the samples measured in Tucson had been prepared in Rehovot. Boaretto et al. (2005) carried out a comprehensive interlaboratory comparison and concluded that samples prepared in Groningen, Tucson, and Rehovot produced comparable ^{14}C determinations. Many determinations are duplicates from either the same sample or samples from the same locus, and are considered to be the same age.

[4]The number of dates from the Iron IIB phase is small, and some fall into the plateau of the calibration curve following ~750 BCE. Beth Shemesh Stratum 3 started according to the excavators in Iron IIA and continued well into Iron IIB. Kuntillet ‘Ajrud was occupied for a short period during the first part of Iron IIB. Most of the dates from there are of wood samples; only 4 are from short-lived samples (Carmi and Segal 1996).

Table 2 ^{14}C dates from Tel Rehov Iron Age layers unpublished previously.

Period	Stratum	Locus	Catalog #	Lab #	Sample material	^{14}C date
Late IB	D-3	7863	R14	5230	Olive stones	2884 ± 34
		7860	R15	5228		2836 ± 35
		7858	R16	5237		2782 ± 66
Early IIA	VI	7432	R19	5236		2807 ± 23
		7428	R20	5233		2767 ± 13
IIA	V	7453	R27	5232	Charred grain	2953 ± 15
		8465	R28	GrA-45623		2775 ± 40
				GrA-45624		2690 ± 40
				GrA-45650		2735 ± 40
				OxA-24784		2690 ± 30
			R29	Beta-284753		2850 ± 40
				Beta-287772		2720 ± 30
	V–IV	2425	R34	VERA-3223	Cereal grain	2715 ± 35
	IV	10431	R36	Beta-284754	Charred grain	2920 ± 40
				Beta-287773		2770 ± 30

Modeling is performed using the calibration and chronology-building software OxCal. The trapezoidal phase prior (Karlsberg 2006; Lee and Bronk Ramsey 2012) is used in a contiguous framework (Figure 1). The trapezoidal phase prior (for slow transition) is used in this study instead of a uniform prior (for abrupt transition) because:

- Cultural changes can be characterized as slow, non-instantaneous processes (e.g. by pottery assemblages, Brainerd 1951; Robinson 1951);
- The different cultural phases can be overlapped, indicating transitional periods.

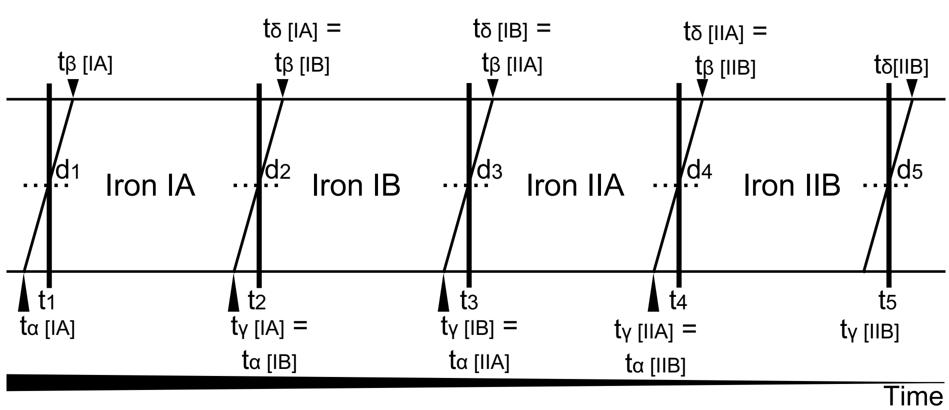

Figure 1 Schematic for the Iron Age model in this study. The trapezoidal parameters give prior estimates of the start (t_α), the start of peak phase activity (t_β), the start of decline (t_γ), and the end (t_δ) of each of the Iron Age phases. The transitional `boundary` parameters (thick vertical lines; t_2–t_4) give the mid-points of the phase transitions and the `transition` parameters (dotted horizontal lines; d_2–d_4) give the duration of transitions.

This framework assumes that the Iron Age phases are contiguous to each other and also allowing a time period for phase transition. The adjacent phases share a transitional `boundary` parameter (e.g. t_2–t_4), each with a period for a `transition` parameter (e.g. d_2–d_4) so the duration of transition can be calculated. This model framework allows the decline of an earlier phase to overlap exactly with the rise of a later, adjacent phase. The transitional boundary parameters therefore represent the mid-point of the phase transitions.

The start and end of each transitional period can also be calculated (e.g. $t_{\gamma\,[IB]} = t_{\alpha\,[IIA]}$ represents the start, and $t_{\delta\,[IB]} = t_{\beta\,[IIA]}$ represents the end of the Iron I/II transition). Parameters t_1 and t_5 are the mid-points of the start and end of the ^{14}C data set used in this study; and parameters d_1 and d_5 denote the gradual cutoff in the data at the start and end of the data set. These end parameters do not have archaeological meanings, since there is no preceding or succeeding data to constrain the model and the samples have not been chosen to be representative of the end points.

Using this framework can be seen as combining efforts and ideas of previous studies (e.g. in Sharon et al. 2007; Mazar and Bronk Ramsey 2008; Finkelstein and Piasetzky 2010a,b): the Iron IB phase is contiguous to the Iron IIA phase and there is a transitional period between the phases and so forth with the other phases. The overlap between successive phases is considered, meaning that problems arising from uncertain attributions are also dealt with. The trapezoidal parameters give prior estimates of the start (t_α), the start of peak phase activity (t_β), the start of decline (t_γ), and the end (t_δ) of each of the Iron Age phases. The different strata are sorted into their associated periods according to Table 3.

The overall framework of the model consists of the application of the function `R_Combine` to produce a weighted average of duplicate ^{14}C determinations of the same sample or of samples from the same locus given the same laboratory number. Formal outlier analyses are utilized to account for outliers in the ^{14}C scale (`type r`) and the calendar scale (`type t`). `Type r` analyses are employed when producing weighted averages of ^{14}C determinations and `type t` analyses are employed to account for possible outlying calibrated ages.

Both outlier models are specified to allow the possible shifts in the specified scale to be drawn from a long-tailed student *t* distribution. The outliers can be in the scale of anywhere between 10^0 and 10^4 yr. These are the models recommended by Bronk Ramsey (2009) for general purposes when the scale of the possible offsets is unknown. When employed, the overall model is not affected by the odd extreme outlier. Each measurement is assigned a prior probability of 5% of being an outlier. Outlying results are down-weighted in the model runs. This utility allows possible outlying ages (e.g. Beta-284754 and 5232 from Table 2, which appears to be too old in comparison to samples in the same context) to be down-weighted objectively during model runs.

For the trapezoidal model, an additional constraint of a hundred years is added for the transition time between phases. This is because at sites like Tel Rehov, the transition from Iron IB to Iron IIA is well defined, and a horizon of a hundred years or more for this transition is considered too wide. Another reason for this constraint is because transition times between the different Iron Age periods are considered short, as suggested by both archaeological evidence and the less-than-a-century difference between the conventional and low chronologies. Limiting the `transition` parameters also provides a domain from which a starting point for the `transition` parameters can be generated, thus it helps the model run smoothly. The model would not start running at all due to the closely spaced events and complicated constraints if the transition times are not limited. Readers can refer to the supplementary materials for detailed `OxCal CQL` listings.

Table 3 Synchronic table of Iron Age sites in Israel included in this study. Only information used in this study is included. The strata numbers are listed and the number of ^{14}C determinations included in each phase are shown in **(bold)**, which includes repetitions of measurements of the same sample. A total of 420 dates are incorporated into the model.

	Iron IA	Iron IB	Iron IIA	Iron IIB
Hazor		XII/XI **(3)**	Xa,Xb, IXa **(14)**	
Bethsaida			6 **(5)**	
Tel Hadar		IV **(9)**		
Beth Shean	N-4, S-3a **(6)**			P-7 **(3)**
Tel Rehov	D-6 **(5)**	D-4, D-3 **(25)**	C-2=VI, D-2 or D-1 (=VI or V), C1b=V, C1a=IV **(83)**	
Tel el Hammah[a]			**(36)**	
Megiddo	K/6 (=VIIA?) **(18)**	K/4(=VIA) **(21)**	H/5 (IVB-VA) **(5)**	
Yoqneam		XVII(b?) **(13)**		
Tell Keisan		9a **(3)**		
Rosh Zayit			**(19)**	
Tel Dor		D2/13, D2/12, D2/9-10 **(18)**	D2/8c, D2/8b **(16)**	
El-Akhwat		**(12)**		
Aphek			X8 **(3)**	
Qasile		X **(21)**		
Beth Shemesh		6, 5 **(9)**		3 **(7)**
Tel Miqne	VIIb **(3)**	VIB,VB **(10)**		
Khirbet Qeiyafa[b]		**(7)**		
Lachish	VI **(3)**		V, IVB **(2)**	
Tel Zayit				**(3)**
Atar Haro'ah			**(16)**	
Kuntilet Ajrud				(4)
Dan			IVA **(1)**	
Tel el Qudeirat[c]				**(1)**
Shiloh		V **(6)**		
Nahal Elah			**(1)**	
Tel es-Safi			IVA **(9)**	

[a]Tell el-Hammah early level is attributed here to early Iron IIA while the excavator and Finkelstein and Piasetzky (2010a,b) attribute this phase to late Iron I. See comments in Mazar and Bronk Ramsey (2008, 2010).
[b]A horizon defined as "transitional Iron I/Iron IIA" in Khirbet Qeyafa may be suggested. These samples are constrained to be between the Iron I/IIA transition using `cross-referencing` in `OxCal`. Three additional dates published in Garfinkel et al. (2012) are not included in our model.
[c]Dates from the Iron IIA context of Tell el Qudeirat (Gilboa et al. 2009) are not included in this study.

We are aware of the methodological issues stemming from using a large database with over 400 dates from 26 sites. There must have been considerable difficulties like differences in excavation quality, stratigraphic attribution of samples, correlation between sites in terms of stratigraphy and pottery assemblages (particularly when some of these sites are not yet published in detail), and quality of measurements in different laboratories done during a timespan of over a decade. It would be much more adequate to examine sequences of dates in each site separately and compare the results. Our holistic approach to this matter is similar to that used in previous similar studies (Sharon et al.

2007; Mazar and Bronk Ramsey 2008; Finkelstein and Piasetzky 2009, 2010a,b). Sequences at individual sites were carried out in the past in the cases of Dor (Gilboa and Sharon 2003), Tel Rehov (Bruins et al. 2005; Mazar 2005), and Megiddo (Mazar and Bronk Ramsey 2008; Fantalkin et al. 2011). The attribution to subphases of the Iron Age in this paper fit the definitions given by the excavators unless otherwise stated.

The posterior Iron Age chronology is summarized in Figure 2 and Table 4, where the start and end of the transition between adjacent phases are listed. Figure 3 and Table 5 summarize the estimates of the mid-point of the phase transitions and their duration.

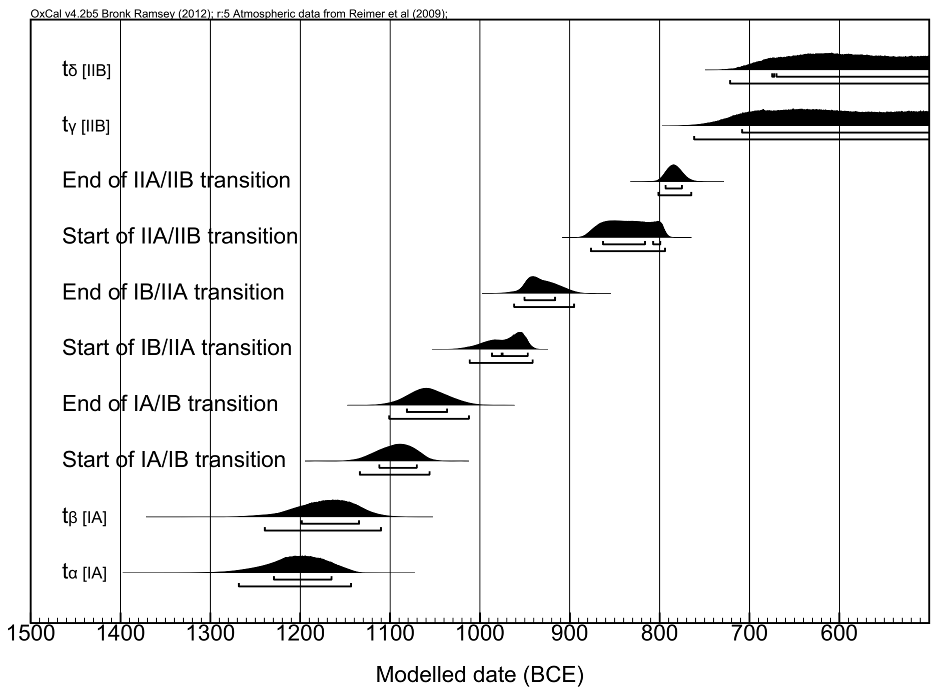

Figure 2 Posterior Iron Age chronology, at 68.2% and 95.4% probability

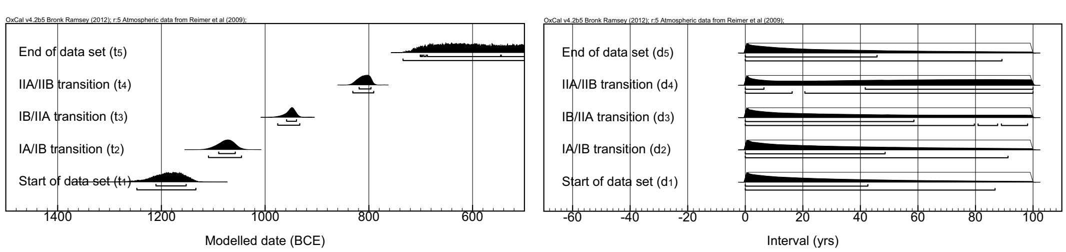

Figure 3 Trapezoid prior estimates of the (a) `boundary` (for mid-point of transitions) and (b) `transition` (for duration of the phase transition) parameters for the Iron Age phases, at 68.2% and 95.4% probability. The model parameters are labeled in brackets.

The new trapezoidal model framework places the start of the Iron I/II transition in the range 987–947 and 1012–942 BCE, and the end of the transition in the range 951–917 and 962–896 BCE at 68.2% and 95.4% probability, respectively. The middle of the transition is estimated to be in the range 959–940 BCE (68.2% probability) and 976–934 BCE (94.5% probability). The duration of this transition is estimated to be between 0 and 59 yr (68.2% probability) and between 0 and 98 yr (95.4% probability).

The outlier analysis function utilized was able to down-weight possible outlying ages (e.g. Beta-284754 and 5232 has been down weighted in 49% and 100% of the model runs) objectively. Results of outlier analysis can be found in the online supplementary material.

Table 4 Trapezoidal prior estimates of the Iron Age chronology, at 68.2% and 95.4% probability. Refer to Figure 1 for a visual representation of model parameters.

		Modeled date (BCE)	
	Model parameters	68.20%	95.40%
End of the data set	t_δ [IIB]	675–436	722–301
	t_γ [IIB]	709–469	762–329
End of Iron IIA / Iron IIB transition	t_δ [IIA] = t_β [IIB]	794–776	802–765
Start of Iron IIA / Iron IIB transition	t_γ [IIA] = t_α [IIB]	864–800	877–795
End of Iron IB / Iron IIA transition	t_δ [IB] = t_β [IIA]	951–917	962–896
Start of Iron IB / Iron IIA transition	t_γ [IB] = t_α [IIA]	987–947	1012–942
End of Iron IA / Iron IB transition	t_δ [IA] = t_β [IB]	1082–1037	1101–1013
Start of Iron IA / Iron IB transition	t_γ [IA] = t_α [IB]	1112–1071	1134–1057
Start of the data set	t_β [IA]	1199–1135	1240–1111
	t_α [IA]	1230–1166	1269–1144

Table 5 `Boundary` estimates (t_2–t_4) for the mid-point of transitions of the Iron Age chronology and their durations (d_2–d_4), at 68.2% and 95.4% probability. Refer to Figure 1 for a visual representation of model parameters.

	Model parameters	Modeled date (BCE)		Model parameters	Years	
		68.2%	95.4%		68.2%	95.4%
End of the data set	t_5	701–449	735–318	d_5	0–46	0–89
Iron IIA / Iron IIB transition	t_4	819–796	831–791	d_4	0–100	0–100
Iron IB / Iron IIA transition	t_3	959–940	976–934	d_3	0–59	0–98
Iron IA / Iron IB transition	t_2	1090–1058	1110–1046	d_2	0–49	0–91
Start of the data set	t_1	1211–1153	1248–1134	d_1	0–43	0–87

DISCUSSION

The Bayesian model built in this study on the Iron age chronology takes into account the archaeological definitions of the Iron Age phases, which were based on relative sequences of pottery assemblages. It draws inference on the start and end of each of the Iron Age phase transitions across the region. The quoted date ranges above in this paper are not restricted to single sites. Since prior measures are drawn from the prior distributions over the parameters, they are sensitive to the prior (Vanpaemel 2010). This means that the prior estimates here, and all previous Bayesian models, are sensitive to the modeling framework, and the prior models used.

The purpose of this paper is to put forward a new flexible modeling approach. This model framework provides an alternative and, in our opinion, more appropriate approach to modeling transitional processes, where phases, and indeed the ^{14}C dates, are found to overlap. The results of the trapezoidal model utilized in this study emphasize the difficulties in achieving precise dates for transitions between phases for the Iron Age in the southern Levant, when chronological debates concern timeframes of <100 yr. One major unresolved problem is the mixture of dates from many different sites into 1 model: the correlation between the stratified sequences in different sites is not always secure and there are also local problems in individual sites concerning the quality of the stratigraphic observations, nature of the samples etc. As can be seen in Table 4 and Figure 2, there is considerable overlap between the calculated dates of adjacent transitional phases even in the 68.2% probability range and much more so in the 95.4% probability range. Results from this model suggest that the Iron I/II transition started in the first half of the 10th century and ended in the second half.

Interestingly, the dates of the beginnings of transitions from Iron IB to Iron IIA and from Iron IIA to Iron IIB as presented in Table 4 would fit the Modified Conventional Chronology while the dates of the end of these transitions would fit the Low Chronology as presented in Table 1. The boundary estimates for the mid-point of transitions as presented in Table 5 is almost half-way between these 2 chronological systems. Future work, utilizing sequences in individual sites, and referring to sub-phases in each of the Iron Age IB and IIA phases, may refine these results.

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