Journal of Archaeological Science: Reports 18 (2018) 535–550

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Testing the Malthusian model: Population and storage at Housepit 54, Bridge River, British Columbia

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ABSTRACT

Considerable debate exists concerning drivers of social change in human societies. One perspective asserts that demographic and economic conditions play a critical role in conditioning human organizational decision-making. Another argument suggests that human agency conditioned by innovative thinking outside of demographic and economic pressures is the more fundamental source of change. The Bridge River site, British Columbia is an optimal locality to explore variable effects of subsistence economy and demography on social change. Previous research indicates that Malthusian processes played important roles in demographic, socio-economic, and political change. This paper presents a test of the Malthusian model drawing data on storage capacity and population size from a single long-lived house within the Bridge River village. Results suggest that household occupants likely experienced two Malthusian periods, persisting through the first but abandoning the house and village during the second. An important implication is that economic and demographic conditions have critical impacts on social process but that specific episodes of collective action also remain dependent upon human agency.

1. Introduction

Scholars have proposed alternative models for dramatic cultural changes evident in many archaeological sequences around the globe. A long standing perspective suggests that fundamental demographic and economic factors play a significant role in shaping human decision making regarding cooperation and collective action. Thus, we expect to recognize change in eco-demo trends in advance of- or in concert with wider cultural shifts (e.g. Binford, 1968, 2001; Cohen, 1981; Kelly, 1991; Johnson, 1982). Such models have become increasingly sophisticated with the application of formal simulations to illustrate the complex relationships between resource conditions, food acquisition and storage, demographics, and cultural practices (e.g. Puleston et al., 2014; Winterhalder et al., 2015). In contrast, an alternative approach gives primacy to human agency recognizing the human ability to innovate and cooperate to achieve significant goals with or without pressure from underlying ecological and demographic factors. Within these scenarios human groups cooperate to realize big new ideas that often results in new forms of human social and political organization (Bender, 1985; Blanton and Fargher, 2016; Clark and Blake, 1994; Pauketat, 2007; Sassaman, 2011). Demographic and economic change may accompany and/or follow such reorganizations.

The Bridge River site, in southern British Columbia has proven to be an important context for examining change in human socio-economic and political organization. Recent research indicates that dramatic demographic and social change occurred in the community during the Bridge River (BR) 3 period at ca. 1300–1000 cal. B.P. that included rapid growth following a short period of near-abandonment in late BR 2 times (ca. 1600–1300 cal. B.P.), formal rearrangement of new houses, expansion of exchange networks, feasting, and the development of material-wealth-based inequality between houses. Prentiss et al. (2012, 2014) argue that material wealth-based inequality emerged during BR 3 in the context of a Malthusian ceiling characterized by resource instability that ultimately led to an economic crisis, population reduction, and eventual abandonment of this and other large villages in the region (see also Kuijt and Prentiss, 2004; Prentiss et al., 2007). They leave open the possibility that new forms of collective action (c.f. Blanton and Fargher, 2016) contributed to the establishment of the early BR 3 pattern as economic instability conditioned later social trends.

The Housepit 54 project at Bridge River (Figs. 1 and 2) provides an opportunity to test the Malthusian demographic hypothesis given the long sequence of discrete occupation floors spanning mid-BR 2 to late BR 3 times. This is accomplished by first establishing the history of the house by examining stratigraphy, floors, and the radiocarbon record. We then project changes in household population and compare that record to a proxy measure of food storage based upon cache pit volume

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https://doi.org/10.1016/j.jasrep.2018.02.015
Received 16 October 2017; Received in revised form 12 February 2018; Accepted 13 February 2018

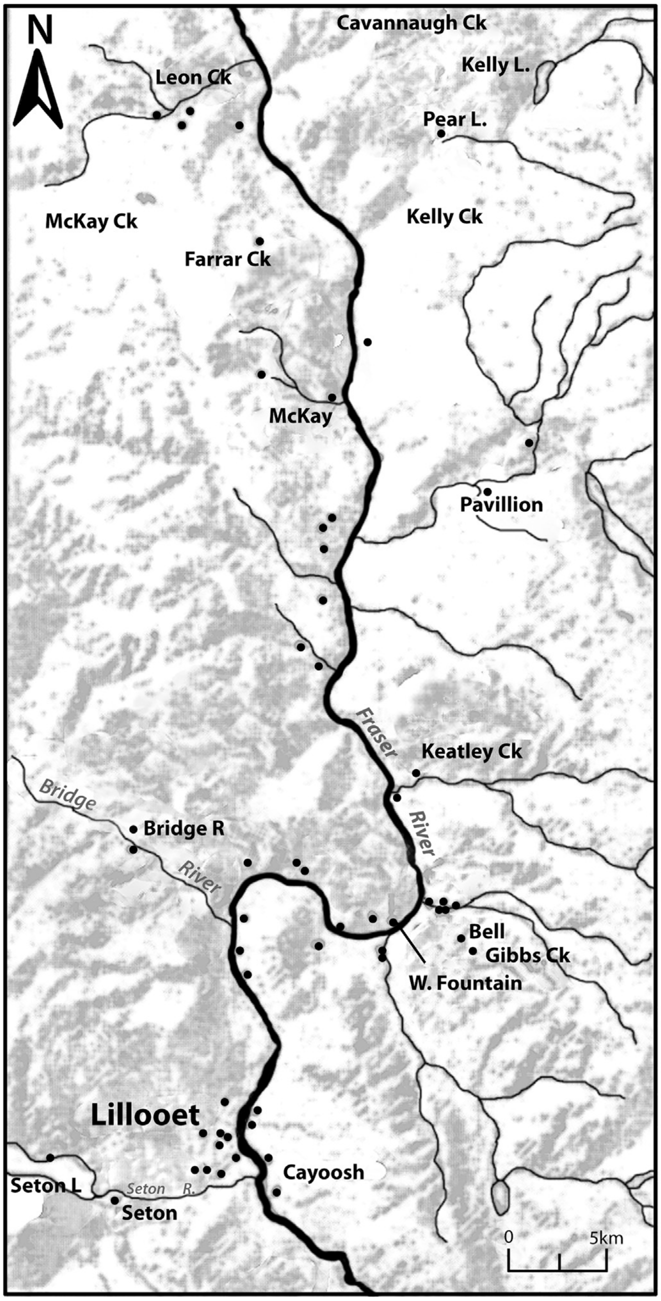

Fig. 1. Location of Bridge River site in Middle Fraser Canyon context, south-central British Columbia.

amassed for each floor. Results support the Malthusian model of village history with the implication that village-wide demographic process was likely driven by variability in household economic pursuits. Housepit 54 managed to survive the late BR 2 demographic down-trend and despite a lengthy period of success and survival during BR 3 times, it appears to have succumbed to challenges facing the entire village by the late BR 3 period. While resource conditions likely played an important role in village demographic and economic history, it does not mean that new forms of collective action did not manifest during the early BR 3 village reorganization.

2. Background

2.1. Demographic theory and food storage

Significant attention has been focused on modeling demographic process associated with food producing societies (Lee, 1993; Lee and Tuljapurkar, 2008; Lee et al., 2009; Puleston and Tuljapurkar, 2008; Wood, 1998). As noted by Wood (1998) Malthusian dynamics are often contrasted with those of Boserup (1965) given very different baseline assumptions about conditions of population growth as related to technology and food production. Boserup's model views population growth as an independent variable driving steady innovation in the means for feeding rising numbers of persons. This model has been useful to some archaeologists, for example, foraging theorists seeking to understand seemingly maladaptive change in foraging decisions (e.g. Broughton, 1994). Wood (1998) points out that Boserupian scenarios, particularly if playing out on a short-term basis, need not be completely antithetical to the unfolding of a long term Malthusian process. However, there is little to suggest such a scenario ever occurred in the Mid-Fraser context (Prentiss et al., 2007, 2011, 2012). Thus, Prentiss et al. (2014) argue that the Malthusian model appears to provide a more comprehensive and accurate scenario to account for change in population, subsistence economy, and social relationships in the Mid-Fraser villages.

Puleston et al. (2014) present a Malthusian model asserting that agrarian populations cycle through three phases: copial, Malthusian transitional interval, and Malthusian phase. The length of the copial phase may be affected by a number of variables. Puleston et al. (2014) suggest that the larger the founding group the shorter the copial phase. Logically, the greater the available agricultural (or fishing/foraging resource) landscape, the longer the copial phase. It stands then that the higher the food yield and/or the higher the background mortality rate, the longer the copial phase as well. Regardless of copial phase time, it is within the short transitional interval that groups have a chance to reverse the trend leading to the harsher Malthusian phase. This may be accomplished most simply by gaining access to more productive food resources (a Boserupian innovation scenario could work here) or reducing numbers of consumers, which can occur via mortality or emigration.

Winterhalder et al. (2015) provide a "variance compensation" model that describes the role of storage within Malthusian cycles. In short, their model offers a number of critical points. First, inter-annual storage is expected when the food resource comes available in seasonal pulses. Thus, the model applies to food producers and fisher-foragers reliant on seasonally abundant food sources such as anadromous salmon. Second, the importance of inter-annual storage is proportional to the degree to which delayed return resources are essential to annual survival. Thus, it might be expected that storage would be reduced in importance when viable options for annual immediate return food procurement or production exist. Third, the model predicts that households dependent upon storage will create facilities large enough to include baseline production and surplus to overcome risks of shortfall. Finally, the model predicts that under normal conditions storage enhances average welfare. However, an important implication is that reliance on storage can also increase the adverse effects of famine conditions. Effects of famine are particularly severe when they occur following a series of low production years thus leaving a group without significant backup resources.

The Malthusian models of Puleston et al. (2014) and Winterhalder et al. (2015) predict significant variation in demographic histories depending upon a wide range of reproductive, demographic, geographic, and ecological factors. Most critically, Puleston et al. (2014) note that the Malthusian Transition Interval may come quickly and unanticipated, particularly in seemingly productive environments, for example Polynesian high Islands. The effects of this "hidden cliff" (Puleston et al., 2014) could superficially resemble alternative scenarios whereby ecological factors could abruptly change resource

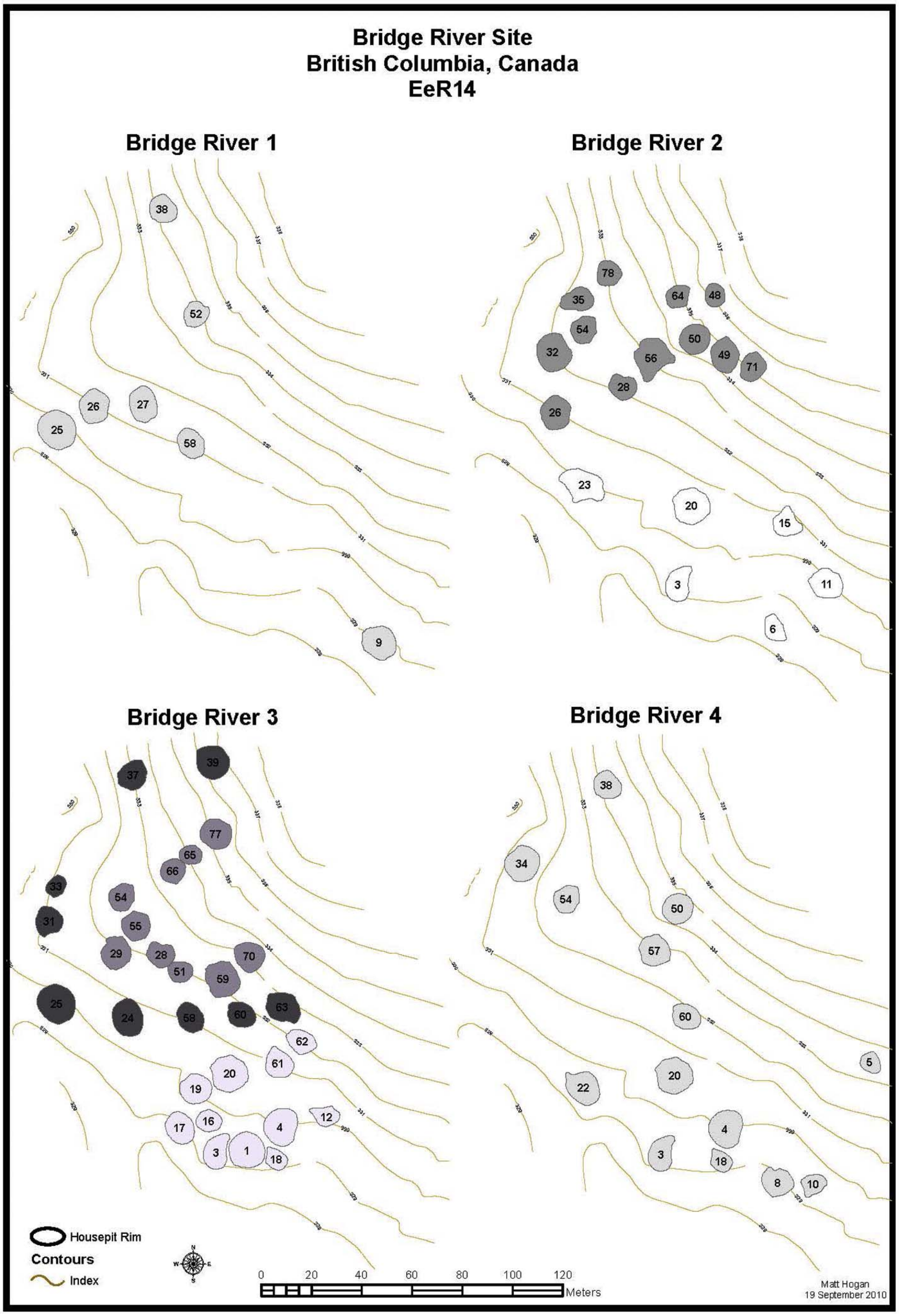

Fig. 2. Bridge River site map illustrating position of Housepit 54 during BR 2 and 3 times as compared to change in overall village.

conditions abruptly affecting the stability of human populations in some ways resembling Malthusian period but skipping entirely the transition. But outside of the most drastic of the latter scenarios (e.g. catastrophic natural process such as disease suddenly destroys critical resource base), Malthusian dynamics would likely remain in play.

Under the Malthusian model we would expect evidence for Puleston et al.'s (2014) three periods as reflected in shifting demography and approaches to subsistence. Thus, with conditions of rising population and productivity we would expect the extent of storage facilities to increase during a copial phase. Entrance into a short Malthusian transition followed by a full-on Malthusian phase would be predicted to include a stabilizing of population growth and depending on severity, the possibility of population decline. In this case we might expect the scale of storage to mirror resource access and household demand. Thus, in a Malthusian phase growth in storage facilities would cease and in the most adverse scenarios it could reverse. However, if groups maintain options for immediate return foraging, it is possible that while investment in storage declines, populations remain stable. Theoretically, an ecological catastrophe scenario could have severe impacts within any of the Malthusian periods and would theoretically be indicated by a sudden and substantial loss of food leading rapid breakdown in society as reflected in population collapse on a sub-generational rate.

2.2. The demographic model at Bridge River

The Bridge River site is a large housepit village intensively occupied during three periods (BR1–3) within the range of ca. 1800–1000 cal. B.P. and again (BR 4) ca. 500–100 cal. B.P. (Prentiss et al., 2008, 2014; Prentiss, 2017a). Analysis of 55 dated housepit floors indicates what appears to be a slow-growth copial phase during the BR 1 period (ca. 1800–1600 cal. B.P.) followed by a likely stable demographic ceiling with an estimated 15–17 co-occupied houses for much of BR 2 (ca. 1600–1350 cal. B.P.). However, during the late BR 2 period (ca. 1350–1300 cal. B.P.) there appears to have been some form of socio-demographic crisis such that all except three houses (Housepits 3, 20, and 54) were abandoned prior to the start of the BR 3 period. At the initiation of BR 3, post ca. 1300 cal. B.P., the village entered a fast-growth copial period, adding 27 new houses over the next 100 years. The trend reversed with the abrupt appearance of a Malthusian phase in mid-BR 3, associated with gradual depopulation of the village leading to full abandonment that lasted several centuries by ca. 1000 cal. B.P. Evidence for village-wide adverse conditions include decline in salmon and deer productivity, emergent inter- and likely intra-household material wealth-based inequality, and steady abandonment of houses beginning with those clearly less well-off as in the case of Housepit 16 (Prentiss et al., 2012, 2014, 2018).

Reduction in salmon access is unlikely to be completely related to over-predation by human groups using pre-modern technologies and thus, subsistence troubles involving salmon could fit to some degree an ecological crisis scenario. However, salmon numbers in the Fraser and Columbia River systems at these dates appear to be correlated with fluctuation in marine fisheries productivity in the eastern Pacific (Hay et al., 2007; Patterson et al., 2005; Tunnicliffe et al., 2001; Wright et al., 2005). If annual salmon runs were of shorter duration and of lowered productivity (c.f. Kew, 1992) during BR 3 times then there would have been greater pressure on human groups to maintain access during those short windows of availability. High populations and increasing control of best fishing places by clan and family groups (c.f. Romanoff, 1992; Teit, 1906) during early to middle BR 3 would have meant that in the worst years some families might not have gained adequate access to those resources with concomitant effects on winter survival and reproductive fitness. High BR 3 populations would likely also have had consequent impacts on other resources inclusive of mammal (Prentiss et al., 2007, 2014) and certain plant resources (Kuijt and Prentiss, 2004). Socio-political demands on the resource base derived from competition between houses via production of goods for exchange and competitive generosity could also have impacted the resource base (Prentiss et al., 2007, 2008, 2012, 2018; Prentiss and Walsh, 2017). Given all of the above it is likely that by mid-BR 3 times some families and house groups would not likely have been able to maintain inter-annual food backups thus leading to the potential for annual winter subsistence crises with associated ramifications for social interactions. Extending this logic one step further, abandonment of houses may have been a logical consequence of food-stressed families seeking alternative subsistence options via increased residential mobility particularly during the winter season. Therefore, we consider it appropriate to focus on the predictions of the Malthusian model (Prentiss et al., 2014) with the caveats listed herein. In developing a test of this scenario we recognize that a single house may not necessarily reflect village- or region-wide developments. Individual houses can be affected by an array of related and unrelated stochastic variables to do with demographics, economics, and socio-political standing (Ames, 2006). However, we do expect the history of a long-lived house to provide insight into the processes of wider village history as it is in this context that demographic, socio-economic and political decisions were actually often made in traditional St'at'imc communities (Teit, 1906).

If intra-house population and subsistence dynamics mirror those of the wider Bridge River village then, all things equal we would expect within long-lived houses a trend that includes stable population and little change in storage practices during much of the BR 2 period followed by coupled decline in household population and storage capacity at the end of BR 2. Then, household population and investment in storage should grow rapidly during a period of < 100 years before declining thereafter (with abandonment by ca. 1000 cal. B.P.). These predictions do not consider the impact of other contingent practices. Development of a feasting tradition during early BR 3 would not be unexpected as evidence for elsewhere in the village points to use of large external roasting ovens after ca. 1300 cal. B.P. and the possibility of feasting events held at select houses (Prentiss et al., 2008, 2012, 2014). Preparation for feasting rituals would have required excess storage beyond minimal annual needs for households (Winterhalder et al., 2015). Acceptance of new house members could temporarily boost populations in households. This would not be unsurprising in a time when other households were suffering economic and demographic failure (Ames, 2006) as might have occurred during late BR2 and mid-late BR 3 times.

To test this model ideally we would examine the history of a long-lived house, in this case, one spanning the BR 2 to 3 periods. We have that opportunity with Housepit 54 given presence of a sequence of 15 intact BR 2–3 floors. Twelve of these are excavated enough to provide insight into these processes between the mid-portion of BR 2 to the later BR 3 period. After establishing the dating history, we focus our analysis on relationships between house population and investment in pit storage. We predict that all things equal, storage and house population should track the wider village history with weakness during the late BR 2 period, growth in early BR 3 and decline during late BR 3.

2.3. *Housepit formation processes*

Traditional St'át'imc winter houses in the Middle Fraser Canyon of British Columbia were semi-subterranean, typically with a substantial post-and beam super structure covered by earth for insulation (Alexander, 2000; Teit, 1900, 1906). Floors were created by either living directly on the original excavated surface or more typically by establishing a layer of clay-silt sediment upon which cooking, heating, storage (cache pits), refuse, and post features were added (Alexander, 2000; Prentiss, 2017b; Prentiss and Kuijt, 2012). Ethnographies suggest that periodically (about every 20 years or so) the wooden roof would need to replaced leading to dismantling and/or burning of the old structure (Alexander, 2000). The debris from the dismantling stage of re-roofing would initially settle on to the top of the temporarily abandoned floor, especially if the roof was burned (Hayden, 1997). Then, owner/occupants of the house (and likely community members) would have the option of either digging out the collapsed/burned roof material and discarding it around the perimeter of the house forming a midden-like rim or simply adding new floor sediments over the previous floor and, if present, collapsed or burned roof sediments and debris. In the former case, this would typically require excavation of not only the old roof but also the previous floor. In the latter, we would expect the previous floor and any roof sediments to be buried by the new floor materials, thus leaving the record of activities on the previous floor substantially intact. Given these formation processes, dating household history should simply be a matter of collecting animal bone or plant materials from discrete features on discrete floors.

If housepit deposits form as a consequence of the excavated floor/roof scenario then it is likely that all archaeologists would find is the final floor as is typical of the Keatley Creek site (Hayden, 1997; Prentiss et al., 2003, 2007). Under the re-flooring scenario where two or more capped floors may be present, it is possible to imagine dating the entire history of the house, as is possible at Bridge River (Prentiss et al., 2008). However, dating Mid-Fraser housepits can be complicated in cases with such long occupation sequences. Excavation of hearths, post-holes and cache pits by occupants at different times may move material of different ages within the sequence. In a continuously reoccupied house floor sequence, middle depth floors would be expected to be most affected given both substantial opportunities for impacts from pit digging by later occupants bringing older material up and younger down. The deepest floors would be less likely to be impacted by the shallowest floors and would also be substantially immune to bias from materials derived from deeper deposits assuming base in sterile substrate sediments. Likewise, most shallow floor deposits would simply have fewer

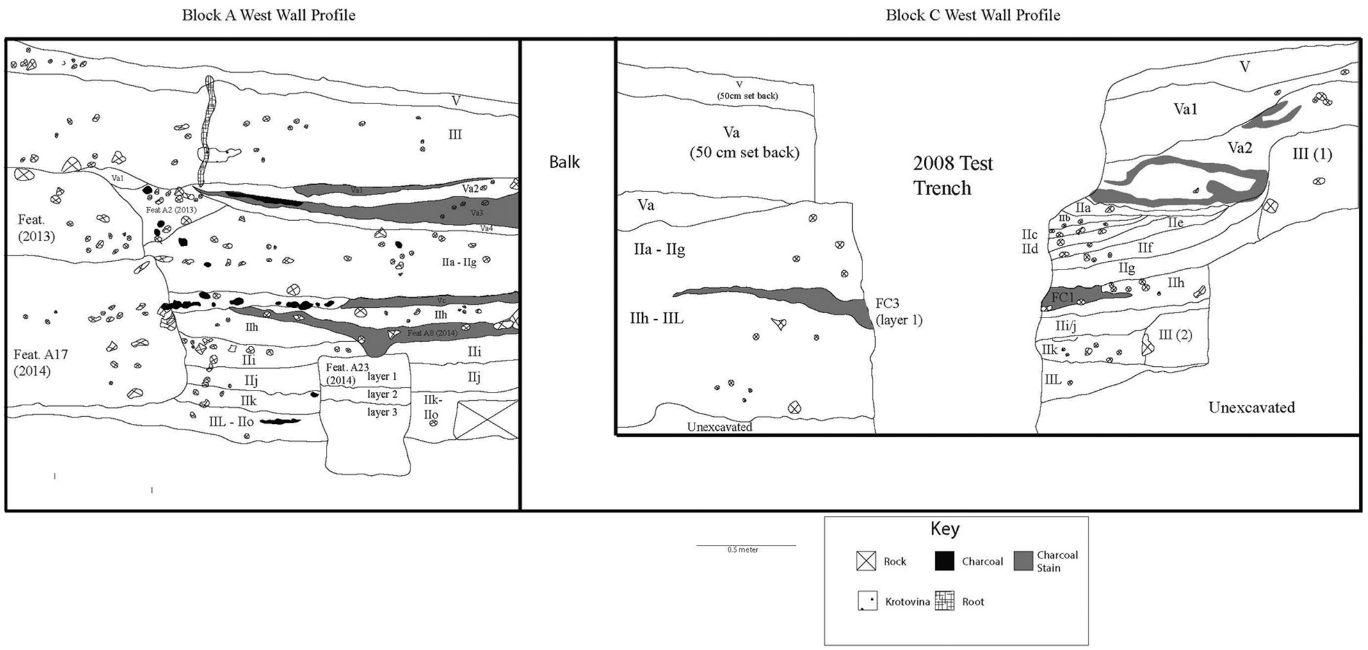

Fig. 3. Profile of west walls for Blocks A and C, Housepit 54. The visibility of individual floor strata varies between profiles and is most obvious on the north end of the Block C west wall and in the lower strata of the Block A west wall.

intersecting pits from other floors dated to different times. Thus, for a continuously occupied house with multiple floors, ideally we would expect to establish a bracketed set of dates defining the period of occupation but with greatest inter-floor inconsistency in middle depths. However, the latter expectation may also be complicated by old wood effects, especially associated with roof beams given the quantity of wood needed to create a layered wooden roof (Alexander, 2000; Teit, 1900) and that the fact that Douglas fir (commonly used in St'át'imc house construction) preserves well in the semi-arid Mid-Fraser context.

2.4. Housepit 54 stratigraphy and floors

Excavations in 2012–2016 of Housepit 54 at the Bridge River site revealed a total sequence of 17 floors and five roof deposits (Figs. 3–4). We used designations "I" for surface, "II" for floor, "III" for rim midden, "IV" for culturally sterile substrate, and "V" for roof. Letters were used to designate progressively deeper floor, roof, and rim deposits. Thus, IIb lies below IIa, which is in turn deeper than II, the latter dated to Fur Trade times (Prentiss, 2017b). Our focus here is on the IIa-IIo sequence. Roof sediments are relatively unconsolidated with relatively high percentages of pebble and cobble-sized clasts and tend to have high quantities of charcoal that include fragments of burned beams and sometimes, mats along with abundant fire-cracked rock (FCR) and lithic artifacts. Faunal remains are present though they tend to be in poor condition given damage for mechanical action and fire. Floor sediments are highly compact and contain high percentages of clay, followed by silt and gravel sized clasts. Most notably, floors contain abundant small artifacts and animal bones, especially those of fish, particularly at each floor surface. While individual roof and floor strata are easily distinguished on both macroscopic and microscopic scales, within-stratum bedding is difficult to distinguish due to effects of insect and plant root bioturbation (Goldberg, 2010).

The Housepit 54 excavation was organized in four 4 × 4 m block areas, each containing 16 1 × 1 m units, with each of those containing four 50 × 50 cm quads (Fig. 5). The deepest floors (IIm-o) are only found in Block A and represent the earliest and spatially smallest iterations of Housepit 54 (Fig. 6). Floors IIl to IIf, present in Blocks A and C represent the establishment and persistence of a larger and likely, rectangular-shaped house (Fig. 7). Floors IIe to IIa are present in all blocks and result from a significant expansion in house size that established the oval house form visible on the site surface (Fig. 8). Stratum IIa1 is a small floor remnant containing a hearth feature found only in the northeast corner of Block D, located above the Va roof but below the stratum II Fur Trade period floor. Much of this floor appears to have been removed by stratum II occupants (Prentiss, 2017b).

Given the well-established floor sequence at Housepit 54 it is appropriate to next ask whether formation processes varied between floors and whether the sequence is continuous or interrupted by periods of abandonment. Our focus in this paper is not on artifact and faunal assemblage content and thus, we post-pone a detailed answer to the question of variation in abandonment process (e.g. Brooks, 1993; Deal, 1985; Schiffer, 1972, 1983; Stevenson, 1982, 1985). However, we do note that every excavated floor in Housepit 54 contains one or more hearth centered activity areas (often with associated cache pits) that includes a range of items from extra-small sized (< 0.5 cm^2) debitage and bone fragments to a wide range of larger flakes, lithic and bone tools, and faunal remains. Given this background and the fact that nearly all tools are broken and/or otherwise exhausted it is clear to us that re-flooring was typically preceded by an orderly abandonment process typical of groups not expecting to return to live on those particular surfaces given that those floors were to be capped by new sediments.

There are two stratigraphic reasons why it is likely that the IIo-IIa floor sequence is continuous. First, there are no non-cultural paleosol sediments reflecting periods of abandonment and accumulation of organics from stable vegetative growth. Second, as noted above, cultural materials on each floor are diverse including fragile fish bones and spatially distributed typically in association with hearth features suggesting that each floor was simply capped without major cleanup and removal at the end of each occupation cycle. Roof materials below the IIa floor are limited to spatially discrete clusters of beams and roof mat materials implying that roofs were generally removed without significant burning, though occasionally remnants were burnt and simply capped by the next floor leaving underlying floor materials intact. The Va roof, capping much of the IIa floor, clearly marks a major ending to the occupation of Housepit 54 as it appears to have been burned substantially in situ leaving significant sedimentary deposits (Figs. 2 and 3).

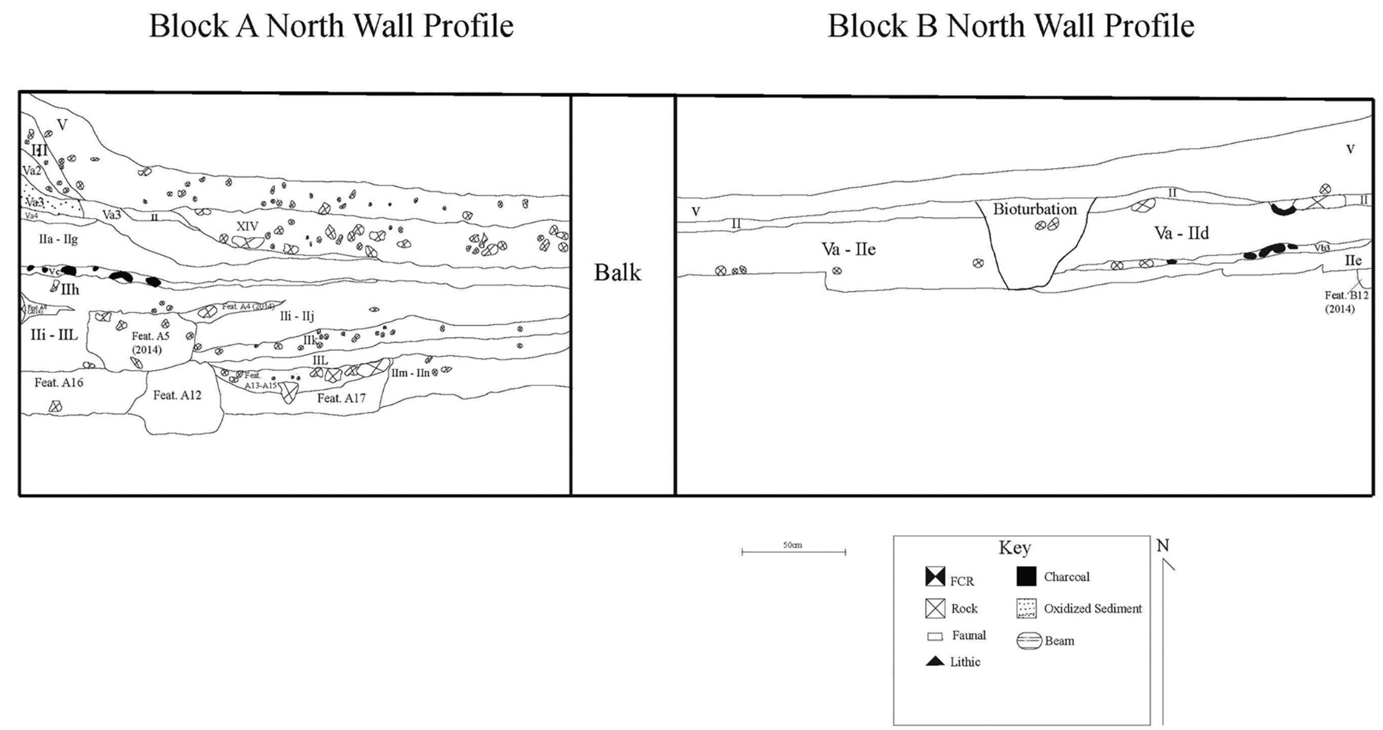

Fig. 4. Profile of north walls for Blocks A and B, Housepit 54. As in Fig. 3, individual floor strata are more obvious in profile within some contexts (e.g. lower Block A) than others (IIa–IIg floors).

3. Analyses and results

3.1. Dating Housepit 54

Samples for radiocarbon dating were identified and collected during excavations at Housepit 54. We chose wood charcoal from hearth features excavated in situ on floors whenever possible though occasionally samples were derived from roof beams, one house post (wood cellulose), and one birch bark fragment (Table 1). Wood charcoal in hearth contexts was consistently highly fragmentary and thus, it was not generally possible to preferentially choose twigs over other wood fragments. A total of 30 radiocarbon samples spanning all floors and several roofs from Housepit 54 were submitted for dating at DirectAMS using the AMS technique. Treatment at the lab followed standard methods (Brock et al., 2010.) and included correction for isotopic fractionation using $\delta(^{13}c)$ values measured on prepared graphite. Two samples derive from mid-19th century contexts and are described elsewhere (Prentiss, 2017b). Of the remaining 28 dates, an additional two (7508 and 7961) are clearly out of stratigraphic position and were thus excluded due to likely old wood bias (Table 1). The remaining 26 dates were then calibrated using the OxCal 4.3 (Bronk Ramsey, 2009), using the IntCal 13 curve to obtain probable age ranges.

Results of calibration at a 95% confidence interval are presented in Fig. 9 (Table 2). These outcomes clearly illustrate a tight date range spanning 1461 to 1115 cal. B.P. (IIn to IIa) based upon mean values. In general, the date distribution mirrors expectations with the most minimal inter-stratum variation in the deepest and most shallow contexts. The IIa1 floor remnant appears to date slightly later with a calibrated mean of 963 cal. B.P. Date 7959 is the most substantially out of stratigraphic order with a mean of 938 cal. B.P. It is possible that the charcoal used for this sample could have originated in stratum IIa1. We did not engage in further modeling of boundaries and phases in OxCal (e.g. De Souza et al., 2016; Kennett et al., 2014; Overholtzer, 2015; Thakar, 2014) given the short accepted distribution for IIa-IIo, the stratigraphic integrity of the floor and roof deposits, and the degree of inter-floor variability within the overall range. With an estimated 346 year range for the formation of the IIa-IIo floor sequence, we can project that on average each floor was occupied for approximately 23 years, close to ethnographic expectations for standard use life of a traditional Mid-Fraser roof superstructure (Alexander, 2000). If this is the case, then floors IIa-IIg likely fall solidly within the BR 3 period, while the IIi-IIo floors were probably occupied during BR 2. Floor IIh lies on the boundary between the two periods and it is interesting that this floor was initiated with a brief incident involving creation and use of roasting ovens covering a large percentage of the floor space (Fig. 7).

3.2. Demography

In order to examine the Bridge River Malthusian model from a single house perspective it is critical to estimate inter-floor variation in population. A number of archaeologists have sought to project archaeological floor areas to estimated house population sizes (Casselberry, 1974; Curet, 1998; Kolb, 1985; Le Blanc, 1971; Naroll, 1962). Hayden et al. (1996) make the important observation that most previous studies estimate households in temperate climates that tend to favor more space per person (thus, Naroll's "constant" of about 10 m per person [Chamberlain, 2006]) than in colder environments where population packing is useful for helping to heat winter dwellings. Drawing upon a range of ethnographic examples from northern North America and Siberia, Hayden et al. demonstrate that density varies from about one to five square meters with an average of $2.2\,m^2$ per person. They point out that estimates for traditional Canadian Plateau house populations vary somewhat (e.g. one [Nastich, 1954], two [Hill-Tout, 1899], and nearly three [Teit, 1900] square meters per person) but these sources are not entirely reliable. Consequently, they develop an archaeological model linking numbers of hearth groups with an assumption of an average of five persons per family to project about three to four meters per person at a large housepit at the Keatley Creek site.

We can make an initial estimate of variation in the Housepit 54 populations over time by dividing floor area by some constant. Since numbers undoubtedly varied and given that we do not need anything more than a heuristic projection we chose two meters per person as it is

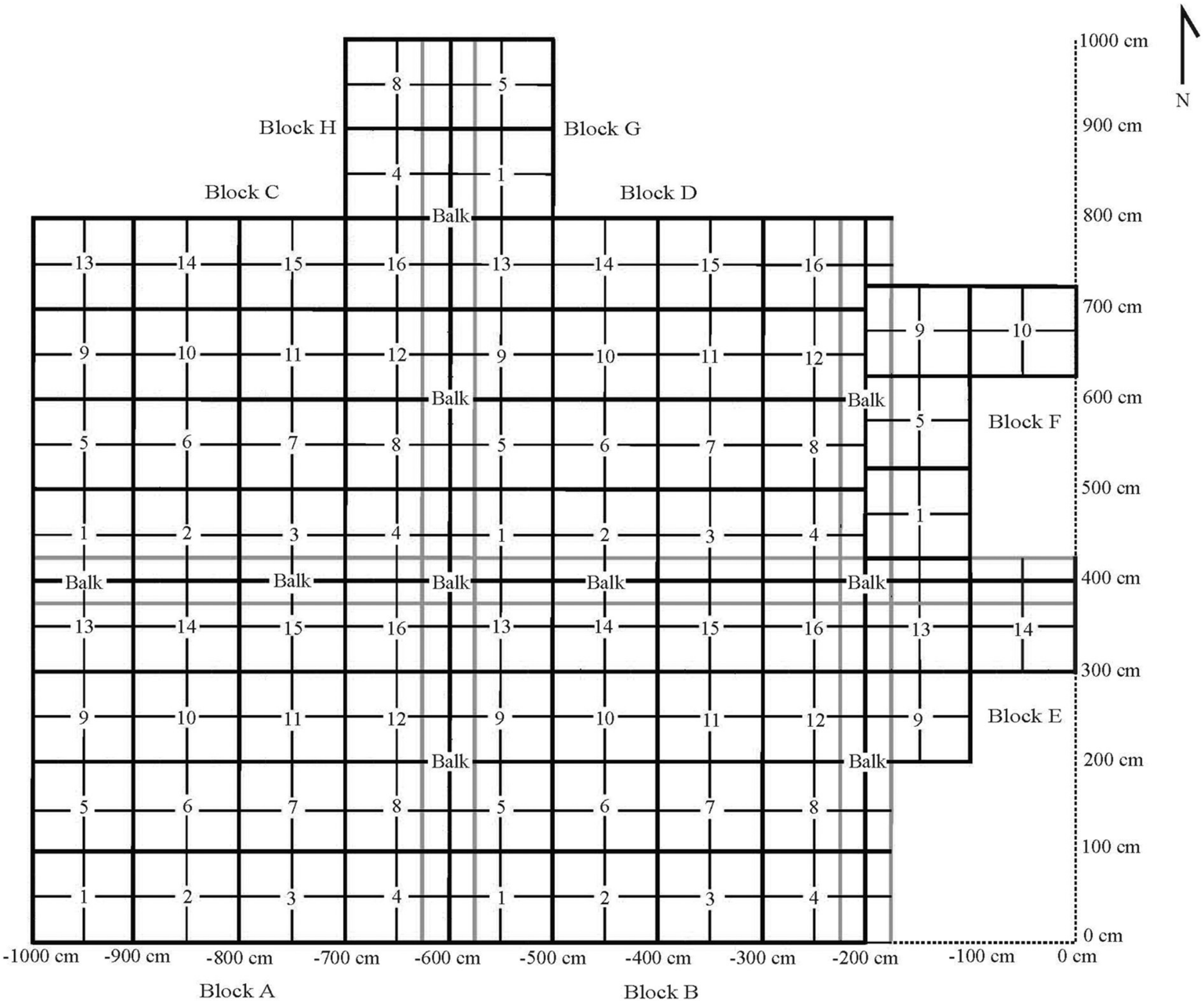

Fig. 5. Housepit 54 excavation grid system.

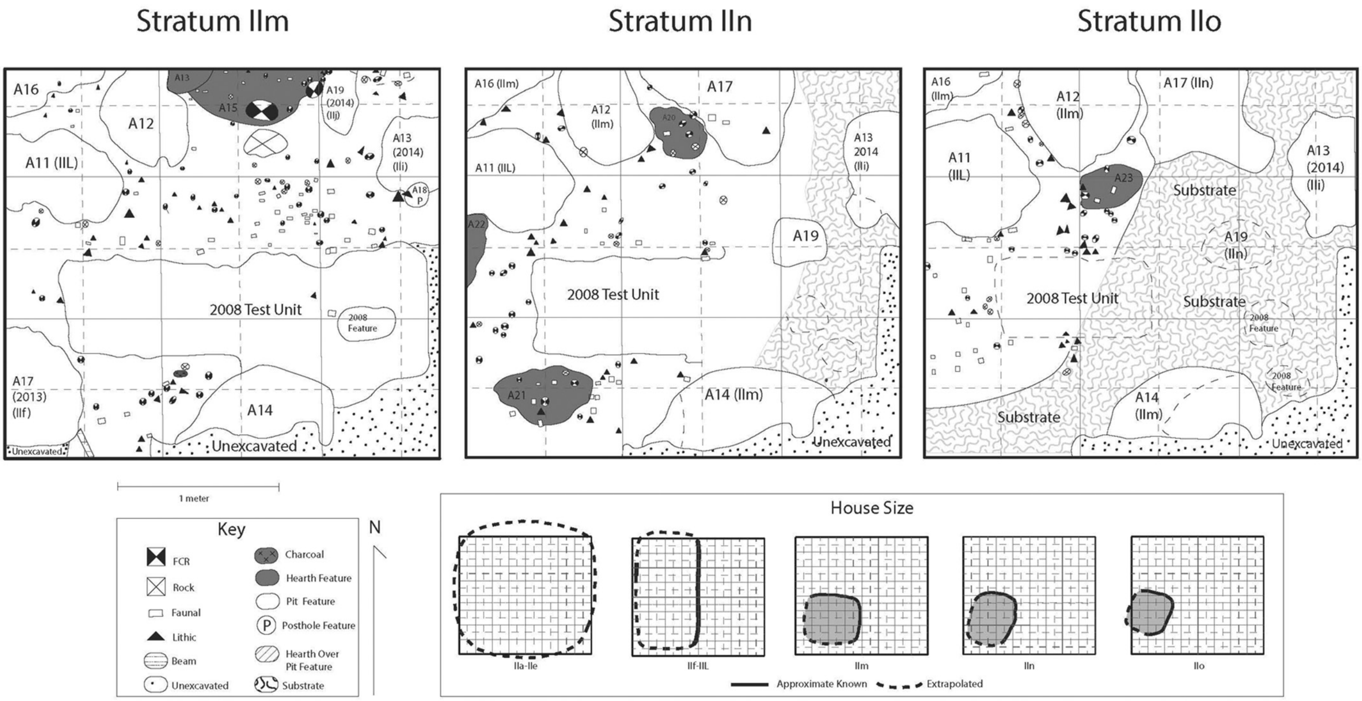

Fig. 6. Plan views of the three earliest floors (IIm-o) in Housepit 54.

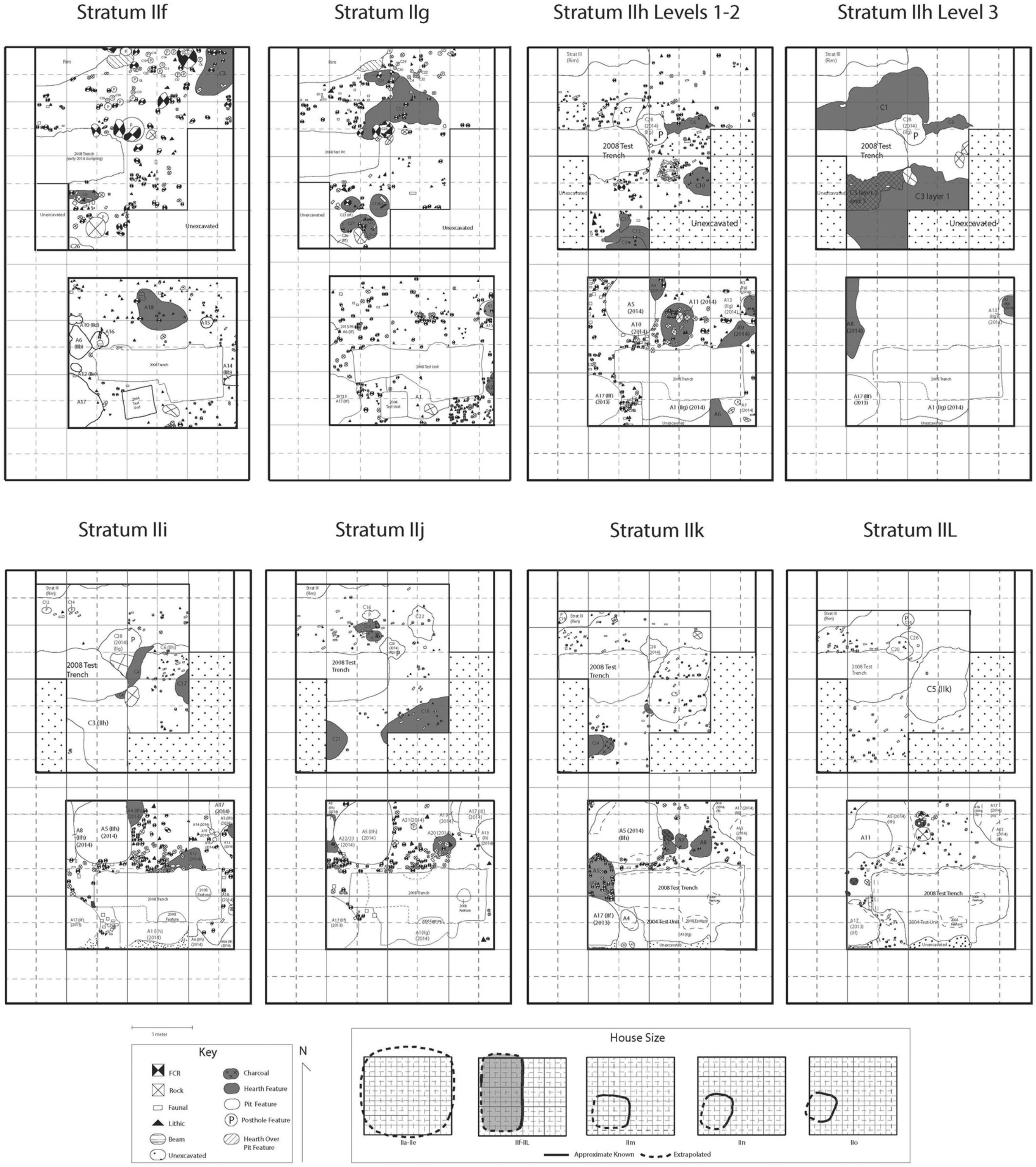

Fig. 7. Plan views of floors IIf-l in Housepit 54.

close to the Hayden et al. (1996) ethnographic mean and seems also an average number for Canadian Plateau houses. We calculate house floor area as the area encompassed by our excavation blocks associated with the three stages in the growth of Housepit 54. Thus, for IIm-o we are limited to Block A (16 m^2). Floors IIf-l reflect the larger rectangular house and thus Blocks A and C (32 m^2). Finally, floors IIa-e represent the final full-sized house with all blocks represented (64 m^2) with the exception of IIa in which the Block D area was converted to a refuse deposit zone. Results (Table 3, Fig. 10) indicate a not surprising pattern of stepped growth due to the expansions in space that developed as Housepit 54 grew. These results suggest the possibility the Housepit 54 twice doubled its population size.

The meters per-person approach is useful in that it provides us with a crude projection of ideal population sizes for each floor based upon previously stated empirical assumptions. However, this approach fails to provide us with a nuanced estimate of population sizes that is

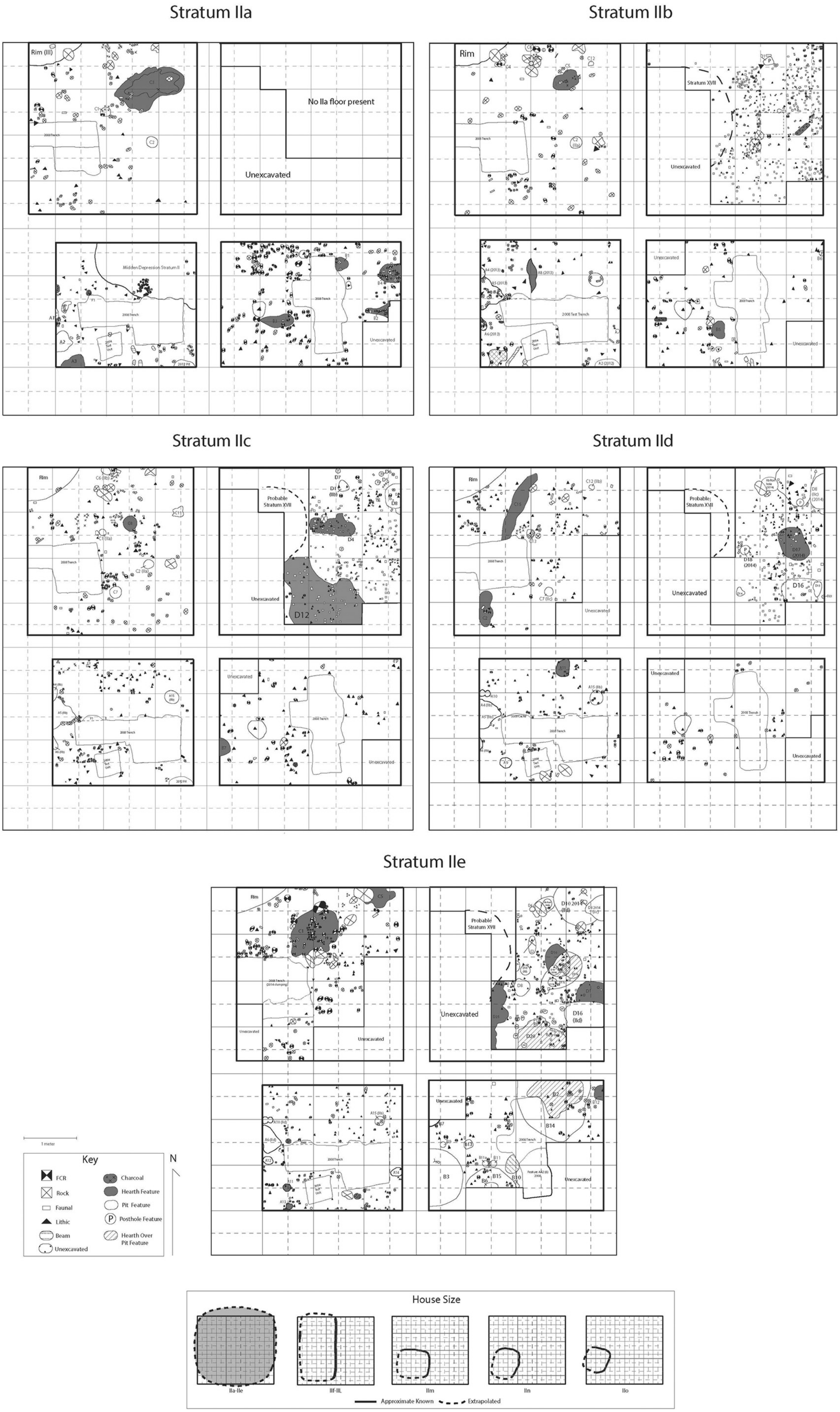

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Fig. 8. Plan views of floors IIa-e in Housepit 54.

Table 1
Radiocarbon record for Housepit 54. All are charcoal dates from hearth features unless noted.

Direct AMS number	Stratum	Stratigraphic order	Feature/ source/year exc.	Uncal. date	1 Sigma error	δ(^{13}c)
2804	IIa1	1	D2(2012)	1047	31	−26.9
3431	Va	2	RB(2013)[a]	1252	21	−8.6
3429	Va	2	RB(2013)[a]	1299	21	−16.7
2011-1	IIa	3	HP (2008)[b]	1173	25	N/A
7496	IIa	3	C3(2014)	1212	23	−22.4
3430	Vb	4	RB(2013)[a]	1390	23	−13.6
7498	IIb	4	B8(2013)	1295	28	−23.2
7499	IIb	4	C5(2013)	1199	26	−26.1
7500	IIc	5	B9(2013)	1273	26	−26.1
7497	IIc	5	D4(2014)	1220	26	−22.8
7501	IId	6	A11(2013)	1339	23	−22.1
7502	IIe	7	B12(2014)	1268	25	−23.9
7503	IIe	7	C2(2014)	1391	26	−20.2
7504	IIe	7	A13(2013)	1204	18	−25.2
7505	IIf	8	A18(2013)	1400	22	−18.3
7506	IIg	9	A2(2014)	1228	22	−21.1
7959	IIg	9	C27(2014)	1010	26	−18.0
7507	IIh	10	A6(2014)	1348	25	−21.0
18722	IIh	10	C3L1(2016)	1539	25	N/A
18723	IIh	10	C3L3(2016)	1560	30	N/A
7508	IIi	11	A12(2014)	2257	31	−21.7
7961	IIi	11	BB(2014)[c]	2188	27	−20.3
7960	IIj	12	A22(2014)	1299	27	−23.8
18724	IIk	13	A7(2016)	1487	30	N/A
18725	IIl	14	A10(2016)	1541	21	N/A
18726	IIm	15	A15(2016)	1555	30	N/A
18727	IIn	16	A22(2016)	1561	26	N/A
18728	IIo	17	A23(2016)	1502	51	N/A

Notes: N/A means not available.
[a] Burned roof beam.
[b] Unburned house post.
[c] Unburned birch bark fragment.

substantially independent of house area. In order to provide the latter we developed an approach based upon fire-cracked rock (FCR) density per floor. Traditional cooking within Canadian Plateau households was typically accomplished by stone boiling and roasting within or over shallow hearths (Alexander, 2000; Prentiss and Kuijt, 2012). It is logical to assume therefore that the more people present the greater investment in cooking activities that generally required hot rocks (stone boiling and within-hearth roasting). Prentiss et al. (2012) found a correlation between relative cache pit volume and FCR density with a multi-housepit sample from the Bridge River site implicating broad relationships between food storage and cooking rates. Thus, a simple plot of FCR density between floors provides a first approximation of possible population dynamics (Table 3, Fig. 11).

Given that FCR densities can be affected by rates of cleanup and discard along with variation over time in preferred cooking procedures (e.g. roasting versus stone boiling), it is useful to cross-check these results with an independent though related measure. To accomplish this we calculated total hearth volume for each floor and plotted the results against the FCR density results (Table 4, Fig. 11). Variation in total hearth volume could also be expected to be impacted by differences in preferred approaches to cooking and heating (Alexander, 2000). Total volumes could also be impacted by variation in approach to the use of space for such activities given that variation could occur if occupants choose to reuse one large central hearth or to create and use several smaller hearths. Nonetheless, all things equal, more people require more cooking, should mean greater investment in hearth volume with population growth and the reverse in decline situations. Results are approximately similar to the trends recognized for FCR density as hearth volumes rise through IIg and drop after IIe. Varying from the FCR pattern, IIg has the highest density followed by a low during IIf. The IIg floor has a particularly expansive hearth and multiple smaller hearths, whereas, while spatially similar, IIf includes fewer hearths and a slightly smaller major hearth at its north end.

FCR density is clearly not a direct measure actual numbers of persons per floor. However, we can project an estimate of population by creating a divisor against FCR densities drawing from a number of ethnographic and archaeological assumptions (Table 5). First, we assume 20 years of occupation per floor. This is now approximately supported by both the ethnographic record (Alexander, 2000) and archaeological data from Housepit 54. Second, based upon ethnography, we assume people resided in winter houses for up to four months per year (Alexander, 2000; Teit, 1900, 1906). On a typical winter day two meals were prepared (Teit1906). Boiling is then assumed to have been accomplished with five rocks that were recycled across 15 cooking events. The latter requires further experimental testing but for now simply serves as a constant in our calculations. Then, 50% of the discarded rocks were removed from the floor to be discarded on the roof or rim of the house as suggested by the floor to roof ratio of FCR counts from Housepit 54 during the Fur Trade period (Prentiss, 2017b). Finally, these estimates are divided by five persons per hearth group (Hayden et al., 1996). Examination of hearth distributions across the Housepit 54 floors suggests variation ranging from one to four hearth groups. Clearly, there are many reasons why these calculations could be off when considered on a daily, seasonal, or even annual basis. However, the predictions could still be relatively accurate when we consider human behavior averaged across years to decades. Regardless, these estimates provide us with a population heuristic specific to the Mid-Fraser context and more specific than what is available with the square meters per person approach.

When we calculate population per floor based upon this system (Table 3, Fig. 11) we recognize a general pattern of growth from the small early floors to a peak on the IIe floor coinciding with the first occupation of the fully expanded house. Despite some variability in scores the overall pattern from IIo to IIe is not that different from that depicted using the square meters per-person approach. Clearly there are expansions in house population between the smallest (IIm-o) and mid-sized rectangular house (IIf-l) and then again at the advent of the full sized house (IIe). However, the FCR density model departs from the square meters projection by indicating a major drop in numbers of house occupants on the IIc and IId floors before a late rise on IIa-IIb. The latter drop in household population comes at the time when the entire village had likely peaked and begun to decline (Prentiss et al., 2014). Interestingly, however, there is no obvious drop in numbers during the late BR 2 period, which likely would have been on the IIi-k floors. An implication is that while most houses were being abandoned at this time, Housepit 54 likely remained somewhat stable at least from a demographic standpoint.

3.3. *Storage*

Traditional households in the Mid-Fraser Canyon area used a variety of storage technologies including boxes, baskets, bags, above ground platforms of various configurations, cache pits, and even sticks and strings strung with dried/roasted geophytes as buffers against intra- and possibly inter-annual risk of food shortage during winter months (Alexander, 2000; Prentiss and Kuijt, 2012). Of these varied approaches to storage, only cache pits are easily recovered archaeologically. Cache pits were constructed inside and outside of houses and used to store dried plant and animal foods including roots, berries, and fish (Alexander, 2000; Hill-Tout, 1899; Teit, 1900, 1906). External cache pits were designed as deep pits (up to nearly two meters deep) covered

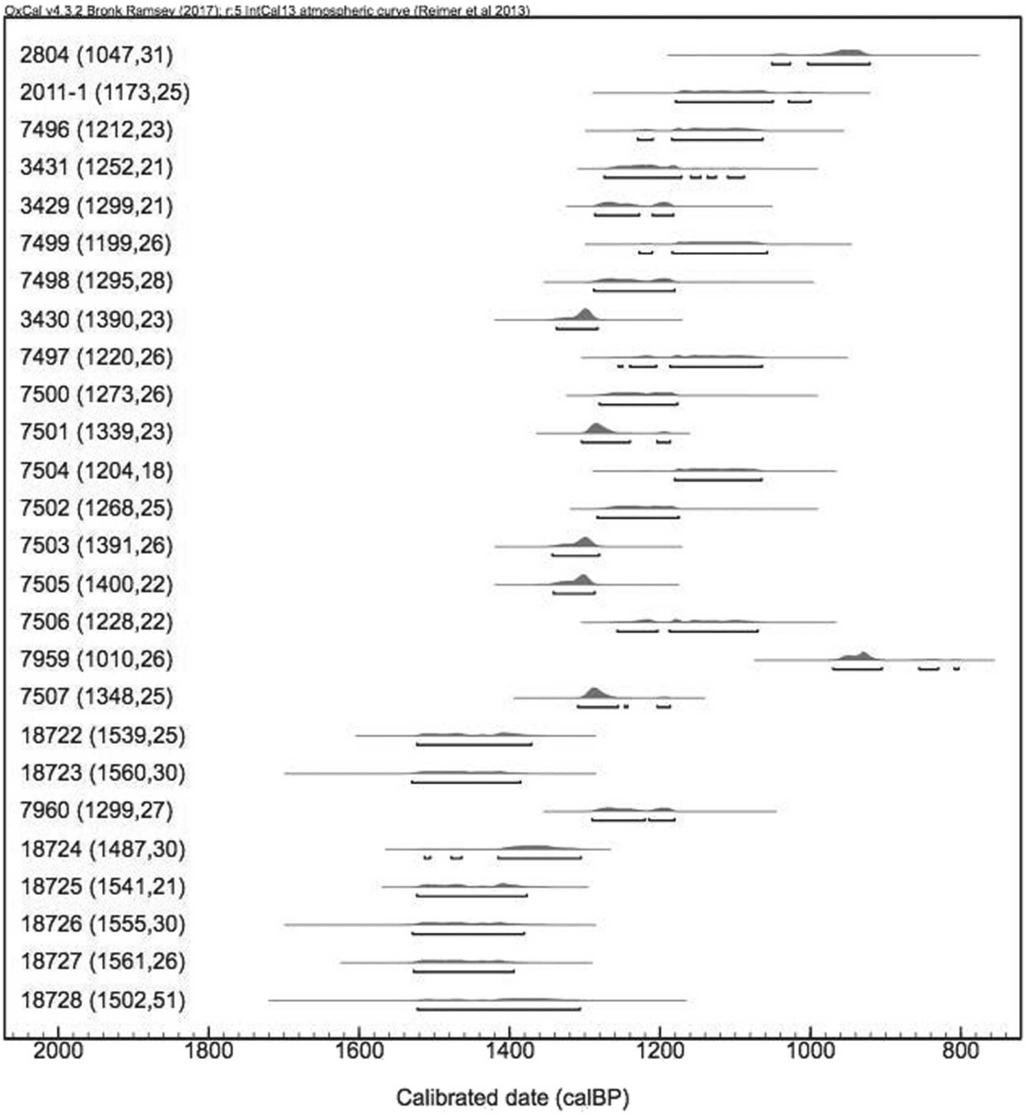

Fig. 9. Radiocarbon sequence for Housepit 54 floors illustrating results of Bayesian modeling at a 95% confidence interval.

in timbers, bark, grass, and soil and lined maple sticks, birch bark, or grass. Food to be stored in these contexts was wrapped and/or layered with birch bark (Alexander, 2000). These efforts helped to reduce the adverse effects of mold and insects. Ethnographers suggest that some pits were designated for storing food expected to be used while others were in effect insurance caches containing surplus (Teit, 1900, 1906). Alexander (2000) argues that external cache pits may have often been favored over above ground storage facilities as they preserved food better and could be hidden from thieves. Internal cache pits tended to be shallower with reduced investment in external protections (e.g. timbers). Being inside they were also inevitably closer to hearth features and warm air in general as compared to the cold winter conditions external to houses. Thus, it is likely that internal cache pits were more typically used for shorter term storage relying upon food transferred from external storage features from within villages or as far away as procurement locations (Alexander, 2000; Romanoff, 1992). Because of this, we suggest that internal cache pit volume is particularly sensitive indicator of abundance in keystone food resources.

Cache pits were excavated in every floor within Housepit 54 except IIa (Figs. 3–4, Fig. 12). They vary in depth from approximately 50 cm to over a meter; width is equally variable. Shapes range from cylinders to bell forms. Cache pit stratigraphy varies with many pits containing one or more layers of unconsolidated refuse that includes abundant FCR, lithic tools, debitage, food remains, and birch bark rolls. Clearly these pits were filled with what is likely refuse from cleaned domestic activity areas implying that once their storage role had ended they were converted to refuse pits. A more limited number of pits contained micro-bedded clay-dominated sediments and relatively limited quantities of all cultural materials. To date, we have interpreted these features as pits recycled multiple times with layers of clay added intermittently eventually filling the pit.

We quantified pit storage by calculating pit volume from excavated portions only. Thus, in a few limited cases we underestimate total pit volume for some floors. The eastern margin of a cache pit from the IIa floor in Block A was identified only in the wall profile (Fig. 3). Very little of this feature was present in the excavation block (perhaps a 1 to 2 cm veneer) and consequently it was not formally designated in the feature record. Feature B14 (2014) on IIe was sample excavated. Feature AA2, 6 (2008) also on IIe, was test trenched though at the time it was thought this was a deep rim deposit. Its actual depth and width are still not clear and thus it was excluded from this analysis. Feature C5 (2016) from IIk was sample excavated. Feature A1 (2014) from IIg was partially excavated in a 2008 test trench and then completed during 2014. We use the more reliable data from 2014 in these calculations and present all feature volume data in reference to excavated floor volume to control for scale of occupation and potential reoccupations

Table 2
Calibrated date ranges for Housepit 54 floor and roof deposits.

Lab#	Stratum	Highest probability	Mean
		Range	
2804	IIa1	1004–921 (87%)	963
3431	Va	1274–1172 (89.6%)	1223
3429	Va	1287–1228 (63.8%)	1258
2011-1	IIa	1179–1050 (87%)	1115
7496	IIa	1184–1064 (88.1%)	1124
3430	Vb	1338–1283 (95.4%)	1311
7498	IIb	1288–1181 (95.4%)	1235
7499	IIb	1184–1058 (92%)	1121
7500	IIc	1281–1177 (95.4%)	1229
7497	IIc	1187–1065 (78.1%)	1126
7501	IId	1304–1240 (89.2%)	1272
7502	IIe	1283–1175 (95.4%)	1229
7503	IIe	1343–1281 (95.4%)	1312
7504	IIe	1181.1065 (95.4%)	1123
7505	IIf	1342–1287 (95.4%)	1315
7506	IIg	1188–1070 (65.9%)	1129
7959	IIg	970–905 (88.7%)	938
7507	IIh	1309–1256 (90.7%)	1283
18722	IIh	1523–1371 (95.4%)	1447
18723	IIh	1530–1386 (95.4%)	1458
7960	IIj	1290–1220 (63.9%)	1255
18724	IIk	1415–1305 (93%)	1360
18725	IIl	1523–1377 (95.4%)	1450
18726	IIm	1529–1381 (95.4%)	1455
18727	IIn	1528–1394 (95.4%)	1461
18728	IIo	1523–1307 (95.4%)	1415

Table 3
Data for two approaches to projecting housepit population. Fire cracked rock (FCR) counted in cobble and pebble sizes.

Square meters per-person				FCR model			
Floor	Square meters	Population estimate	FCR count	Excavated floor volume	FCR count/ floor vol.	NH	Population estimate
IIa	64	32	1736	1.3	1331	4	33
IIb	64	32	1415	1.24	1142	4	29
IIc	64	32	1199	0.93	1292	3	24
IId	64	32	1303	1.07	1220	3	23
IIe	64	32	1460	0.83	1756	4	44
IIf	32	16	1229	0.72	1704	3	32
IIg	32	16	623	0.6	1038	3	19
IIh	32	16	1153	0.92	1249	2	16
IIi	32	16	373	0.57	650	2	8
IIj	32	16	322	0.39	819	3	15
IIk	32	16	534	1.31	409	2	5
IIl	32	16	338	0.52	650	2	8
IIm	16	8	148	0.23	646	1	4
IIn	16	8	82	0.15	535	1	3
IIo	16	8	90	0.15	588	1	4

NH = number of hearth-centered activity areas.

reflected within any single floor. Thus, we present pit volume on a per capita basis.

Results (Table 6, Fig. 13) indicate substantial investment in storage during middle BR 2 times (IIl) that shifts to more limited storage during late BR 2 (IIi-IIj). The trend abruptly reverses in early BR 3 times (IIh-IIh) and peaks on the IIe floor. After this point the trend reverses again leading finally to zero storage volume on the IIa floor. We recognize however that there likely is at least one small cache pit in the southwest corner of Block A on IIa. If that is the case then the actual storage volume from IIa might have been slightly higher though by no means substantial. Slight under-estimations of total per-floor cache pit volume on IIe, IIg, and IIk imply that the pattern recognized in Fig. 12 is likely even more stark than our depiction suggests. Finally, although not expressed in Table 6 and Fig. 13, floors IIm and IIn may represent small houses with substantial investment in cache pit volume (Fig. 6), thus also strengthening our argument.

This pattern effectively replicates what we currently understand about the village-wide demographic history (Prentiss et al., 2008, 2012, 2014). It is also close to our projected demographic history of Housepit 54, though not an exact fit. Given these patterns it seems likely that the history of investments in cache pit creation and use could reflect variation in ability to set aside food stores perhaps as affected by environmental variation (Prentiss et al., 2007, 2014). However, we recognize that we cannot control for every possible scenario that could equally explain variability in cache pit volume across time at Housepit 54. While we think these are less likely we recognize that reduction in storage pit capacity could also be affected by idiosyncratic factors like insect infestations, exploration of alternate storage strategies, and cost-benefit decisions against investment in food storage. Regardless, we argue that our data have implications for our understanding of demography, social change, and household history.

4. Discussion

The Malthusian model at Bridge River suggests that the process by which social change occurred was underlain by a more fundamental demographic process (Prentiss et al., 2014). The BR 2 period was likely for much of its time a stable demographic ceiling socially characterized by relatively egalitarian relations as measured from standpoints of house size differences, wealth/prestige items, and access to non-local lithic raw materials (Prentiss et al., 2018). Eventually these stable conditions appear to have entered a short-lived Malthusian phase that led to the abandonment of nearly all BR 2 houses for a short time. However, before complete abandonment, subsistence resource conditions must have improved tremendously as there was a rapid engagement in house construction eventually forming two arrangements of houses resembling neighborhoods during the early BR 3 period. This rapid growth period was brief and replaced by a persistent Malthusian transition and ceiling period that included emergent wealth-based inequality.

The record of storage from Housepit 54 supports the Malthusian scenario given decline in relative cache pit volume during late BR 2 floors, dramatic increase in early BR 3, and finally relatively steady decline in the later BR 3 floors. It implies that within this long-lived house degree of reliance on storage may have been affected by resource conditions impacting the entire village. Unlike most houses however, Housepit 54 was not abandoned during the late BR 2 period but rather, persisted despite an apparent drop in reliance upon storage. Although we are not prepared to evaluate this yet, these results raise the possibility that house members increased their reliance on greater numbers of immediate return resources, thus permitting them to get by without heavy reliance on stored foods, at least those that would have been staged in short-term use pits within the house. The storage record from the later BR 3 floors also implicates the more adverse and long-term effects of the second Malthusian period in which Housepit 54 membership may have once again engaged in greater immediate-return procurement tactics and perhaps for a short-term even added members as indicated by our demographic projections. However, the BR 3 Malthusian period was evidently more persistent and severe and evidence from the wider region suggests that many villages were impacted (Kuijt and Prentiss, 2004; Prentiss and Kuijt, 2012; Prentiss et al., 2007, 2014). Evidently, Housepit 54 was abandoned for perhaps a century or more before a short reoccupation just under 1000 cal. B.P. as represented by the IIa1 floor. The house was not re-used again until the 19th century (Prentiss, 2017b).

Drawing in part from Gallant (1991), Ames (2006) argues Pacific Northwest households went through inevitable cycles from establishment and early growth to demographic maturity and decline. He notes that small houses with limited membership (e.g. one extended family)

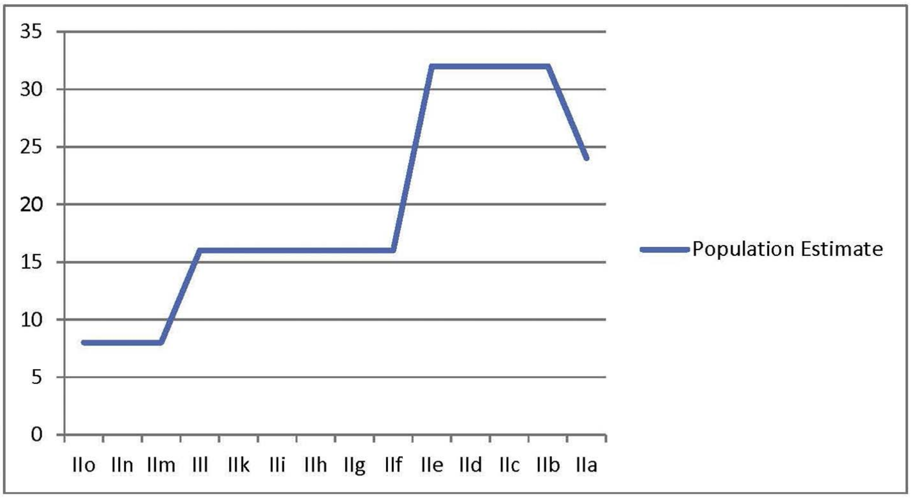

Fig. 10. Population estimate for floors of Housepit 54 based upon a 2 m^2 per person constant.

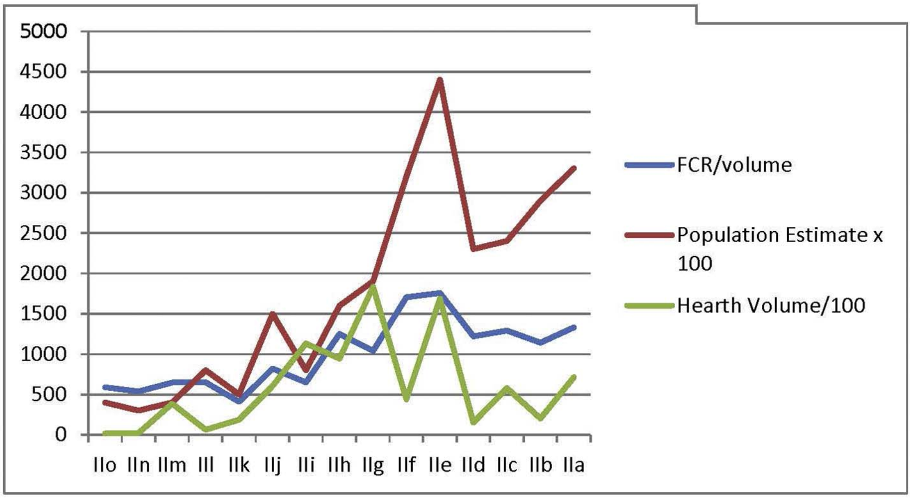

Fig. 11. Relative (hearth volume and FCR density) and projected (population estimate × 100) estimates of populations across the floors of Housepit 54.

Table 4
Hearth volume data per floor in cubic cm.

Floor	Total hearth volume
IIa	71,055
IIb	20,140
IIc	57,682
IId	15,238
IIe	168,780
IIf	43,807
IIg	183,240
IIh	94,306
IIi	113,134
IIj	60,448
IIk	18,462
IIl	6304
IIm	38,718
IIn	2132
IIo	1485

Table 5
Procedure for calculating FCR divisor to estimate house floor population.

1. 20 years per floor
2. 365 days × 20 years = 7300
3. 33% occupation per year = 2409
4. Two cooking events per day = 4818
5. ×5 rocks = 24,090
6. /15 (recycling across fifteen events) = 1606
7. /2(50% removed to roof) = 803
8a. /5 (1 hearth × 5 people) = 160
8b. /10 (2 hearths × 5 people) = 80
8c. /15 (3 hearths × 5 people) = 54
8d. /20 (4 hearths × 5 people) = 40

were most susceptible to factors favoring decline and abandonment while large houses with multiple families were more likely to be buffered against some economic and demographic variance. He suggests that persistence would typically be dependent upon risk-averse subsistence economies and household recruitment to sometimes make up for losses. Ames' (2006) model is largely in line with the predictions of Winterhalder et al. (2015) in asserting that storage would be a critical and risk-averse component of such a household economic strategy. But as we have pointed out, Winterhalder et al. also predict that a series of bad years could deplete backup storage and thus for storage-oriented groups, intense dependence upon storage could lead to even more severe demographic consequences. This scenario could in effect represent Ames' maturity and decline scenario. Our data suggest that Housepit 54 suffered two down-trending food storage periods. The first, in late BR 2 times, did not reach the zero-storage point and demographically, the house persisted. However, the second downward trend eventually did reach the point of near zero pit storage and it would appear that was

Fig. 12. Partially excavated cache pit with surrounding post-holes from IIe floor in Block D of Housepit 54.

Table 6
Data for calculation of relative cache pit volume per floor. Volumes calculated in cubic meters.

Floor	Cache pit volume	Floor volume	Cache pit volume/floor volume
IIa	0	1.3	0
IIb	0.51	1.24	0.41
IIc	0.6	0.93	0.64
IId	0.68	1.07	0.64
IIe	1.1	0.83	1.32
IIf	0.67	0.72	0.93
IIg	0.62	0.6	1.03
IIh	0.72	0.92	0.78
IIi	0.23	0.57	0.41
IIj	0.24	0.39	0.61
IIk	0.84	1.31	0.64
IIl	0.5	0.52	0.96

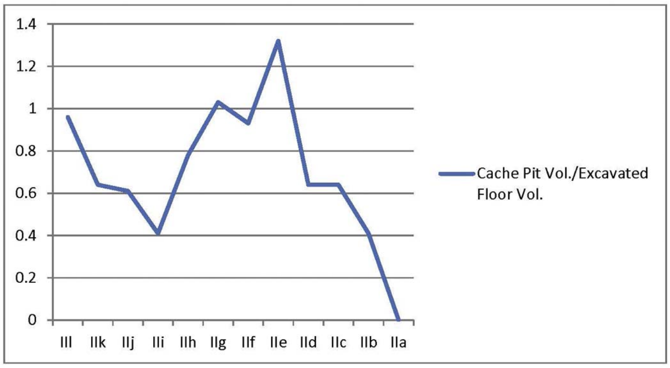

Fig. 13. Ratio of excavated cache pit volume to excavated floor volume from Housepit 54.

associated with subsequent abandonment of the house. This implies to us that persistence of the house was not predicated so much on the presence or absence of subsistence stress but on the severity and persistence of a stressful period.

Interestingly, the temporality of the BR 2 copial, transition, and Malthusian phases is remarkably close to that modeled by Puleston et al. (2014) (Fig. 14). It would appear however, that the BR 2 Malthusian phase as best reflect in the IIi and IIj data from Housepit 54 was interrupted by an equally short-lived early BR 3 copial phase that correlates with evidence for high marine productivity on the central Northwest Coast (Patterson et al., 2005; Tunnicliffe et al., 2001; Wright et al., 2005) that likely generated abundant salmon runs in the Fraser River system during that period (Prentiss et al., 2011). The subsequent transition to the persistent BR 3 Malthusian phase appears to have been very short, perhaps less than a generation and correlated with a significant drop in Northwest Coast marine productivity (Patterson et al., 2005; Tunnicliffe et al., 2001; Wright et al., 2005). This likely reduced inter-annual salmon productivity for an extended period, which in the context of dense population packing and stress on other food sources may have been catastrophic for some families leading to disinvestment in aggregated living situations.

This paper has not focused on the social implications of change in food storage and demography at Housepit 54. However, we can offer several thoughts drawing from data presented elsewhere. In a preliminary assessment of subsistence change, cooperation, and inequality at Housepit 54, Prentiss et al. (2018) argue that the earliest BR 3 floors (IIf-IIh) were characterized by a relatively high degree of cooperation in labor and sharing of goods between family groups. They suggest that this pattern changed after the IIe floor and was replaced by a new household pattern of limited inter-family cooperation and a simultaneous pattern of emergent intra-household inequality in material goods (prestige artifacts, non-local lithic artifacts, dogs, and ungulates). They argue that stress of the second Malthusian period led to a shift in social relations such that individuals and families networked with others external to the houses but did not necessarily share the returns on those activities with other house members outside of specific networks. The house had thus shifted from more of a communalistic to a collectivist endeavor. However, by the final two floors, the pattern of competition and inequality may have shifted back toward greater communality as the house struggled to survive, possibly by recruiting others at a time when many other houses were being abandoned. Clearly, social factors played a role in persistence of the households in Housepit 54 along with that of subsistence economics and demography. Data presented in this paper support the argument that Malthusian dynamics had significant demographic, economic, and social effects at the household level. On a wider scale, the reorganization of the BR 3 village into two arc or ring-shaped arrangements must have required significant consideration and collective action. It is possible that very productive fisheries at ca. 1300 cal. B.P. underwrote a short-lived period of economically good times associated with the early BR 3 population boom and a substantial

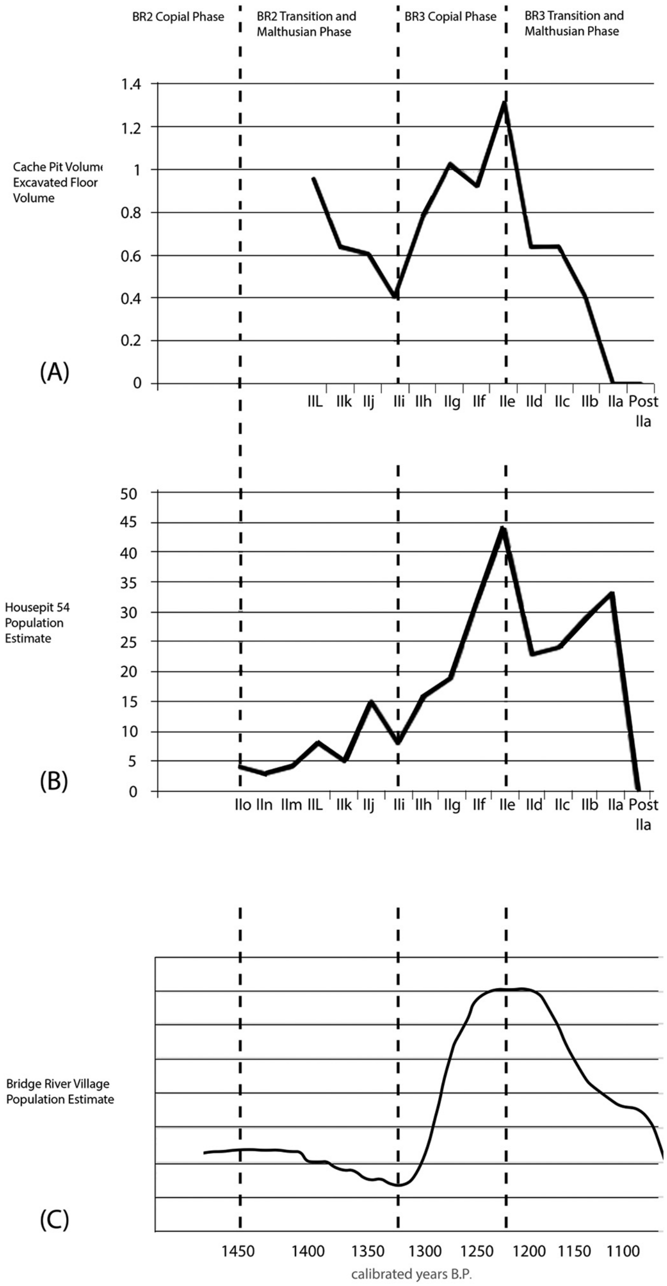

Fig. 14. Summary of observations regarding demography and storage at the Bridge River site. A is cache pit volume; B is the Housepit 54 population proxy based on fire-cracked rock density; C is the village wide population proxy drawn from summed probabilities of dated housepit floors as presented in Prentiss et al. (2012, 2014). The interpreted copial and transitional/Malthusian demographic phases are superimposed on those distributions.

re-shaping of socio-political relationships between houses, groups of houses, and villages.

Acknowledgements

This research was conducted as a collaborative partnership with Xwísten, the Bridge River Indian Band. We thank in particular, Bradley Jack, Gerald Michel, Susan James, and the many Xwísten members who worked on Housepit 54 in the field context. The 2012-2016 research at Housepit 54 was supported by two grants from the National Endowment for the Humanities (Grants RZ-51287-11 and RZ-230366-1). Any views, findings, conclusions, or recommendations expressed in this article do not necessarily represent those of the National Endowment for the Humanities. The 2008 field season at Bridge River that included test trenches in Housepit 54 was funded by a grant from the National Science Foundation (grant BCS-0713013). Radiocarbon dating was conducted by DirectAMS (with thanks to Jim Chatters and the late Ugo Zoppi). Maps in Figs. 1 and 2 were drawn respectively by Eric Carlson and Matt Hogan. We thank the many students and volunteers from the University of Montana, Simon Fraser University, Hamilton College, University of Michigan, and University of Notre Dame who participated in field and lab work at Housepit 54. Finally, we thank Bruce Winterhalder, Kevan Edinborough and two anonymous peer reviewers for their comments on the manuscript. We take full responsibility for decisions made regarding content. Prentiss thanks the University of Montana for sabbatical time and travel funding and the McDonald Institute for Archaeological Research at the University of Cambridge for providing a Visiting Scholar position.

Declaration of interest

The authors declare they have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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