A Paleodemographic Approach to the Middle Jōmon Boom and Bust Population Pattern

Corey Tyler NOXON[1]

ABSTRACT

The Middle Jōmon period boom and bust population pattern in the Kanto and Chubu regions has been of significant interest to researchers in the field. The number of archaeological sites and dwellings in the Kanto and Chubu regions rose and then subsequently fell at greater rates than other regions at the time. Although these patterns have been interpreted as changes in population levels, changes in residential mobility or site locations could also serve as a possible explanation for this pattern. An alternative line of evidence less susceptible to residential mobility changes is needed to help determine if these changes reflected a true population event. To achieve this objective, skeletal remains from the Kanto and Chubu regions were used to calculate juvenility index values for sites dated to the Middle Jōmon period. These index values are obtained by computing the proportion of the number of subadults to the total population and serve as a proxy of birth rates that can be compared to other demographic studies. Monte Carlo simulations were used to address the varying levels of granularity in the associated dates of the skeletal remains. Results show an apparent increase and decrease in birthrates that generally correspond with previous interpretations of residential data. These findings provide additional support to the notion that the Middle Jōmon boom and bust pattern reflected a true change in population sizes as opposed to being driven by confounding factors such as shifts in residential mobility pattern changes.

KEYWORDS: Jōmon, population, paleodemography, juvenility index, sedentism, residential mobility, Monte Carlo simulation

I. Introduction

This paper examines population changes during the Middle Jōmon period in the Kanto and Chubu regions of Japan using age-at-death distribution estimates from skeletal remains. This region and time period has been of particular interest due to an apparent boom and bust population pattern with a sharp increase at the beginning of the Middle Jōmon period followed by an equally sharp drop in population levels towards the end of the period. This pattern stands out in stark contrast to other population changes in the Jōmon period. Although population shifts also appear to be present in other regions during the Middle Jōmon period, the Kanto and Chubu region population patterns are especially pronounced compared to other regions of Japan during the Middle Jōmon period. This

[1] *Ritsumeikan-Global Innovation Research Organization, Ritsumeikan University, 56–1 Tojiin-kita-machi, Kyoto 603–8577, Japan (coreynoxon@gmail.com)*
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apparent anomaly in the region has been of significant interest to researchers. Why were these changes occurring in the Kanto and Chubu regions, but not elsewhere? What factors were behind these changes? Could the changes be related to the changing climatic and environmental shifts occurring around this general time period? Could these changes be the result of large migration events in the regions? Are these apparent changes in the number of site and dwelling counts actual population increases or decreases at all, or are they reflections of changes in residential mobility? A number of other Jōmon population estimation studies have been conducted up until this point trying to better understand this phenomenon. Some approaches, like those done by Koyama (1978) and Imamura (1996) have been focused broad scales, encompassing the entirety of the Jōmon period, while others have specifically focused on time periods and regions directly related or adjacent to this boom and bust phenomenon in the Kanto and Chubu regions (Kobayashi 2004; Yano 2014). All of these studies each contain their own strengths and weaknesses. The studies involving the use of archaeological site counts or dwelling counts benefit from relatively accessible and plentiful data, and more recent studies using summed probability distributions of radiocarbon dates benefit from relatively tight chronological constraints and an increasing amount of data (Crema *et al.* 2016; Crema & Kobayashi 2020). Without population changing however, a change in residential mobility could affect the number of archaeological sites used, the number of dwellings being used, and could affect the amount of materials able to be dated using radiometric methods. Paleodemographic studies relying on skeletal remains, specifically juvenility index measures, which compare the number of subadults to the population as a whole, should not be affected by changes in residential mobility as much as these other population estimation methods. Using skeletal data to infer past birth rates provides another line of evidence to examine Jōmon period population changes, helping to compensate for the shortcomings of other proxies, allowing for a more holistic view of the past.

II. Skeletal analysis in paleodemography

Skeletal remains provide an important line of evidence for paleodemographers to attempt to determine past population structures. As we are not able to directly measure past populations, we have to rely on indirect measures to infer past population levels and changes. The greatest benefit of using skeletal remains is that the data used is linked much more directly to the target phenomenon than other proxy variables. In this case, in order to identify relative increases and decreases in population size at a specified time and place, the evidence used are the skeletal remains of the populations themselves. While a direct count of remains cannot be used to estimate past population sizes, juvenility indices calculated using age-at-death ratios can provide us a proxy of birth rates.

Although the exact method of measurement differs amongst the different fertility indicators, at their core they are all attempting to estimate birth rates based on the proportion of juveniles in the given population in the form of age-at-death ratios. Although it seems somewhat counterintuitive, changing mortality rates have very little effect on these measures compared to changing fertility rates for age profiles (Wood *et al.* 1992). There are a number of different fertility indicators used in paleodemography, such as Masset & Bocquet-Appel's (1977) JA ratio, which measures the ratio of juveniles aged 5–15 to adults aged 20 and older; Jackes' (1986) Mean Childhood Mortality quotient or MCM which measures the average probability of death of different quantiles from a life table, in this case the 5q5, 5q10, and 5q15 values; Jackes' (1992) D20+/D5, which measures the proportion of those living beyond 20 years of age to all of those who lived past 5 years of age, among others. Bocquet-Appel's (2002) juvenility index, either referred to as P(5–19) or 15p5, has now become one of the most widely used indicators in the field, accommodating a wide range of data and strongly correlating to birth rates from simulated stable populations (r2 adj.=0.963) (Bocquet-Appel 2002, p. 642). Using the ratio of juveniles (aged 5–19) to the total population aged 5 and older, the method has shown itself to be able to identify changes in birth rate trends over time.

Bocquet-Appel's original project and subsequent studies utilizing the 15p5 ratio have tended to focus on the topic of population changes associated with the Neolithic Demographic Transition. In his 2002 study, Bocquet-Appel looked at Mesolithic and Neolithic sites in Europe and North Africa and identified this two-step transition associated with the introduction of intensive agriculture. There was a delay between the initial introduction of agriculture to an area, and the subsequent increase in birth rates. This was then likely followed by an increase in infant mortality, and an eventual stabilization in rates. Bocquet-Appel *et al*. (2008) later investigated changes in birth rates in North America related to the NDT. Similar to the findings in Europe and North Africa, the authors again found a pattern of increasing birth rates after the introduction of agriculture followed by a later decrease and stabilization of birth rates. Guerrero *et al*. (2008) conducted similar research in the Levant, as did Kohler & Reese (2014) in the North American Southwest. Although the general pattern of population increase and decrease has been the same around the world, the timing and intensity have varied.

There are weaknesses in these methodologies which will be discussed later, but these paleodemographic methods offer an important contribution for understanding population changes in the past. No other method utilizes data that is closer to the final intended object of measurement – people. Combining these methods with others, such as summed probability distributions of radiocarbon dates (SPD), site counts, and dwelling counts, similar to the analysis by Downey *et al.* (2014), can provide a strong foundation to support claims of population changes in the past.

III. Materials and methods

The skeletal data used in this analysis comes from several different sources. Skeletal data from 371 individuals comes from Yamada's (2006) skeletal database; excavation reports for the large Kitamura site provided data on an additional 156 individuals (Hirabayashi *et al.* 1993); and a total of 766 entries were gathered from the Chiba skeletal database (Chiba Prefecture Cultural Property Center 1999) for a total of 1293 individuals. When individuals lacking estimated ages were removed, the total number was reduced to 795 from 56 individual sites. For the final analysis, sites were further subdivided based on the grouped dates of individuals per site. Subdivided sites that had fewer than 5 individuals associated with them were removed, resulting 42 sites and a total of 611 individuals. These site locations are shown below in Figure 1. Three key pieces of information needed to be gathered in order to proceed with the analyses: site location, time period, and age at death. Raw data was pulled directly from the sources listed above, but additional processing was

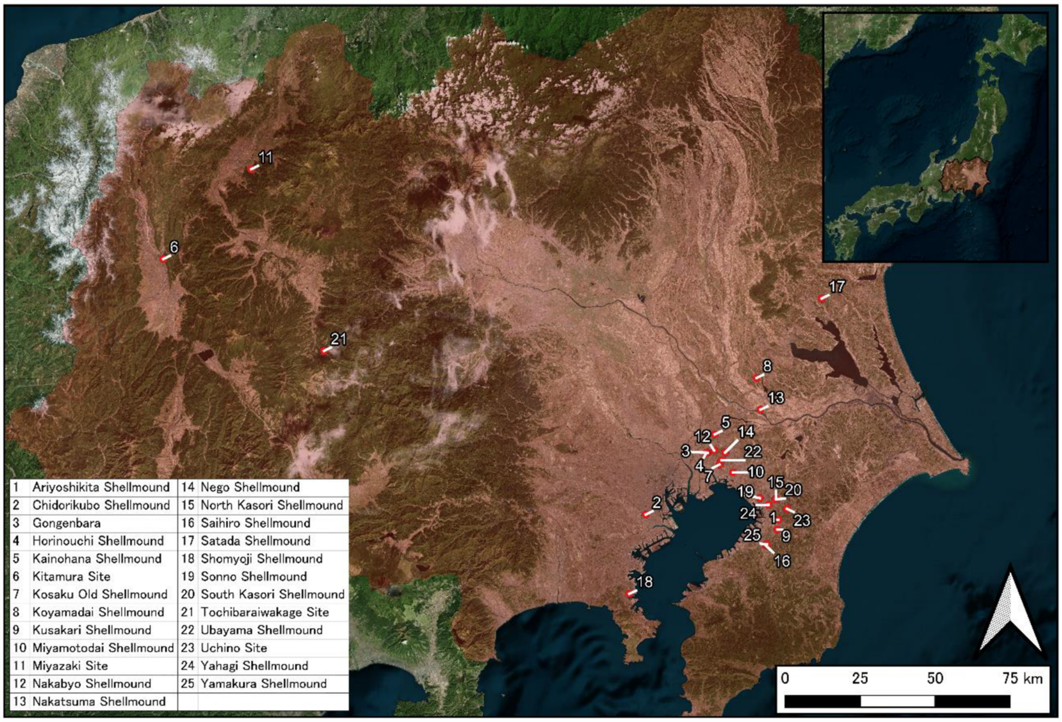

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Figure 1. Map of sites included in the skeletal analysis portion of the study. Created using QGIS (2023).

needed to arrange the dates and age ranges in a uniformed format so that juvenility index values could be calculated for the entire data set.

IV. Analysis

IV.A Initial data processing

IV.A.1 Site definition

In order to compare birth rates at different sites and different time periods Table 1, the definition of what constituted a site needed to be considered. As many of these site locations were occupied either continuously or sporadically for long periods of time, both geographic and temporal contexts needed to be utilized. The Kitamura site is a good example of why this approach was needed. The earliest remains at the Kitamura site were dated to the Kasori E3 period, which spans from 4730 to 4540 calBP, while the most recent remains dated to the Kasori B1 period, which spans from 3900 to 3750 calBP. Rather than considering the Kitamura site as a single entity that spanned over 1000 years, the site was split up into a number of shorter occupations that were determined based on the individuals buried there. This resulted in individuals at the same geographic site being grouped together based upon the time periods they were estimated to have occupied the site, with each grouping being considered a separate site.

IV.A.2 Dating and temporal uncertainty

Temporal uncertainty is an important but difficult problem in archaeology. A number of different methods are used to estimate the age of the artifacts and features archaeologists encounter. Whether they are dated using a relative chronology such as ceramic typology or are dated with an absolute method such as radiocarbon dating, there is still a degree of uncertainty within those age estimates. In some circumstances, the ranges can be quite precise (Kobayashi 2019), but quite often ranges can span from hundreds to over a thousand years. When radiocarbon dates are stated, they are often accompanied by a standard deviation value which expresses the degree of uncertainty inherent in the stated date. In relativistic dating methods, this measurement of uncertainty is often missing. Different measures provide differing absolute spans of time, often lacking consistency between those measures. In the case of ceramic typologies, ceramic styles change over time. Different ceramic types are ascribed through the diagnostic stylistic features present at particular points in time, and these features or sets of features can persist for varying durations. Some typologies might be more refined for certain pottery types, with clear identifying features changing throughout that stylistic period, while others are more difficult to separate into finer subtypes. This leads to an uneven granularity of dates, with

Table 1. Sites

Site	Phase Start (years calBP)	Phase End (years calBP)	n	Reference
Ariyoshikita Shellmound	5415	4395	7	Chiba Prefecture Cultural Property Center 1999
Chidorikubo Shellmound	5415	4395	5	Yamada 2006
Gongenbara	4490	4395	20	Chiba Prefecture Cultural Property Center 1999
Horinouchi Shellmound	4235	3900	8	Chiba Prefecture Cultural Property Center 1999
Kainohana Shellmound	4540	4235	5	Chiba Prefecture Cultural Property Center 1999
Kainohana Shellmound	4490	4235	21	Chiba Prefecture Cultural Property Center 1999
Kainohana Shellmound	4067	3643	6	Chiba Prefecture Cultural Property Center 1999
Kitamura Site	4730	4540	5	Hirabayashi *et al.* 1993
Kitamura Site	4730	4235	9	Hirabayashi *et al.* 1993
Kitamura Site	4730	4050	15	Hirabayashi *et al.* 1993
Kitamura Site	4490	4235	19	Hirabayashi *et al.* 1993
Kitamura Site	4490	3750	9	Hirabayashi *et al.* 1993
Kitamura Site	4235	4050	26	Hirabayashi *et al.* 1993
Kitamura Site	4235	3750	16	Hirabayashi *et al.* 1993
Kitamura Site	4050	3750	23	Hirabayashi *et al.* 1993
Kitamura Site	3900	3750	9	Hirabayashi *et al.* 1993
Kosaku Old Shellmound	4490	3220	29	Chiba Prefecture Cultural Property Center 1999
Kosaku Old Shellmound	3900	3420	5	Chiba Prefecture Cultural Property Center 1999
Koyamadai Shellmound	4490	3220	5	Yamada 2006
Kusakari Shellmound	5310	5270	17	Chiba Prefecture Cultural Property Center 1999
Kusakari Shellmound	5310	4860	6	Chiba Prefecture Cultural Property Center 1999
Kusakari Shellmound	4950	4860	9	Chiba Prefecture Cultural Property Center 1999
Miyamotodai Shellmound	4050	3900	31	Chiba Prefecture Cultural Property Center 1999
Miyazaki Site	3220	2385	8	Yamada 2006
Nakabyo Shellmound	4950	4860	28	Chiba Prefecture Cultural Property Center 1999
Nakatsuma Shellmound	4490	3220	94	Yamada 2006
Nego Shellmound	5230	5100	6	Chiba Prefecture Cultural Property Center 1999
North Kasori Shellmound	5415	4395	5	Chiba Prefecture Cultural Property Center 1999
Saihiro Shellmound	4490	3220	38	Chiba Prefecture Cultural Property Center 1999

Table 1. Continued

Site	Phase Start (years calBP)	Phase End (years calBP)	n	Reference
Saihiro Shellmound	4235	3900	8	Chiba Prefecture Cultural Property Center 1999
Satada Shellmound	5415	4395	6	Yamada 2006
Shomyoji Shellmound	4490	3220	11	Yamada 2006
Sonno Shellmound	4235	3900	8	Chiba Prefecture Cultural Property Center 1999
South Kasori Shellmound	4235	4050	10	Chiba Prefecture Cultural Property Center 1999
South Kasori Shellmound	3900	3420	6	Chiba Prefecture Cultural Property Center 1999
Tochibaraiwakage Site	15540	7050	6	Yamada 2006
Ubayama Shellmound	4950	4490	22	Chiba Prefecture Cultural Property Center 1999
Ubayama Shellmound	4950	3420	5	Chiba Prefecture Cultural Property Center 1999
Ubayama Shellmound	3900	3420	24	Chiba Prefecture Cultural Property Center 1999
Uchino Site	3370	3130	8	Chiba Prefecture Cultural Property Center 1999
Yahagi Shellmound	4235	3900	8	Chiba Prefecture Cultural Property Center 1999
Yamakura Shellmound	4950	4490	5	Chiba Prefecture Cultural Property Center 1999

some pottery types spanning hundreds of years or longer, while others like Tounai 1 being said to only have spanned a few decades (Kobayashi 2019).

This irregularity of temporal spans can result in archaeologists defaulting to using broader representative ranges used to express the age of the object or site in question. Defaulting to broader representative ranges can have drawbacks however, and can have significant effects on subsequent analyses. One example is Crema's (2012) examination of the rate of change of pithouses in the southwest Kantō region. As part of the analysis, Crema explored what effects using different temporal resolutions of 50, 100, and 200 years would have on the end results. The coarser resolutions of 100 and 200 years were unable to detect fluctuations that coarser resolutions were unable to detect a fluctuating pattern around 5000 calBP that the 50-year resolution was able to identify (Crema 2012, p. 456). While being able to use temporal resolutions of 50 years or less would be ideal, it can be quite rare to consistently have material dated to that degree of precision. For the Jōmon period, a single generation scale resolution of 30 years is practically impossible, a resolution of under 100 years based on a pottery subphase would be considered very good, and a period long span of around 1000 years could be attributed to most remains.

If the goal was to include as much data as possible, and the only option available was to directly use dates as is, using longer time spans would allow the coarsest, period long chronologies to be included, but would lessen the temporal precision of the analysis. On the other hand, if a high degree of precision was desired, the coarser measurements could be dropped, but this would come at the expense of a larger sample size. Luckily, Crema (2012) provides a way to incorporate these varying temporal scales while still allowing for an emphasis on a higher degree of temporal precision through the use of Monte Carlo (MC) simulations. The simulation process was conducted using the R statistical software program along with several other additional packages including ggpubr, ggthemes, here, tidyverse, gridExtra, readr, rmarkdown, knitr, and renv (Allaire *et al.* 2022; Arnold 2019; Augie 2017; Kassambara 2020; Muller 2017; R Core Team 2020; Ushey 2022; Wickham *et al.* 2019; Xie 2019). Each site examined in the analysis required a numerical start and end date to be assigned, however, the reference material typically only provided either coarse, period level data, or a more refined range associated with pottery types. Associated numerical dates were interpreted using Kobayashi (2019) as a foundation and can be seen in Table 2.

Once the start and end dates are assigned, the next step of the simulation process was to select a random sample value between the given start and end dates for each site. After all sites have an assigned sample date and the simulation run was completed, the process was repeated until the desired number of simulated dating data sets were completed. Each simulation run represents one possible set of site dates. Repeating this process again produces another set of possible dates, which may or may not be similar to the initial simulation run. The greater the difference is between the possible start and end dates, the greater the degree of temporal uncertainty there is for that particular site. By repeating this process over and over, we are not only able to see a general range of possibilities for these dates but are also able to see what the most likely distribution of dates might be. As the number of MC draws increases, there comes a point when the summary statistics start to converge over time (Figure 2). As more and more draws are done, a range of values begins to be established. Although occasional outliers still exist, repeated draws will tend to fall within the established range. At this point, increasing the number of simulation runs provides little additional variation is exhibited outside the range of, so a balance must be made between computation time and increased convergence. For this study, 2000 simulation runs provided an acceptable level of convergence without requiring an excessive amount of computational time.

IV.A.3 Age at death

While some individuals in these reports have estimated numerical age ranges provided, alternative named age categories are often listed in addition to these categories, or are used in place of numerical ranges. Equivalent numerical ranges for these named age categories

Table 2. Project dating table providing dates for each period used in this analysis and explaining how phases not included in Kobayashi (2019) were interpreted

PotteryTypeJpn	PotteryType	calBPmax	calBPmin	Span	Kobayashi (2019)	Notes
五領ケ台1式	Goryogadai 1	5415	5360	55	C1期	
五領ケ台2式	Goryogadai 2	5360	5310	50	C2～4期	
勝坂1式	Katsuzuka 1	5310	5230	80	C5～6期	
狢沢式	Serizawa	5310	5270	40	C5期	
新道式	Shinmichi	5270	5230	40	C6期	
勝坂2式	Katsuzuka 2	5230	5100	130	C7～8期	
藤内1式	Tounai 1	5230	5200	30	C7期	
藤内2式	Tounai 2	5200	5100	100	C8期	
勝坂3式	Katsuzuka 3	5100	4950	150	C9a~b期	
井戸尻1式	Idojiri 1	5100	5030	70	C9a期	
井戸尻3式	Idojiri 3	5030	4950	80	C9b期	
勝坂式終末	Katsuzuka End	5030	4950	80	C9b期	
加曽利E1式	Kasori E1	4950	4860	90	C10a~c期	
加曽利E1式前半	Kasori E1 Early	4950	4905	45		Treated as first half of 加曽利E1式
加曽利E1式後半	Kasori E1 Late	4905	4860	45		Treated as last half of 加曽利E1式
曽利I式	Sori 1	4950	4890	60	C10a~b期 *	曽利I式 was split into 2 phases, C10a期（加曽利Ela式・曽利I式古）and C10b期（加曽利E1b式・曽利I式新）which were combined here
曽利II式古	Sori 2 Old	4890	4860	30	C10c期	
加曽利E2式	Kasori E2	4860	4730	130	C11期	
加曽利E2式古	Kasori E2 Old	4860	4770	90	C11ab期	
加曽利E2式新	Kasori E2 New	4770	4730	40	C11c期	
加曽利E2式前半	Kasori E2 Early	4860	4770	90	C11ab期 *	Nomenclature used in excavation reports, matched to C11ab期（加曽利E2式古）
加曽利E2式後半	Kasori E2 Late	4770	4730	40	C11c期 *	Nomenclature used in excavation reports, matched to C11c期（加曽利E2式新）
曽利II式新	Sori 2 New	4860	4770	90	C11ab期 *	曽利II式新, 曽利III式, and 連弧文系最盛期 listed in the same phase C11ab期, which is used here
曽利III式	Sori 3	4860	4770	90	C11ab期 *	曽利II式新, 曽利III式, and 連弧文系最盛期 listed in the same phase C11ab期, which is used here

Table 2. Continued

PotteryTypeJpn	PotteryType	calBPmax	calBPmin	Span	Kobayashi (2019)	Notes
連弧文系最盛期	Renkomon	4860	4770	90	C11ab 期 *	曽利 II 式新, 曽利 III 式, and 連弧文系最盛期 listed in the same phase C11ab 期, which is used here
加曽利 E3 式	Kasori E3	4730	4540	190	C12 期	
加曽利 E3 式初頭	Start of Kasori E3	4730	4700	30	C12a 期	
加曽利 E3 式前半	Kasori E3 Early	4730	4635	95		Treated as first half of 加曽利 E3 式
加曽利 E3 式後半	Kasori E3 Late	4635	4540	95		Treated as last half of 加曽利 E3 式
加曽利 E3 式新段階	Kasori E3 New Stage	4600	4540	60	C12c 期 *	Treated as C12c 期
曽利 IV 式	Sori 4	4730	4600	130	C11c~ C12a 期 *	曽利 IV 式 was split into 2 phases, C11c 期（曽利 III 新 ~IVa 式）and C12a 期（期曽利 IVb 式）which were combined to create 曽利 IV 式
加曽利 E4 式	Kasori E4	4540	4490	50	C13 期	
加曽利 E 式前半	Kasori E First Half	4950	4720	230		Ends at midpoint between start of 加曽利 E1 and end of 加曽利 E4
加曽利 E 式後半	Kasori E Latter Half	4720	4490	230		Starts at midpoint between start of 加曽利 E1 and end of 加曽利 E4
曽利 V 式	Sori 5	4540	4490	50	C13 期	
中期	Middle Jōmon	5415	4395	1020	C1 ～ 14 期	
中期前葉	Early Middle Jōmon	5415	5075	340		Treated as first third of 中期
中期中葉	Mid Middle Jōmon	5075	4735	340		Treated as middle third of 中期
中期後葉	Late Middle Jōmon	4735	4395	340		Treated as last third of 中期
中期前半	Middle Jōmon First Half	5415	4905	510		Treated as first half of 中期
中期後半	Middle Jōmon Latter Half	4905	4395	510		Treated as second half of 中期
晩期初頭	Start of Final Jōmon	3245	3130	115	B1 期 *	Treated as B1 期（安行 3a 式）
称名寺式	Shomyoji	4490	4235	255	C14/K1 期～ K3 期 *	称名寺式 spans two phases, C14 期（K1 期）加曽利 EV 式・称名寺 1–2 段階 and K1 ～3 期称名寺 2 式 which are combined here
堀之内 1 式	Horinouchi 1	4235	4050	185	K2 期	

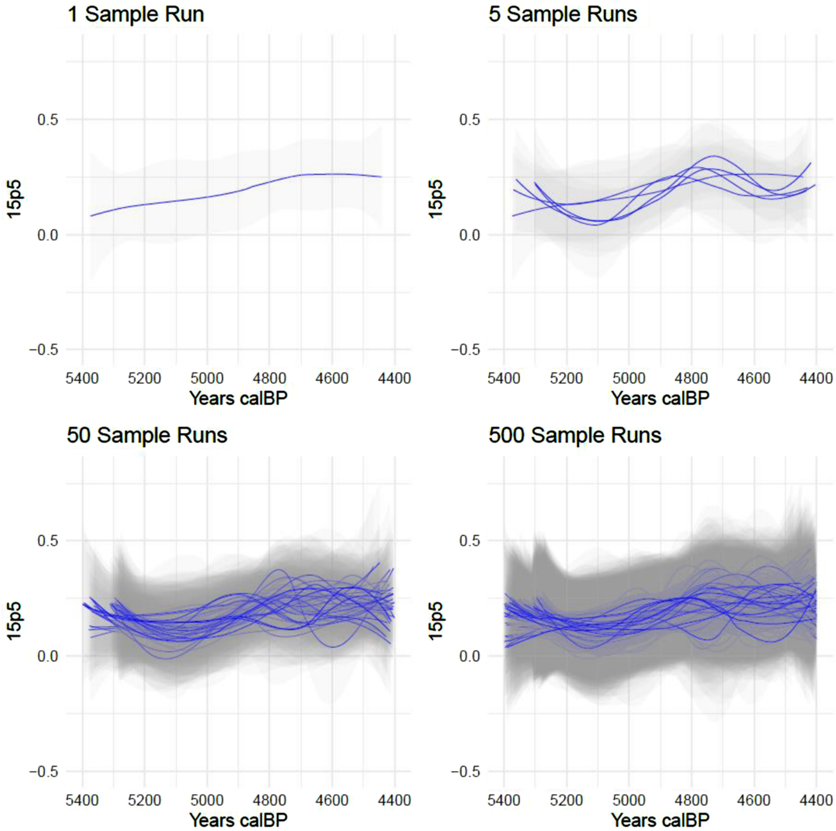

Figure 2. Plots showing how MC simulation runs converge as more simulation runs are incorporated in a plot. Blue lines represent LOESS regressions. Gray areas indicate confidence intervals.

are not always provided, resulting in the need for a method of translating this nominal data into a numerical form. Age categories listed are similar to the five categories used in Krogman (1962) and Ubelaker (1989): Infans (0–13), Juvenis (14–19), Adultus (20–39), Maturus (40–59), and Senilis (60＋). For Yamada's database, nine named age categories were used: shinseijiki 新生児期 (neonatal), nyūjiki 乳児期 (infant, up to –2), yōjiki 幼児期 (child, 2–5), shōniki 小児期 (child, 6–12), shishunki 思春期 (adolescent, 13–16), seinenki 青年期 (adolescent, 17–20), sōnenki 壮年期 (adult, 21–39), jukunenki 熟年期 (middle age, 40–59), and rōnenki 老年期 (advanced age, 60-). In addition to these, other terms such as: taiji 胎児 (fetus), jakunen 若年 (youth), seijin 成人 (adult), and chūnen 中年 (middle aged), were used outside of Yamada's database. Ages were also sometimes referred to by their particular decades, for example, using nijūdai 20 代 to describe someone in their twenties. These descriptions would also occasionally include modifiers such as zengo 前後 (approximately), zenhan 前半 (first-half), or kōhan 後半 (last-half). The system in which nominal age at death data is converted to numerical data is the same that was used in an earlier analysis and is displayed in Table 3 (Noxon 2017).

IV.A.4 Reference sources

Yamada's skeletal database covers a geographic window corresponding to the entirety of present-day Japan. However, in order to arrange the data collected into a manner in which comparisons could be made, some aspects, particularly the dating of individuals, was quite coarse. The Chiba skeletal database and the Kitamura & Kosaku excavation reports provided finer chronological resolutions on average, but there were some data

Table 3. Age category adaptations. Data adapted from Noxon (2017, p. 98)

Age Category	Publication Age Ranges	Adjusted Age Range
taiji 胎児 (fetus)	under 1	under 1
nyūji 乳児 (infant)	under 1 / as 0–4	0–4
yōji 幼児 (child)	1–10*	1–10
shōni 小児	2–12**	1–10
shōnen/shōjo 少年・少女 (child)	8–15	8–15
jakunen 若年 (youth)	10–24***	10–24
seinen 青年 (adolescent)	15–29	15–29
seinen 成年 (adult)	20–50****	20–39
sōnen 壮年 (adult)	30–40	30–40
chūnen 中年 (middle age)	30–49	30–49
jukunen 熟年 (middle age)	late 30s–50*****	35–49
rōnen 老年 (advanced age)	50 and over******	50–70

Sources: Chiba Prefecture Cultural Property Center (1999), Kansai Jōmon Culture Research Society (2000), Toyama Prefecture Cultural Promotion Foundation (2014),Yamada (2006).

*Age category was expanded beyond Yamada's original range due to several instances of individuals with estimated ages up to 10 being described as yōji, including the Ubayama, Yahagi, Kusakari, and Nakabyo sites. **The range of 6–12 as used by Yamada (2006) was often listed, but the category was also linked with younger age categories. The range was adapted to match the 1–10 yōji range. ***Generally under 20 but Ubayama site had one individual listed at 15–19, and the Yahagi site had one individual listed at 10–14; ****Generally under 40; *****Generally 40s; ******Yamada (2006) listed as 60+ while multiple entries in Chiba Prefecture Cultural Property Center (1999) were listed as over 50.

discrepancies between the different sources. Yamada conducted much of his own analysis for his database, and this information differed at times from the original reports. This was most apparent in cases of group burials (Yamada 2006; Chiba Prefecture Cultural Property Center 1999; Hirabayashi *et al.* 1993).

References used for each individual are listed in the data table. There were instances in which the same sites were listed in multiple references. In these cases references were chosen based on the completeness and precision of data contained within the sources. For the Kitamura site, the original excavation reports was used, and for instances where skeletal remains were listed in both Yamada's and Chiba prefecture's skeletal databases, the data from Chiba's database was used (Yamada 2006; Chiba Prefecture Cultural Property Center 1999; Hirabayashi *et al.* 1993).

IV.A.5 Sensitivity analyses

There is a balance that often must be struck between the quantity and quality of data to include in an analysis. Large sample sizes are desired, as they help to offset the effects of stochastic variations. However, this benefit can be negated to some degree if unreliable or questionable data is included in analyses. There is an additional level of complexity involved in deciding where to strike this balance when it comes to calculating juvenility indexes. Individual juvenility index values are calculated at the site level, so in terms of maximizing sample sizes, one would expect to try to include as many sites as possible in the analysis. However, each site is made up of the number of individuals recovered from those sites. Looking at the issue from single sites, the researcher would want to use sites with the greatest number of individuals per site if possible. The minimum threshold ranges from previous studies ranged from upwards of 85 down to sites including as few as 3 individuals (McCaa 1998; Guerrero *et al*. 2008; Kohler & Reese 2014).

On a site by site basis, there is also a question of how representative a site is of the broader population. As this study relies on comparing the number of juveniles to the total population, a site devoid of juveniles would indicate a fertility rate of zero. Absent migration from outside areas, a group with a birth rate of zero would only span a single generation, and while this situation is possible, it is also quite improbable.

To explore and address these issues, a large number of sensitivity tests were undertaken, exploring minimum thresholds for the number of individuals necessary to be at a site to be included in the analysis, the weighting of sites based on the number of individuals at the site based on the work of Kohler & Reese (2014), and the effects that removing sites lacking juveniles would have on the testing results. While there were differences present between the different analyses, the differences were fairly minimal. In the end I made three determinations based on these sensitivity tests.

I concluded to set a minimum threshold of 5 individuals at a site, which set some limits to site quality and resulted in tighter confidence intervals than were present when using higher thresholds. I decided to include sites that lacked juveniles in this study. Their omission from the data sets resulted in an overall increase in juvenility index values, but their complete removal went beyond the limited intervention that I intended for the study. Finally, I determined that weighting data based on the number of individuals at a site would help with both the issues of minimum thresholds for the number of individuals at a site as well as the decision to include sites lacking juveniles. I had some initial concerns that smaller sites and sites lacking juveniles may not be as representative of the population as larger sites and sites with juveniles present. Weighting based on sites size would result in smaller sites being weighted less, and as most sites lacking juveniles were smaller sites, the influence of both would be somewhat reduced. The full set of these analyses are available in the supplementary materials.

IV.A.6 Edge effects

Edge effects are problems that are often discussed in population investigations based on the use of radiocarbon dates as data, but their effect goes beyond that particular methodology (Contreras & Meadows 2014; Shennan *et al.* 2013; Timpson *et al.* 2014). Due to a lack of data leading up to the start of the period of investigation and a lack of data for the time period after the end of the period of investigation, there is often a higher degree of uncertainty at these edge areas. One way to combat this problem is to expand the data used in the analysis beyond the time span in question. Several different approaches were taken to examine whether data from the entirety of the Jōmon period should be included, or if a more limited expansion would be more beneficial. In the end, using the entirety of the Jōmon period appeared to provide more consistent results. The comparison of different included time spans and their effect on subsequent analyses are also available in the supplementary materials.

IV.B Juvenility index calculation and analysis

IV.B.1 Juvenility index

Juvenility index values, represented in this study by 15p5 ratios as described by Bocquet-Appel (2008), were calculated using R during the data preparation phase prior to running MC simulations (R Core Team 2020). This process included several filtering steps. Skeletal data for the Kanto and Chubu regions was first imported into the program, and individuals where the minimum or maximum ages at death were unknown or missing were filtered from the data set.

To determine the 15p5 ratio, individuals under the age of five had to be dropped from the analysis and the number of individuals aged 5–19 are compared to the number of all individuals over five years of age. As age ranges don't always fit within the determined boundaries of 0–4, 5–19, and 5+, percentage values were applied to each category. Table 4 provides an example showing how these divisions were made. While the 0–4 age category is discussed here, the 5+ category represents the total population for this analysis. If an individual had an estimated age range of 3–6 years old, a value of 0.5 would be attributed to the 0–4 age range, since two years of that 4-year span lies within that range. The 5–19 age range would also have a value of 0.5 applied to that category, as half of that estimated age span was within the 5–19 age category. For the total population value, 0.5 would also be applied to the 5+ age category, as half of the estimated age span was in the range of 5 or older. If an individual had an estimated age range of 1–2 years-old, a full value of 1 would be applied to the 0–4 range, as the whole estimated age range resided within the 0–4 age category, and nothing would be applied to the 5–19 or 5+ age categories. An individual with an estimated age range of 18–21 would likewise have a value of 0.5 applied to the 5–19 range and 1 applied to the 5+ range, while an individual with an estimated age range of 35–40 would have a full value of 1 applied to the 5+ age category.

Once these values have been applied to every individual, the individuals were grouped together based on the spatiotemporal sites they were assigned to as described in the previous site designation section. The values for the 5–19 and 5+ age categories were summed for each site, and 15p5 ratio values were calculated by dividing the summed 5+ age category by the 5–19 age category for each site. Once the sites were grouped and the juvenility index values calculated, the final filtering step of removing sites with fewer than five individuals was taken, as discussed in the sensitivity analysis.

IV.B.2 LOESS regressions

With the juvenility index values calculated, the values are first examined using a locally estimated scatterplot smoothing (LOESS) regression, a non-parametric technique used to fit a smooth curve to noisy data (Cleveland & Devlin 1988; Cleveland 1979). One LOESS regression was run for each simulation run, and the combination of these runs provided the probability envelope for juvenility index values. For this analysis, the LOESS regression

Table 4. Age range distribution example

Age Range	0 to 4	5 to 19	5+
1–2	1	0	0
3–6	0.5	0.5	0.5
18–21	0	0.5	1
35–40	0	0	1

was applied through the use of the geom_smooth function included in the ggplot2 package (Wickham 2016). To counteract edge effects, data for the analyses consisted of sites from the entire Jōmon period as long as at least five individuals with estimated ages were present. Despite the extended range, the results of the analyses focus only from 5400 to 4400 calBP, during the Middle Jōmon period. A horizontal line at 0.173 was added to the plots indicating the juvenility index level estimated for a stable population level (Bocquet-Appel 2008).

V. Results

After extensive sensitivity testing, the final analysis included data from the entirety of the Jōmon period in order to help counter edge effects, but focused specifically on the Middle Jōmon period for visualization. The juvenility index values of individual sites were weighted based on the number of individuals at those sites. 2000 Monte Carlo simulations were run, randomly selecting dates from the possible date ranges for each site. LOESS regressions were run for each simulation run with a span of 0.75, and confidence intervals were calculated for all of them.

The plot in Figure 3 has been limited to 100 simulation runs to help visualize the overlap of LOESS regressions and their confidence intervals. Transparency alphas were

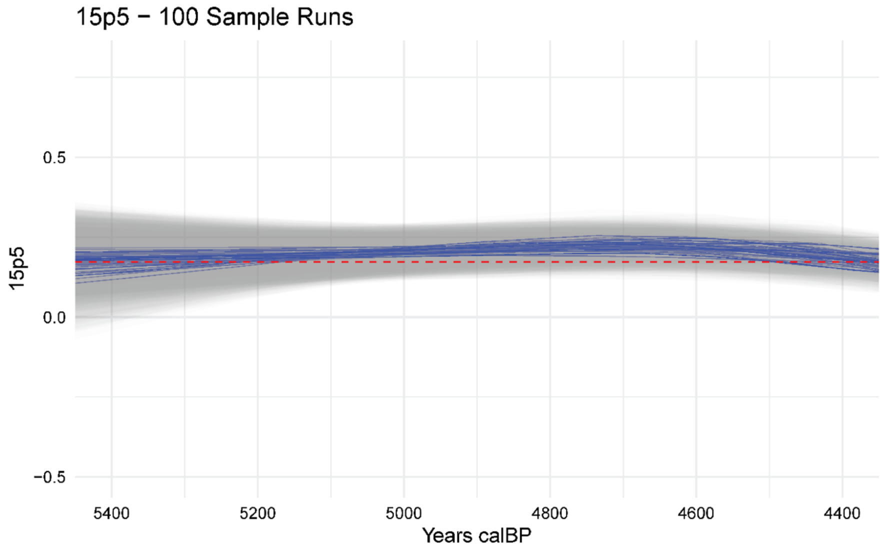

Figure 3. 15p5 juvenility index regressions from 100 MC simulation runs. Blue lines indicate LOESS regressions with spans of 0.75. Gray areas indicate LOESS regression confidence intervals of 95%. Horizontal line indicates a stable population level of 0.173.

set to make the visualizations of each simulation run somewhat transparent. The more the regressions and confidence intervals overlap, the darker they become until becoming full opaque. In Figure 3 you are able to see some slight variations in the LOESS regressions and can see that the inner portions of the confidence intervals where there is more overlap are darker than the outer areas where there is less overlap.

Figure 4 shows the combined 2000 simulation runs calculated from the study. The LOESS regression lines are relatively centered around the stable population line set at 0.173 at the beginning of the period. From approximately 5100 to 4900 calBP every regression line rests above that stable population line. By the end of the period at 4400 calBP the regressions revert back down to levels similar to what were seen in the beginning of the period. We see that the confidence intervals associated with the LOESS regressions were broader in the beginning of the period, but then hit a fairly consistent level around 5000 calBP. It is also important to note that throughout the whole of the Middle Jōmon period, the confidence intervals encapsulated the stable population level line. This indicates that the analysis can not statistically rule out the possibility of a stable population level throughout the period.

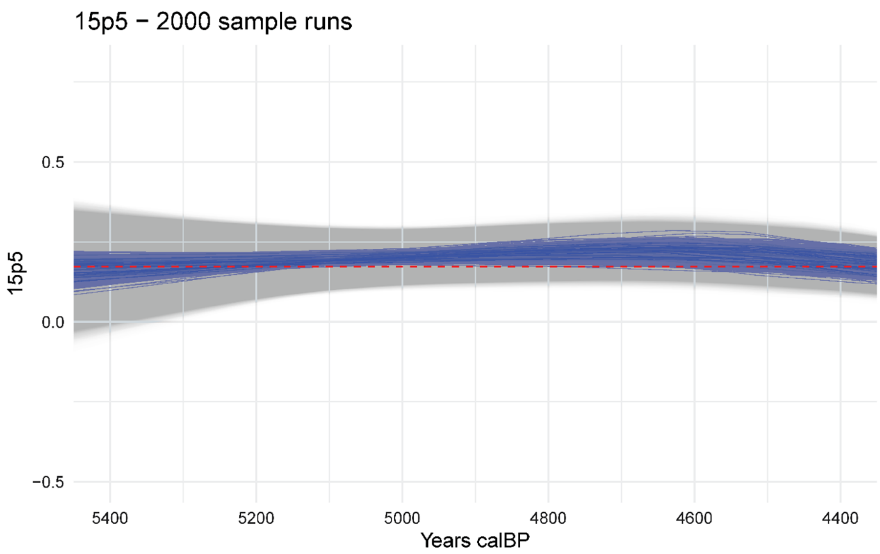

Figure 4. 15p5 juvenility index regressions from 2000 MC simulation runs. Blue lines indicate LOESS regressions with spans of 0.75. Gray areas indicate LOESS regression confidence intervals of 95%. Horizontal line indicates a stable population level of 0.173.

VI. Research limitations

One of the goals of this study was to help compensate for weaknesses present in other Jōmon population studies. This study has its own faults and weaknesses however, which should be clearly addressed. While a Monte Carlo methods approach to site dating acknowledges and attempts to address the inherent uncertainty involved in the dating of archaeological sites and features, issues of age at death estimations, small sample sizes, and the degree to which those samples represent the populations that they came from are all sources of possible bias for this study.

VI.A Age estimations

Age estimation from skeletal remains is improving, but limitations still remain. While a number of skeletal features can be used in the age estimation of juveniles, such as the loss and eruption of teeth, the appearance and closure of epiphyseal portions of bones, as well as the size of certain bones, these features are unable to be used for estimating the ages of mature individuals (Ubelaker & Khosrowshahi 2019, p. 1). In regards to features that are available to estimate the age of mature individuals, researchers have pointed out that a central bias is present, stating that for age estimation based on auricular surface following Lovejoy *et al.* (1985), "The method consistently underestimated the age of older individuals, and overestimated the age of younger individuals" (Buckberry & Chamberlain 2002, p. 232).

In addition to this central bias for mature individuals, Wärmländer & Sholts (2011) broached an even more important issue for age estimation studies, that of representational sample populations to compare to. By identifying regional differences in pubic bone development, the authors stress that appropriate reference samples need to be used, adding that the use of multiple different measures for age estimations would be ideal if possible. Unfortunately, multiple measures are not always possible for Jōmon samples due to poor preservation of remains, as well as the use of group burials, which can introduce additional uncertainty if large numbers of remains are present.

Taking into consideration the strict age divisions relied upon in these analytical techniques, determining accurate ages of individuals is of key importance. Using the juvenility index (15p5) as an example, individuals under the age of 5 are omitted, and the remaining population is categorized as either subadults (aged 5–19) or adults (20 years and older). Therefore, the successful determination of whether an individual is 4 years old or 5 years old and whether an individual is 19 years old or 20 years old could have a significant effect on the accurate estimation of birth rates. For the data set used in this analysis, there were a total of 840 individuals whose estimated ages were listed in their respective reports. Of those 840 individuals, 97 had age ranges that crossed over the 5 to 19 age category.

While it might not make a significant difference, this shows that in at least ten percent of the cases examined in this study even small changes in estimated ages could likely affect the results.

Despite the limitations and difficulties present, there has been recent research examining bone mineral density, dental pulp, and exploring different methods of biochemical analysis which might help to improve the accuracy and precision of age estimations (Ubelaker & Khosrowshahi 2019). As techniques improve, reexamination of skeletal remains can help to refine previous age estimations. For the purposes and scope of the current study, however, I have had to rely solely on the estimations provided in the source materials.

VI.B Sample sizes

In the examination of skeletal remains for the whole duration of the Jōmon period in Noxon (2017), I was able to draw on 1777 individuals from 97 sites for a sample population. While the number of individuals per site can vary significantly, as a point of comparison, we can use an overall average of approximately 18 individuals per site for that study. However, this must be put in the context of being representative of an occupation lasting over 16,000 years for the whole of the Japanese archipelago. The current reexamination of the Kanto and Chubu regions is more limited in scope, focusing on an area covering only 10 prefectures over the span of approximately 1000 years, but it has a more limited sample size. As the site dates vary for every simulation, only summary values are present. Based on those summary values there were an average number of 186 individuals (range of 121 to 328 individuals), coming from an average 16 sites (range of 12 to 21 sites).

In the sensitivity testing section I touched on the idea of testing different minimum thresholds for the number of people at a site to be included in the study. At the current threshold of five individuals per site, the minimum resolution of index values is 0.2. If five individuals were recovered at a site, and they were all adults, that site would have a juvenility index of 0. If one of those five individuals was between 5 and 19, the juvenility index would jump to 0.2, above the 0.173 estimated value of a stable population. If two of the five individuals were between 5 and 19, the index value would jump again to 0.4, which is quite high. If the minimum threshold was raised to 10 individuals, the resolution would increase to 0.1, and if we were able to further increase the minimum threshold to 25 individuals, we could achieve a resolution of 0.04. In the Kanto and Chubu region during the Middle Jōmon period, there was only an average of 1 site (range of 1 to 3 sites) with 25 or more skeletal remains, and an average of only 5 sites (range of 3 to 9 sites) with 10 or more. Although I believe that the sample size available with the current minimum threshold of five or more individuals is able to provide some insight into changes in birth rates over time, the analysis is still vulnerable to stochastic variations, and any results should be viewed with that in mind.

VI.C Issues of preservation and representativeness

Studies relying on the analyses of skeletal remains are inherently limited to areas that provide sufficient preservation of those skeletal remains. Chiba prefecture makes up a large proportion of this study, specifically due to the large number of shell middens present around the Tokyo Bay area. While these areas provide a fantastic opportunity to understand more about the lives and lifestyles of those residing in these regions long ago, a variety of other environments and regions don't benefit from this degree of preservation of skeletal remains. As such, there is a question about whether the results from these areas of good skeletal preservation can be applied to other areas. This is a valid question, and while I believe that they may be applicable in some contexts, I don't believe that they can be applied to all other contexts. Limiting the area of research to the Kanto and Chubu regions helps to some degree, but a great variety of different environments still exist within that limited range. This is another area where the results of the study need to be viewed critically within their contexts.

There is another, more focused aspect of representativeness involved in this study, and that is the degree of representativeness of recovered skeletal remains for the local population of the time. The use of the juvenility index relies on the proportion of juveniles between 5 and 19 years old to all individuals in the population five years old or older in the actual population to be the same as in the recovered skeletal remains. For this reason, the 15p5 ratio omits juveniles under the age of five, as not only do the smaller, more gracile bones not preserve as well as larger, more mature bones, but also mortuary practices for younger individuals can differ from older juveniles and adults (Bocquet-Appel 2002, p. 639; Chamberlain 2009, p. 282). This underrepresentation would result in age-at-death ratios and subsequent birth rate estimations much lower than they were in actuality. While the act of omitting juveniles under the age of five might help mitigate some issues of the representativeness of recovered skeletal sample populations for the original populations, the question of whether the sample is truly representative or not is unknowable. We are unable to confirm with certainty whether additional unidentified burial locations existed for the community, whether migration might have affected the makeup of individuals recovered, or whether a cemetery used by multiple groups would be representative of all the individual groups using that cemetery. This is another limitation of the analysis, and one which must be kept in mind when interpreting the results.

Although there are various ways in which some of these research limitations might be alleviated, the results will still hold some degree of bias. While age estimation techniques might improve, there will still be a degree of uncertainty present, no matter how much better the techniques become. A large proportion of Jōmon-period skeletal remains come from the Kanto and Chubu regions, which helps improve sample sizes for this study. But the numbers are still limited, and they are even more limited in other regions of Japan. By omitting an underrepresented age group, the 15p5 ratio attempts to address some issues of representativeness in the skeletal record, but the effect of that action has its own limitations and drawbacks, and the question of a truly representative sample will always be in question to some degree. This stresses the need for multiple lines of evidence when attempting to understand past population dynamics. By approaching past demographic processes from multiple angles, we are provided a broader, more holistic, and hopefully more accurate view of the past.

VII. Discussion

With the results presented and a clear understanding of the weaknesses present in the methodology, what can we conclude? First of all, the skeletal data in the Kanto and Chubu regions seems to lend some support to the theory of an increase in population during the Middle Jōmon period. Looking only at the regression curves themselves, we see an increasing and decreasing pattern during the Middle Jōmon period that is somewhat similar to those indicated by the number of dwellings or sites in the Kanto and Chubu regions. The LOESS curves of all 2000 simulation runs were above the stable population line set at a level of 0.173 around 5000 calBP. There also appears to be a clear decreasing trend towards the end of the period, with the proportion of regression lines above and below that stable population line is roughly similar to that seen at the beginning of the period. As such, while there might be some support for a Jōmon population boom in the Middle Jōmon period, the skeletal data does not provide any support to a subsequent population bust. It's also important to note that throughout the entirety of the Middle Jōmon period, the 95% confidence intervals of the LOESS regressions encapsulate the stable population level line. This means that the evidence examined in this study cannot rule out the possibility of completely flat birth rates throughout the entirety of the Middle Jōmon period. This isn't to say that there are no insights to be gained from these results, however. With every additional line of evidence added, a more holistic view of the situation can be seen.

One of the main drives behind this research was to examine Jōmon period population dynamics utilizing evidence that was less susceptible to changes in residential mobility. While in a fully sedentary society, using individual dwellings as proxies for a family unit is a reasonable approach. Likewise, if a group is staying within the same general location throughout the year every year, using the increase and decrease of archaeological sites as a proxy for general population increases and decreases makes general sense as well. Unfortunately, for a majority of human history the concept of a fully sedentary society has not been the norm, and evidence shows that the same holds for the Jōmon people. Not only was some degree of residential mobility present throughout the Jōmon period, but it's likely that the degree of residential mobility changed throughout different times and in different areas (Habu 1996, 2001; Suzuki & Suzuki 2009). During the Jōmon period there appears to be a pattern of settlement fissioning and fusion (Suzuki & Suzuki 2009). Fissioning into smaller settlements could result in an increase of site counts, which could inflate population estimates. However, there is also the possibility that the smaller resulting sites could be less likely to be found and documented by archaeologists, which could have the effect of underestimating the population (Bevan & Crema 2021). In addition to these issues, there's also a problem of contemporaneity of dwelling habitation. There is clear evidence of pithouses being repaired or rebuilt throughout the Jōmon period, but it's very difficult to determine if the different phases of occupation were continuous, or if dwellings were left uninhabited for a period of time before a group returned to the area, repaired the dwellings and inhabited them once again (Kobayashi 2009). Just because ten dwellings were found at a site doesn't mean they were inhabited at the same time, or if they were even contemporaneous with each other when viewed at a year to year temporal scale. These are just the issues present when looking at pithouses. Things become even more complicated when other forms of dwelling structures are considered.

The intended use life of a structure can often be a significant factor in weighting the production and maintenance costs of a dwelling (McGuire & Schiffer 1983). In a basic sense, dwellings that are intended to be used for shorter periods of time will generally have less energy put into their initial creation compared to dwellings intended for long-term habitation (McGuire & Schiffer 1983, p. 283). On the other hand, if a dwelling is intended to be used for a longer period of time, or repeatedly over time, a greater initial energy investment in the dwelling's construction will likely be offset by decreased maintenance costs over time. As has been seen in a number of examples across the world, changes in residential mobility and intended durations of stay would likely have affected the types of dwellings the Jōmon people used as well (Binford 1990; Kent 1991; Diehl 1992; Keely *et al.* 2006). A shift away from pithouses to a more ephemeral form of shelter would also result in a likely population underestimation, as less robust, more temporary shelters are less likely to be preserved in the archaeological record (Keely *et al.* 2006).

The possibility of all of these confounding factors related to population estimation from archaeological sites or dwelling counts emphasizes the need for additional lines of evidence that are less susceptible to the effects of shifting residential mobility patterns. As the ratio of juveniles in a population should have little direct correlation to how often a group is relocating throughout the year, or how often they change their main residential area from year to year, skeletal data allows us to view population dynamics independent of these factors. The relatively recent introduction of using the summed probability of radiocarbon dates (SPDs) as a demographic proxy serves in a similar manner to provide an alternative line of evidence. By its very nature, the use of SPDs benefits from an absolute chronological framework, overcoming some of the shortfalls present when using the relativistic dating methods that other analyses often use. There are still difficulties for the methodology to overcome, including a relative lack of independence between the number of sites, dwellings, and radiocarbon samples, and possible issues related to differential sampling intensity (Crema 2022). This only further stresses the importance of needing a holistic view of past population dynamics that includes as many lines of evidence as possible.

With this holistic approach in mind, here is the information we have regarding possible population changes occurring during the Middle Jōmon period in the Kanto and Chubu regions. Several studies have shown a clear increase and subsequent decrease in archaeological sites throughout the period (Imamura 1996; Kobayashi 2004; Koyama 1978; Yano 2014). In addition to this, the number of pithouse dwellings also appears to have been an increase and decreased throughout the period (Imamura 1996; Kobayashi 2004; Crema & Kobayashi 2020; Yano 2014). Looking at more recent analyses using the summed probability of radiocarbon dates as a proxy for demographic changes, we see relatively similar trends, although with evidence of an increase occurring slightly earlier for the radiocarbon data compared to the pithouse data (Crema *et al.* 2016; Crema & Kobayashi 2020). Adding in the paleodemographic analysis from this current study, we now see a possible increase and decrease in birth rates during the Middle Jōmon period in the Kanto and Chubu regions. While each data type and analysis has their own strengths and weaknesses, a similar trend has appeared in each of these studies, with the only significant difference among them being the exact timing of the rise and fall of their prospective measures. As more and more studies are added, the evidence of some form of population shift during the Middle Jōmon period in the Kanto and Chubu regions is only becoming more apparent.

VIII. Conclusion

This paelodemographic analysis derived from skeletal data provides one more piece of evidence that appears to support the presence of a Middle Jōmon period population “boom and bust” event. Previous population studies have shown similar trends of population increases and decreases in the Kanto and Chubu regions, but all suffered from the possible influence of changing degrees of residential mobility. As skeletal data should be more resilient to residential mobility changes, the similar trends shown in this study and in previous ones helps to reduce concerns that prior changes were reflections of mobility change. While the juvenility index values on their own don’t completely preclude the possibility of stable birth rates throughout the Middle Jōmon period, the roughly similar timings of increases and decreases between site counts, dwelling counts, summed probability distributions of radiocarbon dates, and the juvenility index birthrate proxies provided in this study all point towards the direction of a true demographic change. Future work on the topic should be geared towards gaining a better understanding of the timing differences that do exist between the various lines of evidence and a shift from *if* these population events took place to *why* they took place.

Data accessibility

Initial research compendium format modeled after Marwick (2017).
The data and code used in the analysis discussed in this paper is available at the following GitHub repository: https://github.com/coreynoxon/JomonSkeletalDemography
as well as on zenodo https://doi.org/10.5281/zenodo.7634220.

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