Quaternary International 747 (2025) 109967

Contents lists available at ScienceDirect

Quaternary International

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

Abandonment and population fluctuations of prehistoric villages: Focusing on the Geum River Basin during Korea's Bronze Age

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ARTICLE INFO

Keywords:
Radiocarbon data
Summed probability distribution
Population fluctuation
Regional abandonment
Prehistoric settlement
Korean prehistory

ABSTRACT

This study examines population fluctuations in the Geum River basin during the Early and Middle Bronze Age through settlement distributions, changes in the number of settlements and dwellings, and SPDs of radiocarbon dates. Despite broadly shared material culture during the Bronze Age, demographic patterns varied significantly across four subregions—Miho, upper, middle, and lower Geum River—largely influenced by local topography. In the Miho and upper Geum Rivers, limited settlement space constrained population growth. In contrast, the middle Geum River allowed for settlement expansion and in-migration, but this eventually triggered environmental and social stress, leading to abandonment at the end of Early Bronze Age. The resulting dispersal appears to have contributed to population reorganization in the lower Geum River during the Middle Bronze Age. In this period, changes in subsistence strategies and social structure fostered the emergence of large-scale settlements, sustained in part by group ritual practices.

1. Introduction

Why do we, archaeologists, reconstruct the population of past societies? The influence of demographic dynamics on various aspects of society is widely acknowledged. Population movement, such as migration, is often regarded as a key driver of cultural changes. For instance, in Korea, scholars have traditionally explained prehistoric and protohistoric cultural changes, including the initiation of agrarian culture, as results of migrations from China or northern regions of the Korean Peninsula (Ahn, 2000; Bae, 2011; Lee, 2002; Lee and Shi, 2015; Park, 1999a, 2001). Moreover, growing interest in subsistence economies and social structuress has encouraged interpretations grounded in population dynamics.

While various archaeological proxies have been frequently used for population estimation, in recent decades, summed probability distributions (SPDs) of radiocarbon dates have emerged as the most popular method, especially for reconstructing prehistoric demographics. SPDs have brought a new perspective to the study of population dynamics, allowing researchers to estimate diverse temporal aspects of settlement patterns, such as advent or abandonment, continuity or discontinuity, and rates of growth or decline (Ahn and Hwang, 2015; Bocquet-Appel et al., 2009; Collard et al., 2010; Crema, 2022; Crema and Kobayashi, 2020; Crema et al., 2016; Downey et al., 2014; Gamble et al., 2005; Hwang et al., 2023; Oh and Conte, 2022; Palmisano et al., 2017; Seong and Kim, 2022; Shennan, 2009; Shennan and Edinborough, 2007; Shennan and Sear, 2021; Shennan et al., 2013; Tallavaara et al., 2010; Wright et al., 2020).

However, an environmentally deterministic perspective remains influential in explaining such population phenomena. For example, rapid population decline or abandonment of regions is often attributed to catastrophic environmental degradation or a subsequent decrease in available resources, which seems to be plausible explanations. This tendency has been reinforced by the active use of SPDs in population estimation. With the reconstruction of paleoclimatic patterns at finer scales and improved chronological precision through radiocarbon dating in archaeology, researchers increasingly seek to identify correlations between climatic cycles and cultural transformations or population dynamics (Flohr et al., 2016; Hwang and Yoon, 1999; Kaniewski and Van Campo, 2017; Maher et al., 2011; Park, 2021; Park et al., 2019, 2020; Weninger et al., 2009; Williams et al., 2010; Woodbridge et al., 2014; Xu et al., 2019).

However, Many scholars argue that environmental determinism tends to oversimplify the relationship between climatic conditions and humans, treating it as a straightforward causal relationship (Arponen et al., 2019; Ayichew, 2014; Coombes and Barber, 2005; Lespez, 2025; Seong, 2021). For example, this perspective attributes cultural or

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https://doi.org/10.1016/j.quaint.2025.109967
Received 19 January 2025; Received in revised form 20 June 2025; Accepted 26 August 2025
Available online 2 September 2025

demographic change solely to environmental factors, thereby overlooking the institutional and structural diversity within societies and the adaptive strategies employed by individuals and groups. Critics of environmental determinism argue that any proposed causality between environment and human culture requires scrutiny and should be examined through a multi-layered approach that moves beyond the simplistic human-environment dichotomy. Among the sites analyzed, the abandonment of Misa-ri type settlement in the middle Geum River region during the Early Bronze Age has been attributed to a cessation of agriculture due to climate cooling (Lee, 2017; Lee and Son, 2012). However, this explanation focuses only on a specific site, and fails to account for the continued existence of contemporaneous Garak-dong type settlements in the surrounding area. A more detailed discussion and critique of this issue will be presented in section 4.1.

Although the environment undeniably influences various aspects of society, responses to it or its changes are also shaped by complex political, economic, and social factors, both within and beyond society. Assuming uniform responses across regions and groups risks overlooking these factors and the diverse intra- and inter-regional relationships they produce. For example, contrary to the prevailing environmental determinism model, population levels in Korean Peninsula appear to have increased during the Last Glacial Maximum (LGM). While this trend may be difficult to explain at a local scale, macroscopic analysis reveals that (super)regional interactions likely influenced population fluctuations, encompassing regions across Northeast Asia including adjacent parts of China, the Russian Far East, the submerged Yellow Sea shelf, and Japan (Seong and Kim, 2022). Therefore, both macroscopic and microscopic approaches to population studies must consider such interregional correlations and interactions. In the case of the Korean Bronze Age, previous studies have identified broad trends in population dynamics through large-scale analyses (Ahn and Hwang, 2015; Oh, 2023; Oh et al., 2017), yet more detailed research is needed to examine interlinked demographic changes among subregions-phenomena that may be overlooked in macro-level studies. Here, we focus on a smaller region and shorter period for a more detailed and microscopical analysis.

The Geum River Basin in the central-western Korean Peninsula presents a compelling case for this study. Despite substantial homogeneity in material culture, notable differences in settlement patterns and demographic trends are observed across the major reaches of the River. Moreover, archaeological and radiocarbon data suggest that the abandonment of one area may have contributed to the growth of another. Dynamic processes such as population movement, growth and decline, and settlement reorganization appear to have significantly influenced the region during the Bronze Age.

This study examines these demographic dynamics both within and between different parts of the Geum River. In the following discussion, we begin by reviewing the archaeological background and outlining the analytical tools employed. We then analyze population fluctuations using radiocarbon dates and archaeological data. Finally, we propose an explanation for understanding population dynamics in the Geum River Basin by considering socio-economic and physical geographic factors, as well as diverse interactions between humans and both their environment and other human groups.

2. Material and methods

The Geum River, the third largest river in South Korea, flows through Chungcheongnam-do (South Chungcheong Province) and Chungcheongbuk-do (North Chungcheong Province). It merges with its main tributary, the Miho River, in its middle reaches, and then flows southwest into the West Sea (Fig. 1). In the upper and middle reaches of the Geum River, mountainous terrain and highlands are well-developed, resulting in a deeply meandering river valley and complex drainage network. Despite this, several large and small basins also formed. In contrast, the lower reaches have undergone prolonged erosion, forming flat terrain with scattered low hills, as well as extensive floodplains and alluvial plains. These geomorphological conditions, combined with abundant water resources, have made the lower Geum River region one of the major granaries of the Chungcheongnam-do to this day. Similar topographic characteristics are also observed in the Miho River, which has supported the agricultural development of Chungcheongbuk-do. Furthermore, the Geum River's substantial water volume and wide channel have historically made it a vital waterway, linking the West Sea and the inland regions. From prehistoric times to the present, it has played a diverse role not only in subsistence economies but also in

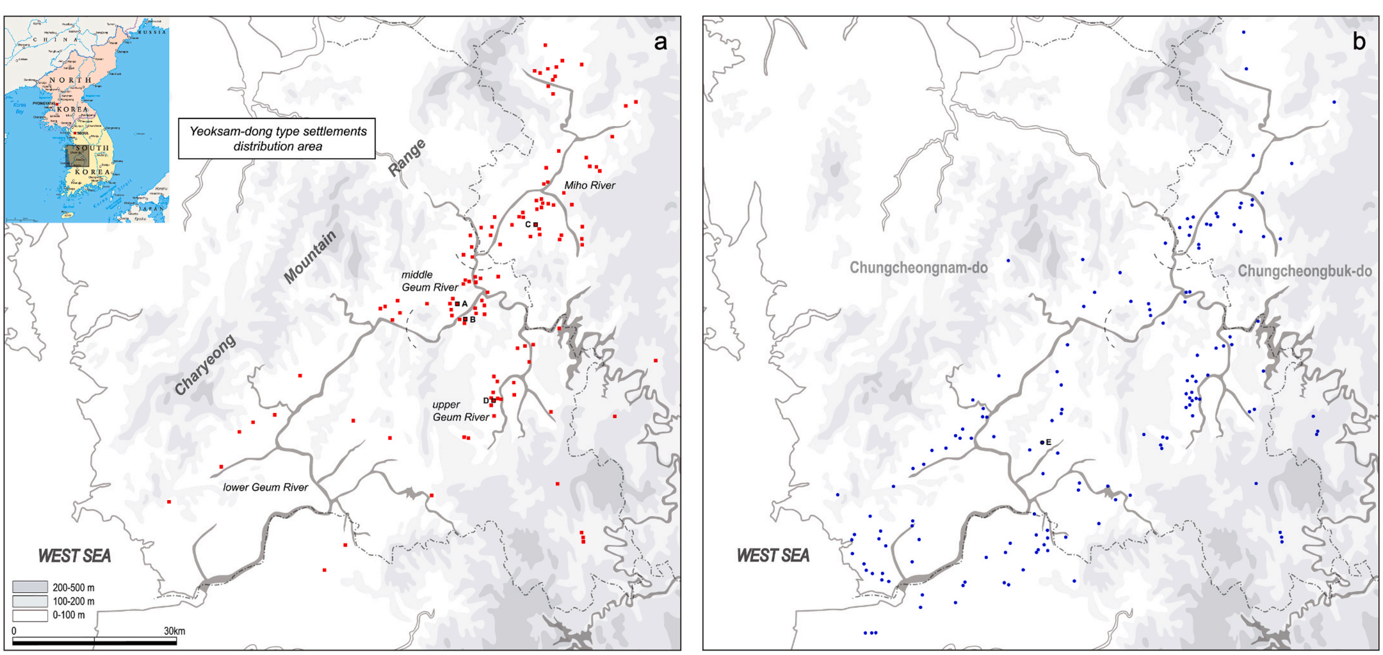

Fig. 1. Map showing the study area during a) the Early Bronze Age and b) the Middle Bronze Age. Red squares and blue dots indicate the location of settlements. Distances from A (Songdam-ri) to B (Daepyeong-ri), C (Biha-dong), D (Yonggye-dong), and E (Songguk-ri) are approximately 3 km, 20 km, 20 km, and 33 km, respectively. (color print needed). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

politics, cultural exchange, military, and transportation. Numerous shell middens dated to the Bronze Age have also been identified in the river's lowermost reaches near the West Sea, indicating its significance in ancient subsistence strategies.

Extensive excavations and surveys conducted in the Geum River Basin have yielded substantial data on settlements. This has enabled the collection of numerous radiocarbon dates, allowing for a relatively high-resolution analysis of population change.

Previous studies (Ahn and Hwang, 2015; Oh, 2023) on SPDs of the Bronze Age in South Korea indicate a population increase beginning around 1500 BCE, reaching a peak in the 9th-8th centuries BCE, followed by a gradual decline. Regional analyses reveal some variation in the timing of population peaks and growth/decline rates. Still, an overall upward trend from the mid-2nd millennium BCE is observed across most regions, including the Chungcheong region. This initial increase corresponds to the Early Bronze Age and is generally interpreted as reflecting population growth resulting from the successful establishment of agriculture during this period. The peak observed in the 9th-8th centuries BCE corresponds to the middle Bronze Age, characterized by the onset of intensive rice farming, the emergence of large-scale settlement, and increasing social complexity. The subsequent population decline has been interpreted in various ways (Lee and Koo, 2022; Lee, 2016, 2022; Park, 2021; Yoo, 2010), with some views suggesting that it was associated with environmental degradation.

The population trends from the broader-scale SPD analyses are generally consistent with those seen in more localized analyses of the Geum River basin. However, settlement distribution data from the Early to Middle Bronze Age reveals significant regional shifts. Most settlements in the middle Geum River disappeared, while the lower Geum River, largely uninhabited during the Early Bronze Age, experienced a dramatic increase in settlements (see Fig. 1).

This study addresses two key questions to understand these changes in settlement distribution.

First, what happened in the middle Geum River? Did the population integrate into a few large settlements? Or, if this area was abandoned and depopulated, where did the people relocate?

Second, why did settlements in the lower Geum River increase? Did large settlements divide into smaller, dispersed ones? If the population indeed increased, leading to the growth of settlements, where did these people come from?

2.1. Materials

Chronologically, the Bronze Age in South Korea spans from approximately 3500 to 2100 cal BP, divided into the Early Bronze Age (EBA) (3500-2750 cal BP) and the Middle Bronze Age (MBA) (2900-2100cal BP) (Table 1).

In Korean archaeology, the EBA has traditionally been considered to have begun with the southward migration of dry-field farming agricultural groups from the Liaoning region of China and the northern Korea (Ahn, 2000; Lee, 1974; Lee, 1988; Lee, HW, 2002; Park, 1999b). EBA cultural assemblages are typically classified based on pottery decoration and dwelling features, with the Misa-ri, Garak-dong, and Yeoksam-dong type named after their respective type site. Previous studies have suggested that environmental changes contributed to the movement of the Misa-ri type assemblages (Ahn, 2000; Kim, 2004), while political factors were proposed as the cause for the Garak-dong type assemblages (Kim, 2001). However, for the Yeoksam-dong assemblage, an alternative view posits that it may have emerged locally during the final stage of the Neolithic Age (Kim, 2008a, 2018; Hwang, 2017; Hwang and Kim, 2024).

The spatial distribution of these assemblages is divided by the Charyeong Mountain Range in the Chungcheong region. Yeoksam-dong type settlements are more prevalent in the area northwest of the mountain range (Fig. 1). In contrast, numerous Garak-dong and some Misa-ri type settlements are located in the southeastern side, where the Geum River flows.

In the Geum River Basin, Garak-dong type settlements are typically located on flat hilltops. Residential structures tend to be semi-subterranean, rectangular in plan, and have multiple hearths surrounded by stone slabs. Pottery decorated with *iejoongguyeon* (doubled rims) and *dansaseon* (short slanted lines) is the main diagnostic of the Garak-dong type (Fig. 2). During this period, most regions in Korea experienced a rapid transition to an agricultural economy centered on crops cultivation (Ahn and Hwang, 2015). In the case of Garak-dong settlements, the presence of ground stone tools for lumbering, extended-family dwellings, and plant remains suggests a reliance on the swidden farming system (Park, 1999; Yi, 2007; Na, 2013).

Meanwhile, several Misa-ri type settlements show few differences from the Garak-dong type aside from their locations—typically on natural levees within alluvial plains. Given their similar subsistence strategies and toolkits, the two types likely coexisted and interacted, as evidenced by the mixing of their material elements (Choi, 2014; Jeong, 2021).

In the MBA, with the establishment of intensive rice-farming, significant transformations occurred in the subsistence economy and social structure, making a critical turning point in the study of prehistoric Korean society. The material culture of this period is referred to as the Songguk-ri type assemblage, after its type site. Settlements generally consist of clusters of small, round-shaped pit houses without internal hearths and are associated with diagnostic artifacts, such as plain-coarse pottery with everted rims and stone tools (e.g., grooved stone adze, triangular leaping knives) (Fig. 3). They are typically located on the

Table 1
Archaeological assemblages of the Bronze Age in the Geum River Basin.

Period		Dwellings	Pottery	Stonetools
Late Bronze Age				
Middle Bronze Age (900–300BC)		semi-subterranean, circular/square-shaped dwellings with an oval pit in the center, two postholes on both sides of an oval pit, no hearth	jars(everted rim), deep bowls, red-burnished pottery(flask-shaped jars)	stone daggers(one-stepped haft type, tanged type), stone arrowheads(single-tier tanged), grooved stone adzes, triangular leaping knives
Early Bronze Age (1500–900BC)	Phase III	semi-subterranean, (long) rectangular-shaped dwellings with multiple pit hearths, postholes in a central axis, storage pits	jars(upright rims), deep bowls(notched lips, everted rim), red-burnished pottery (pedestalled bowls, jars)	stone daggers(two-stepped haft type, one-stepped haft type), stone arrowheads(triangular-shaped with indented base, double-tiered tanged, single-tiered tanged), double-edged stone axes
	Phase II	semi-subterranean, (long) rectangular-shaped dwellings with multiple stone-lined hearths, foundation stones in 2 rows, post holes in a central axis, storage pits	jars(upright rims), deep bowls (degenerated doubled rims and short slanted lines, notched rim), red-burnished pottery(pedestalled bowls, jars)	stone daggers(two-stepped haft type with grooved blade, one-stepped haft type), stone arrowhead (triangular-shaped with indented base, double-tiered tanged, single-tiered tanged), double-edged stone axes
	Phase I	semi-subterranean, rectangular-shaped dwellings with single stone-lined hearth, foundation stones in 2 rows, storage pits	jars(upright rims), deep bowls(doubled rims and short slanted lines, denticulated pattern), red-burnished pottery (pedestalled bowls, jars)	stone daggers(two-stepped haft type with grooved blade, grooved blade), stone arrowheads (triangular-shaped with indented base, double-tiered tanged), double-edged stone axes
Neolithic				

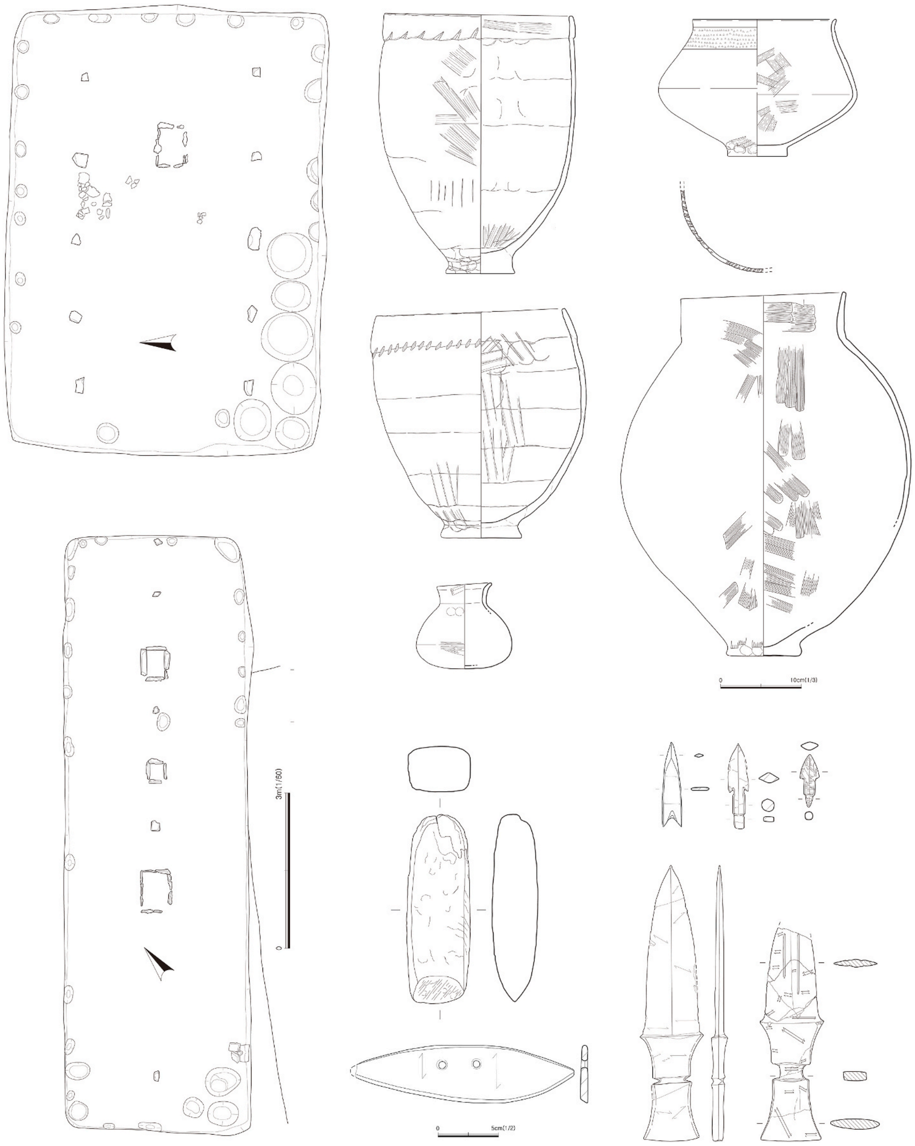

Fig. 2. A Garak-dong type assemblage during the Early Bronze Age in the Geum River Basin.

lower slopes of hills, providing easy access to the adjacent lowland area where agricultural fields were situated. Contrary to EBA settlements, which primarily consist solely of habitation areas, those from the MBA period show functional differentiation, with designated zones for dwellings, storage, burials, rituals, and defense. Furthermore, changes in dwelling form reflect a shift in household structure, from communal living of multiple households in large dwellings to individual households occupying smaller residential units. With these changes in settlement, the increased construction of rice paddies and the use of stone tools for wooden farming tools indicate the emergence of a full-scale agricultural society (Fig. 4).

Several researchers evaluate the emergence of the Songguk-ri type assemblages during the MBA as a groundbreaking transformation that reshaped many aspects of Bronze Age society. This transformation involved not only changes in tool technology and subsistence strategies, but also economic restructuring (Kim, 2005; Lee, 2002), the management and appropriation of surplus (Kim, 2008b), and the development of social inequality and hierarchical organization (Kim, 2006b, 2007; Lee, 2009), changes in household composition and settlement structure (Ahn, 2000; Kim, 2006a; Lee, 2007), as well as the introduction of a new burial system and the appearance of prestige goods (Kim, S., 2001; Hwang, 2021).

Spatially, the Geum River Basin can be divided into four subregions based on its reaches and cultural traditions: the Miho River region, upper Geum River region, middle Geum River region, and lower Geum River region (see Fig. 1). Garak-dong type settlements during the EBA are primarily distributed across mountainous hills in the Miho River and the upper to middle Geum River, with some located in basins near tributaries and on alluvial plains. This represents a relatively narrow distribution considering the scale of the river. In contrast, Songguk-ri type settlements of the MBA are found predominantly on low hills adjacent to alluvial plains in the lower Geum River, reflecting the gradual expansion of Bronze Age habitation zones. Based on the spatial-temporal distributions of these two types, several studies have explored the relationship between them (Kim, 2006; Lee, 2005, 2009; Song, 2001; Yi, 2018).

2.2. Method

In this study, the primary analytical tool for examining population fluctuations is SPDs of radiocarbon dates. Based on the assumption that population size is directly proportional to the number of radiocarbon dates (Rick, 1987), SPDs provide a reliable representation of past population fluctuations. However, there are inherent limitations and issues

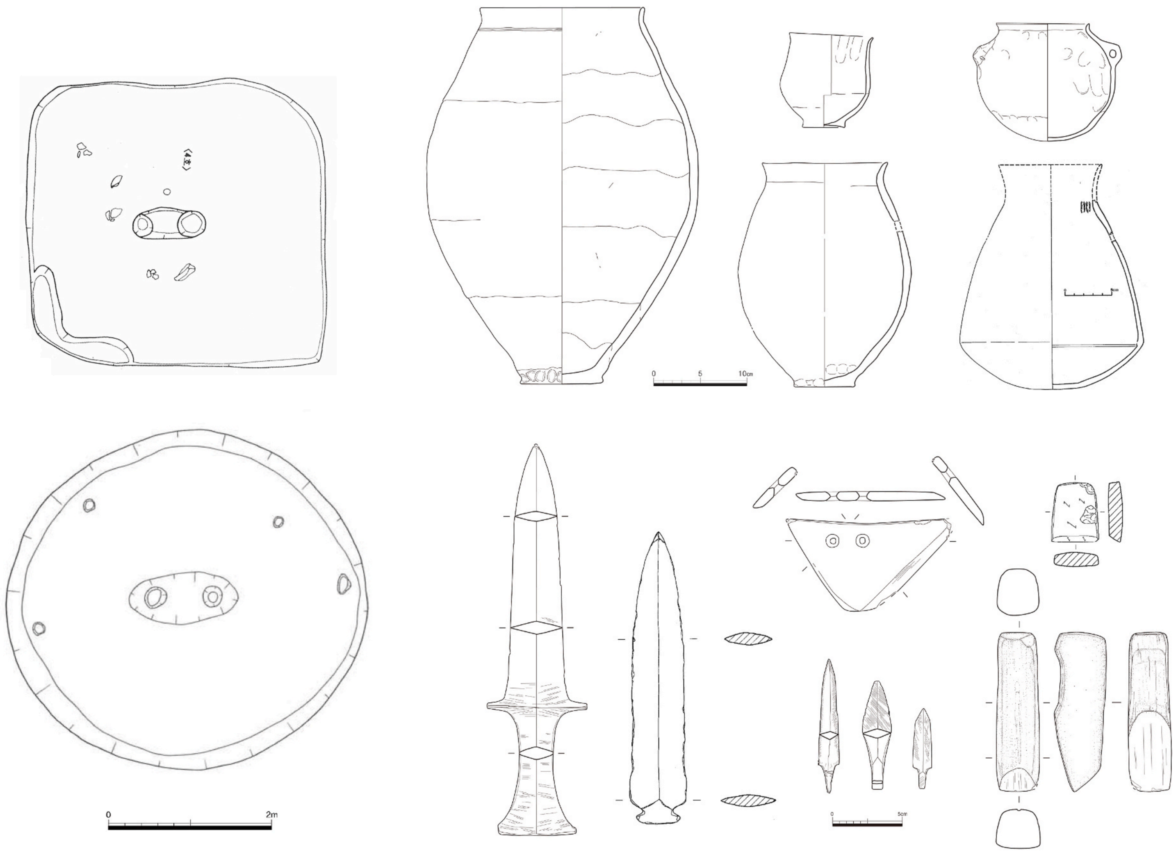

Fig. 3. A Songguk-ri type assemblage during the Middle Bronze Age in the Geum River Basin.

when using radiocarbon dates, which must not be overlooked. These include not only calibration curve effect and sampling bias but also a fundamental issue: to what extent can radiocarbon dates accurately reflect the actual population size of the past (Palmisano et al., 2017; Kim, 2021)?

In Korea, these issues are especially prominent during two periods: The Late Neolithic and the transition from the Late Bronze Age to the Early Iron Age.

In highly mobile hunter-gatherer societies, discrepancies may arise in the traces of human activity between residential sites (e.g., settlements, dwellings) and outdoor features (e.g., campsites, shell middens, outdoor resource extraction sites, and storage facilities). In the Late Neolithic of Korea, radiocarbon dates from residential sites indicate a sharp decline, interpreted as a shift toward non-sedentary, high-mobility subsistence strategies in response to environmental change, rather than an actual population decrease. Supporting this interpretation, the number of outdoor features and radiocarbon dates from these features increased during this period (Ahn and Hwang, 2015; Ahn et al., 2015).

Changes in building traditions can also influence the SPDs. Toward the Early Iron Age, the number of residential sites decreased relative to burials, which might be interpreted as a population decline (Lee and Koo, 2022). However, as previous research noted (Crombé and Robinson, 2014), more superficial structures are more susceptible to erosion or post-depositional processes, affecting the dating possibilities. In the Early Iron Age, pithouse depth was shallower than during the Bronze Age. Additionally, the majority of arable land in Korea is situated in highly weathered, acidic soils (Hong et al., 2010). In this type of archaeological context, only limited datable materials, such as charred wood, could be preserved (Kim et al., 2019).

While residential sites typically provide the most direct proxy of human activity, SPDs are likely to exaggerate population decline in these cases, depicting a more dramatic decrease than what likely occurred in reality. These issues can be addressed through a detailed examination of radiocarbon dates and various statistical procedures, such as combining multiple dates, rolling-mean, and the Markov chain Monte Carlo (MCMC) method, and a detailed examination of the old wood effect and outliers (Ahn, 2012; Ahn and Hwang, 2015; Hwang, 2014; Hwang and Yang, 2015; Hwang et al., 2016; Oh and Conte, 2022; Palmisano et al., 2017; Ritchie et al., 2016; Shennan and Edinborough, 2007). Hence, overall trends in population distribution changes should be examined by adjusting radiocarbon dates appropriately and comparing them with archaeological data (Balsera et al., 2015), including settlement and dwelling counts. To this end, we analyze SPDs alongside relative chronology based on dwellings and pottery typology.

For this study, 776 radiocarbon dates for dwellings in the Geum River Basin were obtained. The following procedures were adopted to minimize errors in using radiocarbon dates: First, outliers were identified and excluded. These outliers include dates with a standard deviation exceeding ±100 years, indicating low reliability; dates differing by more than 100 years from others within the same dwelling, suggesting they are not contemporaneous, and dates significantly diverging from the established chronology. Second, when multiple radiocarbon dates were identified from a single dwelling, a single calibrated date was derived using R_combine and Outlier order in the OxCal 4.4 version. As a result, 532 radiocarbon dates were selected. These dates were aggregated to compare the SPDs of each subregion using the R packages Bchron and rcarbon.

In addition, to conduct a detailed analysis of population fluctuation derived from SPDs, the duration of settlements was estimated using the Span in OxCal. The duration of settlements can be estimated by considering the orientation of dwellings or their overlapping relationships. When sufficient radiocarbon dates are available, it is possible to simply calculate the difference between the earliest and latest dates; however, this approach may disregard the error ranges or probability

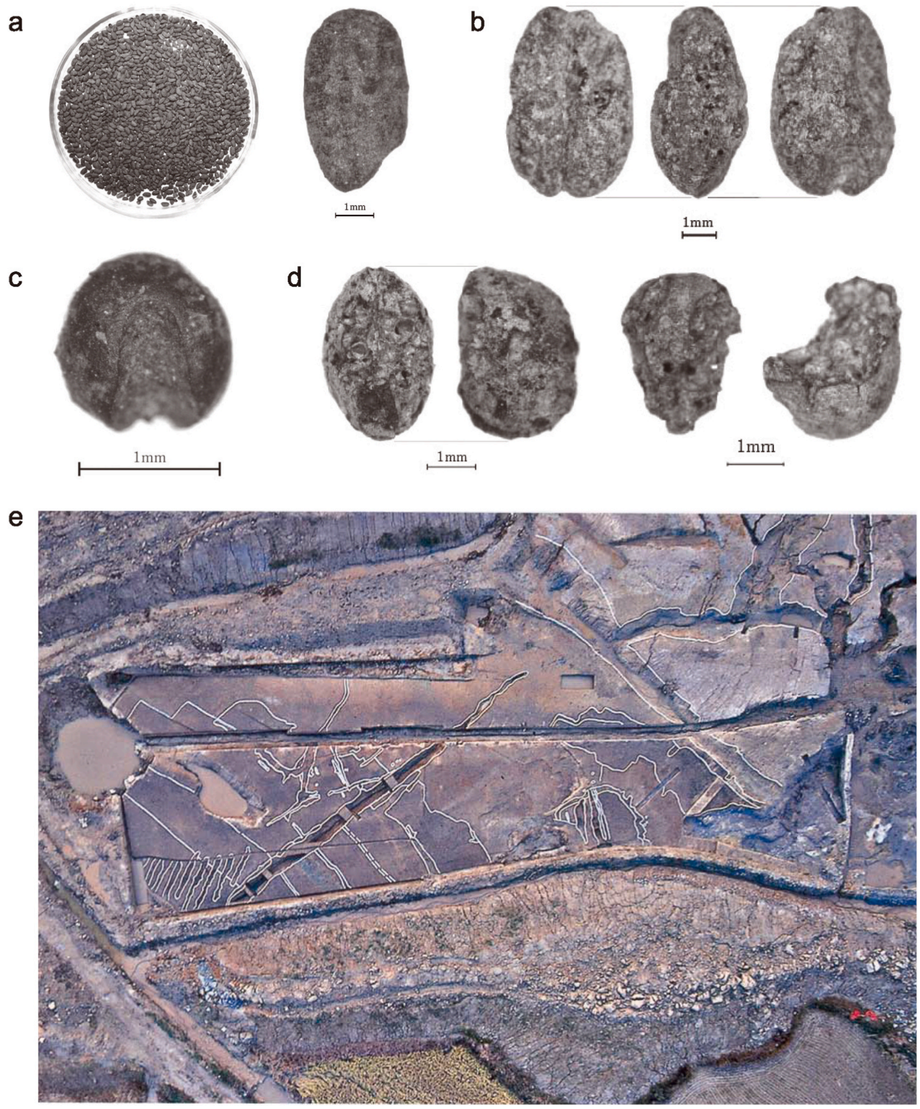

Fig. 4. The charred crop remains and a rice paddy field during the Middle Bronze Age in the lower Geum River: a. Oryza sativa, b. Triticum aestivum, c. Setaria italica, d. Glycine max from Songguk-ri site, e. a rice paddy field in Majeon-ri Site.

distributions of each date. The Span provides a reliable range by accounting for probability distributions and uncertainties associated with radiocarbon dates.

3. Result

3.1. Settlement data

238 Bronze Age settlements were identified in the Geum River Basin. A total of 2233 dwellings were uncovered, of which 2108 could be assigned to specific periods according to the relative chronology. These settlements and dwellings data were used to estimate the change in settlement and population distribution (Table 2).

There is no significant fluctuation in the Miho and upper Geum Rivers. In the Miho, the number of dwellings between the early and middle Bronze Age shows little variation, but the average number of dwellings per settlement increased. In the upper Geum River, the total dwellings increased by 62, while the average per settlement remains the

Table 2
Number of dwellings and settlements during the Bronze in the Geum River Basin.

Region	Miho River			upper Geum River			middle Geum River			lower Geum River		
Total site no.	93			48			34			63		
Period	EBA		MBA	EBA		MBA	EBA		MBA	EBA		MBA
	Misa-ri	Garak-dong	Songguk-ri	Misa-ri	Garak-dong	Songguk-ri	Misa-ri	Garak-dong	Songguk-ri	Misa-ri	Garak-dong	Songguk-ri
Site no.	1	69	38	3	27	37	1	27	19	–	15	90
Dwelling no.	2	281	272	17	158	220	70	292	78	–	40	679
Dwellings per site	2	4.1	7.2	5.7	5.9	5.9	70	11.2	4.1	–	2.6	7.5

same at 5.9.

In the middle Geum River, the number of EBA dwellings and the average number of dwellings per settlement are the highest among the four subregions. However, both declined sharply during the transition to MBA. These figures make it difficult to conclude that there was an aggregation into a few large settlements. Instead, it appears that the remaining settlements in this subregion were relatively small in both size and number.

To examine this settlement pattern in detail, EBA settlements in the middle Geum River were divided into three phases based on dwelling and pottery typology (Table 3). In this region, settlements and dwellings increased over time, showing nearly a fourfold growth by the late EBA. Notably, the significant growth of three sites-Songwon-ri, Songdam-ri, and Jangjae-ri-stands out, with settlements of comparable scale not observed in the Miho or upper Geum Rivers.

In contrast, in the lower Geum Rive, both the dwelling counts and the average per settlement increase significantly. If a few large settlements from the EBA had dispersed into numerous smaller ones, the overall size of the settlements would have decreased. However, this pattern indicates that as the number of settlements increased, their size also grew.

3.2. SPDs

The SPDs of the entire Geum River Basin (Fig. 5) do not significantly differ from those of the whole Chungcheong region or others on the Korean peninsula. However, settlement data indicates different population fluctuations by subregions, which are further analyzed using SPDs (Fig. 6). For this analysis, 532 radiocarbon dates were used.

Before interpreting SPDs, several factors must be considered. As discussed above, a significant shift in dwelling tradition occurred during the transition to the MBA. In the EBA, multiple households resided in a large dwelling, whereas in the MBA, each household occupied a smaller, individual dwelling. Even if the number of households and family members remained constant, it is natural that the number of dwellings increased in the MBA. However, MBA dwellings present challenges for radiocarbon dating due to the lack of hearths or structural materials, which reduces the availability of datable samples. Moreover, the Hallstatt plateau effect discourages researchers from collecting datable materials from MBA contexts. Such archaeological aspects should be considered when interpreting SPD distributions.

Table 3
Number of dwellings by phase of the Early Bronze Age in the middle Geum River.

Site	Phase I	Phase II	Phase III
Gongju Dangam-ri Sogol•		10	10
Sejong Songwon-ri Manjadong			
Gongju Dangam-ri Danggol			1
Gongju Jecheon-ri	4	5	1
Gongju Dangam-ri Makeumgol	1		1
Gongju Dangam-ri Eomgogae		2	11
Sejong Dogye-ri	1		1
Sejong Yongho-ri(35)	3	4	
Sejong Habkang-ri(68–1)		1	7
Sejong Seoksam-ri		3	
Sejong Yongho-ri Yongsan		4	5
Sejong Hwangryong-ri	3	1	1
Sejong Bonggi-ri(119•120)			1
Sejong Jangjae-ri	3	5	22
Sejong Botong-ri	7		2
Sejong Unam-ri Gamagol			1
Sejong Bonggi-ri(116)	5	1	1
Sejong Songwon-ri	3	12	36
Sejong Songdam-ri(28•29•30)	9	12	49
Sejong Songdam-ri(34)		1	4
Sejong Yeongi-ri		4	4
Sejong Yongho-ri		6	5
Sejong Yongpo-ri		1	
	39	72	163

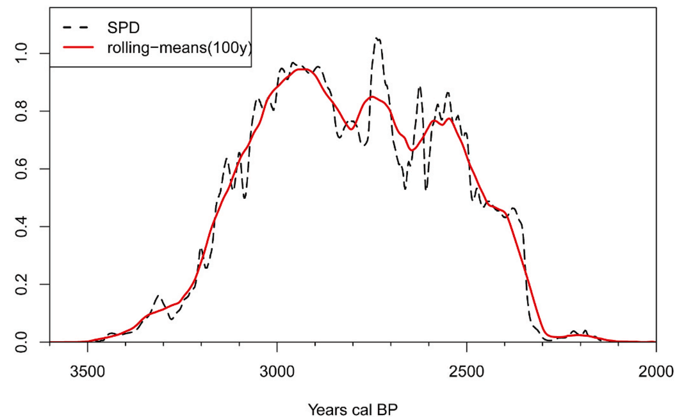

Fig. 5. The summed probability distribution for calibrated dates (dashed line) and 100-year rolling means (red line) for whole Bronze Age features (dwellings, burials, pits, etc.) in the Geum River Basin. (color print needed). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

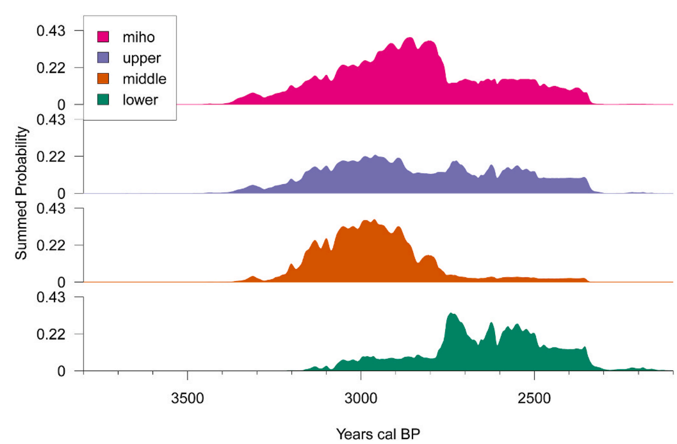

Fig. 6. The summed probability distribution for Bronze Age dwellings in subregions of the Geum River Basin (color print needed). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

The SPD of the Miho River shows population fluctuations similar to those of the entire Geum River Basin. While a notable decrease in population is observed between 2800 and 2700cal BP, this slope is likely exaggerated due to the aforementioned issues. The SPD of the upper Geum River exhibits the least variation among the four subregions. After reaching a peak of around 3000cal BP, population density declines moderately but maintains relatively stable levels until 2300cal BP.

In the middle Geum River, a dramatic population increase is observed, peaking around 3000cal BP-an exceptional growth given the smaller size of this subregion compared to the Miho or the upper Geum River. After 2900cal BP, population density declines rapidly and remains extremely low until the end of the Bronze Age. In contrast, the lower Geum River shows the lowest population density during the EBA. However, between 2800 and 2750cal BP, it experiences a sharp increase and sustains a relatively high level until 2300cal BP.

Based on settlement data and SPD, the duration of settlements was estimated using the Span analysis in OxCal. In regions with no significant population fluctuations, such as the Miho or the upper Geum River, EBA settlements likely persisted through the transition to the MBA without interruption. In contrast, in the middle Geum River, where population fluctuations were pronounced, the duration of EBA settlements would have been relatively short. For the Span analysis, two regions were compared: the upper Geum River (Yonggye-dong, Yongsan-dong) and the middle Geum River (Songwon-ri, Songdam-ri, Jangjae-ri) (Fig. 7, Table 4). At the 2-sigma range, the estimated durations were as followed: Yonggye-dong (264–604), Yongsan-dong (233–504), Songdam-ri (0–323), Jangjae-ri (89–352), Songwon-ri (46–391). Although the small number of radiocarbon dates likely resulted in relatively broad ranges, the duration of settlements in the middle Geum River is shorter than in the upper Geum River.

In conclusion regional variation in population fluctuation patterns is also evident in the SPD analysis. Notably, the middle and lower Geum Rivers exhibit marked cycles of population growth and decline, suggesting the presence of interrelated processes. However, unlike the settlement data, the SPD curve indicates an overall population decline in Geum River Basin after 2900 cal BP (see Fig. 5). This discrepancy is largely attributable to the limitations in dating MBA features, as discussed above. In their SPD-based analysis of Bronze Age demographic trends in the Geum and Mangyeong River basins, Hwang et al. (2023) addressed this bias by incorporating the total area of all identified dwellings into the SPD model. Their findings reveal a significant population increase associated with Songguk-ri settlements, reaching levels comparable to those of the EBA. This comparison highlights the importance of integrating both archaeological settlement data and SPD results, rather than relying on a single line of evidence, to gain a more accurate understanding of regional population dynamics.

4. Discussion

The varied locations and distribution patterns of Bronze Age Settlements in the Geum River Basin reflect subregional differences in subsistence economies and topography. Changes in settlement systems over time are also evident, which can be traced through population growth, settlement expansion, abandonment driven by environmental and subsistence pressures, and subsequent population movement and reorganization. In the following discussion, we examine patterns of social and cultural change, from the expansion and disintegration of EBA settlements to the adoption of rice-paddy agriculture and population reaggregation during the MBA.

4.1. The growth and dissolution of Early Bronze Age settlements

Garak-dong type settlements generally remained small to medium in scale throughout the EBA. In contrast, those of the Yeoksam-dong and Misa-ri types expanded into medium to large-scale from the mid-EBA onward. This difference appears closely linked to the topographical contexts in which these settlements were located. Garak-dong settlements were situated along flat crests of narrow and steep hills in the Miho and upper Geum River, where topographic constraints limited spatial expansion (Miho River: 1–26 houses, M = 4.1, SD = 5.1; upper Geum River: 1–20 houses, M = 5.9, SD = 5.2) (Fig. 8). In contrast, Yeoksam-dong settlements, although similar in subsistence strategies, were established on broader and more gently sloping ridges, enabling relatively unrestrained growth (1–185 houses, M = 11.5, SD = 24.6; based on raw data in Na, 2013). A similar pattern is observed in Misa-ri settlements in the middle Geum River, which were located on alluvial plains.

Table 4
Median values and probability intervals (68.3 % and 95.4 %) for the estimated duration of early bronze age settlements using span analysis in OxCal.

site	m	68.3 probability	95.4 probability
Daejeon Yonggye-dong Oettangol	432	335–525	264–604
Daejeon Yongsan-dong	387	297–456	233–504
Sejong Songdam-ri	164	73–254	0–323
Sejong Jangjae-ri	234	133–317	89–352
Sejong Songwon-ri	262	104–363	46–391

However, the middle Geum River's Garak-dong settlements show a difference pattern. The number of dwellings in sites ranges from 1 to 76 (mean = 10.8, SD = 17.4), and the emergence of large settlements is pronounced. Furthermore, the whole subregion appears to have been abandoned at the end of the EBA due to a rapid population decline.

To understand the rapid population increase and the regional abandonment, it is necessary to first examine the underlying causes of the growth. The exceptionally accelerated expansion suggests the involvement of multiple, complex factors. First, unlike the isolated hills of the Miho and upper Geum River regions, the mountainous hills in this subregion stretch continuously, allowing numerous dwellings to be located successively along the same ridges; Second, the dissolution of Daepyeong-ri site, a Misa-ri type settlement, and its integration into Garak-dong type settlements likely contributed to this growth and abandonment.

The Daepyeong-ri site was a large settlement comprising 71 dwellings, located on natural levee adjacent to the river. Its SPD peaks around 3200-3100 cal BP, and archaeological evidence—such as the extension and rebuilding of dwellings, and the overlapping of multiple dwellings within a short period—supports the interpretation that the site reached its demographic peak during this time. Following this, a decline began around 3000 cal BP, and the settlement appears to have been abandoned by approximately 2800 cal BP (Fig. 9). Previous studies (Lee, 2017; Lee and Son, 2012) have attributed this abandonment to climatic cooling around the 10th century BCE, suggesting that rice farming—indicated by grain impressions and plant opal—was severely affected by the deteriorating climate. However, this pattern of abrupt abandonment is not observed in the Miho and the upper Geum River. Notably, the adjacent Garak-dong settlements in this subregion show signs of population growth during the same period. Therefore, to explain the

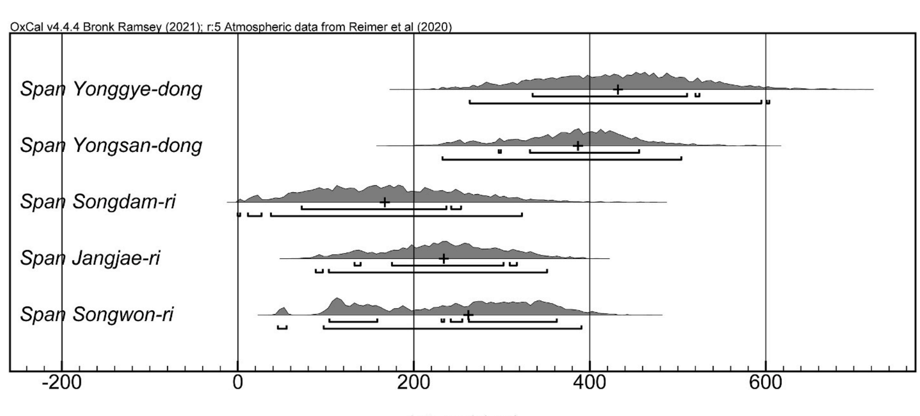

Fig. 7. Estimated duration of EBA settlements using Span in OxCal.

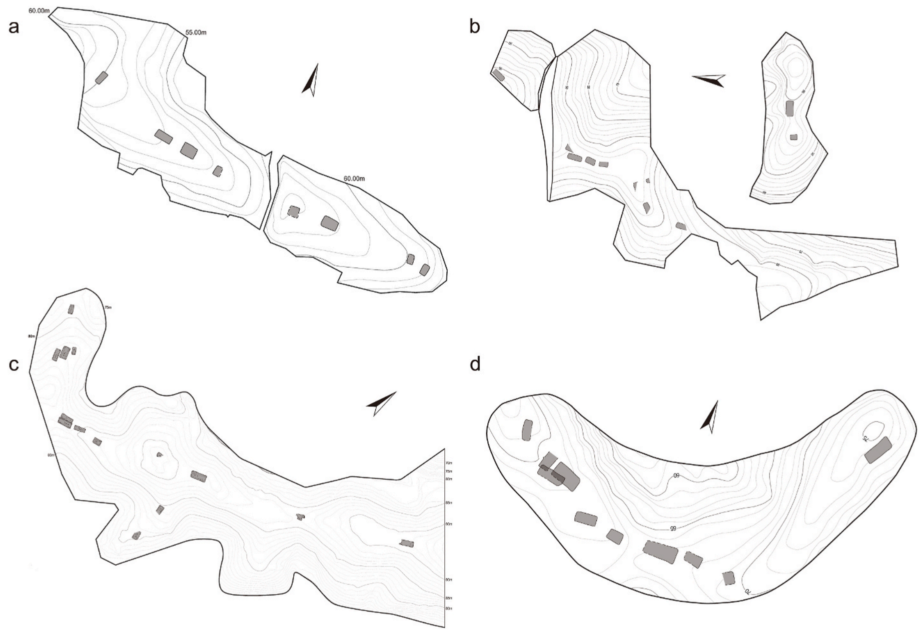

Fig. 8. EBA Settlement patterns of houses in the Miho and the upper Geum River: a. Biha-dong site, Cheongju, b. Yongjeong-dong site, Cheongju, c. Yonggye-dong site, Daejeon, d. Gwanpyeong-dong site, Daejeon.

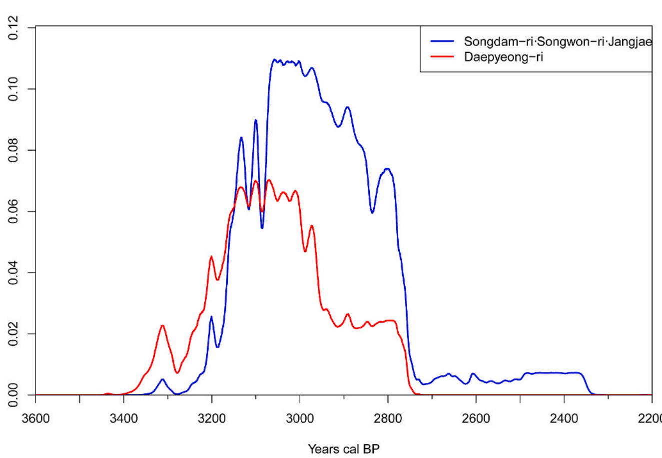

Fig. 9. SPDs of Daepyeong-ri and aggregated data from Songdam-ri, Songwon-ri, and Jangjae-ri site. (color print needed). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

dissolution of the Daepyeong-ri settlement, there is need to consider other environmental factors (e.g., soil salinization, degraded fields, depletion of soil fertility) or internal factors like overpopulation.

In any case, Daepyeong-ri settlement appears to have collapsed, and it is possible that some of its population relocated to neighboring Garak-dong settlements. Both the number of Garak-dong settlements and dwellings increased over time in this subregion (see Table 3, Fig. 9). Moreover, in large settlements such as Songdam-ri (with 76 dwellings), Songwon-ri (56), and Jangjae-ri (31) (Fig. 10), numerous cases of overlapping structures were identified. These dwellings share similar major axes, suggesting that they were constructed within a short time span, possibly reflecting a sudden inflow of population.

Then, how did this situation lead to the regional abandonment of the middle Geum River? Immigration from outside, combined with natural population growth, likely created challenges both within and beyond settlements. As population density increases, competition for productive land also intensifies, prompting communities to defend their territories and secure access to arable land (Varien et al., 2000). In this process, land tenure systems become more structured and less flexible, thereby limiting opportunities for new land use and access to essential resources (Kohler, 1992; Kohler and Van West, 1996). The noticeable increase in settlements across the landscape would have accelerated this trend, contributing to growing tensions and disputes across communities, including social issues such as conflicts with immigrants and scalar stress (McCool et al., 2022; Nakagawa et al., 2021; Valdez, 2007). Once the threshold for managing internal and external stresses was exceeded and the environment degradation progressed, it is assumed that large settlements disintegrated, eventually resulting in the abandonment of the entire region (Spielmann, 1998).

Interestingly, a similar pattern is observed in EBA settlements on the northeast side of the Charyeong Mountain Range. Although there are some differences in pottery decoration and dwelling structures compared to Garak-dong settlements, both shared a common social unit—extended family living together and practicing dry-field farming. However, as noted earlier, Yeoksam-dong settlements not only had a significantly higher average number of dwellings than Garak-dong settlements but also underwent disintegration at the end of the EBA. One notable example is Baekseok-dong, a large village comprising of 185 dwellings. Kim (2003) argues that this densely populated site eventually collapsed due to demographic and subsistence-related pressures. Such pressures likely led to abandonment of many settlements in this region and the dispersal of their population to areas where alternative subsistence strategies were viable, including newly available arable land and shell middens that had remained unused during the EBA. This period marks the transition from the EBA to the MBA, characterized by changes in material culture (e.g., pottery, stone tool, residential structure). Following this dispersal, population appear to have regrouped in the West Sea coast and the middle Geum River, where population density had been relatively low during the EBA. This reaggregation is attributed to the regularized rice-paddy agriculture and innovations in agricultural. (Kim, 2003).

Although the disintegration process in the middle Geum River may not have fully aligned with the case of the Yeoksam-dong settlements, the similarities in population dispersal and reorganization at the regional level are highly noteworthy. Moreover, the formation of the Songguk-ri type assemblage in the lower Geum River during the MBA

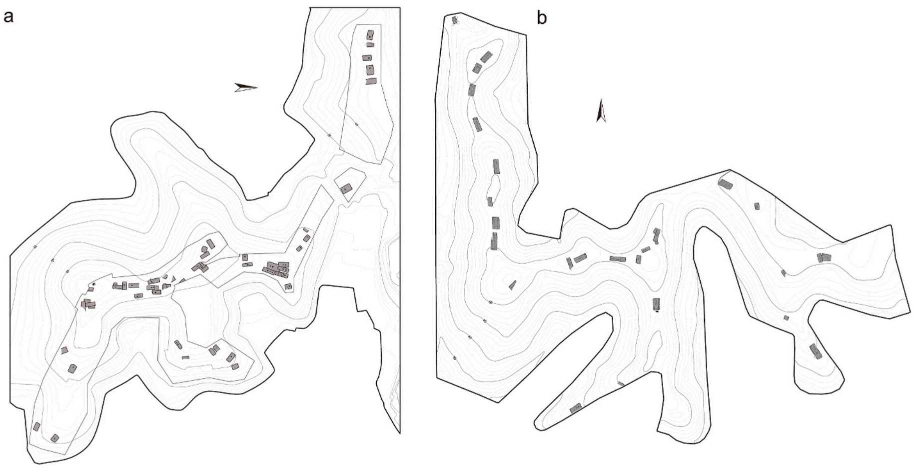

Fig. 10. EBA Settlement patterns of houses in the middle Geum River: a. Songdam-ri site (28), Sejong, b. Jangjae-ri site, Sejong.

appears to have been closely linked to these dynamics, offering important implications.

4.2. The adoption of wet-rice agriculture and regional population reorganization in the Middle Bronze Age

Where was the destination for groups who left the middle Geum River? SPD data suggest that they moved to the lower Geum River, which offered several advantages as a destination. Unlike the middle Geum River, the lower region was less geographically constrained and largely unoccupied during the EBA, resulting in low competition for arable land and abundant available resources.

The migration likely began in the late Phase II of the EBA, when the land tenure system had become more formalized. This is evidenced by the presence of Garak-dong settlements both near the Gongju area, between the middle and lower Geum River, and as far south as the lower Geum River. In the late Phase III, as settlements—including large ones—collapsed across the middle Geum River, population outflow appears to have accelerated. These migrant groups who settled in the lower Geum River adopted new material cultures and subsistence economies centered on wet-rice cultivation, and reorganized their social systems accordingly.

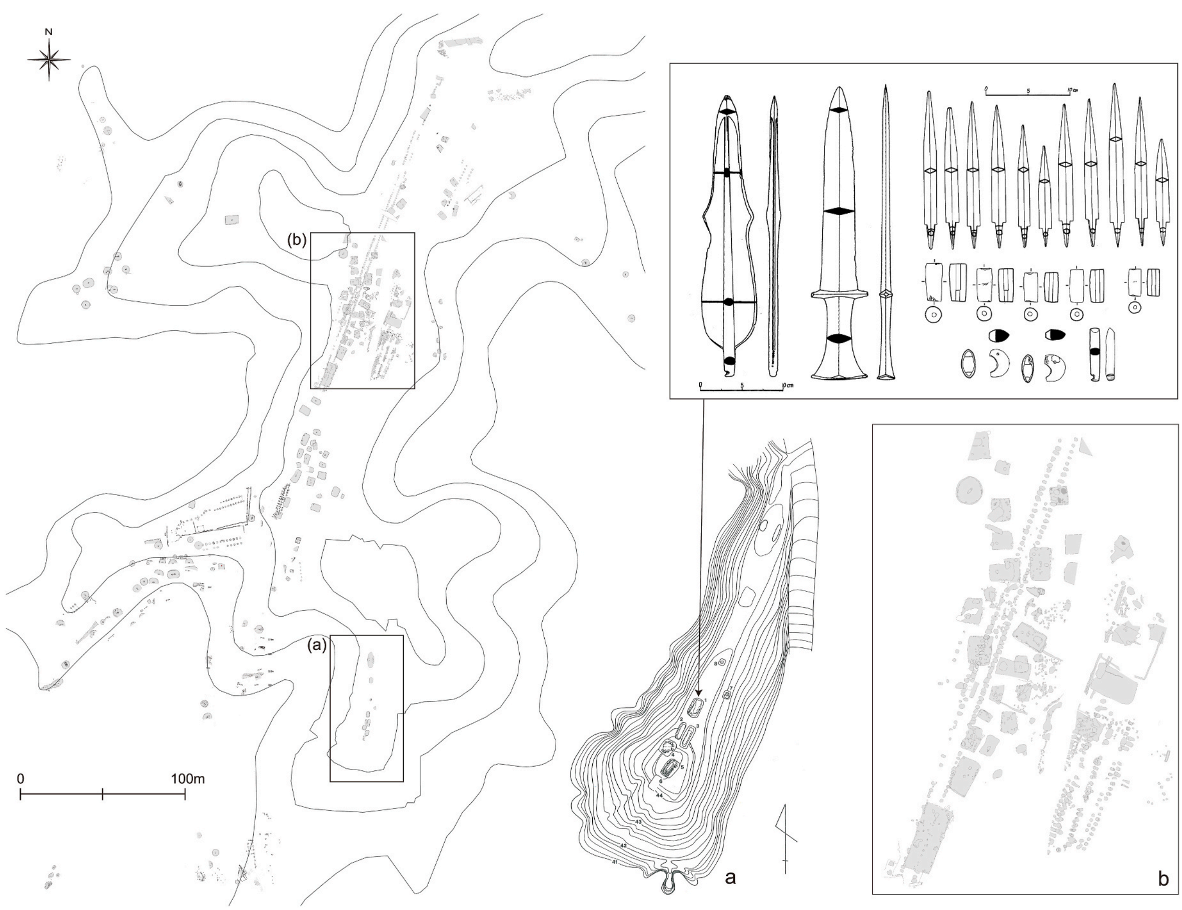

Fig. 11. Songguk-ri site plan showing a) burial area for elites and burial goods and b) two rows of post-moulds towards the ritual space.

Consequently, the lower Geum River experienced the most rapid growth during the MBA. Additionally, large settlements reemerged, a notable phenomenon. The Songguk-ri site, located on the middle Geum River, is a large settlement comprising 107 dwellings, large ground-level buildings, several rows of rows of large wooden poles, extensive earthen works, ceremonial structures, and burial areas for the elite. Based on these facilities, this site is considered a political and ritual center in this subregion (Fig. 11). Such large settlements are also identified in other regions within the Songguk-ri cultural sphere. This suggests a mechanism that managed or mitigated conflicts inherent in large population aggregations, unlike the EBA.

First of all, why did large settlements emerge in the MBA? During this period, a mature agricultural society centered on wet-rice cultivation was established. As Kim et al. (2023) argue, rice farming requires collective labor, particularly in paddy fields relying on irrigation systems. In societies without metallic agricultural tools or animal power like the Bronze Age in Korea, a larger population provided a significant advantageous for farming. Consequently, wet-rice farmers practicing tended to favor aggregation.

However, as noted earlier, population increase is more likely to accompany conflicts. One of such conflicts is scalar stress (Alberti, 2014; Bandy, 2004; Friesen, 1999; Johnson, 1982; Rappaport, 1968). When face-to-face interactions among group members increase dramatically, surpassing the human cognitive capacity to process social information, stress from communication, or scalar stress emerges (Johnson, 1982). Excessive scalar stress can lead to reduced group satisfaction, diminished decision-making quality, decreased consensus, and increased conflict. To mitigate such stress, groups adopt various strategies, including the development of hierarchical organization, group reorganization, fissioning into smaller groups, or increasing the size and frequency of group rituals.

It is widely recognized that group rituals play a key role in integrating groups by strengthening norms, fostering solidarity, and mitigating internal conflict through common ideology (Hegmon, 1995; Johnson, 1982; Johnson and Earle, 1987; Mentel, 2022; Munson et al., 2024; Peebles and Kus, 1977; Rappaport, 1968, 1971). For example, Johnson (1982) suggests that ritual dress or paraphernalia can serve as tools for information transfer, substituting for decision-making or interactions that group members would otherwise need to engage in. Additionally, rituals may alleviate communication stress by encouraging group members to participate in regulated activities and interactions. Constructing communal cemeteries or ritual places, as well as holding group ceremonies such as funerals, can be understood as forms of such group rituals.

During the MBA, significant social complexity developed, and the presence of special individuals with higher social status appeared. Thereby, large core settlements with complex facilities, hierarchical settlement systems emerged, dividing settlements according to their function (e.g., storage-focused settlements) (Kim, 2006; Kim, 2008; Kim, 2014). Large core settlements held a dominant position in terns of size, population, social structure, and economic base. They maintained cooperative relationship within a settlement network that included both small settlements and functionally specialized settlements (Lee, 2016). In particular, ceremonial structures (e.g., rows of large wooden poles, land division facilities, large-scale architectural remains, separate burial areas, stone-piled features, ditch-shaped features) aimed at integrating social groups emerged in core settlements, indicating the growing significance of group rituals during this period.

Based on these observations, the need for large-scale aggregations likely increased during this period due to the transformations in subsistence economies and social structures. The development of group rituals seems to have functioned as mechanisms to sustain these aggregations.

Songuk-ri type assemblages in the middle Geum River rapidly spread to other regions, including Miho and upper Geum River. In these subregions, both Garak-dong and Songguk-ri type assemblages have been identified within the same sites, and Span analysis indicates that some of these settlements persisted through the transition from the EBA to the MBA (e.g., Daejeon Yonggye-dong Oettangol, Yongsan-dong site; see Table 4). This suggests that that local Garak-dong communities in these regions adopted new materials and gradually reorganized their settlement and subsistence systems. In contrast, this pattern is far less evident in the middle Geum River. Although there are a few cases where Garak-dong and Songguk-ri types coexist within the same site, the overall pattern suggests a clear temporal and spatial separation between the two. Songguk-ri type settlements tend to appear only after the abandonment of earlier Garak-dong sites, with little evidence of cultural continuity or transformation from within.

This is supported by the relatively limited number of sites and dwellings where both types have been identified in the middle Geum River—only 11 sites with 47 dwellings—compared to 18 sites with 164 dwellings in the Miho River and 20 sites with 140 dwellings in the upper Geum River. This contrast is also reflected in the SPDs from three regions that show the chronological overlap between two types. The proportional overlap of SPD curves is 4.93 % in the Miho River, 5.53 % in the upper Geum River, and only 0.49 % in the middle Geum River (Fig. 12). This pattern indicates that the appearance of Songguk-ri type settlements in the middle Geum River occurred significantly later in the other two regions, likely caused by population replacement or migration, rather than in situ transformation.

These patterns are closely linked to regional geographical conditions and the shift in subsistence strategies during the MBA. In the Miho and the upper Geum River, relatively broad alluvial plains surround low isolated hills are formed around low isolated hills—areas where Garak-dong settlements were formally located. This environmental setting also made them suitable for the subsequent establishment of Songguk-ri settlements centered on wet-rice agriculture. By contrast, the middle Geum River is characterized by a seires of hills adjacent to mountainous terrain. While such terrain was appropriate for Garak-dong settlements, it lacked the extensive alluvial plains and low hills favorable for paddy

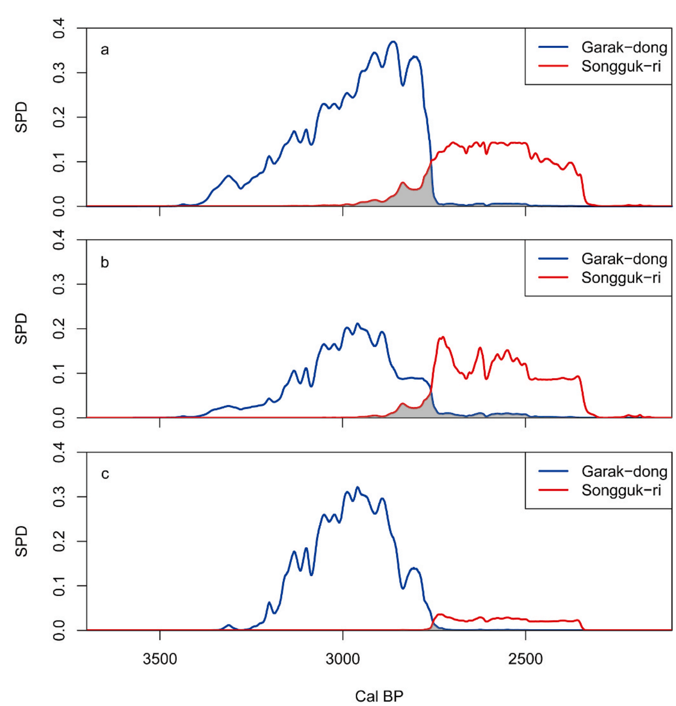

Fig. 12. SPDs of Garak-dong and Songguk-ri type settlements in three subregions. Shaded areas represent the periods of chronological overlap between two types: a. Miho River, b. upper Geum River, c. middle Geum River (color print needed). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

farming. This likely constrained the spread of Songguk-ri settlements in the region. Consequently, despite being largely unoccupied following the regional abandonment during the EBA, the middle Geum River did not experience a population increase comparable to that of the Miho and upper Geum Rivers.

5. Conclusion

This study examines population fluctuations in the Geum River Basin during the Bronze Age through archaeological evidence and summed probability distributions (SPDs) of radiocarbon dates. The analysis revealed distinct rates, timings, and patterns of demographic changes across four subregions—the Miho River, upper Geum River, middle Geum River, and lower Geum. Notably, population decline in the middle Geum River and the corresponding increase in the lower Geum River appear to be interrelated.

Despite a broadly shared material culture and subsistence economy during the EBA, demographic trajectories diverged by subregion, largely due to topographical variation. In the Miho and upper Geum Rivers, limited settlement space constrained the growth of communities beyond a certain size. In contrast, the middle Geum River, with its more favorable terrain, supported both natural population growth and further increases through in-migration from surrounding areas. However, increasing population density eventually led to environmental degradation, resource stress, and sociopolitical strain, triggering dispersal and regional abandonment.

This outmigration appears to have contributed to the reorganization of populations in the lower Geum River during the MBA. In this period, changes in subsistence strategies and social structures created a need for large-scale population aggregation. Group rituals may have helped mitigate the stresses of this concentration and supported the cohesion of large communities. Although the new material culture and subsistence economy of the MBA spread throughout the river, their adoption was also shaped by local topographical conditions.

Population fluctuations are closely correlated with various social phenomena. Identifying long-term, large-scale population trends and their climatic and environmental drivers can provide significant insights into past ways of life. However, due to uneven environmental and social landscapes, prehistoric societies likely developed along divergent trajectories across regions. While this study focused on settlement counts and SPDs, future research incorporating factors such as fertility, mortality, and mobility could yield more comprehensive understandings—not only for the Geum River but also for other regions with well-preserved and extensively documented prehistoric datasets.

CRediT authorship contribution statement

Jeongeun Lee: Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Jaehoon Hwang:** Writing – review & editing, Validation, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Hwang's work was supported by the Ministry of Education, Republic of Korea and the National Research Foundation of Korea, Republic of Korea (NRF-2023S1A5A2A01080588).

Data availability

Research data used in the research will be available on request.

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