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A Bayesian approach to calculating Pre-Pottery Neolithic structural contemporaneity for reconstructing population size

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1. Introduction

Identifying contemporaneous use of structures in the archaeological record is critical for reconstructing population size. Demographic analyses that do not sufficiently account for structural contemporaneity may result in inflated population estimates and inaccurate theories regarding spatial and social dynamics. Unfortunately, contemporaneity adjustments are not commonly utilised in population reconstructions and are virtually absent in population estimates of central and southern Levantine Pre-Pottery Neolithic (PPN) settlements (c. 10,000–6,400 cal BC; Kuijt and Goring-Morris, 2002, 366). A rare example is provided by Rollefson and Köhler-Rollefson (1989), who applied a conjectural value of 80% structural contemporaneity when estimating the population of late PPN ʻAin Ghazal.

The PPN was an important period in human history, in which there was extensive demographic transformation from mobile hunter-gatherer communities to sedentary, village-based, agro-pastoralist societies, with increasingly larger and diverse populations. This aggregation of people is directly associated with major developments in subsistence, technology, and ritual and symbolic practices, and the emergence of more complex social, economic, religious and political systems. To understand the link between population aggregation during this period and the developments that occurred, it is essential that more accurate and precise demographic data is derived, using more scientifically robust methods, including those that attempt to quantify structural contemporaneity.

The lack of consideration of structural contemporaneity in central and southern Levantine PPN population estimates is due partly to methodological difficulties with identifying contemporaneous structures, as well as the commonly used method for estimating population sizes, whereby a density value (usually in the range of 90–294 people per ha) is multiplied by site extent (Rollefson and Köhler-Rollefson, 1989; Kuijt, 2000, 2008; Campbell, 2009). As density values are derived from ethnographic settlements (Jacobs, 1979; Watson, 1979; Kramer, 1982b; Van Beek, 1982), which demonstrate some building disuse or abandonment, the method can be argued to inherently incorporate some consideration of structural contemporaneity, though not precisely quantified, nor directly transferrable to all PPN sites. Furthermore, recent research has revealed that the commonly utilised density coefficients for reconstructing central and southern Levantine PPN settlements are not suitable due to lack of comparability in settlement and social structures, as well as considerable environmental differences (Birch-Chapman, 2017; Birch-Chapman et al., 2017). In order to produce more accurate population reconstructions for this region and time period, empirically robust methods should be explored for quantifying structural contemporaneity.

To identify contemporaneous structures within a settlement phase, archaeologists typically establish relative chronologies of structures, assigning them to distinct occupation phases based on assessment of bonded and abutting boundary walls and patterns of circulation within and between buildings (Wilcox, 1975; Kramer, 1982a; Hemsley, 2008). However, this is a difficult process, particularly for complex, multi-phase sites or where remains have been heavily degraded. Furthermore, archaeologically-defined phases may have in fact spanned hundreds of years and contain archaeological remains that reflect unrelated human activities (Kuijt, 2008). For population estimates, more precise methods are required for quantifying momentary contemporaneity. Promising methodological advancements in this field have been made by those attempting to reconstruct population estimates of pueblo settlements in Southwest USA. Several studies have estimated momentary population: that is, the population size at any one point in time (Varien et al., 2007; Brown et al., 2013; Ortman, 2016). One method that deserves examination in the context of central and southern Levantine PPN settlements is that developed by Varien et al. (2007). To calculate the average number of momentary households in pueblo settlements in the Mesa Verde region (c. A.D. 600–1300) they applied the following equation:

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$$\text{Average number of momentary households} = \frac{\text{building use-life}}{\text{period length}} \times \text{total number of households}$$

Estimates of building use-life and period length were derived from assessments of cooking pot accumulations (Varien and Potter, 1997; Varien and Ortman, 2005; Varien et al., 2007, 280). Brown et al. (2013) later applied the same method to estimate the average number of momentary rooms in Chacoan and post-Chacoan settlements in the Middle San Juan region, New Mexico (c. A.D. 900–1300). The equation essentially produces a household contemporaneity value: that is, a proportion of households living contemporaneously.

To apply this equation to central and southern Levantine PPN settlements, which are characterised by a lack of pottery, other methods are required for deriving building use-life and period length. In this paper, a method involving Bayesian chronological modelling of radiocarbon dates from structures is presented, with final building use-life and phase length estimates applied to the equation to calculate a structural contemporaneity value: that is, the percentage of structures in contemporaneous use. Calculation of structural contemporaneity values forms part of a much wider project reconstructing site-specific population estimates for all PPN settlements in the central and southern Levant (Birch-Chapman, 2017). A review of current methods for estimating PPN building use-life and period length (i.e. occupation span and phase length) is provided in this paper, followed by a discussion of the use of Bayesian chronological modelling for this purpose. The newly developed method is then applied to a case study and phase-specific structural contemporaneity values are proposed. This is followed by a discussion of implications of contemporaneity adjustments for population reconstructions of PPN settlements.

The case study for initial exploration of this method is the PPNB (c. 8800-6700 cal BC) settlement of Beidha (Fig. 1). Beidha is a small (≤0.35 ha) settlement in southern Jordan that demonstrates the transition from a semi-sedentary hunter-gatherer community to a well-established sedentary agro-pastoralist society. The extensive and well-documented PPN occupation evidence (Kirkbride, 1966, 1985; Byrd,

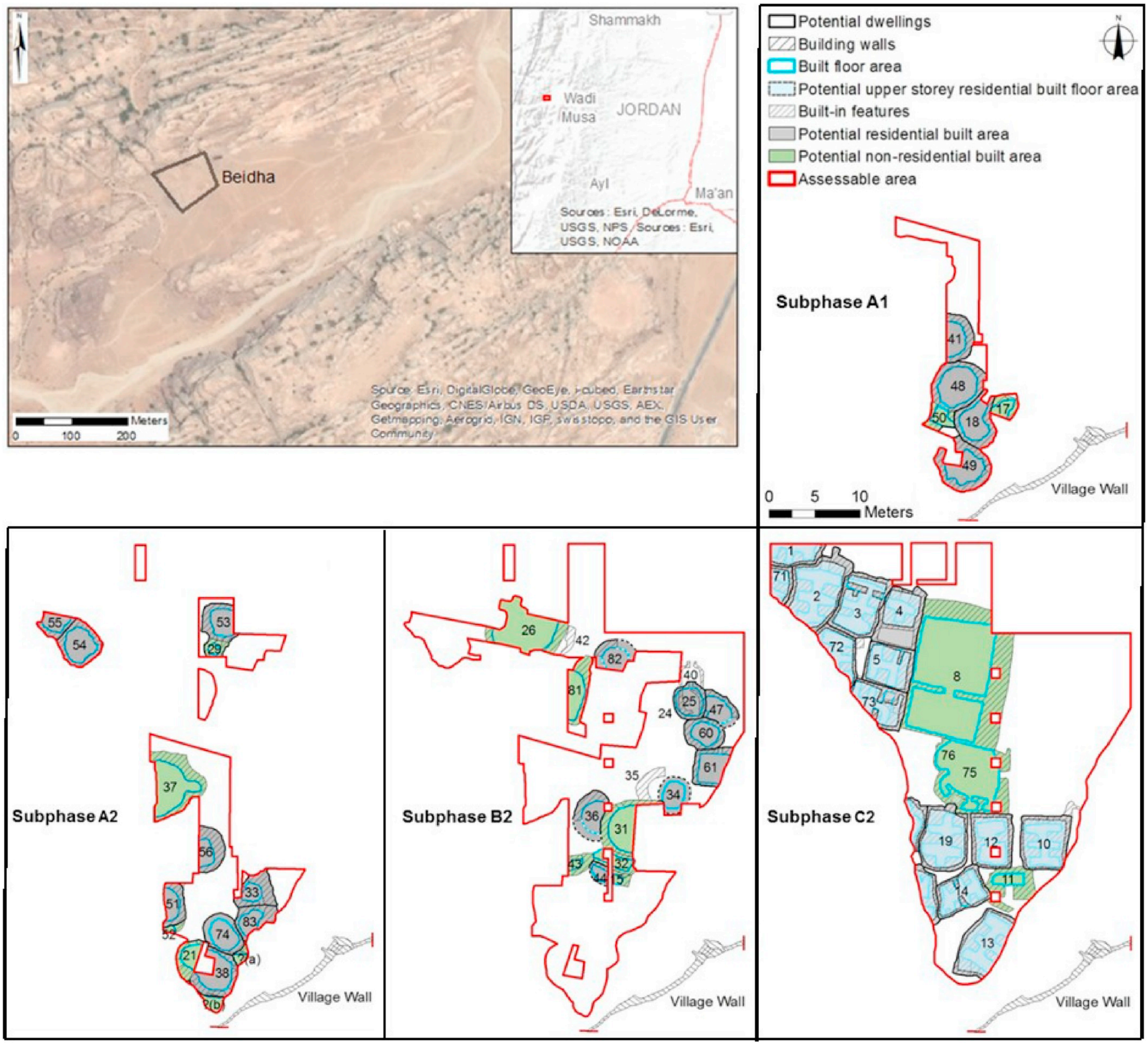

Fig. 1. Location of PPN Beidha and site plans for Subphases A1, A2, B2 and C2 (plans adapted from Byrd, 2005).

2005; Birch-Chapman et al., 2017) and large dataset of radiocarbon dates compared to other PPN settlements present an excellent opportunity for exploring the proposed methodology to calculate structural contemporaneity. The major building phases and radiocarbon dating for Beidha relate to Subphases A1, A2, B2 and C2, which are assessed in detail in this research. Four additional central and southern Levantine PPN settlements were similarly assessed: Netiv Hagdud, Ghwair I, ‘Ain Abu Nekheileh and Basta. Final structural contemporaneity values and population estimates for these sites are presented in this paper, with data and analyses available in the supplemental material.

2. Theoretical and methodological background

2.1. Previous methods for estimating PPN building use-life and period length

Building use-life estimates for central and southern Levantine PPN settlements are rarely published and, where present, are predominantly based on ethnographic and experimental research on structures comparable to those that existed during the PPN (Rollefson and Köhler-Rollefson, 1989; Kuijt and Finlayson, 2009). Research suggests that construction type and material, and evidence for building maintenance are the best indicators of use-life. Common construction elements during the earlier PPN include semi-subterranean, curvilinear structures with stone, mud brick, pisé (compacted earth) or wood and daub walls, and wood and daub roofing, as at Nahal Oren (Goring-Morris and Belfer-Cohen, 2013), Dhra’ (Kuijt, 2001), Wadi Faynan 16 (Mithen et al., 2011), Netiv Hagdud (Bar-Yosef and Gopher, 1997), and Zahrat adh-Dhra’ 2 (Edwards et al., 2004). These construction elements persisted in later PPN periods in more marginal and arid regions, such as at Beidha (Kirkbride, 1966; Byrd, 2005) and Shkārat Msaied (Kinzel, 2013). As the PPN progressed, rectilinear architectural forms emerged (Khalaily et al., 2007; Balbo et al., 2012). In later periods, many of these comprised multiple storeys with durable, load-bearing stone walls and buttresses, and some even had sub-floor air or water channels, such as at Basta (Nissen, 2006), Wadi Hamarash I (Sampson, 2013), el-Hemmeh (White, 2013), and es-Sifiya (Makarewicz et al., 2006). These architectural developments are interpreted as reflecting longer term occupation (Kuijt and Goring-Morris, 2002).

From the earliest PPN period, evidence for cleaning activities and building maintenance takes the form of reflooring and wall recoating. In later periods, building maintenance and remodelling was often considerable, including internal partitioning, blocking of openings, addition of annexes and supporting walls, and multiple reflooring and replastering episodes interpreted as deliberate attempts to extend the building’s use-life (Kuijt and Goring-Morris, 2002; Kinzel, 2013).

Archaeological, experimental and ethnographic research into building use-life suggests that structures predominantly made with earthen and light organic materials (e.g. wood and daub) may have been utilised for around six to 15 years without maintenance, and up to 50 years with maintenance (Cameron, 1990; Reynolds, 1995; Diehl, 2001; Ortman et al., 2007; Kuijt and Finlayson, 2009; Arnoldussen, 2008; Varien, 2012). Research into the use-life of predominantly stone and mud brick structures suggests these were probably occupied for at least 50 years with maintenance, though possibly 100 years or more (Ahlstrom, 1985; Rollefson and Köhler-Rollefson, 1989; Hodder and Cessford, 2004; Cessford, 2005; Matthews, 2005).

Period length in this study refers to total occupation span or phase length, where multiple phases exist. For PPN sites, estimates of period length are usually broad and often comprise vague statements regarding relative longevity (e.g. “a relatively short-lived settlement”) or distribution across PPN periods (e.g. “the site spanned the PPNA and PPNB”). Most estimates are derived from uncalibrated radiocarbon date spans (Bar-Yosef et al., 1991; Henry and Albert, 2004; Byrd, 2005). More recently, refined (though still broad) estimates have been derived from stratigraphically informative calibrated radiocarbon dates (Edwards et al., 2004; Mazurowski et al., 2009; Manning, 2014).

2.2. Bayesian chronological modelling of building use-life and period length

Bayesian modelling is increasingly utilised for reconstructing chronological information (Buck et al., 1996; Bayliss, 2007; Bayliss et al., 2011), and has significant potential for producing more accurate and precise estimates of PPN building use-life and period length. Bayesian chronological models, founded on Baye’s theorem (Bayes, 1763), produce revised probability distributions (‘posterior density estimates’) from calibrated radiocarbon dates (‘standardised likelihoods’) and prior chronological information derived from archaeological, ethnographic or experimental interpretation (‘prior beliefs’) (Bronk Ramsey, 2009; Bayliss et al., 2011).

Bayesian chronological analysis is usually conducted on large radiocarbon datasets to explore the timing of large-scale events and processes, such as human dispersals, the emergence and spread of agriculture, and typological or technological changes (Whittle et al., 2011; Higham et al., 2012; Riede and Edinborough, 2012; Wicks and Mithen, 2014; Porčić and Nikolić, 2016). However, models can be constructed with small radiocarbon datasets and can be used to assess short-term events, such as building use-life and phase length, depending on the availability and accuracy of prior information, and the quantity, precision and stratigraphic distribution of the dated material. Such methods have been employed to estimate boundary dates and spans of structures, burial chambers and settlements from the Neolithic, with radiocarbon date datasets ranging from as little as five determinations (Robb and Marino, 2010; Bayliss et al., 2014, 2016; Marciniak et al., 2015; Tasić et al., 2015; Bánffy et al., 2016; Czerniak et al., 2016; Kerns, 2016; Richards et al., 2016; Draşovean et al., 2017; Card et al., 2018).

The limited number of radiocarbon dates for PPN settlements and the paucity of information regarding context, sample material and pretreatment makes Bayesian chronological analyses of PPN settlements rare. These include one study by Edwards et al. (2004), who used Bayesian modelling to estimate start and end dates for PPNA Zahrat Adh-Dhra’ 2, Jordan, from nine accelerator mass spectrometry (AMS) dates acquired from wood charcoal fragments distributed across the full extent of the stratigraphic sequence. More recently, Wicks et al. (2016) employed Bayesian modelling using 46 AMS dates from PPNA WF16, Jordan, to establish site and structure (termed ‘object’) boundary dates, incorporating an offset command to account for the effect of old wood. This offset was calculated from the difference between ages derived from mature and juvenile wood charcoal samples (Wicks et al., 2016, 13–14). The model produced a site span of approximately 1590 years (c. 11840 to 10240 cal BP), and indicated intense activity for approximately 350 years centred on c. 11250 cal BP. Despite the relatively large number of dates modelled for a PPN site, the chronological resolution of models for individual structures was not well constrained due to the limited number of AMS dates per structure, plateaus in the calibration curve, stratigraphic inversion of dates probably resulting from post-depositional processes and old wood effects. These rare examples demonstrate the potential for using Bayesian chronological modelling to estimate PPN phase length and building use-life. The relatively large number of radiocarbon dates ($n = 23$) available for Beidha compared to other PPN sites enables exploration of this technique here (Benz, 2018).

3. Methodology

The number of contemporaneous structures per phase was calculated from building use-life, phase length and the total number of buildings identified in the phase (using information available from published site plans, Harris matrices and chronostratigraphic interpretations) following the equation utilised by Varien et al. (2007), detailed above. This equation was later simplified to produce a structural contemporaneity value calculated thus:

$$\text{Percentage of buildings in contemporaneous use} = \frac{\text{average building use} - \text{life}}{\text{phase length}} \times 100$$

Site-specific estimates of building use-life and phase length were derived from a combination of the following:

i. Assessment of chronological information relating to phases and the construction, use and abandonment of each structure from archaeological reports (i.e. prior beliefs);
ii. Assessment of existing building use-life estimates for structures comparable to those from the PPN, as derived from archaeological, ethnographic and experimental research (i.e. prior beliefs); and,
iii. Assessment of span estimates derived from Bayesian chronological modelling of radiocarbon dates (i.e. posterior density estimates).

The first two assessment types form the prior beliefs that underpinned the Bayesian chronological models. The final phase length and building use-life estimates employed in the structural contemporaneity equations were predominantly based on posterior density span estimates. Where these were inconclusive or unrealistic (i.e. too restrictive or excessive), more weight was given to the prior beliefs.

The following sections outline the exact process taken for determining prior beliefs regarding phasing, phase length and building use-life, using Beidha as a case study. This is followed by an outline of the process for Bayesian chronological modelling and the application of this method to Beidha.

3.1. Establishing prior beliefs regarding phasing, phase length and building use-life at Beidha

Chronological information relating to Beidha was predominantly sourced from Byrd's (2005) detailed assessment of the archaeological features uncovered by Kirkbride (1966). The original phasing model for Beidha, proposed by Byrd (2005), was founded on assessment of the structural features, primarily the construction, occupation and abandonment relationships. Three main phases were identified: A, B and C (Byrd, 2005, 15) (Fig. 2). Phases A and C were divided into two subphases each by Byrd (A1 and A2; C1 and C2), with detailed site plans provided for these (Byrd, 2005, 180–196). Based on evidence for earlier and later Phase B remains, in the current investigation, Phase B was split into Subphases B1 and B2, with a Subphase B2 site plan constructed following close scrutiny of published chronostratigraphic information. Based on the archaeological evidence and analysis of conventional

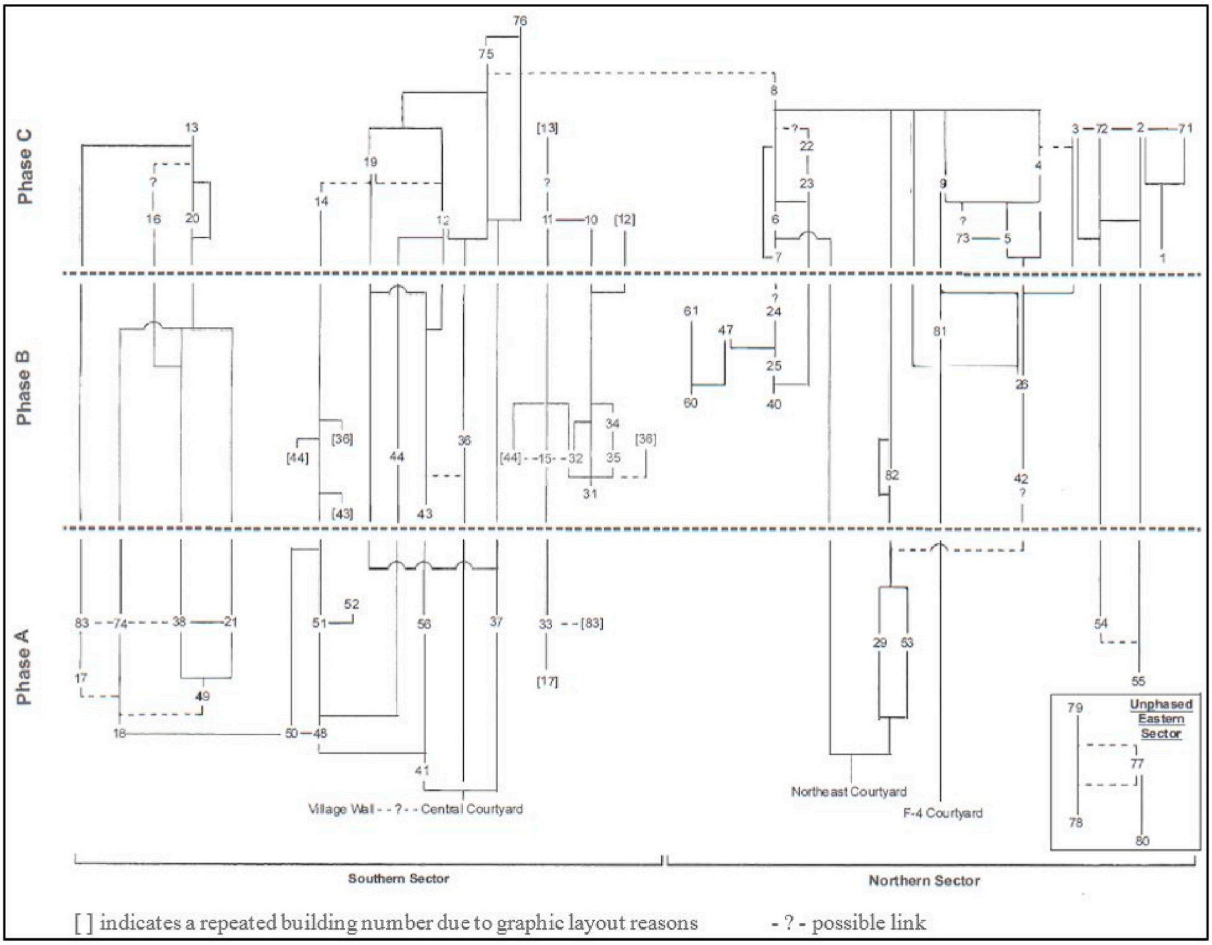

Fig. 2. Beidha Neolithic building sequence across Phases A, B and C (Byrd, 2005, 178).

radiocarbon dates derived from radiometric assays obtained during the 1960s (Barker and Mackey, 1968, 4; Stuckenrath and Lawn, 1969, 152; Tauber, 1968, 323–324; Vogel and Waterbolk, 1972, 49–50), Byrd (2005, 27) proposed that Phase A began c. 7000 BC and probably ended c. 6700 BC. Unfortunately, several divergent dates, probably resulting from post-depositional disturbance, prevented establishment of Phase B or C boundary dates. Instead, proposing that the final subphase (C2) may have ended in the Late PPNB, Byrd suggested a span of 150–250 years each for Phases B and C. Byrd did not propose subphase spans.

To establish building use-life estimates, results of previous studies that produced use-life estimates for structures comparable to those investigated in this research were assessed (Table 1). The two main structural indicators of building use-life are construction material and degree of maintenance. In this research, a building use-life range was suggested for nine building types categorised by material (i.e. earthen; earthen/stone; stone) and maintenance (i.e. none/minimal; moderate: some remodelling, replastering, etc.; considerable: multiple remodelling or reflooring episodes, annexes, blocked entrances, etc.). For each building assessed in this investigation, archaeological evidence for construction material and maintenance was examined in order to assign a suggested building use-life range.

At Beidha, construction during Phases A and B included freestanding and interconnected, curvilinear structures with earthen roofing material and walls of earthen and stone material. Phase C construction included agglomerated, rectilinear and often two-storey, predominantly stone structures (Byrd, 2005, 28). Structures across all phases generally demonstrate a moderate to considerable amount of maintenance and remodelling, indicating deliberate attempts to extend the building use-life (Table 2). A summary of suggested subphase lengths and building use-life estimates based on Byrd's analysis and prior archaeological, ethnographic and experimental research is provided in Table 3.

Table 2

Beidha PPN building information (Byrd, 2005) and building use-life suggested in this investigation.

Subphase/ Building		Predominant construction material*	Degree of maintenance	Suggested use-life (years)
A1	18	Earthen/stone: *Wooden posts and stone cobble/block walls; large central post supporting beam, clay, read and large stone slab superstructure*	Considerable: *Plastered walls; two floor levels with intervening fill deposits; considerable remodelling: blocked entrances, addition of annexes*	55–75
A1	48	Earthen/stone: *Similar to Building 18*	Considerable: *Plastered walls and floor; Building 50 added as annex (modified several times)*	55–75
A2	54	Earthen/stone: *Similar to Building 18*	Moderate-considerable: *Plastered walls, floor and ceiling; multiple plastering episodes; possible earlier floor layer; remodelling: blocked entrance/s*	35–75
A2	74	Earthen/stone: *Similar to Building 18*	Moderate: *Plastered floor*	35–55
B2	26	Earthen/stone: *Similar to Building 18 plus mudbrick upper walls*	Moderate: *Plastered walls, floor and ceiling; remodelling episode*	35–55
C2	8	Stone: *Stone block/slab/rubble fill walls; wooden posts for additional support of heavy superstructure*	Considerable: *Plastered floor; at least four major re-modelling and re-plastering episodes*	75–100

3.2. *Bayesian chronological modelling of radiocarbon dates*

Bayesian chronological modelling of radiocarbon dates was conducted to determine precise start, transition and end dates, as well as span estimates for subphases and building use-life. Models were creating using OxCal v.4.2.4 (Bronk Ramsey, 1995, 2001; 2005, 2009; Bayliss et al., 2011) and calibrated using IntCal 13 (Reimer et al., 2013). Dates were statistically assessed to identify outliers for removal prior to analysis. Chi squared tests (χ^2; Ward and Wilson, 1978) were conducted on sets of radiocarbon dates ordered by phase/subphase in descending chronological order of the earliest calibrated date ranges. Resulting 'T' values higher than the threshold based on the 5% confidence limit (given in brackets) indicated the presence of stratigraphically divergent dates. These dates were subsequently identified by Bayesian chronological modelling of the lower and upper occupation boundaries (i.e. 'start' and 'end' dates) based on the same ordering of dates.

Modelled date ranges are given as posterior density estimates using the 2σ (95.4%) probability ranges and are indicated using italics (Millard, 2014, 557). Convergence values (C) greater than 95% indicate model stability. Model index agreement values below the agreement

Table 1

Suggested building use-life estimates based on prior archaeological, ethnographic and experimental research.

Prior archaeological, ethnographic and experimental research

Predominant construction material	Maintenance		Building use-life (years)	References
Earthen/light organic	Without maintenance		6–15	Cameron (1990); Reynolds (1995); Diehl (2001); Ortman et al. (2007);
	With maintenance		15–45	Arnoldussen (2008); Varien (2012)
			<50	Kuijt and Finlayson (2009)
Stone/mud brick	With maintenance	PPNB-PPNC 'Ain Ghazal	≤100	Rollefson and Köhler-Rollefson (1989)
		Ancient Southwest USA	60	Ahlstrom (1985)
	With considerable maintenance	Neolithic Çatalhöyük	50–100	Hodder and Cessford (2004); Cessford (2005); Matthews (2005)

Suggested building use-life (years)

Predominant construction material	Degree of maintenance		
	None/Minimal	Moderate	Considerable
Earthen	6–15	15–35	35–50
Earthen/stone	10-35[a]	35–55	55–75
Stone	20–50	50–75	75–100

[a] Based on the mid-point of estimates for earthen and stone structures, with an average span of 20 years added successively for earthen/stone structures with moderate and considerable maintenance based on the average length of spans otherwise suggested.

Table 3
Prior beliefs regarding phasing, phase length and building use-life at Beidha.

Phase length		Building use-life			
Phase	Suggested length (years) (Byrd, 2005)	Subphase: Building	Longevity statement (Byrd, 2005)	Construction and maintenance[a]	Suggested use-life (years)[b]
A	300	A1: 18	Considerable	E/S, C	55–75
		A1: 48	Considerable	E/S, C	55–75
		A2: 54	Reasonable	E/S, Mod-C	35–75
		A2: 74	Reasonable	E/S, Mod	35–55
B	150–250	B2: 26	–	E/S, Mod	35–55
C	150–250	C2: 8	Considerable	S, C	75–100

[a] Predominant construction material - E: Earthen, S: Stone; Maintenance - Mod: Moderate, C: Considerable.

[b] Based on use-life estimates for comparable structures (see Table 1 for references).

Table 4
OxCal commands used in the Bayesian chronological models.

OxCal command	Operational definition (Bronk Ramsey, 2005)	Use in model
Boundary	"To define which events in a model are from well-defined periods and to estimate the boundaries of these periods."	To delineate the beginning and end of a phase but is not directly dated
Phases	"To group events between which there are no known relationships but which may all share some relationship."	For datasets with: - unclear phasing or subphasing information - unknown internal ordering of dates - dates that are not in chronostratigraphic order
Sequences	"Allows the information that one event precedes another to be incorporated into the resultant probability distributions."	For datasets with: - clear phasing and subphasing information - dates that conform to the stratigraphic sequence
Gaps	"To ensure a gap between events in a sequence"	Inserted where a phase or subphase has not been directly dated to allow for a temporal break between known and dated phases/subphases
Building phases		Where more than one structure occurs within a phase/subphase, individual 'building phases' can be grouped within overall 'phase/ subphase building phases' to allow for potential overlap between the dates of the structures within these phases
Span	"Group function or query which gives the span of events"	To determine the duration of occupation, a phase, subphase or structure

threshold ($A \leq 60\%$) highlight statistical outliers, prompting assessment of the physical and spatial characteristics of the dated material to determine whether these represent residual or intrusive samples and should, thus, be removed from the datasets. The refined date datasets were assessed to determine appropriate model construction (Table 4). A combination of 'phase' and 'sequence' models were applied, with gap periods and building phases included where necessary.

Of the 23 radiocarbon dates associated with the PPN occupation of Beidha (Benz, 2018), four have insufficient contextual information for inclusion in this analysis (Table 5). Chi-squared testing on the remaining 19 dates indicated that at least one date does not conform to the stratigraphic constraints ($df = 18$ $T = 60.4$ (5% 28.9) [fail]) (Supplemental material: Section A, Table 1). Divergent dates were identified via Bayesian chronological modelling of the lower and upper occupation boundaries (Supplemental material: Section A, Table 2). Convergence values indicated that all models were stable ($C > 95\%$). Model index agreement values indicated five statistical outliers ($A \leq 60\%$). Removal of these, following assessment of the dated material that suggested these were probably residual or intrusive samples, resulted in acceptable agreement index values ($A > 60\%$) in a subsequent run of the model. Chi-squared testing confirmed the stratigraphic coherence of the refined dataset of 14 dates ($df = 13$ $T = 6.7$ (5% 22.4) [pass]). Date AA13036 was later excluded as it was not sourced from a building. A refined dataset of 13 dates was used in the final chronological model (Fig. 3; Table 6).

To determine the relationship between Subphases A1, A2, B2 and C2, and hence the type of model to construct, Byrd (2005) detailed analysis of the stratigraphic relationships between subphases at Beidha was assessed. A contiguous relationship was perceived between Subphases A1 and A2, while the relationship between Subphases A2, B2 and C2 was classed as sequential due to their separation by Subphases B1 and C1, which were not directly assessed due to an absence of radiocarbon dates. The model was thus constructed to produce a 'transition' date between Subphases A1 and A2, and estimated 'end' and 'start' dates between Subphases A2, B2 and C2, to allow for intermittent subphases (Supplementary material: Section A, Text file 1). Based on the archaeological evidence for Subphases B1 and C1, and the suggested building use-lives previously established for similar structures, a potential 'gap' period of at least 30 years was included in the model for Subphase B1 and at least 70 years for Subphase C1 (Supplemental material: Section A, Table 3).

'Phase' subsets were constructed for each building to estimate building use-life. Because more than one structure occurred within Subphases A1 (Buildings 18 and 48) and A2 (Buildings 54 and 74), individual 'building phases' were grouped within overall 'subphase building phases' to allow for potential overlap between the dates of these structures. The span function was used to calculate the duration of the total occupation, and of each subphase and building.

Results based on 1σ (68.3%) and 2σ (95.4%) probability ranges were initially assessed. Based on the prior chronostratigraphic information and the considerable developments that occurred throughout the PPN occupation at Beidha, the 1σ probability ranges were considered too restrictive and unrealistic. The broader span estimates based on the upper end of the 2σ range were considered most valid and are used here to reconstruct final span estimates for inclusion in the structural contemporaneity equation.

4. Span estimates and contemporaneity values for PPN Beidha

4.1. Modelled span estimates

The results of this study have produced some interesting temporal parameters that can add to the important research conducted by Byrd (2005). The model indicates that the PPN occupation of Beidha began sometime between *8220* and 7810 cal BC, during the Middle PPNB (8600-7400 cal BC), terminating approximately 600 years later sometime between *7810* and 7460 cal BC, at the end of the Middle PPNB or perhaps at the beginning of the Late PPNB (7400-6700 cal BC) (Fig. 3; Table 6; Supplemental material: Section B, Figs. 1 and 2). The final occupation span produced in this study (~600 years) compares well with Byrd (2005) suggested span or 500–800 years and to the commonly published span estimate of 600 years for the PPN occupation of Beidha (Gebel, 1987, 346; Rollefson, 1989, 169). However, the majority of radiocarbon samples used for modelling were sourced from structural elements and it is highly probable that earlier start and end dates have resulted from old wood effects (Wicks et al., 2016). It is, therefore, likely that the Phase C settlement did indeed extend into the Late PPNB, as Byrd (2005) suggests.

Modelled dates indicate that Subphase A1 spanned around 140 years, terminating sometime between *8190* and 7770 cal BC, with Subphase A2 spanning around 80 years and terminating sometime between *8160* and 7740 cal BC. The modelled span of 220 years for Phase

Table 5
Information relating to the Beidha PPN radiocarbon dates (n dates = 23) and justification for exclusion from analysis. Dates in descending chronological order of the earliest unmodelled 2σ calibrated range BC.

Lab reference	Context		Material[a]	Radiocarbon date		Justification for exclusion
	Subphase: Location			Conventional ^{14}C age (BP)[b]	Unmodelled 2σ cal range (BC)	
P1380	A2	Building 74: central post	CH: Pistacia	9128 ± 103	8640–7990	Poor agreement; considerably earlier than other PPN dates despite being from Subphase A2; one of three dates (including GrN5136 and K1083) derived from the same object - considerably earlier than the other two dates; potential old wood effect: potential timber re-use or tree potentially felled (or wood collected) years before use.
K1086	A1	Building 18: possible roof beam	CH: Quercus	8940 ± 160	8470–7600	
beta 235216		3.35 m; Neolithic layer right above sterile sand	CH	9110 ± 50	8460–8240	Insufficient contextual information
BM111	B2	Building 26: beam roof fall directly above floor	CH: ?	8790 ± 200	8430–7490	
AA1461		–	CH	8390 ± 390	8430–6470	Insufficient contextual information
GrN5062	C2	Building 8: possible wooden lid of stone-lined pit	CH: Juniper	9030 ± 50	8320–7990	Poor agreement; one of the earlier PPN dates despite being from Subphase C2 (last PPN phase); unclear nature of material (possible lid); potential old wood effect due to long-living species, potential timber re-use or tree potentially felled (or wood collected) years before use.
P1382	C2	Building 8: from near top of stone-lined pit	CH: ?	8892 ± 115	8290–7670	Below agreement threshold (A < 60%) in subphased sequence model (A = 29.5%); date retained as one of only two potentially suitable dates for estimating span of Subphase C2 and Building 8
K1410	A1	Building 48: roof beam	CH: Juniper	8850 ± 150	8290–7590	
K1411	A1	Building 48: wall post	CH: Quercus	8770 ± 150	8260–7580	
K1084	B2	Building 26: beam roof fall directly above floor	CH: Juniper	8730 ± 160	8250–7530	
K1412	A1	Building 48: central post	CH: Pistacia	8720 ± 150	8240–7540	
K1083	A2	Building 74: central post	CH: Pistacia	8640 ± 160	8240–7370	
AA13036	A1	Outdoor area: hearth 5	S: Pistacia	8830 ± 70	8230–7680	Dated material not sourced from a building
K1082	A2	Building 54: large basket of carbonised pistachios	S: Pistacia	8710 ± 130	8220–7560	
GrN5136	A2	Building 74: central post	CH: Pistacia	8810 ± 50	8210–7720	
P1381	A1	Building 18: burnt fill	CH: ?	8765 ± 102	8210–7590	
AA13038		Non-phased, Hearth A	Legumes	8765 ± 80	8200–7600	Insufficient contextual information
P1378	A2	Building 54: central post	CH: ?	8715 ± 100	8200–7580	
K1085	C2	Building 8: from near top of stone-lined pit	CH: Juniper	8550 ± 160	8200–7180	
AA14109	A1	Building 49: upper floor	B: Ovicaprid femur	8646 ± 69	7940–7550	Poor agreement; one of the later PPN dates despite being from Subphase A1; the only date sourced from bone; the only sample (of 7 submitted) to retain sufficient amino acids for dating; carbon contamination often causes younger dates in bone; possibly intrusive disarticulated bone.
P1379	A2	Building 54: large basket of carbonised pistachios	S: Pistacia	8546 ± 100	7940–7350	Poor agreement; two of the latest PPN dates despite being from Subphase A1; date considerably later than K1082 sourced from the same material.
GrN5063	A2	Building 54: large basket of carbonised pistachios	S: Pistacia	8640 ± 50	7790–7570	
AA13037		Non-phased, Hearth B	Legumes	7720 ± 130	7040–6360	Insufficient contextual information

[a] CH: Charcoal; S: Seed/nut; B: Bone.

[b] Dates derived from radiometric assays (Barker and Mackey, 1968, 4; Stuckenrath and Lawn, 1969, 152; Tauber, 1968, 323–324; Vogel and Waterbolk, 1972, 49–50).

A is somewhat lower than Byrd's (2005, 27) estimate of 300 years. The model allowed for a 'gap' of at least 30 years between the end of Subphase A2 and start of Subphase B2 to account for Subphase B1. For Subphase B2, the model indicated a span of 50 years, beginning sometime between *8080* and 7680 cal BC and terminating between *7920* and 7670 cal BC. This produces a modelled span of 80 years or more for Phase B, potentially far more restricted than the span proposed by Byrd (2005) (i.e. 150–250 years). The model allowed a further 'gap' of at least 70 years between Subphases B2 and C2 to account for Subphase C1. Modelled dates indicate that Subphase C2 began sometime between *7810* and 7580 cal BC and terminated sometime between *7810* and 7460 cal BC, spanning up to 80 years. The modelled Phase C span of 150 years or more compares well with the range proposed by Byrd (2005) (i.e. 150–250 years).

The model produced building use-life estimates of 90 and 120 years for Subphase A1 Buildings 18 and 48, respectively; 60 years each for Subphase A2 Buildings 54 and 74; 50 years for Subphase B2 Building 26; and 80 years for Subphase C2 Building 8. Building use-life estimates for Subphases A2, B2 and C2 are comparable to values derived for structures of similar construction and degree of maintenance from previous archaeological, ethnographic and experimental research (see Table 1). However, building use-life values for Subphase A1 are rather high. This probably partly reflects earlier than expected start dates resulting from old wood effects (Wicks et al., 2016). If adjustments were made for old

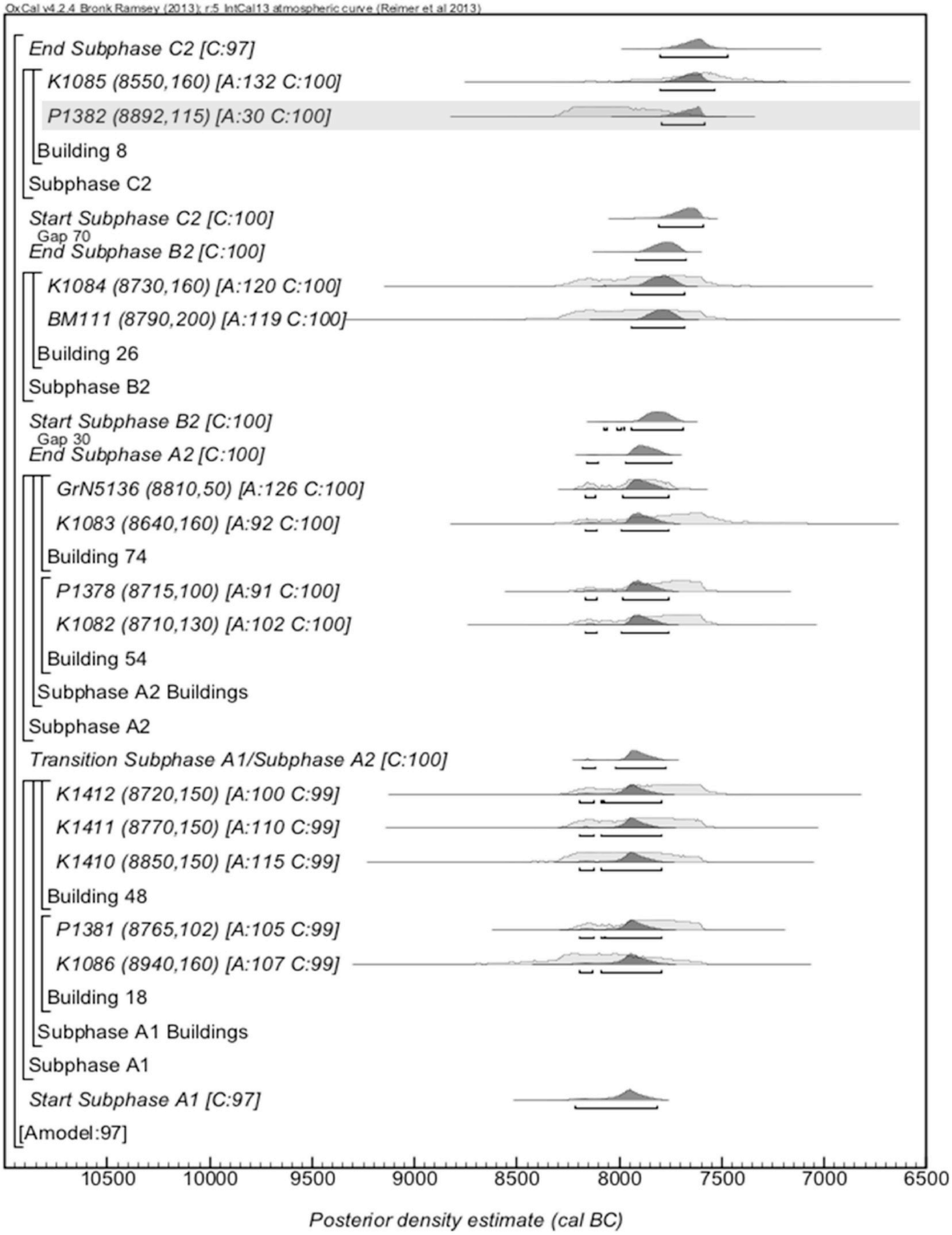

Fig. 3. Modelled boundary (start/transition/end) dates for PPN Beidha occupation and subphases based on posterior density estimates of calibrated dates (BC) (n dates = 13). Date with poor agreement highlighted in grey.

wood effects, it is expected that the relative difference between the Subphase A1 span and the average Subphase A1 building use-life would remain relatively constant. Therefore, the current values are considered suitable for inclusion in the structural contemporaneity equation.

4.2. *Final span estimates and structural contemporaneity values*

The final subphase length and building use-life estimates employed in the structural contemporaneity equation are predominantly based on the maximum span values derived from chronological modelling (Tables 7–10). Modelled subphase length and average building use-life values for Subphases A1 (140 years/100 years) and A2 (80 years/60 years) are considered suitable. However, Subphases B2 and C2 include dates from one structure only, producing identical modelled estimates for subphase length and building use-life. For these subphases, the modelled span estimates are adjusted based on the prior beliefs.

For Subphase B2 and associated Building 26, the modelled spans were 50 years. Evidence exists for reuse of the western wall of Building 26 in the construction of a later Subphase B2 structure (Byrd, 2005, 51). Therefore, if the span estimate is considered accurate for Building 26, as seems reasonable based on research of comparable structures (see Table 1), Subphase B2 must have spanned longer than 50 years. Byrd's (2005, 84) assessment of relative contemporaneity suggests that in the north-eastern corner of the excavated area, only two or three of the six

Table 6

Modelled boundary (start/end) dates for Beidha PPN occupation and subphases, and span estimates based on posterior density estimates of calibrated dates (BC) by order of subphase and building in descending chronological order. Date with poor agreement highlighted in grey.

Building	Lab reference	Unmodelled 2σ cal range (BC)	Posterior density estimate 2σ cal range (BC)	Indices Amodel = 96.5 Aoverall = 95.6	
				A	C
Start Subphase A1			8220–7810		96.5
18	K1086	8470–7600	8200–7790	106.7	99.3
	P1381	8210–7590	8200–7790	104.7	99.3
	Span Building 18		0–90		99.9
48	K1410	8290–7590	8200–7790	114.6	99.3
	K1411	8260–7580	8200–7790	110.1	99.3
	K1412	8240–7540	8200–7790	99.9	99.3
	Span Building 48		0–120		99.8
Span Subphase A1			0–140		99.7
Transition Subphase A1/A2			8190–7770		99.5
54	K1082	8220–7560	8170–7750	102.3	99.7
	P1378	8200–7580	8170–7750	91.1	99.6
	Span Building 54		0–60		100
74	K1083	8240–7370	8170–7750	92.4	99.6
	GrN5136	8210–7720	8170–7760	125.8	99.7
	Span Building 74		0–60		100
Span Subphase A2			0–80		99.9
End Subphase A2			8160–7740		99.7
Start Subphase B2			8080–7680		99.7
26	BM111	8430–7490	7950–7680	119	99.8
	K1084	8250–7530	7950–7680	120.4	99.8
	Span Building 26		0–50		100
Span Subphase B2			0–50		100
End Subphase B2			7920–7670		99.7
Start Subphase C2			7810–7580		99.7
8	P1382	8290–7670	7800–7580	29.5	99.6
	K1085	8200–7180	7810–7530	131.7	99.6
	Span Building 8		0–80		100
Span Subphase C2			0–80		100
End Subphase C2			7810–7460		97.4
Span Beidha			150–600		97.4

Table 7

Occupation span of PPN Beidha.

Occupation span					
Prior beliefs (Byrd, 2005)		Bayesian chronological modelling[b]			Final span (years)
Span (years)	Start date[a]	Span (years)	Start date	End date	
500–800	8470–7600	600	8220–7810	7810–7460	~600

[a] The earliest radiocarbon date after 7,000 BCE as suggested by Byrd, (2005) (6,990 ± 160 BCE), converted to cal BC in OxCal v.4.2.4 (Bronk Ramsey, 2005, 2009).

[b] Posterior density estimates (cal BC) (95.4% probability).

Table 8

Phase and subphase length at PPN Beidha.

Phase/subphase length (Subphases under investigation highlighted in grey)						
Phase/	Subphase	Prior beliefs (Byrd, 2005)	Bayesian chronological modelling			Final spans (years)
		Span (years)	Span (years)	Start date	End date	
A		300	220			
	A1		140	8220–7810	8190–7770	140
	A2		80	8190–7770	8160–7740	80
B		150–250	≥80			
	B1		(≥30)			
	B2		50	8080–7680	7920–7670	70 (increased following consideration of B2 Building 26 span estimate)
C		150–250	≥150			
	C1		(≥70)			
	C2		80	7810–7580	7810–7460	90 (increased following consideration of C2 Building 8 span estimate)

structures may have been occupied at the same time (this equates to 33.3–50% structural contemporaneity), whilst in the central cluster, all structures may have been occupied contemporaneously. This suggests that an average contemporaneity value of around 70% could be applied to this subphase. If the Building 26 use-life estimate remains at 50 years, this would produce a Subphase B2 span of around 70 years. A subphase length of 70 years and an average building use-life of 50 years are, therefore, suggested for Subphase B2.

For Subphase C2 and associated Building 8, the modelled spans were 80 years. The construction of Building 8 represents the beginning of Subphase C2, with abandonment of the structure probably occurring slightly prior to site abandonment (Byrd, 2005, 178). If this use-life estimate is considered reasonable for Building 8, as is suggested by research of comparable structures (see Tale 1), Subphase C2 must have spanned marginally longer than 80 years, possibly 90 years or more. However, the building use-life estimate for Subphase C2 Building 8 (80 years), which was considerably maintained, is not representative of many Subphase C2 buildings that demonstrate lower degrees of maintenance. Research into use-life of predominantly stone structures with moderate to considerable maintenance indicates a potential use-life of 50–100 years (see Table 1). Building 8 demonstrates a longer duration of use compared to other Subphase C2 structures, which were gradually abandoned throughout the subphase (Byrd, 2005, 93–94). A high degree of structural contemporaneity appears to have occurred at least in the earlier stages of Subphase C2, with many Subphase C1 buildings continuing in use alongside Subphase C2 structures built early in the subphase in relatively rapid succession (Byrd, 2005, 93). To estimate population at the height of Subphase C2 occupation, the average building use-life must reflect this high degree of contemporaneity, whilst being less than the span estimate derived for Building 8 (i.e. 80 years). Therefore, an average building use-life of 70 years is suggested for Subphase C2.

The final subphase length and average building use-life estimates produced structural contemporaneity values of 70% for Subphases A1 and B2, 75% for Subphase A2 and 78% for Subphase C2. The estimate for Subphase C2 is comparable to the conjectural 80% contemporaneity value applied by Rollefson and Köhler-Rollefson (1989) to the late PPN settlement of ‘Ain Ghazal, which contained similar architectural features to Beidha Phase C.

5. Implications of contemporaneity adjustments for demographic reconstructions

Bayesian chronological models were similarly constructed for a further four central and southern Levantine PPN settlements: Netiv Hagdud, Ghwair I, ‘Ain Abu Nekheileh and Basta (see section in Supplementary material: Section C for data and analysis). Contemporaneity values based on a combination of prior beliefs and the results of modelling range from approximately 60% (Netiv Hagdud and Basta) to 78% (Ghwair I and Beidha Subphase C2) (Table 11). The highest values were derived for sites that demonstrate similar characteristics to late PPN ‘Ain Ghazal and compare well with Rollefson and Köhler-Rollefson’s (1989) proposed value of 80%. The reasonably limited range indicates that, in the absence of site-specific analysis, an average structural contemporaneity value of around 70% may be suitable for central and southern Levantine PPN settlements.

Calculating structural contemporaneity formed an important part of

Table 9
Building use life at PPN Beidha.

Building use-life					
Subphase/Building	Prior beliefs			Bayesian chronological modelling	Final span (years)
	Byrd (2005)	Archaeological, ethnographic, experimental research			
	Longevity statement	Construction, maintenance[a]	Span (years)	*Span (years)*	
A1	Considerable				100
18		E/S, C	55–75	90	
48		E/S, C	55–75	120	
A2	Reasonable	E/S, Mod-C	35–75		60
54		E/S, Mod-C	35–75	60	
74		E/S, Mod	35–55	60	
B2	Short (NE)/Long (Centre)	E/S, Mod	35–55		50
26		E/S, Mod	35–55	50	
C2	Considerable	S, Mod-C	50–100		70
8	Abandoned shortly before site abandonment	S, C	75–100	80	

[a] Construction - E: Earthen, S: Stone; Maintenance - Mod: Moderate, C: Considerable (see Table 1 for references).

Table 10
Structural contemporaneity values for Subphases A1, A2, B2 and C2 at PPN Beidha

Structural contemporaneity values			
Subphase	Subphase length (years)	Average building use-life (years)	Structural contemporaneity (%) (Building use-life ÷ Subphase length × 100)
A1	140	100	71.43
A2	80	60	75
B2	70	50	71.43
C2	90	70	77.78

Table 11
Structural contemporaneity values and comparison of population estimates prior to and following contemporaneity adjustment.

Site	Structural contemporaneity (%)	Population estimate before and after contemporaneity adjustment	
		Before	After
Netiv Hagdud	60	360–445	215–270
Beidha (A1)	71.43	80–120	55–85
Beidha (A2)	75	105–155	80–115
Beidha (B2)	71.43	105–155	75–110
Ghwair I	77.78	515–785	400–610
‘Ain Abu Nekheileh	65	130–225	85–150
Beidha (C2)	77.78	180–275	140–215
Basta	60.47	9415–13000	5695–7855

an overarching project aimed at reconstructing population estimates for all central and southern Levantine PPN settlements. Various methods were explored for estimating population size (Birch-Chapman, 2017). However, the most viable method was found to be the newly developed ‘storage provisions formulae (SPF)’. These formulae were developed based on Hemsley’s (2008) research into the affordance of space within dwellings at PPN sites. The formulae correlate available residential floor area (A) to the mid-point of the maximum numbers of 1.65 m and 1.83 m tall occupants lying in an extended position, factoring in access routes, hearths and activity zones, and three potential amounts of storage: none, moderate and high (Table 12). The potential amount of storage (both permanent and ephemeral) within the residential floor area was derived from an assessment of the archaeological remains, predominant subsistence strategy and the common relationship between storage facilities and residential area per period.

Table 12
Storage provisions formulae (based on data from Hemsley 2008).

Annual personal storage within the residential floor area	Formula[a]
None	$P = 0.3944A - 0.375$
Moderate (0.46 m^3 per person)	$P = 0.2477A + 0.0339$
Maximum (2 × 0.46 m^3 per person)	$P = 0.1903A + 0.3976$

[a] P: Population; A: Residential floor area.

The formulae were used to calculate total (adult) population from the total contemporaneous residential floor area (Method 1), and the number of people (i.e. adults) per dwelling from the mean residential floor area of complete dwellings and a total contemporaneous dwelling number estimate (Method 2). The mean of Methods 1 and 2 were used to form the final population estimate range.

Comparison of population estimates before and after adjustments for structural contemporaneity demonstrates the impact on final estimate ranges. It also highlights the potential impact on subsequent interpretations of individual sites and PPN periods more broadly, particularly when assessing the links between demographic characteristics and changes in subsistence practices, strategies aimed at reducing scalar stress and promoting social cohesion, and developments in social complexity, such as increasing independence of dwelling units and development of social hierarchies (Birch-Chapman, 2017).

Whilst contemporaneity adjustments have relatively minor impact on population estimates for smaller settlements (e.g. Beidha or ‘Ain Abu Nekheileh), they can have considerable impact on estimates for larger settlements. The largest settlement assessed here is the Late PPNB settlement at Basta (∼13 ha). Excavations across multiple areas exposed interlocking, multi- and split-level structures on artificially constructed terraces supported by massive retaining walls (Gebel et al., 2006; Nissen, 2006). In this investigation the population of Basta is estimated at approximately 5700–7900 people, based on around 60% structural contemporaneity. This estimate exceeds the pre-existing estimate range for this site, which was based on site extents of 10–14 ha at 90 to 294 people per hectare ($P = 900–4116$; Kuijt, 2000, 2008), and 9.8 ha at 35 m^2–116.3 m^2 site area per person ($P = 839–2789$; Campbell, 2009). This is not unexpected given that the density values used in the pre-existing estimates have been demonstrated to be insufficient for estimating population size of central and southern Levantine PPN settlements (Birch-Chapman et al., 2017; Birch-Chapman, 2017). Without adjusting for structural contemporaneity in this investigation, the population of Basta would have been estimated at approximately 9400–13000 people, exceeding the current population size estimate for the largest known Neolithic settlement: Çatalhöyük ($P = 5000–8000$; c. 14 ha) (Matthews, 1996; Cessford, 2005; Hodder, 2006; Düring, 2007). Failing to adjust for contemporaneity would, therefore, have considerable impact on any subsequent interpretations of Basta and the LPPNB more broadly.

6. Limitations of this research and future research opportunities

Whilst this research highlights the potential for using Bayesian chronological modelling to estimate contemporaneity values, there are several issues that must be addressed prior to the regular adoption of this method. First, extrapolating data from the excavated areas of sites can be problematic as excavation often centres on areas of dense archaeological material, usually structural remains that are poorly preserved and complex, and not necessarily representative of the entire settlement. In this research, the percentage of the estimated total site extent that contained areas with structural features that could be assessed ranged from 0.3% at Basta to 31.92% at Beidha Subphase C2 (Beidha A1: 13.22%, A2: 14.68%, B2: 30%; Netiv Hagdud: 7.12%; Ghwair I: 4.41%; ‘Ain Abu Nekheileh: 11.28%). Accounting for structural contemporaneity partly counteracts issues associated with deriving population estimates from these assessable areas, though additional methods are required for addressing representativeness.

Second, the quantity of radiocarbon dates for PPN settlements is often inadequate for Bayesian analysis. Only a handful of dates exist for most PPN central and southern Levantine sites, with the largest collections sourced from PPNA WF16 (n dates = 46) (Wicks et al., 2016) and PPNA/B Jericho (n dates = 45) (Benz, 2013). For the PPN settlement at Beidha, only 13 of the 23 dates available were considered suitable for use in Bayesian chronological modelling, with only two to three dates available for each subphase and structure. Such limited samples may produce misleading or ineffectual results. In this case, the modelled dates are similar to the unmodelled calibrated dates. Ideally, the method should be applied to a larger dataset, with dates collected from targeted stratigraphic areas with the greatest potential to reveal start, end and transition dates for short-term episodes, such as phase length and building use-life.

Third, the precision of dates can affect the resolution of chronological models. Precision refers to the error ranges attached to radiocarbon dates (Hoggarth et al., 2016). Greater precision allows events to be dated more accurately. Ideally, only radiocarbon dates with error ranges of below 100 years, and preferably 60 years should be used in models as larger errors “blur probability distributions” and lead to erroneous chronological interpretations (Kennett et al., 2008, E107). Unfortunately, the majority of the dates available for Beidha have error ranges that are close to or exceed 100. This is partly due to the use of radiometric dating, which typically produces dates with lower precision than those derived from more recent and now commonly used Accelerator Mass Spectrometry dating.

Fourth, the majority of radiocarbon samples are sourced from construction elements, including wooden posts often from tree species that live for several centuries. Old wood effects may result from both the age of the mature wood and from the use and re-use of wood from trees that may have been felled for a considerable period (Wicks et al., 2016). Unfortunately, limited samples per phase and structure prevented calculation of old wood effects in this analysis. To avoid these effects, samples should preferably derive from short-lived plant materials, such as seeds and nuts (although these are more susceptible to post-depositional admixture), or from wood charcoal from twigs and juvenile branches (Bayliss, 2007; Wicks et al., 2016).

A final suggestion stems from the limited information available regarding context, sample material and pre-treatment within publications and radiocarbon date databases. Context forms an essential part of the prior chronological information required for constructing models and for removing statistically divergent dates on archaeological grounds (i.e. residual or intrusive material) (Bayliss, 2007; Bayliss et al., 2016). In addition, context and sample material affect susceptibility to post-depositional factors prior to excavation and during collection, storage and processing (Brock et al., 2010). Elaboration of useful radiocarbon date databases, such as the Platform for Neolithic Radiocarbon Dates (PPND) (Benz, 2013) and the radiocarbon CONTEXT database (Böhner and Schyle, 2008) will enable construction of more informative models.

7. Conclusion

This paper details a more empirically robust method than currently exists for establishing site-specific structural contemporaneity values (i.e. the percentage of structures in contemporaneous use). In this research, structural contemporaneity values were reconstructed specifically for the purposes of estimating population size of central and southern Levantine PPN settlements. These settlements were selected for exploratory analysis as these represent a period of major demographic transition in which population aggregation is directly linked to the development of more complex social, economic, religious and political systems.

This research examined the potential to reconstruct structural contemporaneity values using precise estimates of building use-life and phase length. These were derived from a combination of (i) chronostratigraphic information; (ii) archaeological, ethnographic and experimental research; and (iii) Bayesian chronological modelling of spans of radiocarbon dates. To our knowledge, this is the first empirical assessment of structural contemporaneity values for PPN settlements and the first to successfully use Bayesian chronological modelling for this purpose.

The methodology was first developed using data from the PPN site at Beidha, southern Jordan, and applied to a further four sites: Netiv Hagdud, Ghwair I, ‘Ain Abu Nekheileh and Basta. Structural contemporaneity values ranged from around 60%–80%, and a standard value of 70% is suggested for central and southern Levantine PPN settlements in the absence of site-specific analyses.

This research highlights the potential for using Bayesian chronological modelling to refine short term episodes, such as phase length and building use-life, even with small datasets of radiocarbon dates. Issues and opportunities for further development are discussed, including strategic sourcing of radiocarbon samples from specific contexts and short-lived material, and provision of more information regarding context, sample material and treatment. This will enable development of more accurate phase length and building use-life estimates, thereby increasing the precision of structural contemporaneity values.

Population reconstructions must incorporate contemporaneity adjustments in order to make more meaningful conclusions about the relationships between demographic parameters and human socio-cultural developments. It is anticipated that the relative simplicity of the method presented will encourage routine application to settlements during the PPN and in other periods and regions, and encourage further development by researchers in future.

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Appendix A. Supplementary data

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