**Supplementary Information 7**

**Qualitative Analysis of the Archaeological Databases**

**§1. Methods**

We scored 172 cultural traits for a total of 255 Neolithic-Bronze Age archaeological sites/phases from the West Liao river basin (33), the Amur (Jilin, Heilongjiang and Liaoning) (32), the Primorye (4), the Liaodong peninsula (37), the eastern steppes (1), the Shandong peninsula (4), the Yellow River basin (2), the Korean peninsula (57) and the Japanese Islands (85). Sites with several major cultural phases were scored separately. The sites date from 12,900-1700 BP and include the Early Neolithic to Bronze Age in northeast China, the Middle Neolithic Zaisanovka culture in the Primorye, the Middle-Late Neolithic Chulmun and Bronze Age Mumun cultures in Korea, and the Bronze Age Yayoi culture in western Japan. A few of the Japanese sites also contain features from the Neolithic Final Jōmon (n=5) and the following Kofun era (n=1). Categories of cultural traits scored comprised ceramics (70), stone tools (38), buildings and houses (9), plant and animal remains (26), shell and bone artefacts (17), and burials (12). All features were scored as present (1) or absent (0) following published site reports or other literature (SI 6). In addition to the database of archaeological features, we compiled a list of the earliest cultivated crops from each region of Northeast Asia directly dated by radiocarbon from published sources and from the radiocarbon database of the National Museum of Japanese History (https://www.rekihaku.ac.jp/up-cgi/login.pl?p=param/esrd/db\_param) (SI 9). This list comprises a total of 268 samples with (China: 82; Primorye: 12; Korea: 31; Japan (excluding the Ryukyus): 119; Ryukyu Islands: 24). Radiocarbon dates on rice from the Nabatake site (Saga) were omitted since several of the results from that site published in the early 1980s appear unreliable. Our two databases were supplemented by published datasets for faunal remains[[1]](#endnote-1),[[2]](#endnote-2), dolmens[[3]](#endnote-3), and spindle whorls[[4]](#endnote-4).

Given the different histories of archaeology and preservation contexts across Northeast Asia, scoring of the archaeological database was designed to be as broad and inclusive as possible. Ceramics were not scored on established typologies but by using basic decorative techniques and vessel shapes as a way to facilitate inter-regional comparisons. For example, ceramic steamers were scored as one feature even though as many as six different types have been identified in Chinese Neolithic sites[[5]](#endnote-5). In Korea and Japan, full reports which typically illustrate every artefact were available for most sites. In China, we also relied on shorter preliminary reports published in academic journals. Where reports provided no further details, features were scored as broad categories. For instance, some reports would just mention the presence of ‘microliths’ while others would list specific categories of microlithic tools. When no details of ceramic manufacturing techniques were provided in published reports, we scored ‘handmade’ and ‘coarse fabric’ as default conditions. Important farming-related features not scored in our database include paddy and other field remains and wooden agricultural tools. These features are common in Bronze Age Korea and Japan, but not found in Northeast China and the Primorye.

The definition and translation of archaeological features, especially ceramic types, has been a controversial issue in East Asia. In China, the same terms may be used in different ways in different parts of the country[[6]](#endnote-6). Our database gives provisional English translations for the scored features together with the original terminology from the source materials (SI 6).

**§2. Archaeological periodisation**

Northeast Asia has very early pottery dating back to the terminal Pleistocene[[7]](#endnote-7), and Holocene societies in the region are characterised by high levels of sedentism and material complexity. The term ‘Neolithic’ is widely applied for such societies in the region even in the absence of cereal farming[[8]](#endnote-8),[[9]](#endnote-9),[[10]](#endnote-10). A growing archaeobotanical record shows that several plants, including soybeans, adzuki beans and barnyard millet, were cultivated in Northeast Asia prior to the spread of the cereal crops discussed here[[11]](#endnote-11). Bronze was introduced into western China in the late third millennium BC[[12]](#endnote-12). By the second millennium BC, bronze was widely used on the steppes and in the Central Plains area of the Yellow River[[13]](#endnote-13). Bronze also spread into Northeast Asia, initially from the steppe region, and broader social changes influenced by new patterns of trans-Eurasian interaction make it appropriate to label the Mumun (1300 – 400 BC) and Yayoi (1000 BC – AD 250) cultures of Korea and Japan, respectively, as Bronze Age. We also use this term for the early metal cultures of the Primorye often classified as ‘Palaeometal’ by Russian archaeologists.[[14]](#endnote-14)

**§3. Neolithic and Bronze Age population dispersals in Northeast Asia: archaeological interpretation**

The West Liao river area was one of several apparently independent centres of millet domestication in northern China[[15]](#endnote-15). Soybeans, adzuki beans and other plants such as *Perilla* sp. were also cultivated in several regions of Northeast Asia11,[[16]](#endnote-16), but the cereal plants discussed in this paper spread from the West Liao and other agricultural centres. This raises the question of the role of population migration versus cultural diffusion, a long-standing debate in archaeology. In Northeast Asia, colonial legacies have made ancient population migrations especially controversial[[17]](#endnote-17),[[18]](#endnote-18), and it is sometimes argued that farming spread primarily through diffusion rather than migration[[19]](#endnote-19). A common assumption in Northeast Asian archaeology is that agriculture could be added to existing subsistence systems with minimal social disturbance through the transmission of new ‘information’ about farming[[20]](#endnote-20),[[21]](#endnote-21). However, such assumptions play down the extent to which cultural repertoires consist of linked complex behaviours transmitted through social learning at a population level[[22]](#endnote-22). This has further implications for how social identity is reproduced in material culture[[23]](#endnote-23). Complex cultural systems like agriculture require ‘direct and durable experience’ for transmission, implying either the migration of colonising groups or stable, long-term interaction between native foragers and incoming farmers[[24]](#endnote-24). The latter is often assumed in Northeast Asia but, with some exceptions[[25]](#endnote-25), archaeological research typically looks at technical *variants* of material traits rather than the whole system reproducing those traits. For instance, variation in the direction of burnishing on the necks of pottery vessels between southern Korea and northern Kyushu has been interpreted as a direct reflection of cultural ancestry and even used to estimate the number of peninsular migrants into Bronze Age Japan[[26]](#endnote-26). In this example, later research has shown greater variety in burnishing direction than originally understood and has also suggested that burnishing direction may be influenced by functional considerations related to vessel size and shape[[27]](#endnote-27). In contrast to such approaches, here our main interest is to identify ancestor-descendant relationships. Very few previous studies have attempted to analyse the material remains of long-distance farming dispersals across Northeast Asia[[28]](#endnote-28),[[29]](#endnote-29), and the present study represents the first attempt to analyse this process in a quantitative as well as a qualitative fashion.

Agricultural dispersals in Northeast Asia involved several levels of ecological and behavioural complexity. While the high productivity of wet rice cultivation may have encouraged population ‘packing’ rather than migration, millet farming tended to spread outwards by migration albeit producing low-density settlement patterns[[30]](#endnote-30). From the Late Neolithic, however, the spread of rice together with West Asian barley and wheat changed these earlier population dynamics leading to Bronze Age maritime farming expansions around the Yellow Sea and on to Japan. Bronze Age Korea and Japan both have evidence for the simultaneous diffusion of both artificially irrigated paddies and rain fed (so-called ‘dry’) fields[[31]](#endnote-31). Crops were moved beyond previous ecological boundaries and there was a significant expansion in arable land[[32]](#endnote-32).

***§3.1. Domesticated plants and animals***

One of five apparently separate centres of the early cultivation of foxtail (*Setaria italica*) and broomcorn (*Panicum miliaceum*) millet was the West Liao basin where millets were being grown by 6000 BC15. The domestication of these crops likely reflects a slow process[[33]](#endnote-33),[[34]](#endnote-34). In our data, foxtail millet was found at slightly more sites (17%) than broomcorn (14%). Millet cultivation spread north and east to the Primorye and the Korean peninsula by the fourth millennium BC[[35]](#endnote-35). By around 4000 BC, rice began to spread north from the Yangtze basin and was combined with millet in numerous Middle Neolithic sites in northern China15,[[36]](#endnote-36). Millets also moved south at this time and were combined with rice at Middle Yangtze sites such as Chengtoushan[[37]](#endnote-37). Wheat (*Triticum aestivum*) was present in Shandong by around 2600 BC[[38]](#endnote-38), and barley reached central/eastern China by the first millennium BC[[39]](#endnote-39). In our data, wheat and barley are not found in the West Liao or Primorye regions. Wheat may have been first introduced to the central Yellow river zone of China as an elite crop38. The combination of millets with rice, barley and wheat formed a farming package which expanded very quickly across Bronze Age Korea and Japan.

Rice is not found in the Liao river basin or the Russian Far East during the prehistoric period. The *Xin Tang shu* mentions rice from Nosŏng (Ch. Lucheng) at the time of the Parhae kingdom (AD 698-926), probably referring to a place in eastern Jilin. Archaeobotanical analyses of Parhae sites have produced a range of crops including millet (foxtail, broomcorn and barnyard), barley, wheat, soybeans and adzuki beans but no rice[[40]](#endnote-40).

Cannabis was only reported at 5 sites in our sample but is known from other sites in Northeast Asia where it appears to have been cultivated very early. A marked increase in cannabis remains from many regions of Northeast Asia ca. 3000-2000 BC has been linked with new Bronze Age patterns of cultural interaction across Eurasia, possibly involving ritual use of the plant as a drug[[41]](#endnote-41). The pattern of cannabis finds from Japan is consistent with such an interpretation.

Our data show that the consumption of acorns and walnuts remained common in farming societies in the Primorye, Korea and Japan, but was rare in northeast China. This may reflect the scarcity of systematic flotation in northeast China. Previous research has noted a decline in nut use associated with the development of rice agriculture in the lower Yangtze[[42]](#endnote-42). In the Amur basin, Korea and Japan, nuts were widely exploited into ethnohistoric times[[43]](#endnote-43). In Japan, Yayoi nut processing is usually seen as an influence from Jōmon culture, or else as evidence that early farming was unstable, but, as with fishing, evidence for specialised production needs to be considered. At the Nagano-konishida site (Fukuoka), as many as 15 water reservoirs for processing nuts were discovered[[44]](#endnote-44), suggesting more intensive production than typical for Jōmon villages[[45]](#endnote-45).

Domesticated animals played an important role in the spread of the Neolithic in western Eurasia. In Europe, dairying was a key factor in expansions north of the Mediterranean climatic zone[[46]](#endnote-46) and was present in Mongolia by around 3000 BC[[47]](#endnote-47). In Northeast Asia, however, uncertainties remain over the role of domesticated animals in Neolithic/Bronze Age population dispersals.

Although it is likely that pigs were being raised in northeast China by at least the Middle Neolithic[[48]](#endnote-48), the history of pig domestication in Northeast Asia is complicated by introgression with wild boar populations and is poorly understood[[49]](#endnote-49). Domesticated pigs were reported at 14% of sites in our database but not all of the reports provided morphological or other criteria to support that identification. The earliest domesticated pigs in our data are from Xinglongwa in the West Liao basin (c. 8400-7200 BP)[[50]](#endnote-50). Pigs are reported from the Primorye by the Bronze Age[[51]](#endnote-51),[[52]](#endnote-52). In line with earlier observations[[53]](#endnote-53), we find no evidence for domesticated pigs from Neolithic or Bronze Age Korea. Pigs seem to have been introduced to Japan with cereal farming in the early first millennium BC49, implying that they were also present in Korea by at least that time. All pig identifications from Japan reported in SI 6 were based on morphological criteria (brachycephalisation, brevicollis, frequencies of alveolar pyorrhea and 3rd molar size) developed by T. Nishimoto in the 1990s[[54]](#endnote-54),[[55]](#endnote-55). While Nishimoto argued that pigs were introduced to Japan with cereal farming, other zooarchaeologists have proposed that management of some wild boar populations had already begun in the preceding Jōmon period, perhaps associated with legume cultivation[[56]](#endnote-56).

Recent studies have argued that the chicken was rare or absent in Neolithic north China to where it was introduced in the Bronze Age or later from south China and perhaps also from West Asia[[57]](#endnote-57),[[58]](#endnote-58), although this conclusion is apparently contradicted by ancient DNA analysis[[59]](#endnote-59). In our data, chickens are only found at 9 sites, 7 of which are from Japan. The reported chicken remains from the Neolithic Haminmangha site (c. 6000-5000 BP) require further confirmation. Chickens first appear in Korea and Japan around 2000 years ago[[60]](#endnote-60), but are rare in Japan until the medieval period[[61]](#endnote-61). Chickens are rarely found in the Primorye until the modern era51.

Aurochs (*Bos primigenius*) were exploited in Neolithic northeast China and are known from one of the sites in our sample (Houtaomuga)[[62]](#endnote-62), but were not scored in our database. Domesticated cattle (*Bos taurus*) were introduced from West Asia by the third millennium BC[[63]](#endnote-63). The earliest domesticated cattle in China are from the Yellow river basin[[64]](#endnote-64). Only 5 sites in our sample have reported cattle remains from both Neolithic and Bronze Age contexts (Jimo Beiqian, Shandong, 5500-5200 BP; Qixia Yangjiaquan, Shandong, 5500-4600 BP; Huangjiaweizi, Jilin, 4000 BP; Zhaogezhuang, Shandong, ca. 4000-3500 BP; and Xiajiadian, Inner Mongolia, 4200-3600 BP). At two of these sites (Jimo Beiqian and Zhaogezhuang), the reported cattle remains were bone tools. In the Primorye, cattle appear from the Iron Age 51. In Japan, the earliest direct radiocarbon dates on cattle are from the Matsuzaki site (Aichi) in Kofun period contexts. (Two earlier first to third centuries AD dates from the same site appear to be unreliable).

Horses were reported from 9 sites/phases (3.5%) in our database with finds from the Bronze Age West Liao, Ordos and Heilongjiang regions. The horses reported from Neolithic Haminmangha and Houtaomuga may be wild or represent later contamination. The first evidence for the use of horses in transportation dates to around 2000 BC with chariot burials of the Sintashta culture.

Mounted horseback riding developed by the early first millennium BC. In the eastern steppe region, recent research finds no evidence for the dietary exploitation of horses before the Late Bronze Age, around 1200 BC. After that point, however, horses started to play a key role in diet, ritual and mobility, enabling the first effective use of the dry eastern steppe lowlands[[65]](#endnote-65). Horses are not known in the Primorye until the Iron Age51, 52. The date of the arrival of horses in Korea is unclear. Horses reach Japan from the end of the fourth century AD[[66]](#endnote-66).

Introduced from West Asia, domesticated sheep (*Ovis* sp.) are reported from northern China as early as the fifth millennium BC[[67]](#endnote-67). In our sample, sheep were reported at 4 Neolithic (Baiyinchanghan, Inner Mongolia; Houtaomuga, Zuojiashan and Huangjiaweizi in Jilin) and 8 Bronze Age (Zhukaigo, Ordos; Upper and Lower Xiajiadian, Yaowangmiao, Zhizhushan and Jinggouzi in Inner Mongolia; Dawangshan, Liaodong; and Zhaogezhuang, Shandong ) sites/phases. A single *Ovis* sp. bone came from Houtaomuga Phase III; while no direct date is available, the phase itself dates to 4800-3500 BC. The sheep remains from Bronze Age Zhaogezhuang (Shandong) were oracle bones. Sheep have been reported from at least two medieval sites in the Primorye but are extremely rare in that region51. It is unclear when ovicaprids first reached Korea and Japan. The *Nihon shoki* (AD 720) records a gift of ‘one camel, two sheep, and one white pheasant’ from the Korean kingdom of Paekche to the Japanese court in AD 599[[68]](#endnote-68). Goats were part of the last Transeurasian farming/language dispersal in the medieval era when Ryukyuan spread with agriculture to the Ryukyu islands[[69]](#endnote-69).

Dogs were surprisingly rare in our data, present at only 16% of sites. This result is consistent with previous findings that dogs are numerically few in Neolithic and Bronze Age sites in Northeast Asia. Previous research has reported 26 Yayoi (Bronze Age) sites with dogs from Japan (forming a total MNI of around 230) but only 5 such sites from Korea[[70]](#endnote-70). Most Yayoi sites have canid MNIs <5 but a few have much higher numbers with MNIs >50. In our sample, the Haru-no-tsuji, Aoyakamijichi, Kamei and Asahi sites fall into the latter category; at Haru-no-tsuji, dogs comprised more than half of the mammal sample. Morphological differences between Yayoi- and Jōmon-period canids have been used to suggest that domestic dogs were re-introduced to Japan with agriculture in the Bronze Age[[71]](#endnote-71), a scenario supported by genetic evidence, although the Yayoi timing is assumed rather than proven in such genetic research[[72]](#endnote-72). Other archaeologists have been less certain about the morphological changes, emphasising instead the cultural change involved in the frequent consumption of dogs in Yayoi society70.

Common carp (*Cyprinus carpio*) aquaculture, known in China by 6000 BC, spread to Japan by the late first millennium BC in association with wet-rice farming and has been reported at one of the Japanese sites we scored (Asahi)[[73]](#endnote-73). This aquaculture was presumably also present in the wet-rice cultures of Liaodong and Korea but no evidence is currently available. A decline in fishing at the onset of the Neolithic has been reported for several parts of the world including Japan[[74]](#endnote-74),[[75]](#endnote-75),[[76]](#endnote-76). Our data show a number of sites with both fish/shellfish remains and domesticated plants. There are 8 such sites in Liaodong, 3 in south Korea, 2 in the Primorye and 9 in western Japan. In Japan, the introduction of cereal agriculture in the Bronze Age led to new economic niches wherein farmers engaged in much less fishing than previously, but more specialised maritime adaptations developed in coastal areas61,[[77]](#endnote-77).

***§3.2. Agricultural tools***

Early farming systems in East Asia utilised many similar stone tools to those used for wild plant gathering and processing. However, wet rice farming involved more specialised tools than early millet agriculture5. By the fourth millennium BC, specialised farming tools including ploughs, sickles and harvesting knives had started to appear[[78]](#endnote-78). In Northeast Asia, these farming tools became especially common after the Late Neolithic/Bronze Age integration of millet with rice, barley and wheat. Though wooden farming tools were not scored (see §1 Methods), wooden mortars and pestles become widely distributed from the Late Neolithic. The main farming tools scored in our database were triangular stone ‘ploughs’, reaping knives and sickles. Stone reaping knives were found at 44% of sites but stone sickles were much rarer, recorded at only 7% of sites. Our data support the close relationship between reaping knives and other polished stone tools in Bronze Age Korea and Japan found in previous research[[79]](#endnote-79).

Our data generally support models of an east/west Eurasian dichotomy in Neolithic and Bronze Age culinary traditions[[80]](#endnote-80). Although wheat and barley are found at 15% and 4% of sites, respectively, there is no evidence for the roasting of these cereals or for bread production. Instead, cereals in Northeast Asia were boiled or steamed. However, our data do show major regional variations in the use of ceramic steamers (see §3.4). Grinding slabs also display considerable regional variation. Common in Neolithic northeast China, grinding slabs are almost always present in both Neolithic and Bronze Age sites in Korea. In Japan, however, grinding slabs are not common in the Bronze Age Yayoi period.

The presence of hunting tools into the Bronze Age in our data is consistent with ethnohistoric information showing the persistence of hunting across Northeast Asia[[81]](#endnote-81). In the West Liao basin, microliths remained common in the Neolithic and were still in use by the late Hongshan (5500-5000 BP)[[82]](#endnote-82), but the timing and processes behind their eventual disappearance remain poorly understood[[83]](#endnote-83). In other parts of Northeast Asia, microliths disappeared by the end of the Pleistocene[[84]](#endnote-84).

Obsidian was the only lithic raw material scored in our data, but was found at 21% of sites. The main obsidian sources in Northeast Asia are limited to the Mount Paektu/Changbai range in north Korea, the Basaltic Plateau of the Primorye, and several sources in Japan[[85]](#endnote-85). Our data confirm the importance of long-distance obsidian exchange networks in Neolithic Northeast Asia, networks which were not necessarily directly linked to population dispersals.

While metal tools were not scored in our database, it should be noted that bronze was first introduced to northeast China in the second millennium BC. In the Primorye, bronze was found from around 900 BC and iron from 500 BC[[86]](#endnote-86). In Korea, bronze appeared by at least the eighth century BC. Bronze and iron became widely used in Kyushu from around 400 BC and iron gradually replaced stone tools such as axes, chisels and sickles. By the third century AD, iron tools had spread into the eastern archipelago as far as the southern Tohoku region[[87]](#endnote-87). The Korean roots of the earliest bronze objects to reach Japan are clear but there is debate over whether the introduction of bronze to the archipelago was associated with renewed large migrations[[88]](#endnote-88).

***§3.3. Houses and settlements***

The semi-subterranean pit house remained ubiquitous across Northeast Asia from the Neolithic to the Bronze Age and later. 71% per cent of our sites have pit houses as compared to 17% per cent for surface buildings. Only 5 sites (Erdaojingzhi, Dalian Dawangshan II, Aoyakamijichi, Nishikawazu, Yokono) have surface buildings only. Though not reflected in our data, evidence for the diffusion of specific types of domestic architecture has been discussed in the literature. The clearest examples are the Songguk-ri and T’eppyong’ni type pit houses which diffused from southern Korea to north Kyushu27,[[89]](#endnote-89).

Walls, ditches and other defensive architecture such as watch towers spread widely across Northeast Asia in the Bronze Age. There is little evidence of inter-group violence associated with millet dispersals of the Early to Middle Neolithic. Skeletal trauma at the Boisman site in the Primorye appears to show violent conflict in a hunter-gatherer context[[90]](#endnote-90). By contrast, the integration of millet with rice, barley and wheat led to the widespread occurrence of moated, defensive villages, weapons, and human skeletons with violent trauma in Late Neolithic and Bronze Age contexts[[91]](#endnote-91),[[92]](#endnote-92),[[93]](#endnote-93).

***§3.4. Ceramics and Food Preparation***

Fig. SI 7.1 shows the overall frequency of the 25 scored ceramic decorations. Not surprisingly, the most common were generic techniques such as incised wares (present in 32% of sites), diagonal designs (25%), impressed and applique wares (20%). Despite previous claims that cordmarked pottery is diagnostic of early rice cultivation[[94]](#endnote-94), cordmarked and string/cord designs were rare in our sample.

**Fig. SI 7.1**. Frequency (%) of the 25 ceramic decorative techniques across our data in SI 6. Numbers in parenthesis refer to the features scored in SI 6.

Many of the ceramic decorations show similar relative frequencies across the regions scored. Over time there is a clear toward reduced levels of decoration (Fig. SI 7.2). Plain (undecorated) pottery (which was not scored in our sample) is especially common in Bronze Age Korea and Japan; in fact none of the pottery from Japan has any of the decorative features scored here.

**Fig. SI 7.2.** Decorative design indices from Neolithic and Bronze Age West Liao, Liaodong, the Korean peninsula, and the Amur (= Liaoning excluding the Liaodong peninsula, Jilin and Heilongjiang). The index was calculated as total number of scored decorative features ÷ number of sites for each region. The figure shows a clear decrease in ceramic decoration in the Bronze Age, especially in Korea.

In terms of vessel shapes, Late Neolithic and Bronze Age China is characterised by a high diversity of forms[[95]](#endnote-95). An increase in the diversity of ceramic vessel forms is also found in Japan from the third millennium BC, perhaps a result of continental influences. Across East Asia, cereals were boiled or (later) steamed, a tradition which predates agriculture80. In northeast China, tripods appeared from the Lower Xiajiadian phase.[[96]](#endnote-96) Tripods and steamers were not, however, found in the Primorye. In South Korea, tripods and flat-based perforated steamers do not appear until the Proto-Three Kingdoms period (first to third centuries AD). In Japan, steamers were introduced from the Korean peninsula in the fifth century AD, probably from the kingdom of Paekche[[97]](#endnote-97). Steamers were used with clay ovens (*kamado*) but did not become widely used and most archaeologists assume that cereals were usually boiled until the contemporary era.

Many parts of Eurasia saw the spread of new food processing technologies such as dairying and beverage fermentation during the Neolithic and Bronze Age, but the evidence for such techniques in Northeast Asia is poor. Milking is found in Mongolia by around 3000 BC[[98]](#endnote-98), but there is currently no evidence for milking in Neolithic/Bronze Age Northeast Asia. The use of dairy products is known from historical records in Shandong, Korea and Japan in the sixth to eighth centuries AD but seems to have been mainly limited to elites[[99]](#endnote-99). Beverage fermentation using rice, honey and fruit has been reported from Jiahu in central China from as early as the seventh millennium BC[[100]](#endnote-100). In Neolithic northern China, millet was widely used for alcohol production[[101]](#endnote-101). While it is likely that fermented millet and, later, rice beverages were found in Neolithic Northeast Asia, no direct evidence has so far been reported. In Japan, fruit may have been fermented into wine at Neolithic Jōmon sites such as Sannai Maruyama[[102]](#endnote-102).

***§3.5. Ornaments***

The most common ornaments in our data were stone beads (24 % of sites), ornamental stone rings (7 %), unspecified bone ornaments (4%), phallic stones (2%), and bone *huang* rings (0.39%). Jade or jadeite was reported at 23% of sites. Ornaments are a poor indicator of farming dispersals in our data. Jade exchange networks existed prior to farming across Northeast Asia. The exchange of jade may have involved some small-scale migrations[[103]](#endnote-103), but in most cases probably reflects trade. In China, jade ornaments remained auspicious symbols of power even in the Bronze Age[[104]](#endnote-104). A similar role for jade in Bronze Age and later Japan may reflect this Chinese ideology. The widespread distribution of cowrie shells in China also suggests long-range exchange networks not directly associated with farming or language dispersals. At Dadianzi, a site in Chifeng belonging to the Lower Xiajiadian culture (2000-1200 BC), grave goods included 659 cowrie shells which may have come from the Indian Ocean[[105]](#endnote-105). In Bronze Age Japan, a shell exchange network developed with the Ryukyu Islands but there is no evidence of farming or language dispersals there until around the tenth century AD[[106]](#endnote-106).

***§3.6. Textile technology***

Our results confirm previous findings that spindle whorls are one of the most diagnostic archaeological traits of Neolithic expansions in Northeast Asia[[107]](#endnote-107). During the Neolithic, spindle whorls seem to have been primarily used with previously utilised fibres (hemp, ramie etc). In the Bronze Age, the wool of sheep and goats began to be widely used in Europe and Central Asia[[108]](#endnote-108), but wool was rare in Northeast Asia. A burial at the Xingxingshao site in Jilin, dated to the first millennium BC, produced a cloth woven from hemp together with goat and dog hair[[109]](#endnote-109). The use of dog hair in weaving amongst northern tribal groups in Northeast Asia is mentioned in Tang sources[[110]](#endnote-110). In China, silk may have been used from as early as 8500 BP[[111]](#endnote-111). By the Bronze Age, silk was used for at least elite clothing across Northeast Asia including Japan.

***§3.7. Burials***

Prehistoric mortuary customs have been an important topic of research across Northeast Asia and burials often provide evidence for shared links between elite cultures in particular109. However, our data show few direct links between mortuary customs and population dispersals. While the agricultural societies analysed here all developed elaborate mortuary architecture by at least the Bronze Age, there was nevertheless considerable regional diversity. The earliest millet farming societies in Northeast Asia largely lacked elaborate burials, although the Hongshan culture (4500-3000 BC) is an exception with its platforms and stone cairns. Various ritual activities seem to have been performed around these cairns for long periods, possibly suggesting a cult of ancestors[[112]](#endnote-112). Cairn burials are rare in Jilin and Heilongjiang where earthen pit graves remained the norm into the Bronze Age. At the Lower Xiajiadian culture (2000-1200 BC) Dadianzi site, a cemetery of over 800 burials mainly consisted of earthen pits in which individuals were laid in wooden coffins, though some tombs contained stone cists. Thirteen tombs at Dadianzi contained bronze vessels of local production imitating Erlitou bronzes from the Central Plains. Biological anthropologists have suggested two groups of different ancestry in this cemetery, one similar to populations from the Yellow river, the other closer to Amur basin groups. The majority of the Erlitou-like bronze vessels were found in burials of the ‘Yellow river related’ group[[113]](#endnote-113).

There are currently no burial sites known for the Zaisanovka culture associated with the earliest millet farming in the Primorye. The only well-documented cemetery of the Primorye is Boisman-2 (Boisman culture c. 7500-4000 BP) which consists of two groups of earthen pit tombs located under a shell midden[[114]](#endnote-114). At Zaisanovka 7, a Bronze Age pit burial was also found in a shell midden context[[115]](#endnote-115). Ancient DNA from a Bronze/Iron Age burial at Pospelovo-1 has recently been reported[[116]](#endnote-116). In Korea, Neolithic burials are few but show a wide variation including earthen pit burials (sometimes in shell middens), cremation in jar burials buried inside a house (Sangch’on B), or multiple burials covered with stones (Yokchido)[[117]](#endnote-117). In Japan, burials of the Neolithic Jōmon period were mainly primary single graves in earthen pits containing few or no grave goods, though other types such as secondary jar burials for adults, primary jar burials for infants, cremation, and inhumation inside abandoned houses also occur[[118]](#endnote-118). In the Late and Final Jōmon phases in northern Japan, burials become more elaborate[[119]](#endnote-119), possibly under the influence of Bronze Age Eurasia. The following Yayoi period saw the adoption of many mortuary customs into Japan from the Korean peninsula but this process was characterised by considerable complexity and negotiation[[120]](#endnote-120).

Dolmens may be the clearest evidence of a link between farming dispersals and mortuary customs. A dataset published in 1997 reported 66 dolmen sites in Liaoning (mostly on the Liaodong peninsula), 34 in Jilin, at least 1929 on the Korean peninsula, and 123 in Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto and Kagoshima prefectures)3. However, the lack of absolute dating for the dolmens of northeast China and northern Korea makes it difficult to validate the common argument that dolmens first appeared in Jilin or Liaoning and then spread to Korea[[121]](#endnote-121),[[122]](#endnote-122). On the Korean peninsula, dolmens appear some time after the beginning of rice farming and could thus be markers of emerging social stratification in Bronze Age society[[123]](#endnote-123). Dolmens similar to those of southern Korea appear in northwest Kyushu at the beginning of the Yayoi period along with Korean-style polished stone daggers and red burnished pottery as grave goods[[124]](#endnote-124). Within the Japanese archipelago, dolmens extended only as far as northwest Shikoku. In other areas of Bronze Age Japan, a range of mortuary traditions including jar burials and moated burial precincts soon developed. Large jar burials were primarily limited to northern Kyushu, but the spread of moated burial precincts into the eastern archipelago may reflect population dispersals.[[125]](#endnote-125)

In summary, our data are consistent with previous interpretations of mortuary traditions in Neolithic-Bronze Age Northeast Asia. The diffusion of dolmens from Liaodong to Korea to western Japan may be an example of a mortuary custom which spread in association with agricultural dispersals but further radiocarbon dating is needed to confirm this hypothesis. In other cases, it is harder to identify specific cultural ancestries from burial features alone but there is nevertheless a clear trend for cemeteries to become more marked and elaborate as agriculture developed. To the extent that formal cemeteries developed as a way to make claims to land, we might expect mortuary customs to be under selection for new features that differentiated them from previous customs.

***§3.8. Ritual***

The wide range of vessel shapes in Neolithic and Bronze Age China is often linked to the provision of food and wine for family ancestors121,[[126]](#endnote-126),[[127]](#endnote-127). In Japan, the performance of rituals for agricultural production and elite ancestors has been interpreted as a continental custom introduced with the ‘Yayoi package’[[128]](#endnote-128). However, our data show that few of the elaborate ceremonial vessels used in China were found in other regions of Northeast Asia.

Oracle bones were found in 13 sites in our dataset with a wide geographical range from the Ordos to Liaodong to western Japan. None of the Korean sites scored here had oracle bones although the custom is known from at least 15 Iron Age/Proto-Three Kingdoms sites on the peninsula[[129]](#endnote-129). The oldest oracle bones in East Asia are from Inner Mongolia from the late fourth millennium BC[[130]](#endnote-130). By the second half of the third millennium BC, plastromancy became more common in the Late Neolithic Longshan culture. Oracle bones with written inscriptions characterise the Bronze Age Shang state in the Yellow river valley but the custom, usually without writing, spread widely across Northeast Asia. In Japan, oracle bones are known from 54 sites dating from the fourth century BC to the third century AD129.

***§3.9. Demography***

Across Eurasia, the increased sedentism of the Neolithic led to population growth[[131]](#endnote-131). In many areas of Northeast Asia, sedentism developed before farming[[132]](#endnote-132). As cereal farming became more important, the type of agriculture engaged in by East Asian societies affected their demographic patterns. Wet rice farmers, who had invested time and labour in elaborate paddy fields, tended to stay in one place, absorbing population growth through extra labour. Millet farmers, by contrast, often adopted a more dispersed or expansionary settlement pattern78. Within millet farming societies in northern China, community structure was also influenced by different risk buffering strategies resulting from environmental conditions[[133]](#endnote-133).

Neolithic population growth could be subject to fluctuations due to climate, disease, or the low resilience of early farming systems[[134]](#endnote-134),[[135]](#endnote-135). Climate change, the immigration of steppe pastoralists, trade and plague have been suggested as possible causes of a Late Neolithic population decline which was also found in Northeast Asia[[136]](#endnote-136),[[137]](#endnote-137),[[138]](#endnote-138),[[139]](#endnote-139). Previous research has identified large population increases in the Bronze Age in China138, Korea[[140]](#endnote-140), and Japan[[141]](#endnote-141).

***§3.9. Qualitative analyses: summary***

Our results generally confirm and provide broader context for previous archaeological analyses of Neolithic and Bronze Age population dispersals in Northeast Asia. Our results clearly show that all scored archaeological features did not disperse in unison as monothetic cultures. Several categories of archaeological artefacts were associated with Middle Neolithic millet farming expansions to Korea and the Primorye35. In the Bronze Age, a larger inventory of items became associated with agricultural dispersals, including wooden farming tools, stone reaping knives, mortars and pestles, and rice paddy fields. Between Bronze Age Korea and Japan, many more specific material culture parallels have been discussed in the literature12,27-29,31,79,82,107,124.

Based on our archaeological database and previous research, several major differences in the dispersal of farming cultures across Northeast Asia can be noted. The great variety in ceramic—and later bronze—vessel forms found in northeast China did not spread to other regions of Northeast Asia, perhaps because the ritual functions of these vessels were not shared outside China. Overall, ceramics were a poor indicator of population dispersals in our data but the macro approach to ceramics employed here could be further expanded with traditional typological methods, which already suggest clear links between Korea and Japan. Mortuary customs also became more diverse over time and, except for dolmens, none of the specific burial types found in northeast China spread beyond that area. Although a combination of five domesticated cereals (barley, broomcorn millet, foxtail millet, rice and wheat) spread quickly across Northeast Asia from the Bronze Age, the spread of domesticated animals was slower and more variable.

Our qualitative analyses support four types of interaction in Neolithic-Bronze Age Northeast Asia: (1) Long-range interaction spheres conducted through trade and exchange without population-level dispersals. Examples here are jade and obsidian exchange networks; (2) Clear association between population dispersals and cultural traits: cereals are the most direct evidence but this category is also supported by spindle whorls, wooden farming tools and semi-lunar stone reaping knives. On a local level, for well-studied regions such as Korea and Kyushu, we can also propose Songgukri and T’eppyong’ni house forms and ceramics as further examples of the association between farming dispersals and material culture; (3) Less secure but nevertheless suggestive associations include artefacts associated with Middle Neolithic millet dispersals, such as chipped stone hoes and polished stone arrowheads; and (4) Cases where the transformation into an agricultural society engendered comparable responses without direct parallels. The best example here is the use of elaborate yet diverse burial customs to make links to territory in increasingly stratified societies in the Bronze Age.

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