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Estimating population size, density and dynamics of Pre-Pottery Neolithic villages in the central and southern Levant: an analysis of Beidha, southern Jordan

Shannon Birch-Chapman, Emma Jenkins, Fiona Coward and Mark Maltby[1]

An understanding of population dynamics is essential for reconstructing the trajectories of central and southern Levantine Pre-Pottery Neolithic (PPN) villages. The aim of this investigation was to derive more empirically and statistically robust absolute demographic data than currently exists. Several methodologies were explored, including those based on dwelling unit size and the number of dwellings; residential floor area per person; population density; and allometric growth formulae. The newly established storage provisions formulae based on the affordance of sleeping individuals within structures was found to be the most viable method. Estimates were adjusted to reflect potential structural contemporaneity calculated from building use-life and phase length estimates based on archaeological, ethnographic and experimental research, and Bayesian chronological modelling of radiocarbon dates. The application of methodologies to the PPNB site of Beidha in southern Jordan is presented. The analysis highlights inconsistencies with current theory relating to population density at Beidha. In particular, the results suggest that nuclear families probably did not form the predominant dwelling unit type during Subphases A2 and B2. In addition, population density was estimated at anywhere between 350 and 900 people per ha. This range far exceeds the ethnographically derived density values commonly utilized for reconstructing PPN village populations (*c.* 90 to 294 people per ha).

Keywords Pre-Pottery Neolithic (PPN), Beidha, population estimates, contemporaneity, population density.

Introduction

Absolute estimates of population size, density and dynamics are essential for reconstructing human social development. Population estimates enable more precise explorations of the relationship between groups of people and developments in subsistence, architecture, technology, economic practices, community organization and ritual practices, in all areas and periods. Demographic data is critical for investigating episodes of settlement aggregation, migration and dispersal; and for exploring the underlying causes, processes and consequences of major transitional episodes. Given the pivotal role that the central and southern Levantine Pre-Pottery Neolithic (PPN) played in the Neolithic Demographic Transition (NDT), and the importance of this region for understanding early village development, the methodological and theoretical limitations of existing absolute population estimates of these villages must be addressed.

This investigation assesses existing estimates, methodologies and underlying theories in order to establish a more empirically robust methodological framework for estimating the population size, density and

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growth of PPN villages in the central and southern Levant. This article presents the results of the initial analysis, conducted on the PPNB village of Beidha in southern Jordan. Beidha is an excellent case study for the exploratory application of methodologies as it demonstrates the full transition from a formative village, characterized by the persistence of hunter-gatherer subsistence and social strategies, to a fully sedentary, agro-pastoralist society (Byrd 2005).

Existing population estimates for PPN central and southern Levantine villages

Population size

An extensive literature review revealed absolute population size estimates for 23 PPN central and southern Levantine villages (Fig. 1). These include around 60 estimates derived from six investigations (Campbell 2009; Gebel and Hermansen 1999; Kuijt 2000; 2008; Ladah 2006; Rollefson and Köhler-Rollefson 1989). All but one (Gebel and Hermansen 1999) employ the same method. This method involves the application of a population density coefficient (i.e. people per ha) derived from ethnographic research in Southwest Asia, to total site extent. All of these investigations employ van Beek's (1982: 64–65) density coefficients of 286 to 302 people per ha to produce maximum estimates.

The majority of estimates ($n = 42$) were produced by Kuijt (2000: 81; 2008: 294) to explore the relationship between population dynamics and sedentism, food production, food storage, social crowding, social inequality and the collapse of large villages at the end of the PPN. Kuijt's (2000; 2008) estimates are based on site area (either estimated directly or based on the mean settlement size of the largest sites per period) and mean population density coefficients of 90 and 294 people per ha, derived from ethnographic research in Iran (Kramer 1982: 162; Watson 1979: 35–47) and North Yemen (van Beek 1982: 64–65). Kuijt (2000: 82–85) acknowledges that this approach requires the acceptance of certain assumptions relating to the representative nature of ethnographic constants and their applicability to PPN sites, and makes the point that the resulting estimates are suitable for comparative analysis and should not be treated as definitive population estimates.

Campbell (2009) produced additional estimates ($n = 10$) for 'Ain Ghazal, Basta and Jericho to investigate the impact of agricultural practices on the environment. Campbell (2009: 137) established low, mid-range and high population values based on estimates of total site extent and ethnographically derived density coefficients of 85.9 (Jacobs 1979: 178), 139 (Kramer 1979: 144) and 294 people per ha (van Beek 1982: 64–65).[1] Estimates based on the maximum coefficient were utilized to explore worst-case scenarios relating to resource exploitation pressure.

Rollefson and Köhler-Rollefson (1989: 75) produced estimates for 'Ain Ghazal ($n = 6$) to explore reasons for settlement collapse at the end of the PPNB. These were based on estimated total site extent and a population density coefficient range of 286 to 302 people per ha, as established by van Beek (1982: 64–65). To investigate the relationship between group size and socio-political complexity at Ghwair I, Ladah (2006: 150) estimated the population based on total site extent and a density coefficient of 286 people per ha, following van Beek (1982: 64–65).

Gebel and Hermansen (1999: 19) employed an alternative method to estimate the population of Late PPNB Ba'ja, as part of a report on the architectural findings. It was hypothesized that extended families of around eight to ten people formed the predominant dwelling unit and that 50 to 60 families occupied around 0.6 to 0.7 ha of densely built houses. A final population estimate range of 400 to 500 people was proposed. Unfortunately, the authors provide no further information as to how these figures were derived.

An assessment of existing estimates indicates that PPN villages may have been occupied by a maximum of around 500 people during the PPNA; up to 1400 people by the Middle PPNB; and up to 4000 people by the Late PPNB. However, the limited methodological basis for these estimates, the considerable estimate ranges and the focus on relative rather than absolute figures reduce the reliability of these estimates and the efficacy of any subsequent analysis of the relationship between population parameters and other demographic or developmental factors.

Population density coefficients

People per ha

Ethnographic analysis of Southwest Asian villages and towns has revealed that the majority have a population density range of around 100 to 200 people per ha, regardless of settlement size or intra-site organization (Antoun 1972; Aurenche 1981; Kramer 1979; 1982; Wossinik 2009). As previously identified, the primary methodology for producing estimates to date has

[1] Campbell (2009) converted people per ha density coefficients to measurements of total site area per person of 116.3 sq m (Jacobs 1979), 71.8 sq m (Kramer 1979) and 35 sq m (van Beek 1982).

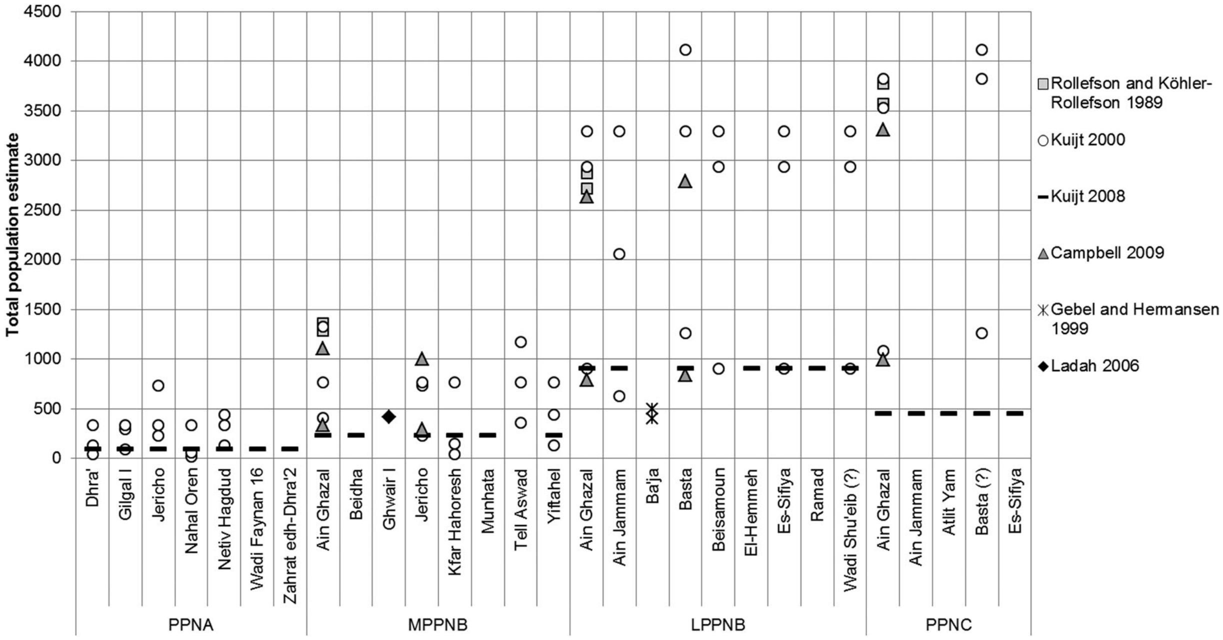

Figure 1 Existing population estimates for PPN central and southern Levantine villages.

been via the application of a people per ha coefficient to total site extent. A range of values falling between a minimum of 90 and a maximum of 294 people per ha (Jacobs 1979; Kramer 1982; van Beek 1982; Watson 1979) is commonly utilized. Kuijt (2008: 290) highlighted the wide range in density values, recommending the use of more conservative, lower values for producing estimates for comparative analysis. There has been no significant attempt to refine these density coefficients for PPN central and southern Levantine villages.

Space per person

Ethnographic research on Southwest Asian villages and comparable villages elsewhere has produced a wide range of personal space estimates from around 1.86 sq m to 13.2 sq m per person (Brown 1987; Clarke 1974; Cook and Heizer 1968; Finkelstein 1990; Hayden *et al.* 1996; Hill 1970; Horne 1994; Kolb 1985; Kramer 1979; 1982; LeBlanc 1971; Naroll 1962; Porčić 2012; van Beek 1982; Watson 1978). This variation is partly due to contextual differences relating to climate, architecture, dwelling unit type and cultural perceptions relating to crowding, privacy and personal space. However, the most significant cause is the inconsistency in the definition of 'space'. 'Space' usually refers to total roofed floor area, although it can refer to total site area, total built area and total residential floor area (that is, the area in which people lived and slept).

When based on residential floor area only, the density coefficient range is considerably reduced to around 2 to 5 sq m per person (Clarke 1974: 286; Hayden *et al.* 1996: 152, 159; Hill 1970: 75). The use of residential floor area density coefficients has greater potential than other methods to produce accurate population estimates, provided that residential floor area can be identified in the archaeological record. Due to the methodological issues associated with identifying residential area, archaeologists have generally avoided this technique for estimating PPN village populations.

People per dwelling

Estimates of the number of inhabitants per dwelling require consideration of two main aspects: the first relates to the composition of the dwelling unit (i.e. an individual, a couple or pair, a nuclear or extended family, or a non-related group); whilst the second relates to the number of people typically thought to comprise that particular dwelling unit. For PPN central and southern Levantine villages, a dwelling unit size of five to six people is commonly utilized, based on the theory that dwelling units predominantly comprised nuclear families (Byrd 2002; 2005; Düring 2001; Kramer 1982; Rollefson and Köhler-Rollefson 1989; Sweet 1960) and ethnographic research on nuclear family sizes in Southwest Asian villages (Antoun 1972; Aurenche 1981; Finkelstein 1990; Kramer 1979; 1982; Sweet 1960; van Beek 1982; Watson 1978; 1979; Wright 1969; Zorn 1994).

Archaeological investigations have attempted to refine dwelling unit size estimates for PPN villages. Analyses of house size and the role of the household indicate that smaller, curvilinear dwellings, which usually comprise undifferentiated residential floor area, may have accommodated individuals, pairs or small nuclear families; whilst larger and rectilinear dwellings, which are often highly compartmentalized and contain considerable storage space, may have accommodated larger nuclear or extended families (Banning 2003; Byrd 2005; Gebel and Hermansen 1999; Rollefson and Kafafi 2013).

Hemsley (2008) explored an empirically based method for estimating dwelling unit size. She examined the multi-sensorial experience of buildings and domestic space at several PPN villages, including Jericho, Netiv Hagdud and Basta, to estimate the average number of people each structure could accommodate. Hemsley (2008: 131) estimated personal sleeping space requirements of 1.24 sq m and 1.77 sq m based on modern human heights of 1.65 m and 1.83 m, respectively. Factoring in the need to avoid installations, such as hearths and surrounding activity zones, access routes and three different degrees of personal annual residential storage (none; moderate: 0.46 cu m; maximum: 0.92 cu m), Hemsley (2008) estimated that smaller, single-roomed structures (≤ 10 sq m) may have accommodated up to four people; whilst larger structures may have accommodated up to 14 people.[2] This method is unique in that it does not incorporate any prior assumptions regarding dwelling unit type or perceptions relating to space preference. The correlation between the total available residential floor area and the maximum number of sleeping occupants afforded within that area presents an opportunity to develop a more empricially robust and systematic methodology for estimating population and dwelling unit size.

Population dynamics

A number of investigations have derived annual population growth rates for early village communities. Carneiro and Hilse (1966) and Hassan (1981) estimated a universal annual population growth rate of around 0.1% for non-industrialized, agricultural village populations; Bandy (2001) estimated 0.08% annual growth rate for formative villages in the Titicaca Basin, Bolivia; and Drennan and Peterson (2008) estimated 0.25% annual growth rate for communities undergoing the NDT in the Chifeng region of the Liao Valley, China and in the Alto Magdalena, Colombia.

There have been two major attempts to estimate population growth within PPN settlements in the central and southern Levant. Eshed *et al.* (2004) examined skeletal evidence from Natufian and Neolithic contexts to establish average annual growth rates of between 0.5% to 1% per annum; whilst Goodale (2009: 160) estimated annual growth rates varying between -1.3% and 2.1% throughout the PPN. Deriving absolute population growth rates for PPN settlements is problematic for various reasons, including issues associated with dating and phasing; difficulties with producing precise and accurate population size estimates; and the fact that there is a limited number of sites with consecutive phases.

Limitations of existing estimates

The summary above highlights several issues with existing absolute estimates of population parameters for PPN central and southern Levantine villages. Firstly, there are few sites for which absolute estimates exist. Secondly, due to methodological issues, investigations rarely attempt to produce absolute population estimates and those which do, emphasize their benefit for comparative analysis rather than as representations of actual population size. For this reason, methodologies and density coefficients are often given insufficient critical assessment prior to their application, and estimates usually display considerable ranges with little attempt at refinement. Thirdly, the majority of estimates are based on a very limited range of methodologies and a narrow selection of density coefficients derived from ethnographic research conducted in Southwest Asian communities several decades ago. An assessment of the architectural and spatial characteristics of these ethnographic examples reveals that these are often not suitable comparables for PPN central and southern Levantine villages, particularly those with predominantly curvilinear architecture. If archaeologists are to develop more insightful reconstructions of human social development during the NDT in this region, more empirically robust methodologies are required for estimating absolute population size, density and dynamics.

Methodologies for estimating PPN central and southern Levantine village populations

A review of archaeological, ethnographic and modern demographic methods for estimating population parameters revealed five methods most suitable for application to PPN central and southern Levantine villages: the housing unit method (HUM); the residential area

[2]Estimates derived for Basta were inconclusive and are not included in this assessment.

density coefficient method (RADC); the storage provisions formulae (SPF); the settlement population density coefficient method (SPDC) and the allometric growth formulae (AGF). Each of these methods is explored in turn to determine whether they produce realistic estimates, and to identify the most empirically robust methodology(ies) for future research.

Method 1: housing unit method (HUM)

The housing unit method (HUM) estimates total population size by multiplying an ethnographically or archaeologically derived value for the number of people per dwelling by the number of dwellings at a site. Nelson (1909) was amongst the first to employ this method, estimating the population of a San Francisco Bay shell mound by multiplying the number of identifiable house depressions by an arbitrary figure of six people per house. The method was subsequently widely explored (Cook 1972; Düring 2001; Finkelstein 1990; Hayden *et al.* 1996; Kolb 1985; Kramer 1979; 1982; Mellaart 1967; van Beek 1982; Watson 1978; 1979). Several methodological issues were identified, the foremost of which related to the definition of the 'household' and the development of a standard empirical figure for household size.

For the purpose of population estimates, the term 'household' has come to mean the total number of people living within a single dwelling, a notion more accurately reflected by the terms 'dwelling unit' (Wilk and Rathje 1981: 620) or 'domestic group' (Hammel and Laslett 1974: 76). For PPN settlements, the predominant 'dwelling unit' is often thought to comprise nuclear families (Byrd 2002; 2005; Düring 2001; Kramer 1982; Rollefson and Köhler-Rollefson 1989; Sweet 1960). Ethnographic research of Southwest Asian villages indicated that these nuclear family dwelling units may have comprised between four and six people (Aurenche 1981; Finkelstein 1990; Kramer 1979; 1982; Sweet 1960; van Beek 1982; Watson 1978; 1979; Wright 1969). Larger dwelling unit sizes of up to eight people are occasionally recorded (Portillo *et al.* 2014).

In this investigation, the theory that PPN dwellings were predominantly occupied by nuclear families is tested via the application of minimum, average and maximum dwelling unit sizes of three, 5.5 and eight people. The application of these dwelling unit sizes produces large population estimate ranges, except where larger family sizes can be excluded due to insufficient residential floor area. As the results of the HUM incorporate the assumption of nuclear family dwelling units, population estimates for villages with single or paired occupancy dwellings will be inflated. Where HUM population estimates are considerably higher than those of other methods, this could indicate dwelling unit sizes smaller than that of a nuclear family. Conversely, where comparability exists between HUM population estimates and those of other methods or where the HUM estimate is lower, this might imply that dwellings did indeed house nuclear (or perhaps extended) family units.

Method 2: residential area density coefficient (RADC) method

A residential area density coefficient (RADC) is a measure of the average amount of residential area occupied by each person. To derive population estimates via this method, the estimated total residential area is divided by an ethnographically or archaeologically derived RADC. Naroll (1962) attempted to derive a universal value for the amount of built floor area per person by examining cross-cultural ethnographic data of built floor area and total population within 18 nomadic and sedentary societies, the majority of which comprised agglomerated, rectilinear architecture. He proposed a standard constant of 10 sq m built floor area per person. Byrd (2002: 72) applied this constant to the mean interior area measurements of 106 domestic structures from southern Levantine sites spanning the Early Epipalaeolithic to the PPNB to determine potential dwelling unit sizes, and suggests that Naroll's (1962) constant is too high for settlements dating to this period. The constant was widely criticized for being too simple (Brown 1987; Byrd 2002; Cook and Heizer 1968; Kolb 1985; Nordbeck 1971; Schacht 1981; Wiessner 1974). In addition, it was acknowledged that space requirements per person are impacted by various factors, including available settlement area, climate, notions of privacy, permanence of settlement, and structure size and shape. As such, subsequent investigations attempted to refine density values for different settlement, dwelling and dwelling unit types (Brown 1987; Byrd 2002; Clarke 1974; Cook and Heizer 1968; Flannery 1972; Hayden *et al.* 1996; Kolb 1985; LeBlanc 1971; Nordbeck 1971; Schacht 1981; Wiessner 1974).

This investigation employs RADCs based on living area only, omitting non-living area, such as walls and stairs, and spaces interpreted as storage areas, workshops and courtyards (Hayden *et al.* 1996; Hill 1970; Kramer 1979; LeBlanc 1971: 211). In this way, RADCs apply to potential sleeping area only, which more accurately reflects the resident population. Unfortunately, the majority of studies either include all roofed floor area in calculations, or do not specify the type of area included. Therefore, values utilized in this investigation are based on a limited number of comparative examples. The minimum RADC employed (1.77 sq m) is based on Hemsley's (2008: 131) estimate of the maximum sleeping space required per person. The mid-range RADC (3.3 sq m) is based on Hayden *et al.*'s (1996: 152, 159) estimates for prehistoric and ethnographic villages containing circular structures in British Columbia and the Arctic Circle, and Clarke's (1974) estimates for Southwest American pueblos containing agglomerated, rectilinear architecture. The maximum RADC (5 sq m) is based on Hill's (1970: 75) estimate for the prehistoric Broken K Pueblo site and Kramer's (1979) estimate for the contemporary settlement at Shahabad Iran.

Method 3: storage provisions formula (SPF)

The storage provisions formula (SPF) is a unique method developed from data produced by Hemsley (2008), who calculated the number of sleeping occupants accommodated within a structure, factoring in access routes, hearths, activity zones and three different degrees of personal annual storage provisions (none; moderate: 0.46 cu m; maximum: 0.92 cu m). From this data, three formulae were constructed correlating the maximum number of sleeping occupants to available residential floor area based on:

- no personal storage ($P = 0.3944A - 0.375$);
- a moderate degree of personal storage (0.46 cu m: $P = 0.2477A + 0.0339$); and
- a high degree of personal storage (0.92 cu m: $P = 0.1903A + 0.3976$).

In these formulae, 'P' is the average number of sleeping occupants and 'A' is the estimated residential floor area.

Two methods are explored in this investigation: the first assigns the total contemporaneous residential floor area estimate as the 'A' variable to calculate total population ('P'); and the second assigns the mean residential floor area of complete dwellings as the 'A' variable to calculate the average number of people per dwelling ('P'), which is then multiplied by the estimated total number of contemporaneous dwellings to produce a final population estimate.

The SPF is considered the most robust and valid method in this investigation for several reasons. Firstly, this unique methodological approach is based almost exclusively on archaeological evidence and empirically derived values for human sleeping space. It does not incorporate assumptions regarding dwelling unit size, the constitution of the dwelling unit or perceptions relating to space preference. All other methods assessed in this investigation are based on several assumptions and employ ethnographically derived coefficients from settlements that may not be readily comparable with PPN villages.

Secondly, assessment of the archaeological evidence for storage within the residential area and a comparison of population and dwelling unit size estimates with estimates of available residential floor area enable the selection of the most appropriate formula (e) for final estimate reconstruction. This not only reduces the final estimate range, but also highlights the most plausible degree(s) of residential storage.

Thirdly, this is the only method that directly calculates dwelling unit size.

Finally, the consistent methodological application of set formulae improves the comparative capability of the results. Due to the more empirically robust nature of the SPF method, SPF estimates are considered the most reliable and are presented as the final estimates for comparative analysis in this investigation.

Method 4: settlement population density coefficient (SPDC) method

A settlement population density coefficient (SPDC) is a measure of the amount of people living within a specified unit of area: in this case, a ha. Population is estimated by multiplying total site extent by an ethnographically derived value for the number of people residing within a ha (Kramer 1979; 1982; van Beek 1982; Watson 1978; 1979). This is the method utilized for the majority of existing estimates and relies on the assumption that there is a direct correlation between settlement size, population size and population density. However, research indicates that this relationship is highly variable. Ethnographic research in Southwest Asia based on single site analysis has produced SPDCs that range significantly from around 16 to 334 people per ha (Antoun 1972; Jacobs 1979; Jeremias 1969; Kramer 1979; 1982; van Beek 1982; Watson 1978; 1979; Wright 1969). Multi-site and regional ethnographic analyses indicate that the majority fall within lower and upper limits of 100 to 200 people per ha (Adams 1981; Kramer 1982; Sumner 1979). Higher population densities are often associated with old or walled settlements, such as Jerusalem (334 people per ha) (Jeremias 1969) and Tell Marib, North Yemen (286 to 302 people per ha) (van Beek 1982); and settlements located in economically advantageous areas (i.e. coastal plains) (Finkelstein 1990).

Different studies have indicated positive (Finkelstein 1990; Sumner 1979) and negative (Aurenche 1981; Whitelaw 1991) correlations between settlement size, population size and density. Sumner (1979) identified higher densities (155 people per ha) within larger villages (≥ 400 people) in the Marv Dasht region and lower densities (70 people per ha) within smaller villages (< 100 people). Similarly, Finkelstein (1990) identified higher densities (189 people per ha) within larger Palestinian villages (> 1000 people) and lower densities (141 people per ha) within smaller villages (< 300 people), suggesting that larger villages would have less abandoned residential space. Aurenche (1981) analysed Western Asian villages divided into four site size classes, revealing a more complex pattern. The largest villages (> 10 ha) contained the lowest population density (31 people per ha), whilst smaller villages (1–3 ha) contained the highest population density (111 people per ha). Similarly, for Lower Xiajiadian period sites in Northeast China (occupied *c.* 3500 years ago), Shelach (2002: 128–29) estimated higher population densities (306–510 people per ha) within smaller sites (< 3 ha) and lower densities (180–420 people per ha) within larger sites (> 3 ha).

In this investigation, commonly utilized SPDCs for estimating PPN village populations are assessed. These include the minimum and maximum ethnographically derived values of 90 people per ha (Jacobs 1979: 178; Kramer 1982: 162; Watson 1979: 35–47) and 294 people per ha (van Beek 1982: 64–65). Also assessed is an average value of 150 people per ha based on ethnographic research in Iran (Kramer 1979: 144; Watson 1979: 35–47) and the common density range of 100 to 200 people per ha for Southwest Asian villages and towns (Wossinik 2009). Population estimates are converted to average dwelling unit size based on the estimated number of contemporaneous dwellings. These estimates and SPDCs are compared to those derived from other methods to determine whether the commonly utilized SPDCs are reliable for estimating the population of PPN villages.

Method 5: allometric growth formulae (AGF)

The allometric growth formula ($A = a \times P^b$) represents the relationship between area (A) and population (P) based on constants for the initial growth index (a) and the scaling exponent (b). Established within the biological sciences (Huxley 1932), the AGF was first applied in an ethnographic context by Naroll (1962) following the discovery of a strong cross-cultural correlation between built floor area and total population. Naroll (1962) calculated the allometric relationship as: $A = 21.7 \times P^{0.84195}$, which was simplified to $P = A/10$ sq m, producing the famous constant of 10 sq m built floor area per person. This simplified constant has been criticized for not reflecting the actual variability indicated by the AGF, or the range in population size and built floor areas of the settlements included in the analysis (LeBlanc 1971; Nordbeck 1971; Wiessner 1974).

Brown (1987) re-examined Naroll's (1962) formula, revealing that there was no linear or allometric relationship between population size and built floor area in smaller settlements and only a moderately strong linear correlation in larger settlements. Brown (1987) and other critics emphasized that considerable cross-cultural and inter-regional variation in patterns of settlement growth would prevent the application of a single constant for converting settlement area to population size. As such, archaeologists sought to develop AGF for different settlement types.

Wiessner (1974) developed different scaling exponents for open, village and urban settlements. Open settlements were described as hunter-gatherer style settlements comprising light organic, curvilinear architecture. Wiessner (1974) proposed a scaling exponent of two ($b = 2$) for these settlements as settlement area was considered to increase by the square of the population size increase. This is based on the notion that open settlements tend to conform to a circumferential pattern, so that when the number of dwellings (or population) doubles, the diameter of the village doubles, resulting in a quadrupling of the settlement size and a reduction in population density (Fig. 2, a). For villages, Wiessner (1974) proposed a scaling exponent of one ($b = 1$) as village settlement was expected to undergo isometric growth, whereby settlement area increases in direct proportion to population size, resulting in constant population density (Fig. 2, b). For urban settlements of high density, multiple-storey structures, Wiessner (1974) proposed a scaling exponent of two-thirds ($b = 0.6667$). This is based on the relationship between area which is two dimensional and population which is three dimensional in urban settings, and reflects the smaller relative variation in settlement area compared to variations in population size and density (Fig. 2, c). Naroll's (1962) scaling exponent ($b = 0.84195$), which was based predominantly on large villages with high density, rectilinear architecture, falls partway between Wiessner's (1974) proposed village ($b = 1$) and urban ($b = 0.6667$) exponents.

In this investigation, Naroll's (1962) formula is applied to estimate the total built floor area (A) using the SPF population estimate as the P variable.

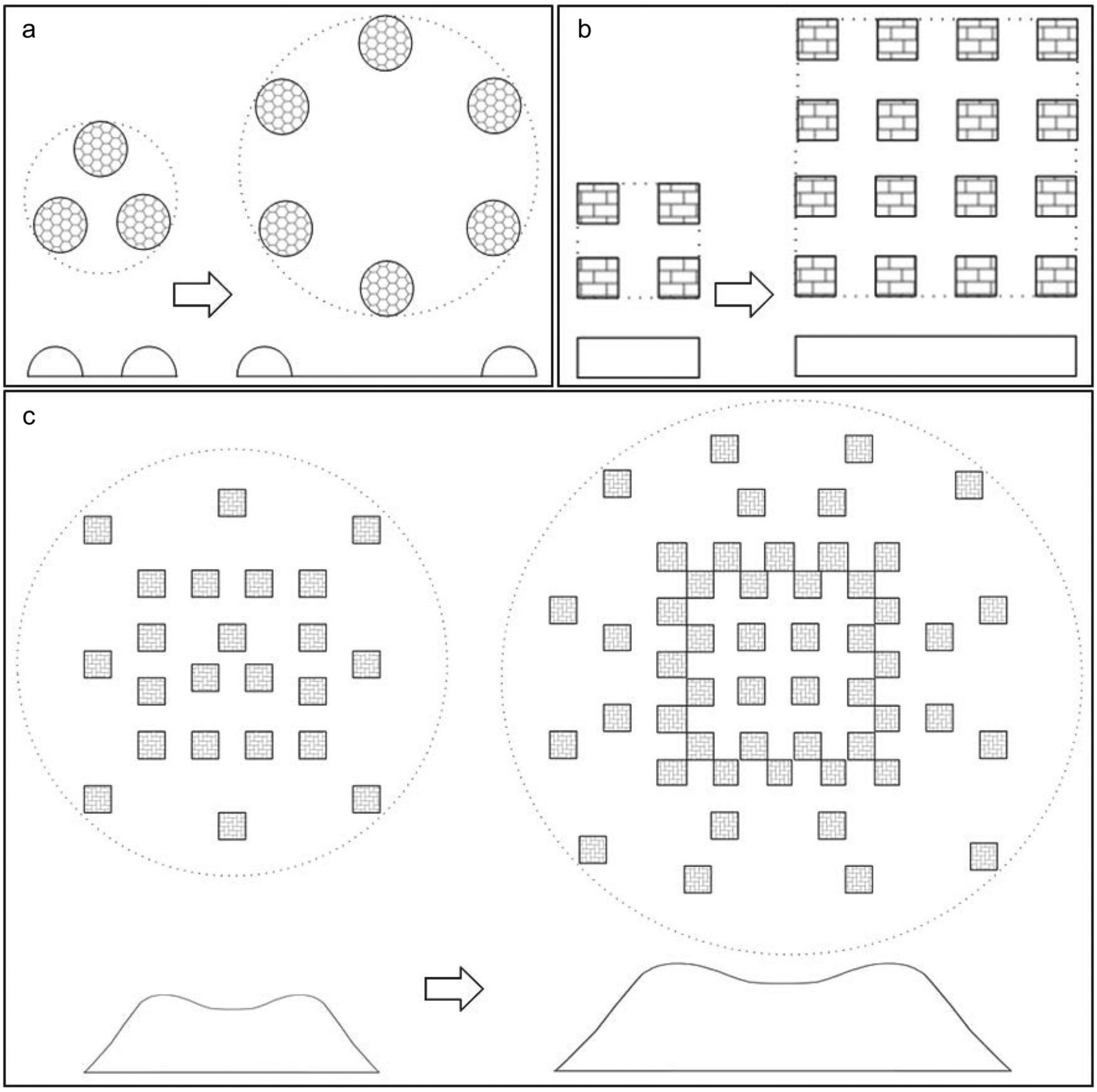

Figure 2 **Allometric relationship between settlement area (dashed lines), population size/number of dwellings (shaded units) and population density (scales underneath) in (a) open, (b) village and (c) urban settlements (adapted from Wiessner 1974: 347).**

Total built floor area is then divided by the SPF population estimate to calculate built floor area per person. This is then converted to residential floor area per person by applying the proportion of residential floor area in built floor area identified in the assessable portion of the site.

In addition, Naroll's (1962) scaling exponent (b = 0.84195) is utilized to re-calculate the initial growth index (a) from the SPF population estimate (P) and the estimated total built floor area (A). Initial growth indices (a) are similarly derived using Wiessner's (1974) formulae based on estimated total site extent (A), the SPF population estimate (P) and each of the three scaling exponents (b = 2; 1; 0.6667). It is expected that different initial growth indices would be derived for different settlement types and that these could be used in conjunction with the original scaling exponents to estimate population from area measurements and an assigned site type.

Estimating the population of Beidha, southern Jordan

Beidha: site description

Beidha is a small PPNB village in southern Jordan, situated in an alluvial valley bordered by steep sandstone cliffs to the north and the Wadi el Ghurab to the south (Fig. 3). Byrd (2005) suggests an occupation span of between 500 and 800 years, from the early MPPNB to the LPPNB. Excavations revealed three main phases: A, B and C. Byrd

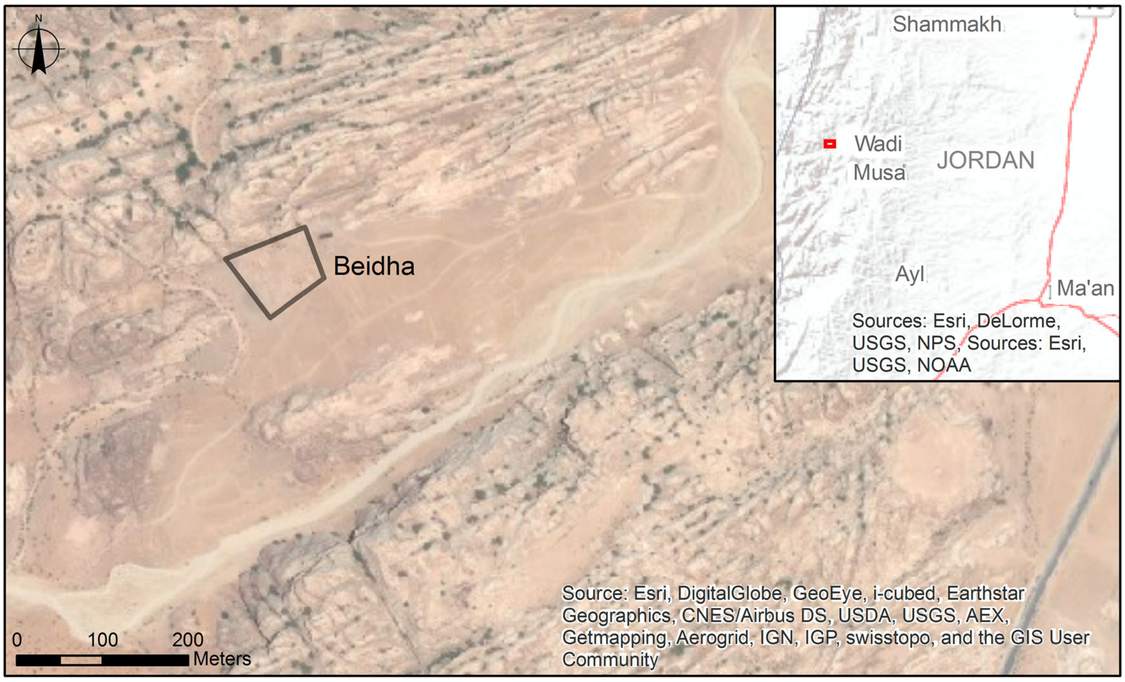

Figure 3 Location map of Beidha showing excavation area.

(2005: 26–27) assessed radiocarbon dates to propose phase lengths of 300 years for Phase A, and 150 to 250 years for Phases B and C in order to place site abandonment in the LPPNB. Each phase is divided into two subphases based on evidence for earlier and later construction episodes.[3] Subphases A1, A2, B2 and C2 are assessed in this investigation (Fig. 4; Table 1). The first three are assigned to the MPPNB and the latter to the LPPNB. Byrd (2005: 131) suggests a total site extent of between 0.15 ha and 0.35 ha. Individual subphase site extents employed in this investigation are based on the potential degree of village expansion as indicated by topographical context, the number and distribution of structures per subphase and information relating to construction timing, longevity and abandonment (Byrd 2005: 73–97). A site extent of 0.1 ha is suggested for Subphase A1; 0.2 ha for Subphases A2 and B2; and 0.3 ha for Subphase C2.

Structures for each subphase were categorized as either residential (i.e. dwellings) or non-residential based on Byrd's (2005) detailed analysis of the architectural features. Byrd (2005: 121) suggests that nuclear families typified the dwelling unit throughout all phases, although Rollefson and Kafafi (2013: 11–13) propose that extended family dwelling units may have occupied large, highly compartmentalized dwellings, such as those that occurred during Phase C. The population of the final subphase (C2) has previously been estimated by Kuijt (2008: 294). He assigned this subphase to the MPPNB, utilizing an average period-based site extent of 2.5 ha and a density of 90 people per ha to produce a population estimate of 225 people.

[3] Byrd (2005) does not divide Phase B into two subphases despite evidence for earlier and later construction episodes.

Major methodological considerations and assumptions

Representativeness

Due to the relatively high proportion of site area excavated (*c.* 13–32%) and evidence for similar archaeological features in eroded areas of the site (Byrd 2005: 7), the excavated area is considered representative of the total site extent.

Contemporaneity

Contemporaneity adjustments are essential when reconstructing population sizes. In this investigation an empirically robust method for determining contemporaneity for each subphase is employed. Utilized by Varien *et al.* (2007), this method calculates a contemporaneity value by dividing the estimated building use-life by the estimated subphase length. Precise span estimates were produced via analysis of chronological information relating to the stratigraphic sequence at Beidha (Byrd 2005); building use-life estimates of comparable structures derived from archaeological, ethnographic and experimental research; and Bayesian chronological modelling of radiocarbon dates (Table 2).

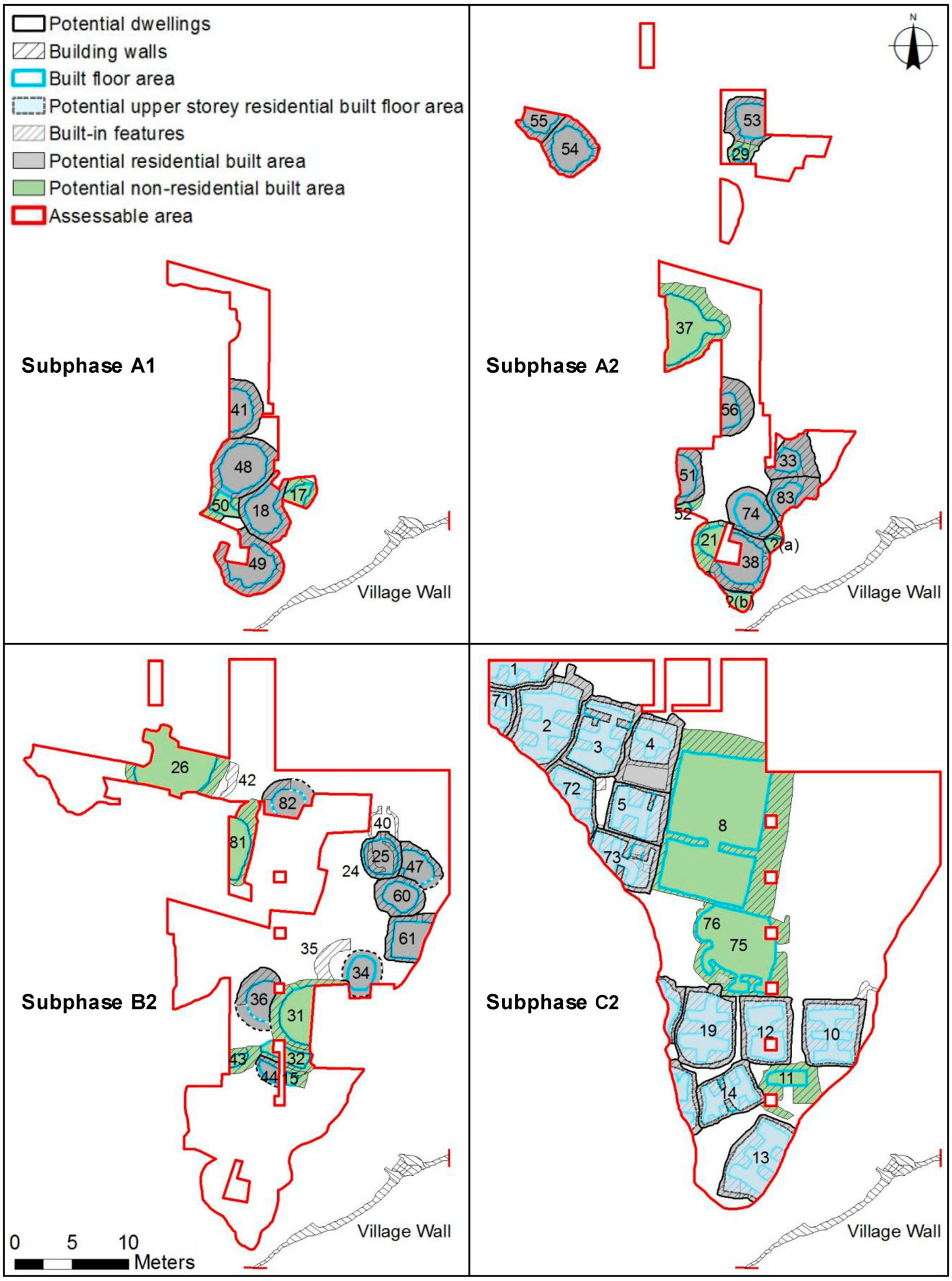

Figure 4 Site plans of Beidha Subphases A1, A2, B2 and C2 (transcribed from Byrd 2005: 180–95).

Phase A and B architecture comprised predominantly curvilinear structures with walls of combined earthen and masonry construction, and organic roofing; whilst Phase C architecture comprised agglomerated, rectilinear and often two-storey structures of predominantly masonry construction (Byrd 2005: 28). Based on maintenance and remodelling evidence, Byrd (2005) suggests that Subphase A1 and C2 structures were occupied for a considerable period, with more restricted average

Table 1 Description of Beidha Subphases A1, A2, B2 and C2 (Byrd 2005; Byrd and Banning 1988; Colledge 2001; Martin and Edwards 2013; Wright 2000).

Phase/ Subphase	Site extent (ha)	Architecture	Residential structures	Non-residential structures	Subsistence	Community organisation
A		Semi-subterranean; curvilinear; stone and mudbrick walls; evidence for re-modelling, re-plastering and re-flooring	Undifferentiated residential floor area	Annexes attached to dwellings; village wall and steps	Hunter-gatherer	Egalitarian; communal activities; little distinction between public and private space
A1	0.1		*n* = 4	Possible mortuary building		
A2	0.2		*n* = 9	Large, central structure		
B2	0.2	As above; emerging rectilinear forms	*n* = 8 More formalized and restricted access; more structured residential floor area	Large, central structures; increasing importance of non-residential built area	Cultivation of pre-domesticated barley and emmer; potential culturally controlled goats	Possible social differentiation; possible household economic units; increasing separation between public and private space
C2	0.3	Rectilinear; stone and sandstone slab walls; two-storey; extensive evidence for re-modelling, re-plastering and re-flooring	*n* = 15 Restricted access; highly compartmentalized; two-storey corridor buildings: ground floor storage/ working areas, upper storey residential area	Large, central, rectangular building adjacent to curvilinear structure (possible storage)	Domesticated wheat and barley; potential goat domestication	Possible centralized control of resources (possible central storage structure; open courtyard area with large hearths); well-established household-based economy

use-life during Subphases A2 and B2. Building use-life estimates of comparable structures indicate that Subphase A1 structures may have spanned around 55 to 75 years; Subphase A2 and B2 structures around 35 to 75 years; and Subphase C2 structures around 50 to 100 years (Ahlstrom 1985; Arnoldussen 2008; Cameron 1990; Cessford 2005; Diehl and LeBlanc 2001; Hodder and Cessford 2004; Kuijt and Finlayson 2009; Matthews 2005; Ortman *et al.* 2007; Rollefson and Köhler-Rollefson 1989; Varien 2012).

Bayesian chronological modelling was conducted in OxCal v.4.2.4 (Bronk Ramsey 1995; 2001; 2005; 2009) to calculate radiocarbon date spans per subphase and building.[4] Span estimates were assessed against the prior chronological information to establish final estimates for reconstructing contemporaneity values. The modelled spans for Subphases A1 (subphase length: 140 years; building use-life: 100 years) and A2 (subphase length: 80 years; building use-life: 60 years) were considered suitable for this purpose. The overall modelled span for Phase A (260 years) compares well with Byrd's (2005: 27) estimate of 300 years. Subphases B2 and C2 include dates from only one structure each, producing identical estimates for subphase length and building use-life. Modelled span estimates were adjusted based on the prior chronological information (Subphase B2 — subphase length: 70 years; building use-life: 50 years; Subphase C2 — subphase length: 90 years; building use-life: 70 years). This analysis has significantly revised Byrd's (2005: 27) tentative estimates of 150 to 250 years each for Phases B and C.

The span estimates produced contemporaneity values of around 71% for Subphases A1 and B2; 75% for Subphase A2; and 78% for Subphase C2. The value derived for Subphase C2 compares well with Rollefson and Köhler-Rollefson's (1989)

[4]This aspect of the project will be discussed more fully in a future article.

Table 2 Estimates of PPN Beidha occupation span, phase/subphase length, building use-life and structural contemporaneity. Subphases assessed in this investigation highlighted in grey.

	Phase	Subphase	Byrd 2005	Archaeological, ethnographic and experimental research		Bayesian chronological modelling	Final values	
			Years	*Construction, Maintenance**	*Years*	*Max years*	*Years*	*Structural contemporaneity (%)*
Occupation span			500–800			600	~500	
Phase/ subphase length	A		300					
		A1	*(150)*			140	140	
		A2	*(150)*			80	80	
	B		150–250					
		B1	*(100)*			(≥ 30)		
		B2	*(100)*			50	70	
	C		150–250					
		C1	*(100)*			(≥ 70)		
		C2	*(100)*			80	90	
Building use-life	A	A1	Considerable	E/M, C	55–75		100	71.43
		Building 18		E/M, C	55–75	90		
		Building 48		E/M, C	55–75	120		
		A2	Reasonable	E/M, Mod-C	35–75		60	75
		Building 54		E/M, Mod-C	35–75	60		
		Building 74		E/M, Mod	35–55	60		
	B	B2	Short (NE)/Long (Center)	E/M, Mod	35–55		50	71.43
		Building 26		E/M, Mod	35–55	50		
	C	C2	Considerable	M, Mod-C	50–100		70	77.78
		Building 8		M, C	75–100	80		

* Construction — E: Earthen, M: Masonry; Maintenance — Mod: Moderate, C: Considerable. (Earthen structures: Arnoldussen 2008; Cameron 1990; Diehl and LeBlanc 2001; Kuijt and Finlayson 2009; Ortman *et al.* 2007; Varien 2012. Masonry structures: Ahlstrom 1985; Cessford 2005; Hodder and Cessford 2004; Matthews 2005; Rollefson and Köhler-Rollefson 1989).

proposed structural contemporaneity value of 80% for the late PPN village of ‘Ain Ghazal, which comprised similar architectural characteristics.

Elimination of nuclear family sizes from HUM calculations due to insufficient residential floor area

Application of the average (5.5 people) and maximum (8 people) nuclear family sizes to the mean residential floor area of complete dwellings in Subphases A2 (7.26 sq m) and B2 (6.52 sq m) produced personal floor area allocations considerably lower than the lowest ethnographically derived value (1.86 sq m; Cook and Heizer 1968) and the lowest value employed in this investigation (1.77 sq m; Hemsley 2008). As such, these nuclear family sizes were excluded from HUM calculations for these subphases.

Area proportions for Subphase B2

Kuijt (2008) suggests that MPPNB settlements contain an average of 70% built area. The Subphase B2 built area estimate (28.5%) reflects considerable destruction of the occupation evidence by Phase C construction (Byrd 2005: 19). This has resulted in unrealistically low population estimates compared to preceding subphases. To reconstruct more reliable estimates, Subphase B2 calculations utilized proportions derived for Subphase A2, which demonstrates the most comparable structural and spatial characteristics.

Estimating upper storey floor area in Subphase C2

Based on upper storey evidence in five Subphase C2 structures (Buildings 3–5, 14 and 73) and comparable ground-floor plans throughout, Byrd (2005: 85) interprets all corridor buildings as ‘primarily, if not exclusively, two-storey’. All are considered two-storey in this investigation and the upper storey is considered to represent residential area. To avoid overestimating potential upper storey floor area, the three structures (Buildings 3, 14 and 73) that demonstrate the best preserved upper storey evidence were analysed to determine the potential proportion of upper storey area comprising floor area (Table 3). The mean proportion of upper storey interior area comprising internal walls, built-in features and a hypothesized 60 sq cm passage between the lower and upper floors was around 17.5%. The total upper storey interior area of structures without detailed second storey layouts was estimated based on the internal boundary of external walls. This proportion was then deducted from this area to calculate potential upper storey floor area.

Summary of estimates

This section provides a summary of estimates of total population, population growth, the number of people per dwelling, residential floor area per person (RADC), the number of people per ha (SPDC) and initial growth indices for allometric growth formulae (AGF) (Fig. 5; Table 4). As previously justified, SPF estimates are considered most reliable and are presented as the final estimates.

Total population

The SPF indicated a total population of around 50 to 90 people in Subphase A1; 75 to 115 people in Subphase A2; 70 to 110 people in Subphase B2; and 125 to 235 people in Subphase C2. Kuijt’s (2008: 294) estimate for the final phase (P = 225) falls within the range derived in this investigation, although his calculations were based on a density coefficient of 90 people per ha and an average period-based site extent of 2.5 ha (for the MPPNB), which is far in excess of the estimated extent for this phase (0.3 ha).

Estimates for Subphases A2 and B2 were almost equivalent on account of several factors, including equivalent site extent (0.2 ha); comparable mean residential floor area per dwelling (*c.* 7 sq m); and the use of Subphase A2 area proportions for Subphase B2 calculations due to the destruction of much of the

Table 3 Beidha Subphase C2 structures assessed to determine potential upper storey floor area. Final proportion to deduct highlighted in grey.

Building	Total potential upper storey area (excl. external walls)	Upper storey interior walls and built-in features		Passage between lower and upper storey		Potential upper storey floor area: To deduct from upper storey area		Potential upper storey floor area: Remaining
	sq m	*sq m*	*%*	*sq m*	*%*	*sq m*	*%*	*sq m*
3	21.79	2.8	12.85	0.6	2.75	3.40	15.60	18.39
14	15.23	1.15	7.55	0.6	3.94	1.75	11.49	13.48
73*	16.06	3.44	21.42	0.6	3.74	4.04	25.16	12.02
Mean			**13.94**		**3.48**		**17.42**	

* Marginally incomplete structure measures 13.10 sq m. Hypothetical boundary drawn in southwest corner to represent complete structure measuring 16.06 sq m.

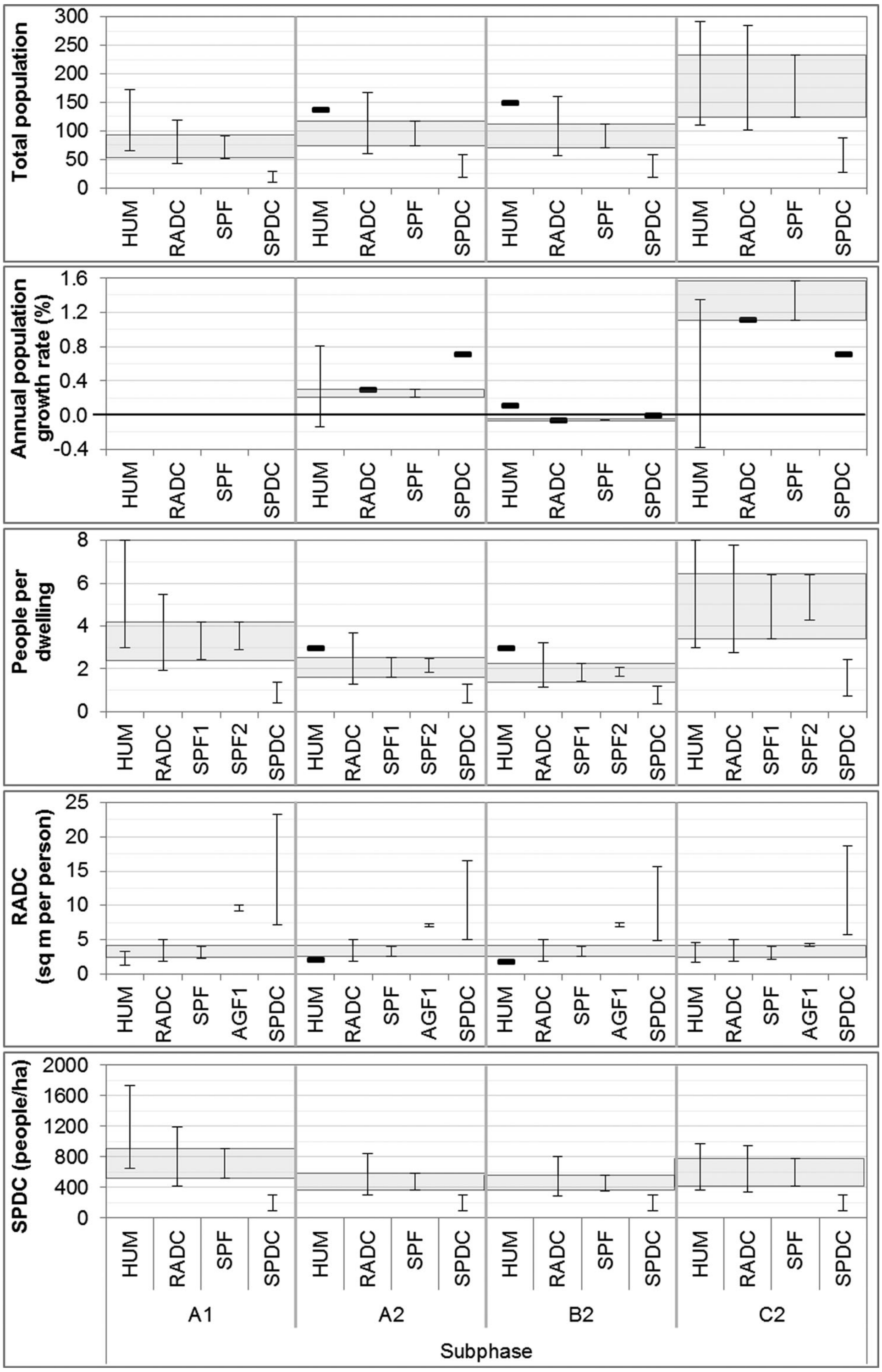

Figure 5 Summary of estimates (SPF estimates considered most reliable and highlighted for comparative analysis).

Subphase B2 occupation by later construction. For this latter reason also, it is probable that Subphase B2 population size has been underestimated. Given the agricultural and architectural developments that occurred at Beidha between Subphases A2 and B2 (i.e. the cultivation of domesticated plants and the transition to rectilinear and more formalized architectural forms), it is highly probable that the population exceeded that of Subphase A2.

The population estimates coincide with a range of hypothesized group size thresholds. Firstly, it is hypothesized that a group size of at least 25 to 40 people is required for the initial transition to sedentism (Bandy 2010; Binford 2001; Fletcher 1981; Kuijt

Table 4 Summary of estimates (SPF estimates considered most reliable and highlighted for comparative analysis).

	Subphase			
	A1	***A2***	***B2***	***C2***
Total population				
HUM	65–175	140	150	110–290
RADC	40–120	60–170	55–160	100–285
SPF	50–90	75–115	70–110	125–235
SPDC	10–30	20–60	20–60	25–90
Annual population growth rate (%)				
Subphase length	*140*	*80*	*70*	*90*
HUM		-0.1–0.8	0.1	-0.4–1.4
RADC		0.3	-0.1	1.1
SPF		0.2–0.3	-0.1	1.1–1.6
SPDC		0.7	0	0.7
People per dwelling				
Total number of contemporaneous dwellings	*22*	*46*	*50*	*37*
Mean residential floor area of complete dwellings (sq m)	*11.6*	*7.3*	*6.5*	*17.2*
HUM	3–8	3	3	3–8
RADC	1.9–5.5	1.3–3.7	1.1–3.2	2.8–7.8
SPF1	2.4–4.2	1.6–2.5	1.4–2.2	3.4–6.4
SPF2	2.9–4.2	1.8–2.5	1.7–2.1	4.3–6.4
SPDC	0.4–1.4	0.4–1.3	0.4–1.2	0.7–2.4
RADC (sq m per person)				
Total contemporaneous residential floor area (sq m)	*210*	*295*	*285*	*505*
HUM	1.2–3.2	2.2	1.9	1.7–4.6
RADC	1.77–5			
SPF	2.3–4	2.5–4	2.5–4	2.2–4
AGF1	9.2–10	6.8–7.3	6.9–7.4	4–4.4
SPDC	7.1–23.3	5.1–16.5	4.8–15.7	5.7–18.6
SPDC (people per ha)				
Total site extent (ha)	*0.1*	*0.2*	*0.2*	*0.3*
HUM	650–1730	690	750	370–970
RADC	420–1190	300–840	280–800	340–950
SPF	520–900	370–590	350–560	420–780
SPDC	90–294			

and Goring-Morris 2002). Subphase A1 (50–90 people) provides the first evidence for a permanently settled community on this site (Byrd 2005).

Secondly, a group size of at least 50 people is considered necessary for transition to farming practices (Drennan and Peterson 2008), with around 100 people required for adoption of a fully sedentary agro-pastoralist subsistence strategy (Fletcher 1981; Kuijt and Goring-Morris 2002). Archaeological evidence indicates agricultural practices relating to domesticated plant forms from Subphase B2 (70–110 people) and full transition to agro-pastoralist practices by Subphase C2 (125–235 people) (Byrd 2005).

Finally, it is theorized that groups of around 150 people either undergo fissioning processes or introduce mechanisms for social cohesion (Dunbar 2003; Fletcher 1981). Cohesive elements are evident in the emergence of large, centrally located, non-domestic structures from Subphase A2 (75–115 people), particularly in Subphases B2 (70–110 people) and C2 (125–235 people), where several non-residential structures appear to be in simultaneous use. In the latter subphase, evidence suggests some form of central or corporate management of stored goods (Byrd 2005).

Elements of intra-community fissioning or sectoring are evident in the increasing household control of resources and production from Subphase A2 (75–115 people) and is again particularly evident in Subphase C2 (125–235 people), where individual dwellings contain considerable space for household controlled storage, and evidence for household-based production and potentially inherited specialist knowledge (Byrd 2005; Dunbar 2003; Fletcher 1981).

Population growth

The consecutive phases at Beidha present a rare opportunity to calculate population growth directly using the archaeological evidence. The SPF population estimates and estimated subphase lengths produced annual population growth rates of around 0.2% to 0.3% between Subphases A1 and A2; -0.1% to Subphase B2; and 1.1% to 1.6% to Subphase C2. These rates fall within the range calculated for the MPPNB (-1.3%-1%) and LPPNB (-0.75%-2.1%) by

Goodale (2009: 160). The growth rate to Subphase A2 compares well with rates derived for other formative and early agricultural villages (0.08%–0.25%) (Bandy 2001; Carneiro and Hilse 1966; Drennan and Peterson 2008; Hassan 1981). The mean annual population growth rate throughout all phases is around 0.5%. This compares well with Eshed *et al.*'s (2004) estimate of 0.5% to 1% for central and southern Levantine communities at the advent of agriculture.

The positive growth rate between Subphases A1 and A2 reflects the initial and increasing transition to a fully sedentary existence and may indeed have been the cause of this transition. The reduced (and perhaps negative) growth rate to Subphase B2 is probably due to an underestimation of population as a result of depleted occupational evidence. Alternatively, low growth may suggest that the population had reached carrying capacity and could explain developments in agricultural practices during this phase. The increased growth rate to Subphase C2 probably reflects a 'boom' period following the full transition to agro-pastoralist subsistence practices. This growth pattern is well documented in early Neolithic settlements (Whitehouse *et al.* 2014). In addition, this high growth reflects the architectural transition to high density, rectilinear housing. It has been suggested that such high growth rates (> 0.08%) often occur within populations that are very large relative to carrying capacity (Porčić and Nikolić 2016: 182–83). This could explain why the settlement was gradually abandoned throughout Subphase C2.

People per dwelling

The SPF methods produced average dwelling unit size estimates of around 2.5 to four people in Subphase A1; 1.5 to 2.5 people in Subphase A2; 1.5 to two people in Subphase B2; and 3.5 to 6.5 people in Subphase C2. These estimates correspond to variations in the mean residential floor area, with larger areas occurring in Subphases A1 (11.6 sq m) and C2 (17.2 sq m), and smaller areas in Subphases A2 (7.3 sq m) and B2 (6.5 sq m).

The lower dwelling occupant numbers produced in Subphases A2 and B2 could reflect erroneous interpretation of smaller structures as representing residential space and larger structures as representing non-residential space. In addition, it is probable that later construction destroyed more substantial Subphase B2 residential structures.

Subphase C2 dwelling unit size estimates are considerably higher than those derived for the previous phases. This could reflect the potential changing structure of the residential unit in terms of size, composition and economic function (Byrd 2005). In addition, architectural developments, including addition of substantial upper storey residential area, greater compartmentalization and more restricted access routes, would have enabled increased residential density whilst satisfying needs of privacy and personal space.

The results indicate that nuclear families could have formed the main dwelling unit in Subphases A1 and C2. However, estimates suggest paired occupancy on average in Subphases A2 and B2. These results challenge the current theory that nuclear families formed the main dwelling unit throughout the PPN sequence at Beidha (see Byrd 2005) and could support the theory that individual structures within circular hut compounds were occupied by individuals or smaller units as part of a larger family group (Flannery 1972).

A comparison of population estimates derived from the HUM and SPF methods revealed potential correlations between dwelling unit size and residential architecture. During Subphases A1, A2 and B2, residential architecture predominantly comprised curvilinear dwellings with undifferentiated residential floor space; whilst in Subphase C2, residential architecture comprised two-storey, highly compartmentalized dwellings, with large upper storey residential areas and substantial ground floor area for storage and additional activities (Byrd 2005). For the subphases with curvilinear architecture, estimates derived from the HUM were considerably higher than those of other methods. This occurred even when employing the minimum nuclear family size only (3 people), as was the case for Subphases A2 and B2, where the available mean residential floor space (*c.* 7 sq m) enabled removal of higher nuclear family sizes from the HUM calculations. This could indicate that nuclear families did not form the main dwelling unit in these subphases. Conversely, the HUM estimate for Subphase C2, which employed all nuclear family sizes (3–8 people), appears to have produced reasonable population estimates, highlighting the potential for nuclear family dwelling units in the latest phase.

Residential area density coefficient (RADC)

The SPF method produced estimates of 2.2 to 4 sq m residential floor area per person across all phases, with marginally higher minimum personal space allocation for Subphases A2 and B2 (*c.* 2.5 sq m). The comparability in RADCs across all phases is partly due to the SPF method. For each subphase, estimates were based on the SPF for limited storage (none to moderate). This produced similar correlations between the number of occupants and available space.

The RADCs fall within the range derived for comparable villages and the range utilized in RADC population estimates in this investigation (1.77–5 sq m). Interestingly, despite the larger available residential floor area in Subphases A1 and C2, the results do not suggest an increase in personal space allocation.

An assessment of RADCs produced via other methods highlights some interesting information. Firstly, RADCs based on the HUM for Subphases A2 and B2, which employed the minimum nuclear family size (3 people) only, further suggest that these dwellings did not accommodate nuclear families. Population estimates based on the average and maximum nuclear family sizes (5.5 and 8 people) would have produced RADCs considerably lower than the minimum RADC employed in this investigation (1.77 sq m).

Secondly, RADCs based on Naroll's (1962) AGF allowed for one person, on average, per dwelling during Subphases A1, A2 and B2, and four people per dwelling during Subphase C2. The comparability between the Subphase C2 RADCs derived from the AGF and the SPF suggest that Naroll's (1962) formula may be suitable for estimating population parameters of settlements with high density, rectilinear architecture, though not for settlements with curvilinear architecture.

Thirdly, the SPDC method produced excessive RADC ranges, with the minimum RADC (based on 294 people per ha) resulting in around 1.5 people per dwelling in Subphases A1, A2 and B2, and three people per dwelling in Subphase C2. The maximum RADCs (based on 90 people per ha) exceeded the mean residential floor area of complete dwellings in all subphases. These results suggest that the commonly utilized SPDCs are too low to accurately estimate the population of PPN Beidha.

Settlement population density coefficient (SPDC)

The SPF method produced SPDCs of around 520 to 900 people per ha for Subphase A1; 370 to 590 people per ha for Subphase A2; 350 to 560 people per ha for Subphase B2; and 420 to 780 people per ha for Subphase C2 (Fig. 6). These SPDCs far exceed the range commonly used for estimating PPN central and southern Levantine populations (90–294 people per ha) and are more comparable to those derived for enclosed Bronze Age settlements (Ugarit, Syria: 550 people per ha; Mesopotamia: 380–750 people per ha) (Wossinik 2009; Kennedy 2013) and Iron Age settlements (Palestine: 400–500 people per ha; Jerusalem: 395 people per ha) (Jeremias 1969; Shiloh 1980; Zorn 1994).

The high SPDCs may be due to the restricted topographical context of Beidha and the placement of a village wall bounding the settlement to the south. However, it is improbable that settlement sprawl was restricted in any significant way given the low estimated population sizes for all phases and the open spatial distribution of structures particularly in Phases A and B. This theory is supported by the combination of population increase with declining density from Subphases A1 to A2. The high SPDCs are probably due to the nature of the architectural construction, which included clustered and interconnected curvilinear dwellings in Phases A and B, and high density, interconnected, two-storey, rectilinear housing in Phase C (Byrd 2005). Further analysis will reveal whether high SPDCs were a characteristic of PPN villages in the central and southern Levant.

Initial growth indices derived for the allometric growth formulae (AGF)

Allometric growth formulae (AGF) were applied to explore the suitability of scaling exponents (*b*) and to derive initial growth indices (*a*) for different settlement types. Re-calculation of the initial growth index utilized in Naroll's (1962) formula (AGF1) ($a = 21.7$) based on the SPF population estimate (P) and estimated total built floor area (A) produced relatively consistent values for Subphases A1, A2 and B2 (minimum: *c.* 8–11; maximum: *c.* 12–17), and a range comparable with the original index for Subphase C2 (*c.* 15–26) (Table 5). The comparability between constants derived for sites exhibiting predominantly curvilinear architecture (Subphases A1, A2 and B2) and predominantly rectilinear architecture (Subphase C2 and Naroll's (1962) original dataset) indicate the potential for Naroll's (1962) formula to be refined for different settlement types.

The initial growth index calculated for Wiessner's (1974) formula (AGF2) for village settlements was relatively consistent across all phases (minimum: *c.* 11–18; maximum: *c.* 19–29), suggesting that an average index range of around 15 to 25 may be suitable for estimating the population of all PPN central and southern Levantine villages when applying this formula. Similarly, the comparability between indices derived for open settlement types (Subphases A1, A2 and B2) (minimum: 0.12–0.16; maximum: 0.37–0.41) suggests that an average index range of around 0.14 to 0.38 may be suitable for application of the open AGF to PPN villages with curvilinear architecture. In this preliminary analysis, only one phase demonstrated characteristics of an urban settlement (Subphase C2). Thus, further analysis is required prior to the assessment of indices for this settlement type.

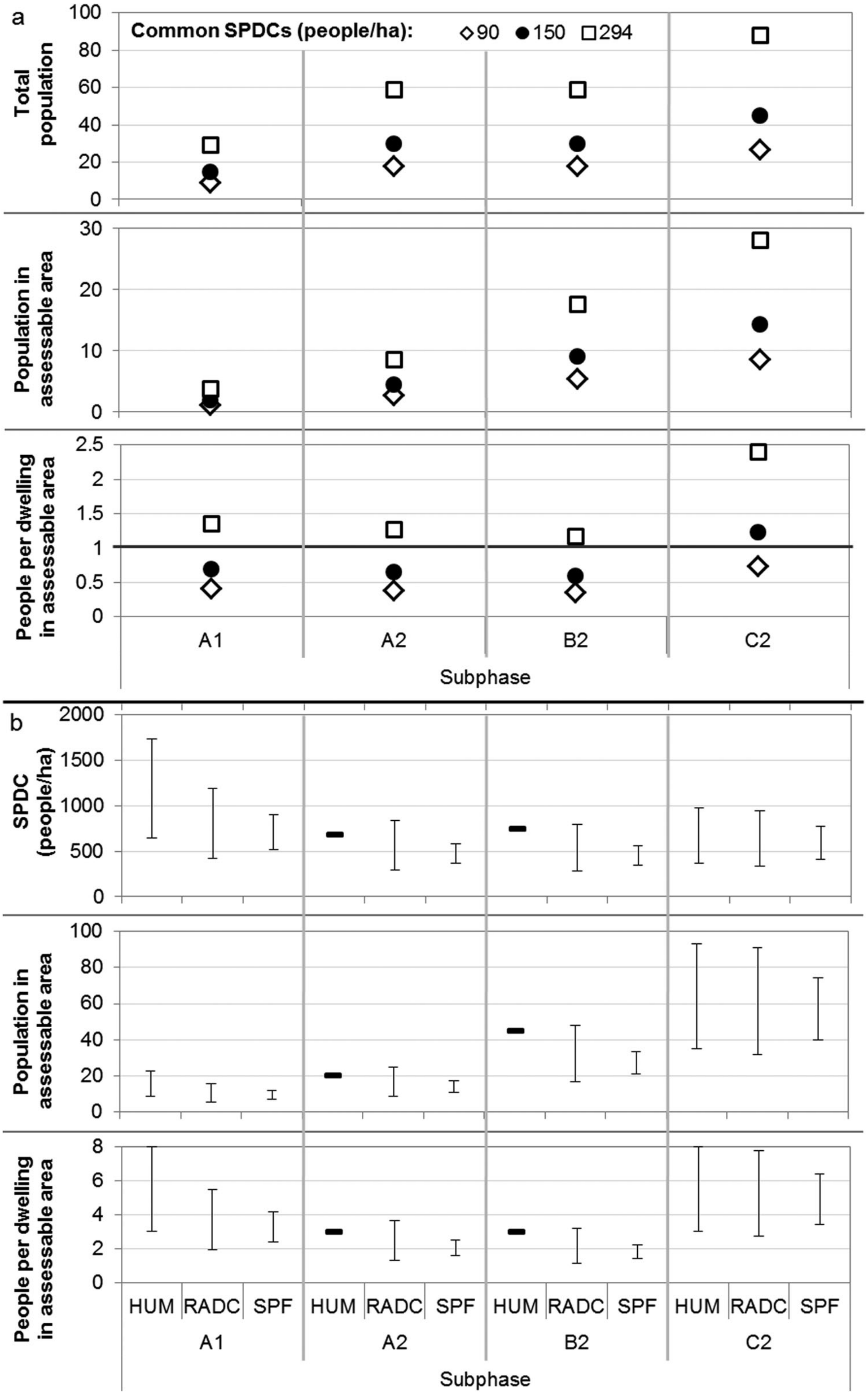

Figure 6 **Data derived from SPDC methods for Beidha Subphases A1 to C2: (a) from commonly utilized SPDCs; (b) from HUM, RADC and SPF population estimates.**

Implications for existing methodologies and theories

The most significant findings from this analysis relate to the suitability of the settlement population density coefficient (SPDC) method and commonly utilized SPDCs for estimating population parameters; and the theory that nuclear families typified the dwelling unit at Beidha and other PPN villages (Byrd 2002;

Table 5 Initial growth indices derived for Beidha Subphases A1 to C2 (applicable settlement types highlighted).

		Subphase			
		A1	*A2*	*B2*	*C2*
Naroll's (1962) AGF1		7.7–12.3	10.8–16	11.3–16.6	15.1–25.6
Wiessner's (1974) AGF2	Open	0.12–0.37	0.15–0.37	0.16–0.41	0.06–0.19
	Village	11.1–19.2	17.1–27.2	18–28.5	12.9–24.1
	Urban	49.6–71.7	83.7–113.8	86.5–117.6	79.1–120.2

2005; Düring 2001; Haviland 1972; Kramer 1982; Sweet 1960).

The SPDC method has been the primary method for estimating PPN central and southern Levantine village populations. However, this investigation has highlighted several issues with this technique. Firstly, as this method is based on total site extent, the same population estimates are produced for sites of equivalent estimated total site extent regardless of intra-site organization or other impacting factors, such as topographical context, climate, or perceptions relating to privacy, space and overcrowding. Secondly, application of the commonly utilized SPDC range for PPN settlements (90–294 people per ha) results in broad estimate ranges, particularly for the larger sites. Thirdly, when adjusted to reflect average dwelling occupant numbers in the assessable area based on the estimated number of contemporaneous dwellings, it is apparent that commonly utilized SPDCs may underestimate population (Fig. 6).

The minimum SPDC (90 people per ha) resulted in average dwelling unit sizes of less than one person in all subphases, whilst the average SPDC (150 people per ha) produced average estimates of less than one person in Subphases A1, A2 and B2 and just over one person in Subphase C2. Application of the maximum SPDC (294 people per ha) produced average dwelling unit sizes of one person for Subphases A1, A2 and B2, and around 2.5 people in Subphase C2. If dwellings were indeed occupied by nuclear families, as Byrd (2005) suggests, this could reflect two adults and a child. However, it is improbable that these high density, highly compartmentalized, two-storey dwellings with considerable ground floor storage space and large upper storey residential areas were occupied by such small family units.

It is apparent that the commonly utilized values for population density and the theory that dwellings at Beidha were predominantly occupied by nuclear families of around five to six people (Byrd 2005) are not compatible. There could not have been a maximum population density of 294 people per ha on the one hand and a dwelling occupant size of five to six on the other. The results do not correlate. Either the population density was higher or the dwelling unit size was smaller. Based on this preliminary analysis, it appears that both the commonly utilized SPDCs and the theory that PPN dwellings were occupied by nuclear families require re-evaluation.

As part of this reconsideration, SPDCs were reconstructed from HUM, RADC and SPF population estimates and converted to population and average dwelling unit size in the assessable area (Fig. 6). This investigation produced SPDCs ranging from around 500 to 900 people per ha for Subphase A1; 350 to 600 people per ha for Subphases A2 and B2; and around 400 to 800 people per ha for Subphase C2. These values are considerably higher than the maximum commonly utilized SPDC (294 people per ha) and all produce more realistic estimates of population and dwelling unit size in the assessable area. Subphases A1 and C2 both comprise large residential areas and dense structural layout and both produced comparatively high density values; whilst Subphases A2 and B2 comprise small residential areas and lower structural density, resulting in reduced population density, though still higher than the commonly utilized range.

SPDCs derived from HUM population estimates were assessed to determine potential dwelling unit sizes. HUM estimates for Subphases A2 and B2 were based on the minimum nuclear family size of three people only. The resulting SPDCs suggest that even this dwelling unit size is too high for these subphases. Conversely, the SPDC based on the HUM population estimate for Subphase C2, which employed the entire range of nuclear family sizes (3–8 people), indicates that this may be a suitable dwelling unit size range for this subphase.

This analysis suggests that the commonly utilized SPDCs (90–294 people per ha) are too low to accurately estimate the population of PPN Beidha and that different SPDCs could be developed for different settlements types.

Conclusion

This research examines existing estimates, commonly utilized methodologies and associated theories in order to establish an empirically robust methodological framework for estimating absolute population parameters of PPN villages in the central and southern Levant.

Five methodologies were selected for detailed analysis and comparison: the housing unit method (HUM), the residential area density coefficient (RADC) method, the storage provisions formula (SPF), the settlement population density coefficient (SPDC) method and the allometric growth formula (AGF). Assessment of these methodologies and the resulting estimates revealed that the SPF is the most empirically robust method for producing potentially reliable absolute population estimates. This method relies on less ethnographic data and fewer assumptions than other methods explored in this investigation. It has the advantage of producing direct estimates of dwelling unit size in addition to total population size, and can highlight the potential degree of storage within the residential floor area.

The SPF method indicates that the population of Beidha increased from around 50 to 90 people in Subphase A1 to around 125 to 235 people in Subphase C2, with a mean annual population growth rate of around 0.5%. These estimates correspond well with current group size threshold theory relating to initial transition to sedentism (25–40 people), adoption of agriculture (≥ 50 people) and agro-pastoralist subsistence practices (≥ 100 people), and introduction of mechanisms for social cohesion within larger groups (≥ 150 people) (Bandy 2010; Binford 2001; Drennan and Peterson 2008; Dunbar 2003; Fletcher 1981; Kuijt and Goring-Morris 2002). The results also compare well with population growth rates derived for early agricultural and formative villages (0.08–1%) (Bandy 2001; Carneiro and Hilse 1966; Drennan and Peterson 2008; Eshed *et al.* 2004; Hassan 1981).

Preliminary analysis indicates that current theory relating to population density and the composition of the dwelling unit, as well as methodological practices relating to commonly utilized values for the number of people per dwelling, residential floor area per person (RADC) and the number of people per ha (SPDC) require re-evaluation. Nuclear families are often considered to represent the main dwelling unit in Neolithic societies (Byrd 2002; 2005; Düring 2001; Haviland 1972; Kramer 1982; Sweet 1960). However, this analysis indicates that nuclear family dwelling units may not have occurred within some PPN settlements. In this investigation, subphases with predominantly curvilinear architecture combined with small mean residential areas (Subphases A2 and B2) produced dwelling unit size estimates that suggest paired occupancy on average. Conversely, subphases with larger mean residential areas (Subphase A1 and C2) produced dwelling unit sizes that could reflect nuclear family units, particularly in the latter subphase (3.5 to 6.5 people).

Ethnographically derived RADCs are often not employed in population estimates due to the inconsistency in RADC measurements. However, this assessment has produced a relatively limited range of 2.2 to 4 sq m residential floor area per person across all phases. It appears that changes in architecture, including increases in available residential floor area, may not alter the amount of personal residential floor area allocation. These RADCs correspond well with archaeological and ethnographic estimates of RADC in comparable villages in Southwest Asia, Southwest America and the Arctic Circle (1.77–5.00 sq m per person) (Clarke 1974; Cook and Heizer 1968; Hayden *et al.* 1996; Hemsley 2008; Hill 1970; Kramer 1979). The consistency of the results indicates that this RADC range could be utilized to estimate the population of PPN central and southern Levantine villages.

Almost all PPN village population estimates to date have utilized the same simple methodology for rapidly estimating population based on site extent and an ethnographically derived population density range of 90 to 294 people per ha. However, this analysis indicates that this range is too low to accurately estimate the population of PPN Beidha, and that different density coefficients could be derived for, and applied to, different PPN settlement types. This investigation produced SPDCs ranging from around 350 to 900 people per ha, with higher density values correlating to higher structural density and larger mean residential floor areas. The high SPDCs achieved in this investigation raise a number of questions concerning the ways in which people were able to live in very densely populated villages without sophisticated water or transport technologies, and the causes and consequences of transitions and developments in subsistence strategies, architecture, economic practices and social organization.

Another method for rapidly estimating population is the allometric growth formula (AGF). This method has been largely abandoned in archaeology given the variable relationship between human population size, population density and settlement size. However, re-calculation of initial growth indices has revealed that specific indices could be derived for different PPN settlements types. Naroll's (1962) original index of 21.7, or a range from around 15 to 26 (derived from Subphase C2), may be suitable for estimating the population of PPN villages with predominantly rectilinear architecture; whilst a reduced index range of around 10 to 15 (derived from Subphases A1, A2 and B2) may be suitable for application to PPN villages with predominantly curvilinear architecture. For Wiessner's (1974) AGF, this assessment indicates that an initial growth index range of around 15 to 25 (derived from all subphases) may be suitable when applying the AGF for village settlements; and an index range of around 0.14 to 0.38 (derived from Subphases A1, A2 and B2) may be suitable when applying the formula for open settlements. Further analysis is required prior to development of a suitable index range for urban settlements.

The results of this analysis challenge current theory relating to the use of residential space at Beidha, particularly with regard to population density and the theory of predominantly nuclear family dwelling units. The results indicate that commonly utilized ethnographically derived coefficients require revision and that different constants could be developed for different settlement types. This research has the potential to contribute significantly to our understanding of population dynamics in central and southern Levantine PPN villages and presents multiple avenues for methodological and theoretical research into population parameters in other regions and periods.

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