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Evidence of millet and millet agriculture in the Far East Region of Russia derived from archaeobotanical data and radiocarbon dating

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ABSTRACT

Agriculture based on broomcorn and foxtail millet has been identified as one of the main drivers of population expansion and/or resource and innovation transfer across Neolithic and Bronze Age Eurasia. However, accurate reconstruction of spatio-temporal patterns of millet spread within and outside China remains a challenging issue. Here we use a representative set of 27 millet-based radiocarbon (^{14}C) dates from southern Primorye to reconstruct when millet cultivation became part of hunter-fisher-gatherer subsistence in this vast southeasternmost region of Russia. The spatio-temporal distribution of the ^{14}C data demonstrates the following picture. After the earliest conventionally accepted (although not directly dated) appearance of millet at the Krounovka-1 site in the Suifen (Razdol'naya) River catchment west of Khanka Lake around 3521–3356 BCE (95.4% probability range of calibrated ages of wood charcoal), millet agriculture is registered at the site Gvozdevo-4 located on the southern coastal plains northeast of the mouth of the Tumen (Tumannaya) River in the first half of the 3rd millennium BCE. Several archaeological sites (Novoselishche-4, Bogolyubovka-1, Rettikhovka Geologicheskaya-1, Risovoe-4) with directly dated millet indicate the spread of millet cultivation across the fertile plains around Khanka Lake during the second half of the 3rd millennium BCE. The dates obtained from the Olga-10 site on the eastern coastal plains along the Sea of Japan suggest that millet contributed to the food economy there from the beginning of the 2nd millennium BCE. The presented dataset shows the presence of millet in the north-eastern part of the study region (i.e. at the Glazovka-gorodishche site) in the second half of the 1st millennium BCE. Our dataset demonstrates that millet has been cultivated in southern Primorye since the Late Neolithic, when small-scale agriculture was introduced by Zaisanovskaya culture groups archaeologically documented in the study region and neighbouring regions of China and North Korea. This indicates that millet was an integral part of the subsistence economy of the local populations throughout the entire period under review.

1. Introduction

The Maritime Region (in Russian *Primorye*) occupies the southernmost part of the Russian Far East (RFE), which also includes the Amur Region and Island Sakhalin (Fig. 1). Primorye is surrounded by the Sea of Japan in the east and south and has a joint border with China in the west and North Korea at its southernmost point. The area has a long history of archaeological research. Although the first archaeological excavations were carried out at the end of the 19th century, systematic archaeological research began only in the 1950s under the leadership of

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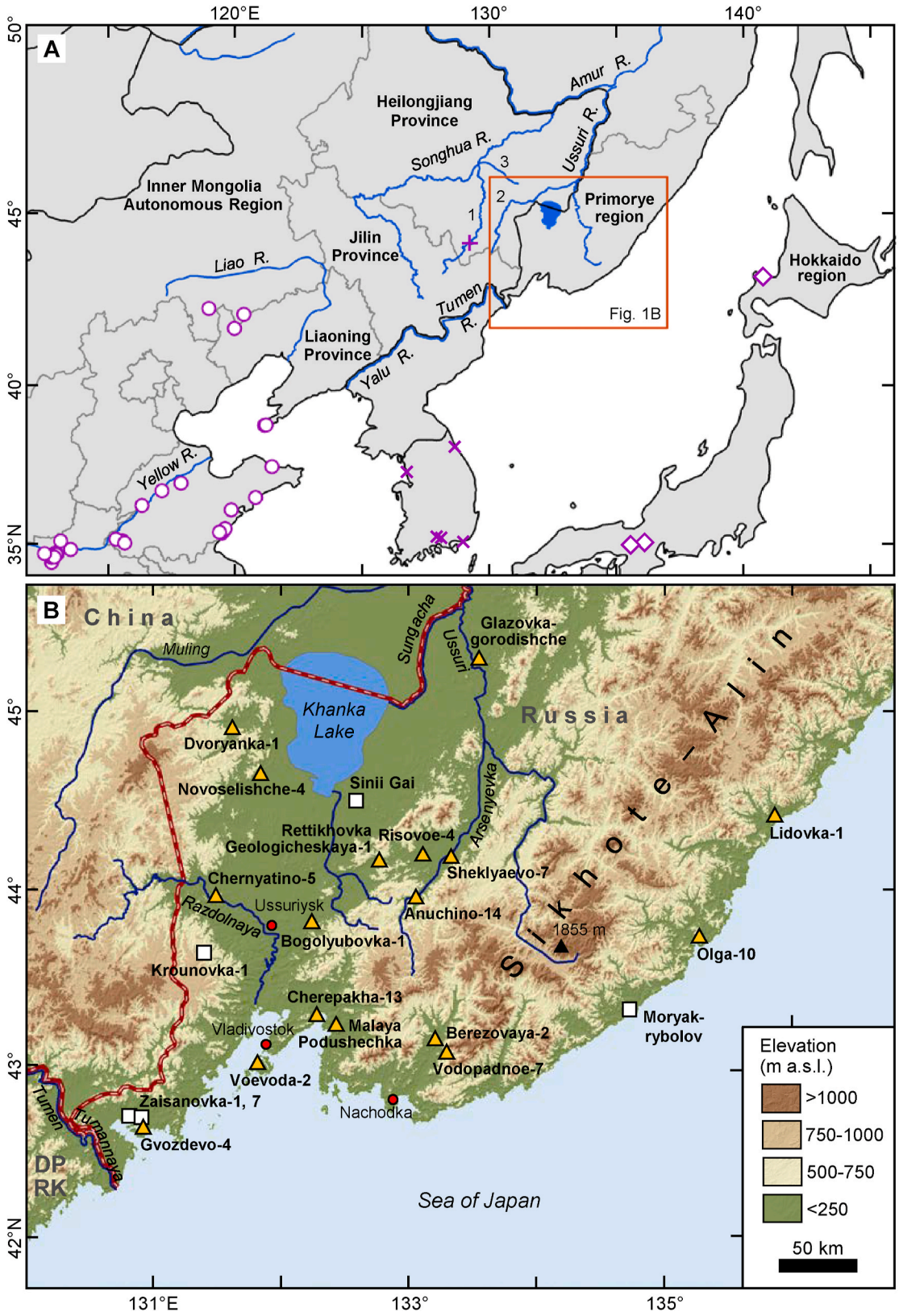

Fig. 1. (A) Overview map showing the location of the study region (inset) and locations of archaeological sites with directly dated millet remains in the Lower Yellow River and Liao River regions (circles), Heilongjiang Province (plus), the Korean Peninsula (crosses) and Japan (diamonds) as presented in Leipe et al. (2019). (B) The physical environment of southern Primorye in the southern Russian Far East with locations of archaeological sites (triangles) with directly dated millet remains (Table 2) and those mentioned in the text (squares). Smaller rivers are labelled by numbers: 1 – Mudanjiang River, 2 – Muling River, 3 – Woken River. Topographic information is based on GTOPO30 data (Earth Resources Observation and Science Center/U.S. Geological Survey/U.S. Department of the Interior, 1997). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

A.P. Okladnikov (see Klyuev, 1994; Parzinger, 2006 for a detailed overview and references). Since then, many sites have been excavated, which represent a range of archaeological cultures from the Upper Palaeolithic to the Middle Ages (e.g. Andreeva, 1977, 2005; Dyakov, 1989; Kradin, 2018). Although different aspects of material culture of the prehistoric populations living in the region have been studied, to build a robust absolute chronology for the archaeological culture sequence in the region remains a major task for current and future research. Systematic application of AMS radiocarbon (^{14}C) dating to short-lived plant material is particularly promising.

The onset of the Neolithic (i.e. appearance of pottery) in the RFE has been dated to ca. 12,000–11,000 ^{14}C BCE (Kononenko, 2005; Shevkomud and Yanshina, 2012; Tabarev, 2014) based on conventional ^{14}C dates. Recently, early pottery remains from sites in the Amur River Region have been recovered from contexts AMS-dated to ca. 14,250 BCE (Shoda et al., 2020). Most of the long Neolithic period in the region was characterised by subsistence based on fishing, hunting and gathering and the exploitation of the rich resources offered by local boreal forests, rivers and the sea (e.g. Okladnikov and Derevyanko, 1973; Andreeva, 1991; Vostretsov, 1998; Tabarev, 2014). Great progress in the understanding of local subsistence economies, especially in terms of plant use, has been achieved by systematic flotation-based archaeobotanical studies (e.g. Sergusheva, 2008a; Sergusheva and Vostretsov, 2009). Agriculture in the form of millet cultivation comprising broomcorn (*Panicum miliaceum*) and foxtail (*Setaria italica*) millet reached Primorye as early as the middle of the 4th millennium BCE (e.g. Kuzmin, 2013; Li et al., 2020; Miyamoto, 2014; Sergusheva and Vostretsov, 2009). Leipe et al. (2019) also suggested the appearance of millet in the region sometime after 3700 BCE, based on Bayesian modelling of direct millet ^{14}C dates. Direct dating of cultivated millet remains from the oldest cultural layers is necessary to provide a definitive answer in the discussion. The role of agriculture in the subsistence after its first introduction and spread of agriculture in the region are two other discussed questions (Vostretsov, 2005; Tabarev, 2014). According to archaeological data, agriculture started to play a more important role in southern Primorye in the second half of the 1st millennium BCE among the Krounovskaya culture communities (Vostretsov, 2005). However, the real flourishing of millet-based agriculture in this territory occurred later, in association with the medieval states. During the Bohai (698–926 CE), Liao (916–1125 CE) and Jin (1115–1234 CE) period, the local population was engaged in the cultivation of at least 14 plant species, such as millets (including newly introduced *Echinochloa esculenta* (barnyard millet) and *Sorghum bicolor*) and other cereals, legumes, oilseeds and fibrous and vegetable crops (Sergusheva, 2014; Kradin, 2018).

In this study we combined a set of published and newly obtained ^{14}C dates directly derived from charred remains of broomcorn and foxtail millet from archaeological sites across southern Primorye to reconstruct the spread of millet cultivation across the region. To discuss possible driving forces behind the spread of millet we employed published archaeological site data from Chinese provinces for estimation of population dynamics as well as archaeological and palaeoenvironmental records from the wider study region.

Compared to previous semi-continental-scale publications primarily dealing with the onset of millet domestication and the spread of millet cultivation (e.g. Leipe et al., 2019; Wang et al., 2019; Li et al., 2020; Stevens et al., 2021), the current paper has a regional focus. For example, Leipe et al. (2019) applied a Bayesian modelling approach to the millet dates from a larger area of eastern Asia in order to estimate the onset of millet cultivation in eight large (geographically and archaeologically defined) subregions. In contrast to Leipe et al. (2019), our study is not built on modelling, but on the millet-based absolute age determinations, thus allowing us to verify the modelling results. The 13 newly obtained direct dates not only double the available dataset but represent, in addition to the previously published dates, 7 more archaeological sites, 6 more archaeological cultures/variants and dates from foxtail millet, which has not been directly dated in the region until now. Last but not least, the main goal of the current study is to fill the chronological gaps in the existing data and to confirm continuous millet cultivation in Primorye between the Late Neolithic and the Early Middle Ages.

2. Regional setting

Primorye occupies an area of 165,900 km^2 between 48°24′ and 42°17′ N in the south-eastern part of Russia (Fig. 1A). The study region of southern Primorye is characterised by distinct altitudinal settings (Fig. 1B). The vast low-elevated plains in the western part are drained by the rivers Sungacha and Ussuri flowing to the Amur in the north and by the Suifen (Razdol'naya) River flowing to the Sea of Japan in the south. The central part of the Khanka-Ussuri Plain is occupied by the freshwater Khanka Lake (68–70 m a.s.l.), which stretches over ca. 4190 km^2 and has a maximum depth of about 10 m (Alpat'ev et al., 1976). To the east, the relief is dominated by the sub-longitudinally oriented mountain ranges of Sikhote-Alin with the Oblachnaya Mountain rising to 1855 m a.s.l. (Fig. 1B). A narrow strip of coastal alluvial plains traversed by numerous rivers and streams lies between the Sikhote-Alin Mountains and the Sea of Japan.

Strong seasonality is the most pronounced feature of the regional monsoonal climate (Petrov et al., 2000). Winters are cold due to the prevalence of continental air masses from Siberia (winter monsoon). Summers are warm and humid due to the prevalence of air masses from the Pacific Ocean (summer monsoon). The modern climate data from the coastal city Vladivostok situated in the southern part of the region demonstrate a mean January temperature of −12.3 °C, mean August temperature of 19.8 °C and annual precipitation of 833 mm of which ca. 65% falls between June and September (Pogoda i klimat, 2021). Further north, in the inland region near Khanka Lake, the climate becomes more continental, with mean temperatures of −16.6 °C in January and 20.9 °C in August and a mean annual precipitation of 590 mm (Weatherbase, 2021). A generally humid climate promotes the widespread distribution of forests, which cover over 75% of the territory and consist of boreal and temperate species (Alpat'ev et al., 1976; Kolesnikov, 1969).

Meadow and swamp vegetation communities are common in the river valleys and intermountain depressions and communities with dominance of shrubby pine and shrubby alder occur at higher elevations in the mountains. The colder areas in the north of Primorye are occupied by spruce and fir-spruce-dominated boreal forests (taiga), while cool mixed broadleaf-conifer forests play an important role in the southern part of the region, where they reach up to 800–900 m a.s.l. The species composition of these forests is very rich and similar to the 'Manchurian-type' forests of north-eastern China and northern Japan (Alpat'ev et al., 1976). It was reported that 1 ha of forest in the valley of the Ussuri River may consist of up to 25 species of trees and up to 30 species of shrubs, 5–6 species of lianas, 15 species of ferns and as many as 100 species of herbaceous angiosperms (Kolesnikov, 1969; Mokhova et al., 2009). Remains of forest-steppe vegetation have been described in the lowland areas around Lake Khanka, which receive less rainfall and have higher evaporation losses (Alpat'ev et al., 1976). These lowlands and the floodplain terraces of the large rivers have been intensively used for agriculture during the past hundred years and modified by human activities to a kind of 'anthropogenic steppe' (Mokhova et al., 2009).

3. Archaeological culture sequence

The Primorye region is home to a number of archaeological cultures and local variants defined by characteristic features of material complexes (mainly typology and diversity of pottery and stone toolkits) and house constructions (e.g. see Andreeva, 2005; Parzinger, 2006; Tabarev, 2014 for details and references). The chronological boundaries, still vaguely defined based on a limited number of ^{14}C dates, are commonly presented in non-calibrated ^{14}C years. The first culture with agricultural products and practices is the Late Neolithic Zaisanovskaya culture

Table 1
Description of archaeological sites (see Fig. 1B for locations) and cultural layers from which the dated millet remains (Table 2) were obtained.

Archaeological site	Brief site description
Gvozdevo-4	The site is located at the promontory end of the 20–25-m-high hill at the left bank of the Gladkaya River, ca. 6 km from its confluence to the Expedition Bay of the Sea of Japan. The site has an area of ca. 9000 m^2. In 2003, 2007 and 2009 a total of 150 m^2 were excavated and the remains of five above-ground buildings and six pit dwellings were discovered. The found structures suggest a relatively long period of settlement. Two habitation horizons very similar in finds were recorded and assigned to the Zaisanovskaya culture (Khasansky variant). Two ^{14}C dates: 2110 ± 60 BCE (LE-8975) on carbonised wood from the lower part of the cultural layer (Moreva, 2013) and 2180 ± 40 BCE (AA-60612) on carbonised food soot from a ceramic vessel (Krutykh et al., 2010). Ground constructions (7–15 m^2 in area) are represented by the frame-and-pillar structures with bases of a round, rectangular or square shape slightly deepened into the ground. Round structures are characterized by smaller size (from ca. 3.5 m^2), while rectangular structures were much larger (up to 55 m^2). All pit dwellings correspond to the lower level of settlement. Stone tools: retouched knives made of large obsidian flakes, retouched and polished arrowheads, polished adzes with an oval cross-section, straighteners of arrow shafts, fragments of polished discs. All vessels made without potter's wheel have a flat bottom, simple open shapes with or without a slightly pronounced neck and with ornamentation done by pinning and stamping. The surface of the vessels has been polished. Some containers have traces of red stain. The ceramic collection of the site contains a significant number of bowls, which, with rare exceptions, are not ornamented. More than 50 ceramic vessels with complex-figured ornaments stand out as an independent (possibly ritual) group. Among the ceramic artefacts there are spindle whorls with triangular and biconical sections, miniature vessels, beads and a realistic figurine of a deer (Moreva et al., 2009). In 2009, water flotation was applied to more than 150 l of soil from both habitation horizons. In total, 6 grains of *P. miliaceum* were found in 3 samples from both horizons as well as remains of wild plants such as *Juglans mandshurica*, *Corylus* sp., *Phellodendron amurense* and *Quercus mongolica* (Krutykh et al., 2010). Two millet caryopses from dwelling pit No. 5 (lower habitation level) were AMS-dated (Table 2).
Rettikhovka Geologicheskaya-1	The site is located southeast of Khanka Lake and occupies a gentle southern slope of a hill 200 m from the bank of the Malaya Vassianovka River, which belongs to the basin of the Ilistaya River. The river valley near the site is rather narrow and limited by hills with prevailing heights of up to 400 m. Part of this archaeological settlement site has been destroyed, the preserved area occupies about 3600 m^2. The ground survey revealed 16 depressions with a diameter of 5–7 m grouped in four rows on narrow, possibly artificially made, terraces. In 1999, 2004 and 2009, two squares with a total area of 132 m^2 were excavated and revealed remains of a dwelling and utility structure. Both constructions are referred to the Prikhankaisky variant of the Zaisanovskaya culture. The collection of artefacts also contains a few items assigned to the Olginskaya culture of the Late Iron Age (Kolomiets, 2005). However, this culture does not form a cultural layer at the study site. The long-term dwelling representing the frame-and-pillar construction was built in a sub-rectangular pit with an area of more than 20 m^2. The pit was partially destroyed by modern road construction. Several pits, 60–70 cm deep, were found in the central part of the dwelling. The floor was covered with a 3–5 cm thick layer of clay. The ^{14}C dates obtained from charred wood fragments from this layer were published: 1330 ± 45 BCE (SOAN-4238), 1440 ± 55 BCE (SOAN-4239), 1360 ± 45 BCE (SOAN-4240) (Kolomiets et al., 2002b). The remains of the outbuilding located next to the living house are represented by a sub-rectangular platform (20–25 m^2) cut into the slope with a floor covered with clay. The charred wood pieces from the lower part of the filling were ^{14}C-dated to 1660 ± 80 BCE (SOAN-6108), 1290 ± 85 BCE (SOAN-6109) and 1450 ± 100 BCE (SOAN-6110) (Kolomiets and Krutykh, 2011). Both buildings burned down in a fire, which ensured a good preservation of the archaeological material. In the cultural deposits of the outbuilding, sherds of 19 vessels were found, almost all of them large in size, without traces of use for cooking on fire. This, together with the absence of a hearth, the presence of tools associated with woodworking and processing of raw plant materials, as well as abundant finds of millet grains, suggests that this structure was a utility building for keeping household implements and storing food (Kolomiets and Krutykh, 2011). The collection of stone implements found at the site contains retouched, polished and unmodified items. Retouched items are represented by arrowheads and spear points. They are small in size, petiole, rhombic or truncated-leaf-shaped, flat and made of flint or obsidian flakes. Woodworking tools include massive rectangular axes, elegant fully polished adzes and chisels. The grinding slabs and hand stones show traces of long use, possibly of grain processing. Two large grinding stones were found in the pit of the outbuilding structure. Two trapezoidal hoes were also reported (Kolomiets et al., 2002a; Kolomiets and Krutykh, 2011). The pottery collection is represented by numerous vessels. All of them are made without potter's wheel, flat-bottomed and have a standard ornamentation made with a comb. The sizes of the vessels vary greatly - from very small ones, with a volume of about 1 L, to very large containers, the volume of which exceeds 50 L (Kolomiets et al., 2002b; Kolomiets and Krutykh, 2011). Fragments of two vessels in the form of scoops with a round bottom and a protruding handle were also found in the filling of the outbuilding (Kolomiets et al., 2002a). Several flotation samples were obtained from the filling of the outbuilding, in which numerous caryopses of millet were found. One analysed sample contained 1615 caryopses of *S. italica*, 370 caryopses of *P. miliaceum* and 1862 fragmented caryopses of undifferentiated cultivated millet (Sergusheva, 2008a). The analysed samples also contained a few nut and seed remains of wild plants including *Juglans mandshurica*, *Corylus* sp., *Phellodendron amurense* (Sergusheva, 2006). Three AMS dates were obtained to identify the age of the millet grains (Table 2).
Bogolyubovka-1	The site discovered in 1985 by Yu.V. Krivulya is located at a tributary the Osinovka River, a tributary of the Ilistaya River which flows into Khanka Lake. It is represented by 11 compactly and haphazardly located shallow depressions. In 1988, 2006 and 2007, an area of 179 m^2 in the western part of the site was excavated. A single cultural layer contains material from the Zaisanovskaya culture (Prikhankaisky variant). The remains of two pit dwellings were studied. The pits had rectangular outlines and a floor area of 30 and 24 m^2. No fire places were identified, but holes from pillars were found. Unbroken stone and ceramic artefacts are absent, with a few exceptions represented by small items. This, as well as the absence of traces of fire, indicates a relatively long period of use and subsequent abandonment of the settlement by its inhabitants. The toolkit is represented by rather simple implements with traces of degradation of the techniques of splitting and retouching. Knives and scrapers were made by splitting obsidian pebbles without or with minimal processing of the working edges. Flat retouched arrowheads triangular in plan with a straight, pointed or slightly concave base were made of obsidian and flint flakes. Polished tools are represented by fragments of flat elongated arrowheads as well as medium-sized flat chisels and other woodworking tools. Hoes of elongated rectangular outlines with a rounded working part were made from massive slate slabs. There are numerous finds of fragments of grinding slabs and rollers with traces of intensive use. The main group of pottery vessels is characterized by a low quality of processing, admixture of the larger mineral particles in the clay and surface ornaments made with a comb tool. The second group (14% of all finds) includes carefully done thin-walled, carefully polished vessels made of finer material and decorated in the upper third of the body with a rectangular meander. A set of small discs (reminiscent of game pieces) made from the walls of ceramic vessels were discovered at this site. A wood fragment from the lower deposit layer of dwelling No. 2 was ^{14}C-dated to 1940 ± 60 BCE (SNU 07260) (Garkovik, 2008). In 2006, 2007, water flotation was applied at the site. Single caryopses of *P. miliaceum*, one caryopsis resembling *S. italica* as well as numerous remains of wild edible plants (e.g. *Quercus mongolica*, *Juglanse mandshurica*, *Corylus* sp., *Vitis amurensis*, cf. *Malus manshurica/M. baccata* and *Phellodendron amurense*) were identified, suggesting the importance of wild plants (Garkovik and Sergusheva, 2014). The 3 caryopses of broomcorn millet from dwelling No. 2 were AMS-dated (Table 2).
Vodopadnoe-7	The site discovered in 2012 by I.Y. Sleptsov has a total area of 656 m^2 and is located in a ca. 150-m-wide valley of the Vodopadnaya River, 12 km from its confluence with the Partisanskaya River. Two rounded depressions of 7 and 12 m in diameter were recorded and an area of 138 m^2 was excavated in 2016 and 2017. The remains of three dwellings were revealed. Two of them were assigned to the Zaisanovskaya culture (South-eastern variant) (Dorofeeva et al., 2017) and the third one to the Palaeometal Epoch. The Late Neolithic houses are represented by square frame-and-pillar structures without fire places and with a floor area of about 23 and 33 m^2. Both dwellings were located at a distance of 1.5 m from each other, functioned at the same time and became a victim of the fire. The ^{14}C dates 2086 ± 65 BCE and 2315 ± 130 BCE were obtained from carbonised wood fragments from both dwelling pits (Dorofeeva and Klyuev, 2020). The collection of stone artefacts contains retouched and polished items. Among the retouched tools are arrowheads, spear points, scrapers and arrow shaft straighteners. In both pit houses, a compact accumulation of retouched arrowheads (17 and 26 specimens) was found, apparently in quivers. All of them are small in size and weight, flatten, have triangular, diamond or leaf shape and made of chalcedony, obsidian, silicified tuff or slate. Polished tools are represented exclusively by tools for woodworking (i.e. adzes, axes and chisels). Hoes are of two sizes: 15–18 cm long (5 items) and 25–30 cm (5 items). Grinding slabs representing plates of oval or sub-rectangular shape, 41–43.5 cm long and 26–29 cm wide, with traces of long-term use and rollers were made of sandstone. The hand stones are scaphoid with a total length of 35.5 and 40 cm, a length of the working surface of 21 and 26 cm and a width of 7.5 cm. The pottery finds are represented by sherds of numerous

(*continued on next page*)

Table 1 (*continued*)

Archaeological site	Brief site description
	ornamented vessels (i.e. 50 items were reconstructed). All of them are flat-bottomed and made by hand from clay with an admixture of sand. Small, medium-sized and large vessels were found with an opening rim of up to 40 cm in diameter. The Palaeometal Epoch dwelling had a rectangular shape and an area of ca. 43 m^2 and was constructed in place of the Late Neolithic dwelling. On the floor and along the walls, numerous remains of stone artefacts and non-ornamented pottery vessels of different shape were found. Flotation was applied to ca. 600 l of sediment and 10 samples from the Late Neolithic pits No. 1 and 2 and 12 samples from the younger pit No. 3 were analysed (Sergusheva, 2020). The Late Neolithic samples revealed 27 caryopses of *P. miliaceum*, 21 caryopses of *S. italica* and 3 caryopses of undifferentiated millet. Millet from dwellings No. 1 and No. 2 were AMS-dated (Table 2). Samples from the Palaeometal dwelling revealed one caryopsis of *S. italica* and one undifferentiated seed of domesticated millet.
Novoselishche-4	The site occupies a gentle south-eastern slope of an isolated low-mountain massif at the western periphery of the Khanka Plain. It is situated near a small stream in the upper reaches of the Udobenka River, a tributary of the Molokanka River, which enters Khanka Lake located ca. 27 km east of the site. The site was discovered in 1988 by V.E. Ermakov and N.A. Klyuev. The excavations performed in 1989–1992, revealed several archaeological complexes assigned to the Late Neolithic Zaisanovskaya culture, the early Palaeometal Epoch and the Iron Age. Two depressions visible on the surface were excavated, in which the remains of four residential complexes were examined. One of the dwellings assigned to the Krounovskaya culture of the Iron Age was constructed above the dwelling of the Zaisanovskaya culture. In the second depression, the relatively well-preserved remains of two dwellings were investigated: a ground structure of the Palaeometal Epoch (Chernyatino-2 type) and a semi-dugout of the Prikhankaisky variant of the Zaisanovskaya culture (Klyuev et al., 2002). The material complex of the Zaisanovskaya culture was presented in the most complete way. The more intact dwelling of this period had a subrectangular pit (ca. 9.3 × 5.8 m) with the floor covered with clay. Judging by the arrangement of the postholes, the dwelling had a frame-and-pillar structure. An oval-shaped hearth (1.2 × 1.0 m) was located in the centre in a cup-shaped pit with a thickness of hearth deposits up to 28 cm. The dwelling was destroyed by fire. Altogether, 18 clusters of pottery sherds, retouched stone arrowheads and a hoe were found in this dwelling. In the pottery assemblage, two groups of vessels stand out: coarse-made (predominate) and fine pottery, which differ in both the manufacturing technique and the ornamentation. Ceramics associated with the ground dwelling of the Paleometal period are distinguished by the composition of the clay mass including crushed freshwater mollusc shells. The vessels have sparse ornamentation located exclusively in the upper part. The stone tools are represented by hand stones with segmental cross-section, polished crescent-shaped knives, fragments of grinding slabs. The material assemblage of the Krounovskaya culture is rather typical and includes stone axes and polished knives, ceramic vessels of simple open shapes, without ornamentation, with stump-shape handles. Charred wood from the dwelling of the Zaisanovskaya culture was ^{14}C-dated to 1890 ± 70 BCE (AA-13400) and 1805 ± 35 BCE (AA-36748) (Klyuev et al., 2002). A charcoal sample from the dwelling assigned to the Palaeometal Age was dated to 1030 ± 50 BCE (GIN-6951) (Klyuev et al., 2002). The Krounovskaya culture dwelling was not dated, but its archaeological material is similar to the other sites of this culture dating back to the interval between the 4th/3rd centuries BCE and 2nd/3rd centuries CE. In 1991, an archaeobotanical collection of seed and fruit remains was obtained from the two dwellings using the flotation method. Further analyses revealed millet caryopses (Table 2) in the samples from both dwellings along with remains of wild plants (*Quercus* sp., *Phellodendron amurense*, *Corylus* sp., *Vitis amurensis*). In the sample from the Zaisanovskaya culture dwelling, two species of millet were found, i.e. *P. miliaceum* (48 caryopses) and *S. italica* (4 caryopses), while the sample associated with the early Palaeometal dwelling revealed 369 intact and 58 fragmented caryopses of *P. miliaceum* (Klyuev et al., 2002; Sergusheva and Klyuev, 2006; Sergusheva, 2008a; Shapovalov et al., 2011). Millet-based ^{14}C dates obtained for the Late Neolithic (Sergusheva, 2008a) and Palaeometal Epoch dwelling (Sergusheva and Klyuev, 2006; Kuzmin, 2013) are presented in Table 2.
Risovoe-4	The site with a total area of ca. 5000 m^2 is located on the flattened top of a low-elevated rocky hill on the floodplain of the Tikhaya River, which flows to the Arsenyevka River, a left tributary of the Ussuri. The site was discovered in 2012 by I.Yu. Sleptsov and N.A. Klyuev. In 2013, 2014, an area of 118 m^2 was excavated. The archaeological materials indicate that the site was occupied from the Early Neolithic to the Middle Ages, however, there are no stratigraphically undisturbed cultural layers. Remains of three dwelling pits were recorded during the excavation typologically assigned to the Middle and Late Neolithic and the Palaeometal period (Klyuev and Moreva, 2014; Klyuev et al., 2016; Gridasova, 2018). Most of the time, the hill was inhabited during a short period. A few intervals of a longer occupation are associated with more solid dwellings. The oldest dwelling on the site belongs to the Rudnaya archaeological culture of the Middle Neolithic. Its foundation pit, ca. 36 m^2 in area, had a rectangular shape with rounded corners and an oval stone-lined hearth in the centre. Most of the pit and its filling were destroyed by subsequent constructions, i.e. a similarly sized dwelling of the Late Neolithic (Prikhankaisky variant) and a dwelling of the Palaeometal Epoch with a square pit of ca. 25 m^2. Pot sherds and stone artefacts associated with various habitation stages were collected and soil material was taken for water flotation. Single caryopses of *P. miliaceum* and *S. italica* were found in several samples. Two AMS dates on broomcorn millet caryopses from two samples associated respectively with the Middle Neolithic and Late Neolithic/Early Palaeometal layers, showed the same Late Neolithic age (Table 2).
Olga-10	The site is located on the left bank at the mouth of the Avvakumovka River, which flows into the Sea of Japan. It occupies the southern promontory extremity of a mountain spur with a height of about 40 m facing the river. The site represents a permanent settlement with 5 depressions from former dwellings with a diameter of 6–6.5 m. Two of the dwellings were destroyed by looting. In 2010, 113 m^2 of the area was excavated and two dwellings were studied. The main occupation phase of the site was assigned to the Margaritovskaya culture of the Palaeometal Epoch, however, outside the dwelling pits, separate fragments of ceramics representing the Late Neolithic were found. Judging by the paucity of these finds, they mark the remains of a short-term camp, which was destroyed during the construction of the later dwellings (Batarshev et al., 2014). Both investigated pit dwellings were square in shape, with a depth of 0.4–0.6 m and an area of 29 and 42 m^2. A large utility pit adjoined the north-eastern corner of both dwellings. In the filling of the first, 7 vessels were found, and in the second 3 vessels. In the centre of dwelling No. 1, a rectangular hearth deepened into the floor was revealed. A significant number of pole pits was recorded on the floor of both dwellings. Wood fragments (possibly burnt remnants of the wooden roof) from dwelling No. 1 were ^{14}C-dated to 1350 ± 45 BCE (SOAN-8365) and that from dwelling No. 2 were dated to 1565 ± 65 BCE (SOAN-8366) and 1420 ± 55 BCE (SOAN-8367) (Batarshev et al., 2014). The archaeological material in the deposits of both dwellings is identical and typical for the Margaritovskaya culture. The stone industry is based on the use of flakes and elongated chips and the prevalence of techniques of edge and two-sided retouching. The main types of retouched items comprise arrowheads of triangular and rhombic shapes, elongated triangular drills and trapezoidal-elongated scrapers. The polishing technique was used exclusively for the production of jewellery items such as cylindrical beads. The pottery production was characterized by the use of crushed rock for the preparation of clay paste, covering the walls of vessels with engobe, presence of pot-shaped vessels with a weakly pronounced neck and bowls of different shapes. From the lower part of the sediment filling of both dwellings, 487 L of soil were collected and 35 flotation samples were obtained. In total, 106 carbonised seeds and fruits were found in 31 of them, including 15 caryopses of *P. miliaceum* and *S. italica* (that slightly predominate) and numerous nut and fruit remains of edible wild plants (e.g. *Quercus mongolica*, *Pinus koraiensis*,*Juglans mandshurica* and *Corylus* sp. (Batarshev et al., 2014, 2015). Two seeds of *S. italica* from dwelling No. 2 were AMS-dated (Table 2).
Sheklyaevo-7	The site is located on the left bank of the middle reaches of the Arsenyevka River valley. It occupies a flattened top of a round hill with an area of ca. 150 m^2. The 10-m-high hill is surrounded by a swampy lowland and an oxbow of the Arsenyevka River. The site was discovered in 1999 by N.A. Klyuev. In 2003, 2004, the entire area of the site (172 m^2) with a round depression 7 m in diameter at the top of the hill was excavated. The maximum thickness of cultural deposits in the depression reached 90 cm. The site is multi-layered and the archaeological material belongs to the period from the Middle Neolithic to the Palaeometal Epoch (Klyuev et al., 2003; Batarshev et al., 2012). During this time, eight stages of habitation were identified, including four short-lived occupation phases (i.e. without a permanent dwelling) and four stages when permanent dwellings were constructed (i.e. one above ground and three in a pit deepened into the ground). These subsequent construction activities at the relatively small area of the site led to a significant mixture of archaeological materials from different cultural complexes (Batarshev et al., 2012). The oldest dwellings (No. 1 and No. 2) were typologically attributed to the Middle Neolithic. Several ^{14}C dates, 4505 ± 50 BCE (AA-60059), 4170 ± 45 BCE (AA-60054), 4095 ± 50 BCE (AA-60055), 2440 ± 45 BCE (AA-60058), 2480 ± 45 BCE (AA-60051) and 2485 ± 45 BCE (AA-60053), on carbonised wood remains and food soot from the pottery sherds were obtained, which support this interpretation (Moreva and Klyuev, 2011). The last long-term construction on the site was dwelling No. 3 of the Late Neolithic. Its sub-square pit had an area of 16 m^2 and four post holes from support pillars. In the central part of the house, a

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Table 1 (*continued*)

Archaeological site	Brief site description
	rectangular hearth and a utility pit were discovered as well as remains of several pottery vessels assigned to the Prikhankaisky variant of the Zaisanovskaya culture (Klyuev et al., 2003). Additionally, a limited number of potteries fragments similar to that from sites of the Palaeometal Epoch (Chernyatino-2 type) were reported (Batarshev et al., 2012). A flotation sample obtained from the lower part of the utility pit contained a single caryopsis of broomcorn millet and several fragments of gathered wild plants: *Crataegus pinnatifida*, *Phellodendron amurense*, *Juglans mandshurica* (Sergusheva, 2008a, 2008b, 2008b). The AMS date of the millet caryopsis from this sample (Table 2) falls into the Palaeometal period.
Anuchino-14	The settlement site (ca. 1000 m^2 in area) occupies the flattened top of a 30-m-high hill in the valley of the Rudanovsky Spring, a right tributary of the Arsenyevka River. It was discovered in 1998 by N.A. Klyuev and investigated during four seasons. The area of 354 m^2 was excavated and two cultural and chronological stages of an ancient settlement were discovered, represented by the remains of one Late Neolithic dwelling (Prikhankaisky variant of the Zaisanovskaya culture) and two dwellings assigned to the Palaeometal Epoch (Klyuev and Sleptsov, 2001). The pit of the Late Neolithic dwelling had an oval shape and an area of about 60 m^2. In its central part there were several posthole pits and an oval-shaped hearth (1.4 × 0.9 m) deepened into the floor. The dwelling was destroyed by fire. One of the later dwellings was built at the same place, which resulted in poor preservation of the Late Neolithic dwelling (Klyuev and Yanshina, 2002). The material assemblage is represented by diverse stone tools, including retouched arrowheads (numerous), asymmetric leaf-shaped knives, scrapers and drills, polished axes and arrowheads as well as by numerous abrasive stones. A hand stone and a hoe were found on the floor of the dwelling. A separate group of stone artefacts includes beads and pendants. The pottery assemblage demonstrates the presence of well-profiled squat vessels with a convex body, a marked neck and ornamentation typical for the Prikhankaisky variant of the Zaisanovskaya culture. Some pottery ornaments are typical of the Voznesenovskaya culture of the Late Neolithic in the Lower Amur region, suggesting advancement of the latter culture to Primorye (Klyuev and Yanshina, 2002). Both dwellings of the Palaeometal time period were built in oval-shaped pits slightly deepened into the ground. The smaller pit was 13 m^2 in area and had 4 postholes and a rounded hearth (0.5 m in diameter and 10 cm deep) in the central part. The larger pit (75 m^2) revealed 8 postholes located along the walls. Archaeological material associated with this occupation phase includes 3 fragments of bronze items. The pottery collection is represented by fragments of non-ornamented vessels, with a pronounced neck and a convex body. In the north-eastern corner of each of the dwellings, two miniature vessels and decoration items were found. The collection of stone artefacts includes retouched (knives, scrapers, arrowheads, drills) and polished items (elongated triangular and teardrop-shaped arrowheads, axes, adzes, reaping knives). There are polished stone artefacts imitating bronze objects (spearheads, daggers and jewellery). Abrasive stones are numerous, including a conical whetstone for working on metal. Charred wood from the filling of one of the pits was ^{14}C-dated to 690 ± 55 BCE (SOAN-4491) (Yanshina and Klyuev, 2005). Two flotation samples obtained from the pit filling in the large dwelling revealed over 80 caryopses of *P. miliaceum* and 3 fragments of a Manchurian nut shell (Sergusheva, 2008b). Several caryopses were dated by the AMS method (Table 2).
Voevoda-2	This site is located on Russky Island, Peter the Great Gulf of the Sea of Japan. It occupies an area of 640 m^2 at the terraced surface of a hill facing the Voevoda Bay. The site was discovered in 2014 by S.V. Batarshev. In 2016, 40 m^2 of the site were excavated and two cultural periods of the settlement were assigned to the late Neolithic and the Early Iron Age, respectively. Most of the found artefacts and remains of long-term living structures are associated with the Late Neolithic, while the finds from the later period suggest a short, probably seasonal, habitation. In the upper part of the cultural layer single fragments of pottery vessels were found and tentatively assigned to the Yankovskaya culture. A charcoal piece from the same layer was ^{14}C-dated to 925 ± 125 BCE (SOAN-9604) (Batarshev et al., 2017a). The Late Neolithic is represented by two dwellings, built one after another within a short time interval. The rectangular pit of dwelling No. 1 had an area of about 12 m^2 and a stone hearth in the centre. Judging from the significant number of finds, the thickness of the cultural layer, the large size of the hearth (178 × 155 cm) and the details of the wall construction it was a permanent residential building. Dwelling No. 2 had a rounded shallow foundation pit with an area of 5.5 m^2 and only a few artefacts. Apparently, it was used only seasonally. The Late Neolithic stone artefacts are represented by polished tools for woodworking (i.e. adzes of a trapezoidal shape and chisels), retouched arrowheads of triangular and truncated-leaf-like shape, numerous grinding and roller stones made of large pebbles. The pottery assemblage is represented by fragments of ornamented containers of a simple shape without a neck and walls slightly diverging from the bottom. A small number of cups and bowls were also found. The described archaeological complex corresponds to the Khasansky variant of the Zaisanovskaya culture. Carbonised wood from dwelling No. 2 was ^{14}C-dated to 2160 ± 125 BCE (SOAN-9607) and that from dwelling No. 1 to 1980 ± 135 BCE (SOAN-9605) (Batarshev et al., 2017a). Several flotation samples obtained from the sediments of both dwellings revealed 15 caryopses of *P. miliaceum* and *S. italica*.Several caryopses of broomcorn millet from dwelling No. 2 were AMS-dated (Table 2) and the obtained date represents the initial stage of the Yankovskaya culture.
Dvoryanka-1	The site is located in the western part of the region near the border to China. It occupies the top and part of the slope of a 45-m-high rocky hill, stretching along the right bank of the Komissarovka River flowing into Lake Khanka. The area of the site is ca. 6000 m^2. Initially, 36 depressions with a diameter of 3–8 m and a depth of 0.3–0.8 m were recorded, 32 of them were grouped in two rows along the northern slope of the hill. Another 4 were situated at the top of the hill, on the area of 33 × 46 m, contoured by a system of fortifications, consisting of two ramparts and two ditches. The site was discovered in 1997 by N.A. Klyuev and studied in 2004–2006. Archaeological excavations were carried out over an area of 262 m^2 in the fortified part of the settlement (Klyuev and Garkovik, 2006). The site revealed several cultural layers, which were assigned to the Middle Neolithic, Palaeometal Epoch and Early Middle Ages. A pit of a Neolithic dwelling was investigated, as well as three structures and secondary burials (carried out in a stone box, on a stone-paved platform and in a pit) dating to the Palaeometal period. The remains of the Neolithic dwelling (partly damaged by the later burial construction) are represented by a rectangular pit (ca. 30 m^2 in area) with post holes indicating a frame-and-pillar house structure. In the central part of the pit, two hearths and several utility pits were identified. One of the hearths was lined with stones. The dwelling burned down. Numerous fragments of pottery vessels, stone tools and animal bones were found on the floor. The archaeological material belongs to the Rudnaya culture of the Middle Neolithic, as convincingly established on the basis of pottery typology and the ^{14}C date 5665 ± 180 BCE (SOAN-5902) obtained for the wood sample from the pit (Klyuev and Garkovik, 2006). In the north-western part of the Neolithic pit, a much younger burial (2.1 × 0.7 m box made of flat stones in a pit) was examined. It contained single remains of at least four individuals, as well as single artefacts, including a fragment of a bronze plate, a drilled fox or dog canine and pottery fragments (Klyuev, 2013). This burial was attributed to the Palaeometal Epoch. Three studied dwelling pits belong to the same cultural and chronological period. All of them are sub-rectangular in shape, with a floor area of no more than 10 m^2 and a depth of up to 0.7 m. No fire places were identified. The archaeological material assemblage contains a few bronze objects (button, plaque and pendant), a large amount of ceramics represented by two main types of vessels (weakly profiled with sloping shoulders and well profiled with a clearly defined neck) and tools and weapons made of stone (e.g. polished and retouched arrowheads, scrapers, engraved chalcedony pebbles). Three ^{14}C dates were obtained from wood samples representing the excavated dwellings: 1000 ± 50 BCE (SNU06-1197), 780 ± 50 BCE (SNU06-1196) and 760 ± 50 BCE (SNU06-1195). This material complex cannot be associated with other cultural complexes of Primorye of the same age. The closest analogies are found in the adjacent territory of China, Jilin province (Klyuev, 2012, 2013, 2013). In 2004, flotation was applied to the sediments from the hearth pit and from the floor of the Neolithic dwelling. The analysed sample contained single grains of millet (*P. miliaceum* and *S. italica*) and numerous remains of edible wild plants (e.g. hazelnut, Manchurian walnut, hawthorn and wild grapes). The discovery of cultivated millet remains in the sediments filling the Middle Neolithic dwelling was questioned (Klyuev et al., 2008). AMS dating of three caryopses of broomcorn millet confirmed their substantially younger Palaeometal age (Table 2).
Lidovka-1	The site with an area exceeding 10,000 m^2 is located in eastern Primorye, on the Sea of Japan coast. It is located on a 12–15-m terrace bounded by an unnamed stream and the Lidovka River next to the village of the same name. The ancient settlement site was discovered in 1974 by O.V. Dyakova. In 1974, 1975 and 1979, excavations were carried out on an area of 1377 m^2 and the site was assigned to the Lidovskaya archaeological culture (named after this site) of the Palaeometal Epoch (Dyakov, 1989). Ten archaeological complexes were discovered and provisionally named by V.I. Dyakov 'hut', 'sanctuary', 'staircase', 'platform', 'frame dwelling', 'summer kitchen', 'long-term dwelling', suggesting their original function. Due to the heterogeneity of the archaeological materials of Lidovka-1, its interpretation as a single-layer site (Dyakov, 1989) was questioned (Garkovik, 1983; Andreeva, Studzitskaya, 1987). Based on significant typological differences in the excavated pottery and comparison to other sites in the region, it was

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Table 1 (*continued*)

Archaeological site	Brief site description
	attributed to the Bronze and Early Iron Age (Yanshina, 2004). However, further research is required to identify the nature of the settlement and to date the cultural-chronological complexes. The 'earlier' phase in the pottery assemblage includes made without potter's wheel vessels often produced from clay mass with crushed shells of freshwater molluscs. Both the vessels with and without a neck, decorated only on the rim, are described. Anthropomorphic clay figurines also belong to the early stage of the settlement. The 'later' phase is represented exclusively by vessels with a neck. In their production, only mineral temper in clay was used. As a rule, these vessels were ornamented at the base of the neck with an adhered roller (Yanshina, 2004). The collection of stone artefacts has not yet been reliably divided into two complexes. The stone toolkit consists of retouched and polished arrowheads; scrapers, drills and cutting tools made from flint flakes; polished semi-moon knives and knives with a handle; polished axes and adzes; grinding plates and 'anvils'; fishing net weights made of pebbles; hoes; pebble cores and scraping and chopping tools roughly made of pebbles. There are also several fragmented items that imitate bronze spearheads of the Karasuk type (Dyakov, 1989). V.I. Dyakov reported two accumulations of charred grains found during the excavation. The first was found in the 'seasonal cooking hearth' under the fragment of a vessel (excavation area No. 1), the second – in test pit No. 5 on the southern outskirts of the settlement (Dyakov, 1997). The very fragile grain remains from the first sample could not be preserved. The caryopses from the second sample were identified by S.G. Varadinov as foxtail millet (*S. italica*) or barnyard millet (*Echinochloa esculenta*), both representing cultivated forms of millet (Dyakov, 1989). The ^{14}C date (SOAN-1424) obtained from this grain sample (Table 2) correlates equally well with both stages of the settlement, during which populations actively used land and marine resources and practiced agriculture based on the cultivation of millet in the 1st millennium BCE.
Cherepakha-13	The site is located in southern Primorye, on the seaside terrace of the west coast of the Muravyinaya Bay, ca. 100 m from the modern coastline. In 2015, the entire area of the site (7616 m^2) was excavated. The excavations revealed remains of 52 dwelling pits, one above-ground structure, 114 utility pits, 26 human burials with relatively well-preserved bone material. Excavated artefacts were assigned to at least five archaeological cultures dating from the Late Neolithic to the Middle Ages (Malkov, 2016; Batarshev et al., 2017b). The site location close to abundant and diverse food resources provided by the sea and the Artyomovka River was favourable and explains the long habitation history. Most abundant cultural remains (i.e. great portion of artefacts, 44 dwelling pits, all burials and utility pits) are associated with the Yankovskaya culture of the Early Iron Age. A preliminary analysis of the pottery material indicates two phases of long-term occupation during that time. Four samples of carbonised wood from the sediment associated with the Yankovskaya culture dwellings were ^{14}C-dated: dwelling No. 2–985 ± 120 BCE (SOAN-9539), dwelling No. 24–1080 ± 105 BCE (SOAN-9603), dwelling No. 31–1010 ± 95 BCE (SOAN-9602) and dwelling No. 48–610 ± 70 BCE (SOAN-9540) (Batarshev et al., 2018). The other three dwelling pits were assigned to the Krounovskaya culture of the Iron Age. Judging from the sediment stratigraphy and the excavated artefacts, occupation of these dwellings was short-lived and probably seasonal. A representative collection of seeds was obtained from the cultural deposits of the Yankovskaya and Krounovskaya cultures using flotation (Sergusheva and Moreva, 2017). Grains of *P. miliaceum* and *S. italica* dominate among the cultivated plant remains. The finds of caryopses resembling barnyard millet (*E. esculenta*) were noted in the samples assigned to the Krounovskaya culture (Sergusheva and Moreva, 2017). All previously known finds of Japanese millet in this region were reported from Medieval sites (Sergusheva, 2014). AMS dates were obtained (Table 2) from millet seeds from the sediments assigned to the Yankovskaya culture phase (i.e. *P. miliaceum* from pit No. 10, representing the first stage of the settlement, and *S. italica* from dwelling No. 48 representing the second stage) and on *P. miliaceum* from dwelling No. 19 representing the Krounovskaya culture phase.
Glazovka-gorodishche	The site is located in the middle reaches of the Ussuri River, on a high ledge of the right bank, up to 72 m above the water level. It represents a small-size fortified settlement (ca. 26 m along the north-south extent and 34 m along the west-east extent) with a system of defence ramparts and ditches. Up to 40-degree-steep slopes and rocky cliffs protect the site from the west, south and southeast. The site was discovered by S.P. Nesterenko in 1986 and an area of 136 m^2 was excavated in 1996–1998 (Kolomiets et al., 2002a). A 34-m-long trench cut two ditches and three ramparts, including the main rampart of the fortified settlement, of up to 3 m height. The excavations revealed three cultural layers assigned to the Neolithic, Bronze and Iron Age, respectively. The poorly preserved and discontinuous Neolithic layer was not ^{14}C-dated. Accurate cultural and chronological affiliation of this layer was not possible due to the poor preservation and paucity of finds. The layer assigned to the Early Palaeometal Epoch was also poorly preserved in the main part of the settlement, but the excavation adjacent to the rampart revealed the remains of dwelling pits, overlapping each other. The artefacts are represented by flat-bottomed pottery vessels, without ornamentation, retouched stone arrowheads and cutting tools made of flint flakes, polished axes and adzes and polished beads. The layer was not ^{14}C-dated. The Iron Age layer is well preserved and rich in finds. It seems that during that time, the inner, highest rampart was additionally reinforced along the ridge with a wooden palisade-type structure. No Iron Age dwellings were found within the excavated area, but the remains of three storage cellars cut into the slope of the terrace. In the deposits from the cellars numerous sintered grains of foxtail millet were found. Water flotation samples were obtained from the two cellars. Archaeobotanical assemblages also contained caryopses of foxtail millet, some of which had glumes, and single caryopses of *Setaria* spp. A large number of fragments of pottery vessels of various sizes, burnt remains of wooden and birch bark vessels and other products and parts of wooden boxes or chests were found in the fillings of the cellars. A few polished stone items and metal objects were also found there. Most of the artefacts from the excavations are fragments of pottery and waste from the manufacture of polished arrowheads. Some of the vessels were made using a primitive potter's wheel. The metal finds are a combination of forged items and items cast from white iron. The archaeological material is attributed to the poorly studied northern Primorye variant of the Poltsevskaya culture. Two ^{14}C dates obtained from charcoal (360 ± 40 BCE (SOAN-3949) and 120 ± 50 BCE (SOAN-3950)) and one on charred foxtail millet (240 ± 50 BCE (SOAN-3951)) allow to date the Iron Age fortification to the second half of the 1st millennium BCE. The site location, the fortifications and the archaeological material (i.e. mainly weapons and few household items) allowed to identify it as a settlement, possibly with military functions for controlling the transport route along the Ussuri River connecting the Amur River region and the northern part of Primorye with the Khanka region (Kolomiets et al., 2002a).
Malaya Podushechka	The site is located 2 km west of the village Novonezhino on the western gentle slope of an isolated small hill in the middle reaches of the Sukhodol River, ca. 12 km from its confluence with the Sea of Japan. The total area is ca. 1000 m^2. The site was discovered by E.V. Shavkunov in 1960. In the 1960s and 1970s ca. 800 m^2 was excavated. The remains of the settlement and the associated burial ground of the Yankovskaya culture and the settlement of the Olginskaya culture (both representing the Iron Age period) were investigated (Andreeva et al., 1986). Altogether, 7 rectangular pits representing remains of the frame-and-pillar dwellings of the Yankovskaya culture were excavated. One of the pits had an area of 50 m^2, the others ca. 20–25 m^2. Remains of ovens with pottery remains from the Yankovskaya culture were found in the settlement (Andreeva et al., 1986). In the central part of the settlement, 20 burials were revealed (Andreeva, 1977; Andreeva et al., 1986). Artefacts of the Yankovskaya culture are numerous and include iron objects along with polished stone products imitating bronze weapons (i.e. daggers, spearheads and arrow points). Among the stone artefacts were polished arrowheads, adzes, axes, chisels, knives, grinding slabs. It was noted that the number of items was low compared to tools associated with agricultural activities (Andreeva et al., 1986). The pottery assemblage is represented by flat-bottomed vessels of various shapes and sizes made without potter's wheel. Pot-shaped containers prevail, among which large and medium ones are more common. Vessels without a neck are represented by bowls and cups. Decorated pottery items are rare (6%). The main ornamental motif is a horizontal straight line made by cutting with stick, sticking or embossing. The assemblage lacks painted ceramics known from other sites of the Yankovskaya culture. A carbonised wood sample from the Yankovskaya culture layer was ^{14}C-dated to 480 ± 50 BCE (MGTs-499) (Andreeva et al., 1986). The remains of the other 7 dwellings were attributed to the Olginskaya culture (Andreeva, 1977). Some of them had a heating system made of stones, known from sites of the Krounovskaya culture. Numerous and diverse iron items include arrowheads, kelts, axes, etc. The number of stone items is much lower in comparison with the Yankovskaya culture layers. Knives predominate, while other items such as axes and adzes are less numerous. Several plates for grinding and sharpening were found. Bowls make up almost 50% of all pottery finds, among them there are quite large exemplars. Pots of various shapes and sizes are also common. Ornaments are not abundant. During excavations, grains of cultivated plants were recorded in various layers. A ceramic vessel of the Yankovskaya culture with seeds of naked barley was reported (*Hordeum vulgare var. nudum*) (Andreeva et al., 1986). Several caryopses of broomcorn

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Table 1 (*continued*)

Archaeological site	Brief site description
	millet (from the excavation of 1967) have been dated by the AMS method (Table 2) and provided a boundary date that represents both Yankovskaya and Olginskaya cultures.
Berezovaya-2	Located in the middle reaches of the Partizanskaya River (south-eastern Primorye), the site occupies an area of about 2500 m^2 on the second and first terraces at the right bank of the valley. It was discovered in 2010 by N.A. Dorofeeva. In 2011, rescue archaeological excavation was carried out over an area of ca. 700 m^2. The remains of two structures and archaeological material assigned to the Yankovskaya culture of the Early Iron Age and single artefacts of the Early Middle Ages were discovered. On the upper terrace, the remains of a construction with a shallow and narrow pit (ca. 5 m^2 in area) were found. However, its architectural features and function remain unclear. At the edge of the same terrace, a working platform was found with a supply of stones and stone implements and fragments of pottery. On the lower terrace, a pit was found, measuring 3 × 4 m, with a depression up to 0.4 m in diameter in the centre. The finds from this pit are represented by single fragments of pottery assigned to the Early Middle Ages (possibly Mohe culture). The main part of the archaeological material excavated at the site is attributed to the Yankovskaya culture. Among the stone artefacts, tools made of pebbles and pebble flakes (e.g. drills, various scraping, cutting tools, etc.) predominate. A complex of stone tools includes fragments of grinding plates and polished axes, adzes and arrowheads, abrasive stones for metal tools typical for the Yankovskaya culture. The pottery assemblage includes fragments of pots with a well-defined neck and a more or less convex body and fragments of bowls and dish-shaped containers. The shape and decor of the potteries made it possible to attribute them to the later stages of the Yankovskaya culture (Gridasova, 2013). Flotation samples were obtained from the cultural deposits collected on the upper and lower terraces. Single millet grains were found in both locations. The AMS date (Table 2) of two caryopses of broomcorn millet from the foundation pit on the lower terrace corresponds to the Early Middle Ages.
Chernyatino-5	This burial ground site is located on the right bank of the Razdol'naya River, 3.3 km south-west of the village Chernyatino. It occupies the western part of a small hollow opened to the river and framed on the other sides by low hills. The ancient settlement Chernyatino-2 is located in the eastern part of this basin, on the river terrace (Nikitin and Gelman, 2002). The site (estimated area about 30,000 m^2) was discovered in 1997 by Y.G. Nikitin and an area of ca. 1500 m^2 has been excavated in 1998–2006. In total, 157 graves (including ground graves, stone crypts and graves with a lining of stones) and two dwelling-pits were investigated. Ground graves are mainly found in the northern part of the burial ground, while stone crypts and stone-lined graves are located in the southern part. Burial structures are represented by wooden coffins and log cabins or only coffins, although in many burials they are poorly preserved. Two methods of burial have been established; corpse placement (in supine position) and cremation (carried out directly in the grave). Graves with secondary cremation are much more common than with primary ones. Pits of two dwellings within the burial ground were examined. Their architectural features and associated archaeological material confirm they were typical dwellings of the Mohe culture. There were two ground graves cutting the floor of one of the dwellings, which were constructed shortly after the dwelling was abandoned and burned down (Nikitin et al., 2007). A representative archaeobotanical collection obtained from this dwelling using water flotation shows seeds of cultivated (i.e. *S. italica*, *P. miliaceum*, *Hordeum vulgare* var. *nudum*, *Glycine max*) and edible wild plants (*Pinus koraiensis*, *Quercus mongolica*, *Corylus* sp., *Crataegus pinnatifida*, *Juglans mandshurica*). Weeds are represented by single seeds of *Setaria faberi*, *S. viridis*, *Echinochloa crus-galli*, *Poa* sp., *Glycine soja*, *Chenopodium album*, *Malva* sp., *Polygonum* sp., *Polygonum aviculare*, *Viola* sp. (Nikitin et al., 2007). Among the items found in the numerous graves, ceramic vessels (jar, vase, amphora and pot-like forms) prevail. The first two types are characteristic of the Mohe culture and are represented mainly by products made without potter's wheel. The amphora-shaped vessels were made on a potter's wheel. Pot-shaped vessels are also made on (or modified with) a potter's wheel. Such vessels are commonly found at sites of the Bohai State (698-926 AD). Metal items are also numerous in the graves. The collection consists of iron swords, spearheads, darts and arrows, armour plates, knives, daggers, buckles, nails, bronze plaques, bells, earrings, rings and figurines of horsemen. There are also jade rings (fragments) and carnelian and glass beads. The burial ground is dated to the period ranging from the late Mohe archaeological culture to the middle stage of the Bohai State (the southern part), i.e. from the 6/7 to 9 century CE. This is partially confirmed by ^{14}C dates obtained from charred wood and caryopses of foxtail millet from two vessels with funeral food from grave No. 60 (Nikitin and Jung, 2008; Obata, 2008, Table 2).

(Table 1). This culture has been introduced by G.I. Andreev and named after the archaeological site Zaisanovka-1 (Fig. 1B; Andreev, 1957). Initially, it was assigned to the 2nd millennium BCE (Andreev, 1960), however, recent publications suggest earlier intervals, i.e. 3450–1350 ^{14}C BCE (Vostretsov, 2018) or 2750–1350 ^{14}C BCE (Krutykh, 2012), which correspond to calendar age intervals from ca. 4300 to 1600 BCE and 3500 to 1600 BCE, respectively. Over 40 archaeological sites assigned to several locally and chronologically defined variants of the Zaisanovskaya culture have been documented in the study region and neighbouring areas of China and North Korea (Krutykh, 2012). In Primorye, the sites are concentrated in the coastal zone and further inland on the plains around Khanka Lake. The most characteristic locations of the habitation sites (settlements and seasonal hunting and fishing camps) include marine, river and lake terraces and hills (Yanshina and Klyuev, 2005; Krutykh, 2012).

The fact that material assemblages from Zaisanovskaya culture sites are strikingly different from those of earlier archaeological cultures of the Middle Neolithic (i.e. Rudninskaya, Vetkinskaya, Boisman) has been repeatedly outlined and discussed in numerous archaeological papers and monographs (e.g. Andreev, 1960; Vostretsov, 1998, 2005; Klyuev et al., 2002; Yanshina and Klyuev, 2005; Sergusheva, 2008a; Sergusheva and Vostretsov, 2009; Tabarev, 2014). These archaeological publications demonstrate a rich stone toolkit and a diverse ceramic assemblage (Table 1; Supplemental Fig. S1), including new types of flat-bottom vessels and bowls with characteristic ornaments (e.g. incised or stamped zigzags, triangles and meanders) made without potter's wheels, and various art objects (e.g. anthropomorphic masks and figurines, ceramic rings, pendants, amulets) as well as the novel appearance of conical and biconical spindle whorls, stone hoes (Fig. 2), grinding plates and pestles and ornamented arrow shaft straighteners. Characteristic changes occur in the architectural tradition. Most of the sites revealed the remains and traces of pit houses (square, rectangular or round frame-and-pillar constructions) with an area of 7–55 m^2 and ground dwellings of various shapes, including previously unknown types of structures for storage and ritual activities. Altogether, the archaeological record reflects a complex hunting-fishing-gathering subsistence economy supplemented by agricultural food production during the Zaisanovskaya culture period (e.g. Andreev, 1957; Garkovik, 1994; Vostretsov, 1998, 2005, 2018; Moreva and Dorofeyeva, 2020; Yanshina and Klyuev, 2005; Sergusheva and Vostretsov, 2009; Krutykh, 2012).

The period following the Late Neolithic in Primorye does not have the classic features of the Bronze Age. Finds of bronze items are extremely rare and they often appear almost simultaneously with iron objects (e.g. Yanshina, 2004; Yanshina and Klyuev, 2005; Zhushchikhovskaya, 2008; Tabarev, 2014). Virtual absence of bronze objects is partly compensated by their replicas skilfully made of polished stone (e.g. daggers and spear points). The term 'Palaeometal Epoch' is commonly used in the regional archaeological literature to emphasize the specific character of this period between the second half of the 2nd millennium BCE and the first half of the 1st millennium BCE (Okladnikov and Derevyanko, 1973; Andreeva and Studzitskaya, 1983; Yanshina, 2004; Yanshina and Klyuev, 2005; Tabarev, 2014; Moreva and Dorofeeva, 2020; Popov et al., 2020). Traditionally, the Margaritovskaya, Sinegaiskaya (site Sinii Gai, Fig. 1B), Lidovskaya and Yankovskaya cultures are attributed to the Palaeometal Epoch (e.g. Andreeva and Studzitskaya, 1983; Dyakov, 1989), although more recent archaeological

records provide grounds for revising this traditional scheme of archaeological cultures (e.g. Yanshina, 2004; Belova and Sidorenko, 2020). The cultivation of millet and breeding of pigs in some areas were archaeologically confirmed in the region at that time, although hunting, fishing and gathering remained very important (see Sergusheva and Vostretsov, 2009; Tabarev, 2014; Popov et al., 2020).

In the 1st millennium BCE, Yankovskaya culture sites reveal single iron tools (Andreeva et al., 1986), and at the later stages of this culture (i.e. 5th–3rd centuries BCE), there is evidence for local production of cast iron tools (Klyuev and Gridasova, 2013). Most of the known Yankovskaya culture sites have coastal locations in southern Primorye and show use of marine resources, accompanied by terrestrial hunting and gathering, and millet agriculture, which, at the later stages, is supplemented by cultivation of naked barley (Andreeva et al., 1986; Vostretsov, 2005; Sergusheva and Moreva, 2017).

The Iron Age Krounovskaya culture spread to western Primorye at a late stage of the Yankovskaya culture. Gradually, this cultural complex seems to have moved south and east, reaching the sea coast (Vostretsov, 2005, 2018). In the life of the Krounovskaya culture population, agriculture played a leading role in comparison with animal husbandry, hunting and gathering (Vostretsov, 2005; Sergusheva and Vostretsov, 2009). Botanical remains indicate the cultivation of millet, including *S. italica*, *P. miliaceum* and possibly *E. esculenta*, as well as naked barley, wheat (*Triticum aestivum*), soybean (*Glycine max*) and hemp (*Cannabis sativa*) (Sergusheva and Vostretsov, 2009; Sleptsov et al., 2008; Sergusheva and Moreva, 2017).

The advanced Iron Age Poltsevskaya and Ol'ginskaya cultures are still understudied and their origin and relationships are still debated (Okladnikov and Derevyanko, 1973; Kolomiets, 2005; Yanshina, 2013). They are conventionally dated to the second half of the 1st millennium BCE. However, the Ol'ginskaya culture chronology relies on only a few ^{14}C dates and thus needs to be verified by future studies. The population of this culture was engaged in agriculture, animal husbandry, hunting, fishing and gathering. Archaeological evidence shows an increase in the number of iron tools and metal products (Kolomiets et al., 2002a).

The Early Middle Ages in Primorye are represented by the Mohe culture. This culture was comprised of many ethnic groups belonging to the Tungusic language family, which occupied the Amur River region and the regions north and east of the territories of imperial China, Primorye and the northern part of Korea (Zhushchikhovskaya and Nikitin, 2015; Piskareva et al., 2019). The Mohe tribes formed the basis for the establishment of the Bohai State (698–926 CE), which suggests that the existence of the Mohe culture is either dated to between 300 and 700 CE (pre-state Mohe) (Kradin et al., 2009) or between the fourth and tenth century CE (Zhushchikhovskaya and Nikitin, 2015). The Mohe economy was based on agriculture, animal husbandry and broad exploitation of wild terrestrial and aquatic resources. Millet and barley cultivation was probably small scale during the early phase of the Mohe period and increased in subsequent periods, as documented by archaeobotanical records from archaeological sites in Primorye (Piskareva et al., 2019). Cultural layers of Mohe sites usually contain little archaeological material, including metal artefacts. At later burial sites, the number of weapons made of iron increases (Zhushchikhovskaya and Nikitin, 2015).

4. Materials and methods

To investigate the spread of millet cultivation into the study region we complied a set of 27 ^{14}C dates obtained from samples of charred millet caryopses (Table 2). The dataset consists of 14 published dates complemented by 13 new dates generated in this study. Except for three samples, for which species identification is not provided in the original publication, the dated samples comprise either broomcorn or foxtail millet grains. The dated millet samples originate from cultural layers at 17 different archaeological sites (Table 1) across southern Primorye (Fig. 1), dating to between the Late Neolithic and the Early Middle Ages. Summary information about each site from which directly dated millet grains were obtained is provided in Table 1. Except for those from the

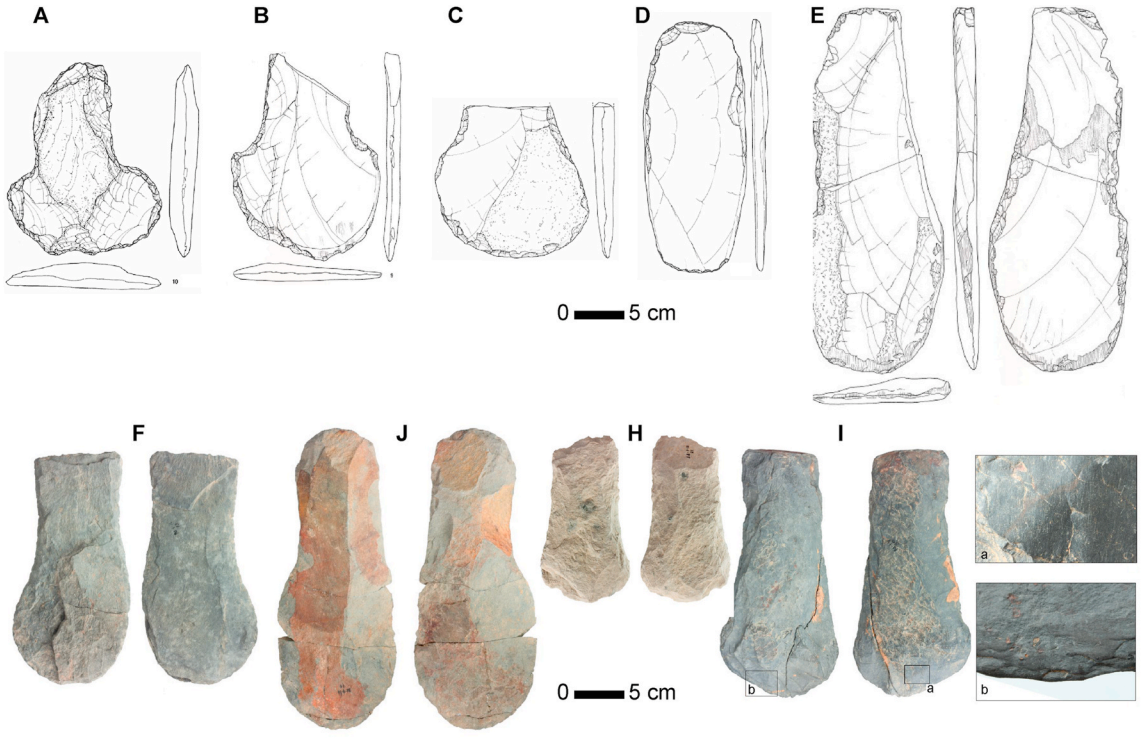

Fig. 2. Examples of well-preserved agricultural tools (stone hoes), which appeared in association with cultivated millet finds at Late Neolithic archaeological sites in southern Primorye: (A–E) from Zaisanovka-7 (Komoto and Obata, 2005); (F–I) from Vodopadnoe-7 (Dorofeeva, pers. comm.). Use-wear analysis of the working surfaces and edges (Ia and Ib) suggested that the traces on the tools correspond to the traces typically left on tools used as hoes.

Table 2
Conventional and calibrated (Reimer et al., 2020) ^{14}C ages of charred millet remains from 17 archaeological sites in the southern Primorye region.

Lab ID	Dated material	Archaeological site	Conventional age (^{14}C BCE/CE)	Calibrated 95% range (BCE/CE)	Reference
Poz-99460	*P. miliaceum*	Gvozdevo-4	2180 ± 35 BCE	2872–2580 BCE	Leipe et al. (2019)
Poz-99527	*P. miliaceum*	Rettikhovka Geologicheskaya-1	1985 ± 30 BCE	2564–2302 BCE	Leipe et al. (2019)
Poz-99525	*P. miliaceum*	Bogolyubovka-1	1975 ± 30 BCE	2557–2297 BCE	Leipe et al. (2019)
Poz-99526	*P. miliaceum*	Vodopadnoe-7	1975 ± 30 BCE	2557–2297 BCE	Leipe et al. (2019)
Poz-96977	*P. miliaceum*	Vodopadnoe-7	1935 ± 35 BCE	2468–2209 BCE	Leipe et al. (2019)
TKa-14081	*P. miliaceum*	Novoselishche-4	1890 ± 35 BCE	2456–2200 BCE	Sergusheva (2008a)
Poz-107963	*P. miliaceum*	Rettikhovka Geologicheskaya-1	1865 ± 35 BCE	2451–2141 BCE	this study
Poz-107964	*S. italica*	Rettikhovka Geologicheskaya-1	1860 ± 50 BCE	2457–2065 BCE	this study
Poz-107961	*P. miliaceum*	Risovoe-4	1750 ± 40 BCE	2203–1961 BCE	this study
Poz-107960	*P. miliaceum*	Risovoe-4	1720 ± 35 BCE	2192–1947 BCE	this study
Poz-108755	*S. italica*	Olga-10	1530 ± 35 BCE	1896–1690 BCE	this study
Poz-107962	*S. italica*	Olga-10	1390 ± 100 BCE	1885–1426 BCE	this study
SNU04-192	millet (undiff.)	Novoselishche-4	1140 ± 50 BCE	1492–1219 BCE	Kuzmin (2013)
TKa-13487	*P. miliaceum*	Novoselishche-4	1065 ± 50 BCE	1411–1116 BCE	Sergusheva and Klyuev (2006)
Poz-99459	*P. miliaceum*	Sheklyaevo-7	995 ± 30 BCE	1260–1048 BCE	Leipe et al. (2019)
Poz-99528	*P. miliaceum*	Anuchino-14	980 ± 30 BCE	1222–1016 BCE	Leipe et al. (2019)
Poz-107958	*P. miliaceum*	Voevoda-2	920 ± 30 BCE	1187–929 BCE	this study
Poz-89805	*P. miliaceum*	Dvoryanka-1	745 ± 30 BCE	902–805 BCE	this study
SOAN-1424	millet (undiff.)	Lidovka-1	585 ± 40 BCE	802–541 BCE	Dyakov (1997)
Poz-107954	*P. miliaceum*	Cherepakha-13	480 ± 50 BCE	756–402 BCE	this study
Poz-107955	*S. italica*	Cherepakha-13	260 ± 30 BCE	377–178 BCE	this study
SOAN-3951	*S. italica*	Glazovka-gorodishche	240 ± 50 BCE	386–103 BCE	Kolomiets et al. (2002b)
Poz-107965	*P. miliaceum*	Malaya Podushechka	230 ± 30 BCE	364–121 BCE	this study
Poz-107956	*P. miliaceum*	Cherepakha-13	170 ± 35 BCE	348–43 BCE	this study
Poz-107957	*P. miliaceum*	Berezovaya-2	400 ± 30 CE	431–587 CE	this study
TKa-13489	*P. miliaceum*	Chernyatino-5	640 ± 45 CE	647–824 CE	Obata (2008)
TKa-13488	*P. miliaceum*	Chernyatino-5	640 ± 50 CE	643–872 CE	Obata (2008)

Malaya Podushechka, Lidovka-1, Chernyatino-5 and Glazovka-gorodishche sites, where the dated seeds were part of a cluster of charred cultivated millet, all dated seeds were obtained by flotation. For conversion of ^{14}C dates to calendar ages we used the online version of OxCal v4.4 (Bronk Ramsey, 1995) and the Intcal20 calibration curve (Reimer et al., 2020).

To discuss Middle Neolithic–Bronze Age population development in the Middle and Lower Yellow River regions and in Northeast China we used a subset of archaeological site data extracted from an existing database (Hosner et al., 2016). This database contains chronological and location information of archaeological sites from the Early Neolithic to the early Iron Age (ca. 8000–500 BCE) covering most regions of China (i.e. 25 Chinese provinces, autonomous regions and municipalities) published in the series 'Atlas of Chinese Cultural Relics' (Hosner et al., 2016). The original dataset with a total of 51,432 archaeological sites is available from the open access data repository PANGAEA (https://pangaea.de/10.1594/PANGAEA.860072). The merits and shortcomings of the data (e.g. less intensive archaeological research in Jilin and Heilongjiang provinces compared to Henan, Shanxi, Shandong and Hebei provinces) as well as quality checks are presented and discussed in the original publications (Hosner et al., 2016; Wagner et al., 2013). Although increased or decreased numbers and densities of archaeological sites are often interpreted in terms of population growth/decline (e.g. Wagner, 2006; Abe et al., 2016; Ma et al., 2016; Leipe et al., 2020; Liu et al., 2021), caution is required in each particular case (Ruddiman et al., 2008). Comparisons of the estimated population figures (e.g. Chen, 1984; Biraben, 2003) with archaeological site numbers at large regional (e.g. Hosner et al., 2016) and provincial (e.g. Zhao et al., 2017) levels, however, show fairly similar trends.

The subset used in the Discussion section of this study represents the Chinese provinces of Shanxi, Henan, Shandong, Hebei, Beijing, Tianjin, Liaoning and Jilin. In addition, we added recently published archaeological site data from Heilongjiang Province (Hosner, 2020) in combination with an up-to-date regional chronology (Leng et al., 2019; Sebillaud et al., 2021). Since the archaeological sites in the compiled datasets covering the period 5000–500 BCE are assigned to one or more

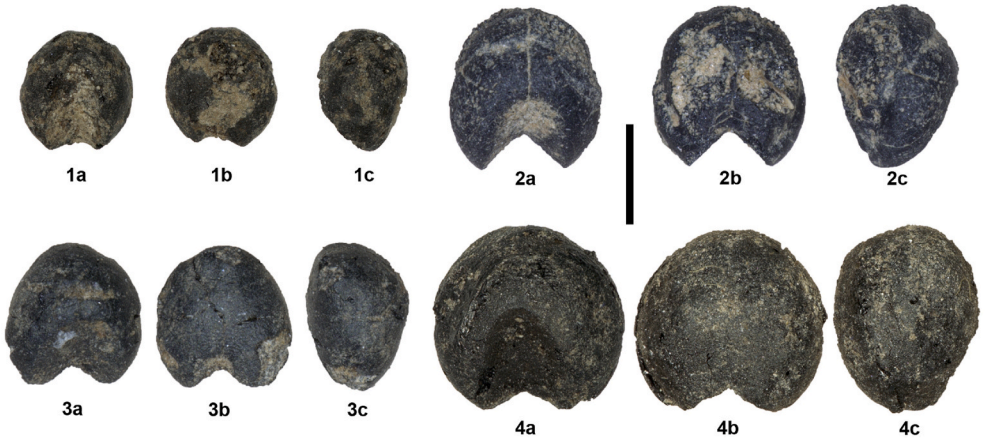

Fig. 3. Selection of carbonised grains of **1** foxtail millet (*Setaria italica*) from Rettikhovka Geologicheskaya-1 (Zaisanovskaya culture) and broomcorn millet (*Panicum miliaceum*) from **2** Vodopadnoe-7 (Zaisanovskaya culture), **3** Sheklyaevo-7 (Early Palaeometal Epoch) and **4** Cherepakha-13 (Yankovskaya culture) in ventral (**a**), dorsal (**b**) and lateral (**c**) view; scale bar = 1 mm. See Fig. 1B for site locations.

well-dated cultural periods, they may represent different time ranges. Therefore, we temporally normalized the site data eliminating the influence of the length of the defined cultural periods by presenting the site numbers by time intervals of equal length, which we randomly set to 100 years. To further enhance comparability, we also normalized the site data on the spatial scale and present it by an equal area unit of 10^4 square kilometres (km^2).

5. Results

The calibrated age ranges (given as 95% probabilities unless otherwise stated) of all 27 ^{14}C dates in the compiled millet dataset span between 2872 BCE and 872 CE (Fig. 3, Table 2). The oldest millet sample dated to 2872–2580 BCE comes from Gvozdevo-4 located at the southern end of Primorye close to the mouth of the Tumen (Tumannaya) River (Fig. 1B). The calibrated ages of the remaining nine dates representing Zaisanovskaya cultural layers cluster (2564–1947 BCE) and originate from the sites Rettikhovka Geologicheskaya-1, Bogolyubovka-1, Vodopadnoe-7, Novoselishche-4 and Risovoe-4 (Table 1) located on the fertile plains and in the river valleys south of Khanka Lake (Fig. 1B). On the coastal plains east of the Sikhote-Alin the oldest millet dates (1896–1426 BCE) are associated with the Early Palaeometal Epoch (Margaritovskaya culture) layers at Olga-10. Altogether twelve dates associated with the regional Palaeometal and Iron Age cultures (Lidovskaya, Yankovskaya, Krounovskaya, Poltsevskaya) have calibrated ages that range between 1492 and 43 BCE. While most archaeological sites from which these millet samples were recovered are located on the plains between Khanka Lake and the Sea of Japan, SOAN-

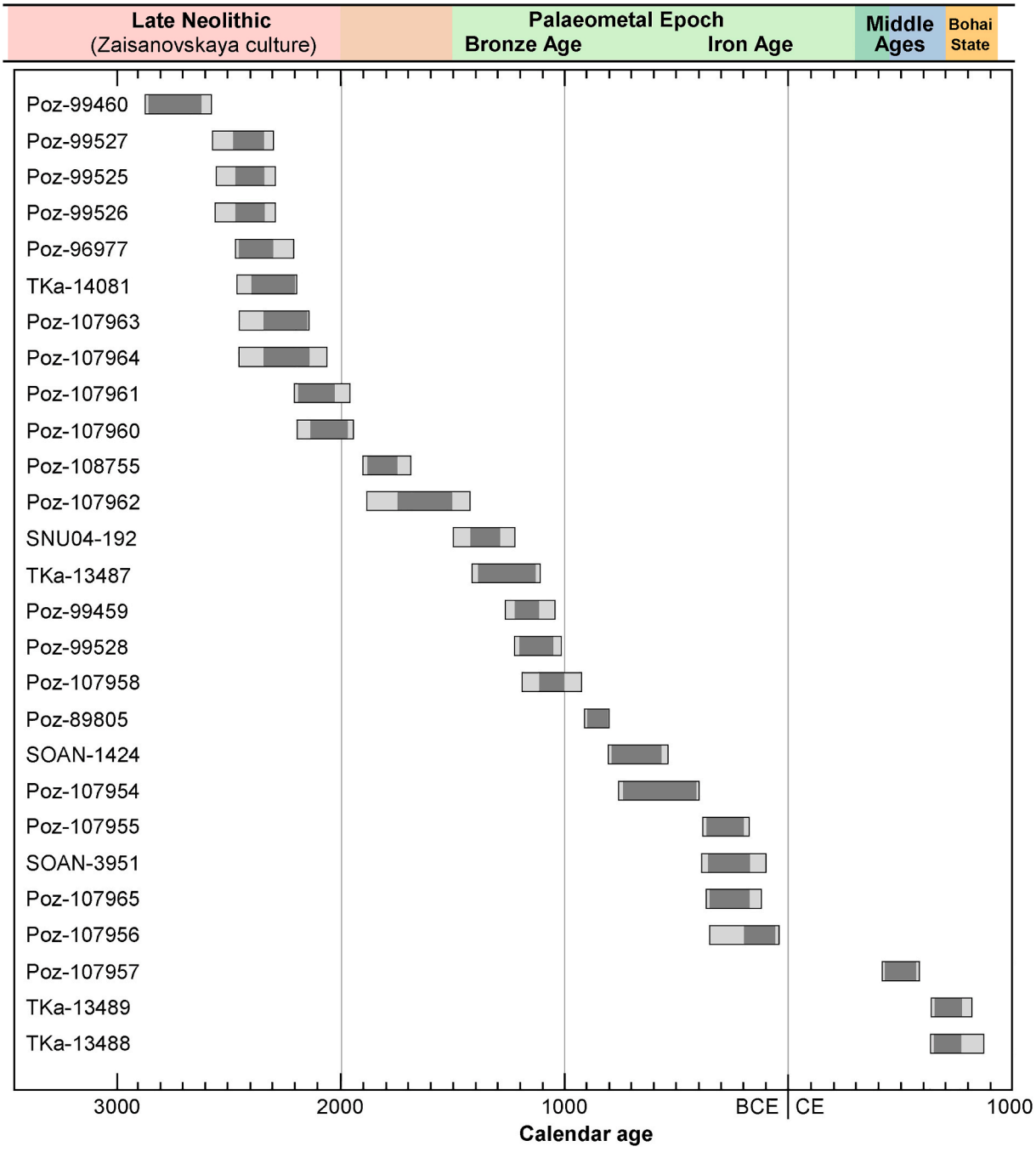

Fig. 4. Probability densities at 95% (light grey bars) and 68% (dark grey bars) confidence levels of calibrated ^{14}C ages of the 27 charred millet remains (Table 2) from archaeological sites in southern Primorye. Conventional archaeological chronological units mentioned in the text are added for convenience.

1424 (802–541 BCE) originates from Lidovka-1 on the Sea of Japan coast and SOAN-3951 (386–103 BCE) from Glazovka-gorodishche about 50 km northeast of Khanka Lake. The Middle Ages are represented in the dataset by three dates with calibrated ages between 431 and 872 CE associated with the Mohe culture (Poz-107957) and the Mohe culture/Bohai state transitional phase (TKa-13488, TKa-13489).

6. Interpretation and discussion

6.1. Timing and routes of millet spread to Primorye

Earlier archaeological and archaeobotanical research in southern Primorye aimed to obtain a representative estimate for the arrival of millet cultivation and put emphasis on archaeological assemblages with millet coming from the oldest layers associated with the Zaisanovskaya culture period. Thus, 37% of the dates in our dataset also correspond to this period (Fig. 4). Previous studies (Komoto and Obata, 2004; Sergusheva and Vostretsov, 2009; Kuzmin, 2013; Miyamoto, 2014; Li et al., 2020) have linked the millet finds from the Krounovka-1 site (Fig. 1B) to the initial appearance of millet cultivation in southern Primorye. These studies associated the recorded millet grains with two AMS dates on wood charcoal (Komoto and Obata, 2004) from the same cultural layer dating to 3521–3370 BCE (NUTA2-5643: 2721 ± 31 ^{14}C BCE) and 3521–3356 BCE (Beta-171,662: 2690 ± 40 ^{14}C BCE) (Fig. 5), which predates the oldest direct millet date 2872–2580 BCE from Gvozdevo-4 (Poz-99460) by at least ca. 500 years. However, using Bayesian modelling based on a subset of the millet-based ^{14}C dates from southern Primorye ($n = 12$) compiled in the current study and one date from the Chinese Heilongjiang Province (Fig. 1A), Leipe et al. (2019) estimated the arrival of millet cultivation in the study region ca. 3700 BCE (lower limit of the 95% probability range). To fill the spatio-temporal gap between the Krounovka-1 and Gvozdevo-4 and to find other millet sites dating to between the late 4th and early 3rd millennium BCE remains an important task for archaeologists working in the region.

The compilation of direct ^{14}C dates reflects a spatio-temporal pattern of millet cultivation spread across Primorye (Figs. 1B and 4) between the early 3rd millennium BCE and early 2nd millennium BCE. Millet presence in the south-western part of the region is indicated by the date Poz-99460 from Gvozdevo-4. Millet cultivation is further supported by tools, such as hand ploughs, hoes and reaping knives, a number of broomcorn millet seed impressions on a pot sherd found at Zaisanovka-7 (Sergusheva and Vostretsov, 2009) located a few kilometres west of Gvozdevo-4 (Fig. 1B) and by foxtail millet remains found at the nearby Zaisanovka-1 site. Dates of organic remains from the site range between ca. 2850 and 2450 ^{14}C BCE (Sergusheva and Vostretsov, 2009), which corresponds to the calendar age interval ca. 3600–2900 BCE and thus

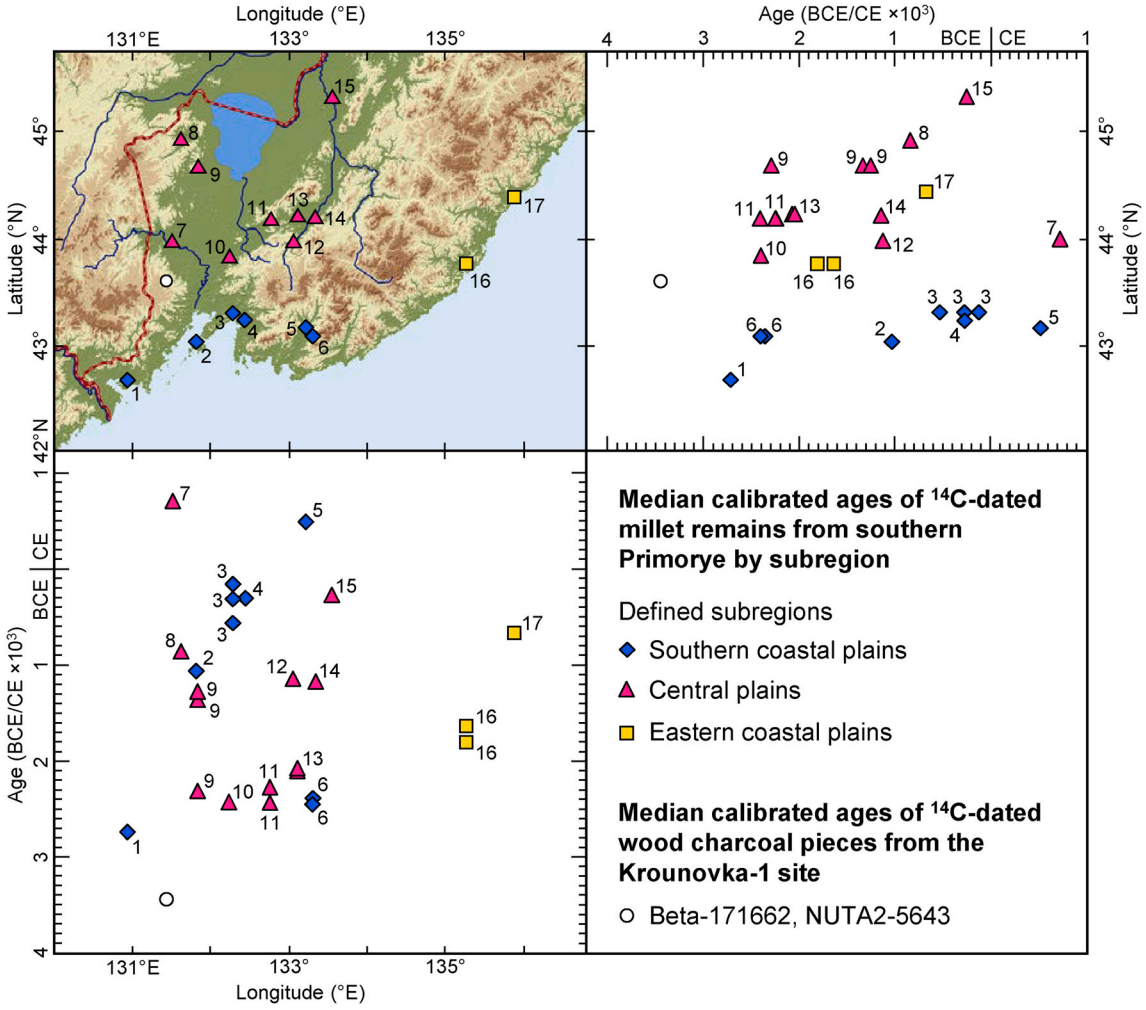

Fig. 5. Spatio-temporal distribution of 27 directly dated foxtail and broomcorn millet remains from southern Primorye by subregion including longitudinal and latitudinal distributions of calibrated median ages and the locations of the associated archaeological sites comprising 1 – Gvozdevo-4, 2 – Voevoda-2, 3 – Cherepakha-13, 4 – Malaya Podushechka, 5 – Berezovaya-2, 6 – Vodopadnoe-7, 7 – Chernyatino-5, 8 – Dvoryanka-1, 9 – Novoselishche-4, 10 – Bogolyubovka-1, 11 – Rettikhovka Geologicheskaya-1, 12 – Anuchino-14, 13 – Risovoe-4, 14 – Sheklyaevo-7, 15 – Glazovka-gorodishche, 16 – Olga-10 and 17 – Lidovka-1 (see Table 1 for further site information).

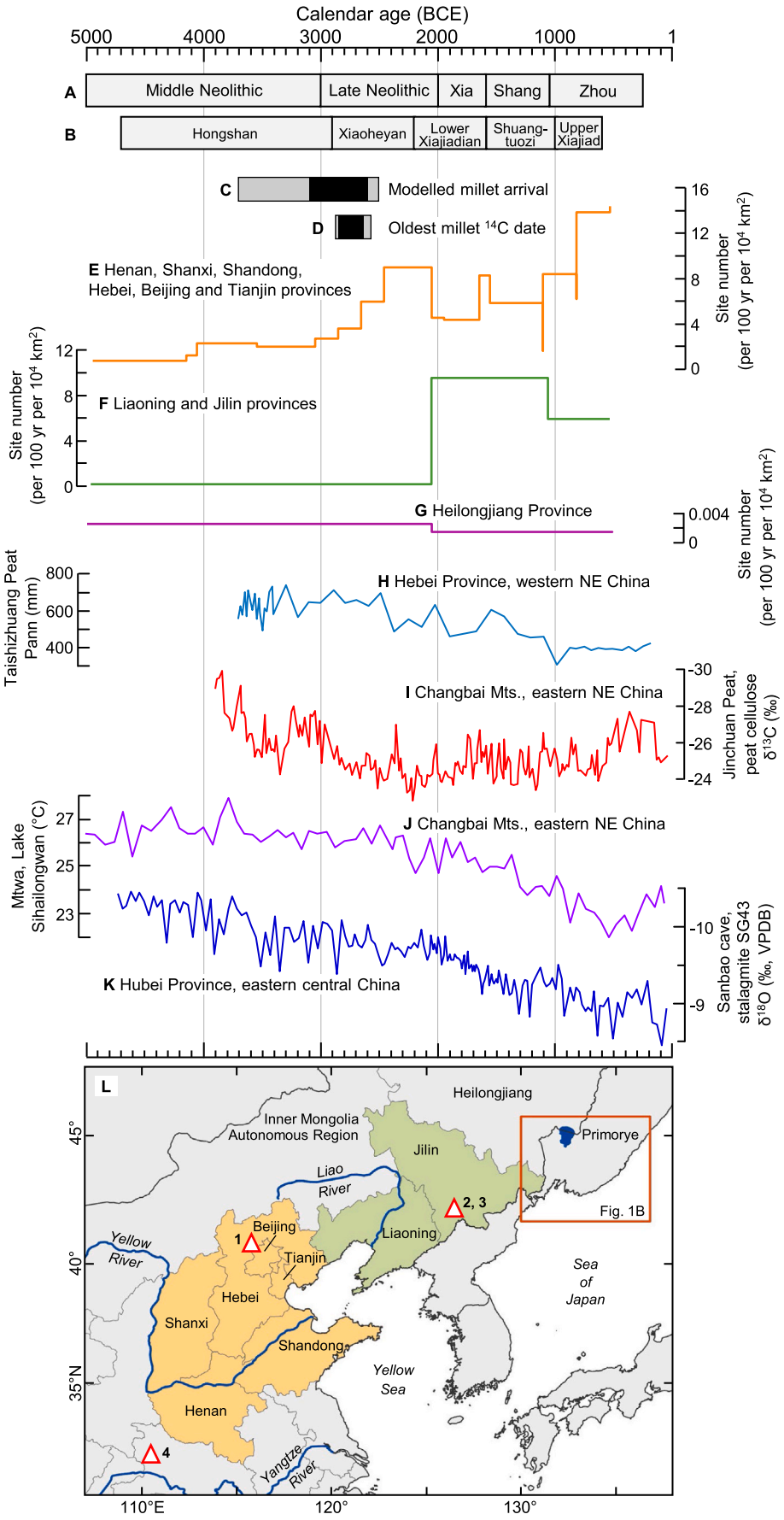

Fig. 6. Figure and map compilation showing (A) the periodisation for the Chinese cultural core region along the Middle and Lower Yellow River and (B) the Liao River regions (after Liu and Chen, 2012; Wagner, 2006); (C) the 95% (light grey bar) and 68% (black bar) confidence intervals of the modelled arrival of millet cultivation to the Primorye region (Leipe et al., 2019) and (D) of the calibrated age of the oldest available direct millet ^{14}C date from this region; the site numbers per century per 10^4 km^2 for (E) Henan, Shanxi, Shandong, Hebei, Beijing and Tianjin provinces, (F) Liaoning and Jilin provinces (Hosner et al., 2016) and (G) Heilongjiang Province (Hosner, 2020); (H) the pollen-based reconstruction of annual precipitation for the Taishizhuang Peat section in northern Hebei Province, Northeast China (Tarasov et al., 2006); (I) the peat cellulose δ^{18}O record from the Jinchuan Peat, Changbai Mountains, Northeast China (Hong et al., 2001); (J) the pollen-based reconstruction of the mean temperature of the warmest month (Mtwa) for a sediment core from the Sihailongwan Maar Lake, Changbai Mountains, Northeast China (Stebich et al., 2015); (K) the δ^{18}O record of stalagmite SG43 from the Sanbao cave in western Hubei Province, eastern central China (Dong et al., 2010); and (L) an overview map showing the locations of provinces with archaeological site data plotted in E (highlighted in orange) and F (highlighted in green) and palaeoenvironmental records in H–K (triangles), including 1 – the Taishizhuang Peat section, 2 – the Jinchuan Peat, 3 – the Sihailongwan Maar Lake, 4 – the Sanbao cave. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

agrees with the arrival of millet cultivation suggested by Bayesian modelling (Leipe et al., 2019). Millet dispersal to the plains and river valleys between Khanka Lake and the Sea of Japan is documented at several different sites dating two to five centuries later. After millet cultivation was well established across these fertile areas, it likely spread to the more remote Sea of Japan coastal region east of the Sikhote-Alin mountain range, as suggested by the oldest directly dated millet assemblages (Poz-108755, Poz-107962) from this region recorded at the Margaritovskaya culture site Olga-10.

Another inference which may be drawn from the ^{14}C dataset is that millet was continuously cultivated in southern Primorye during the discussed period. Although several new crops, such as naked barley and probably soy bean were introduced at the end of the Yankovskaya culture period, cultivation of wheat, barnyard millet and hemp was adopted during the Krounovskaya culture period and the spectrum of cultivars further diversified with the arrival of hulled barley (*Hordeum vulgare* var. *vulgare*), buckwheat (*Fagopyrum esculentum*), perilla (*Perilla frutescens*) and pea (*Pisum sativum*) after the region became part of the Bohai, Liao and Jin states at the end of the 1st millennium CE to the beginning of the 2nd millennium CE (Sergusheva and Vostretsov, 2009), millet cultivation remained an important part of the food economy in the study region (Sergusheva, 2014; Kradin, 2018).

It is more difficult to discern from where and by whom broomcorn and foxtail millet were introduced to Primorye. Both crops originate in the crescent around the Bohai Sea (Fig. 1A). The first convincing evidence of millet cultivation obtained from cultural layers in different parts of the Lower Yellow River and Liao River regions (e.g. Jones and Liu, 2009; Cohen, 2011; Zhao, 2011; Liu and Chen, 2012. Leipe et al., 2019) is directly dated to ca. 6000–5700 BCE, although domestication may have begun ca. 7000 BCE (Stevens et al., 2021) or even as early as 8000–10,000 BCE (Lu et al., 2009; Yang et al., 2012). From these regions in eastern China, millet started to spread discontinuously, arriving to the Middle Yellow River region by around 5000–4400 BCE and to the southern Korean Peninsula between 4500 and 3300 BCE (95% probability range) (Leipe et al., 2019). While a number of archaeobotanical records and direct ^{14}C dates of millet remains are available from South Korea (e.g. Lee, 2017) and southern Primorye (Table 2 and references therein), large parts of the neighbouring territories, including North Korea and most of Northeast China remain poorly studied (Fig. 1A). This lack of information calls into question reconstructions of millet dispersal routes to southern Primorye (e.g. Li et al., 2020 and references therein).

Two different primary routes have been suggested: along the Tumen river Yan (1993), Fig. 1A) and via inland routes crossing Jilin and Heilongjiang provinces leading to the Suifen River valley (Vostretsov, 2005; Kuzmin, 2013; Miyamoto, 2014). Based on historical linguistics, archaeological data and ^{14}C dates, Li et al. (2020) reviewed both previously suggested routes and conclude that the crops arrived via the latter route to Primorye. Since the eastern parts of Jilin and Heilongjiang provinces are mountainous, this would imply that millet spread to southern Primorye most likely northeastward along the Mudanjiang River and then further eastward along the Muling River (Fig. 1A). An alternative route runs northeastward along the Songhua (Sungari) River and then continues southeastward along the Woken River (Fig. 1A).

The early evidence for millet cultivation at the southern end of Primorye may support Yan (1993), who hypothesised immigration along the Yalu and Tumen rivers (Fig. 1A). Both Gvozdevo-4, Zaisanovka-7 and Zaisanovka-1 are located close to the mouth of the Tumen River which, together with the Yalu River, forms a more or less direct and continuous connection route to the Liaodong Peninsula and southern Manchuria crossing the Changbai Mountains. The Liaodong Peninsula was a hub for cultural exchange connecting the Shandong Peninsula and the Yellow River region with the regions north of the Bohai Sea and the Korean Peninsula (Wagner, 2006; Jia, 2007; Liu and Chen, 2012). The earliest directly dated evidence for millet from the Liaodong Peninsula is relatively young. Undifferentiated millet grains from the Guojiacun archaeological site in Dalian City date to 2866–2211 BCE (ZK-0415: 2040 ± 90 ^{14}C BCE) (Institute of Archaeology of the Chinese Academy of Social Sciences, 1991), which is in line with Liu and Chen (2012), who note that millet remains and harvesting tools appear in the region around 3000 BCE. In a more recent study (Ma et al., 2015) broomcorn and foxtail millet seeds were found in cultural layers of the Wangjiacun site (Dalian City) associated with phase III (4500–3300 BCE) of the Xiaozhushan culture period. In addition, elements of the Xiaozhushan material culture are present in records of different Neolithic cultures located north and northeast of the Liaodong Peninsula, including the Zaisanovskaya culture (Jia, 2007). Archaeological sites very similar to those of the Khasansky variant of the Zaisanovskaya culture have been found in the middle reaches of the Tumen River (Moreva et al., 2009). In sum, these findings show the most direct route along the Yalu and Tumen rivers should be also considered in future studies.

A third possible route of millet spread is from the Korean Peninsula northeastward along the Sea of Japan coast. Looking at the spatio-temporal distribution of the millet ^{14}C dates across southern Primorye (Fig. 5), this route seems least plausible. Most of the evidence for millet cultivation from South Korea during the late phase of the Neolithic Early Chulmun period (6000–3500 BCE) comes from archaeological sites along the coastline. This reflects that Early Chulmun populations with a complex hunting-fishing-gathering subsistence supplemented by low-level food production and millet cultivation was marine-oriented and closely tied to coastal environments (Lee, 2017), which especially applies to groups on the east coast (Lim, 2008). The number of sites located further inland started to increase from 3500 BCE during the Middle Chulmun period (3500–3000/2700 BCE), which was paralleled by enhancing millet cultivation (Lee, 2017). If Chulmun populations brought millet to Primorye then they would likely have preferred to settle along the Sea of Japan coastline. However, our millet dataset shows that millet cultivation spread across the more fertile inland regions (Fig. 5) before it continued to disperse northeastward along the coast. Future archaeobotanical research in Northeast China and neighbouring regions will provide further direct evidence for the origin and directions of northeastward millet dispersal and allow evaluation of the outlined hypotheses.

Recent studies on ancient genomes have contributed significantly to a better understanding of the Holocene prehistory and, in particular, of human migrations and spread of agriculture in different regions of Eurasia. However, palaeogenetic studies from the Primorye region are rare (Siska et al., 2017; Wang et al., 2021) and are severely hampered by the regional acidic soils that cause extremely poor preservation of organic remains (Tabarev, 2014). Anthropological material from Zaisanovskaya cultural layers is not yet available (Wang et al., 2021).

For the same reason, isotopic data from Primorye is absent in a comprehensive review of the Late Neolithic/Bronze Age radiation of millet consumption in China and Eurasia (Wang et al., 2019). This isotopic survey finds that significant dietary interconnectivity occurred between north China, Central Asia and Siberia during the 2nd millennium BCE and argues that C_4 signatures of millet consumption may reflect migrations and/or resource transfers between the Bronze Age inhabitants of China and Europe. The stable isotope composition of bone collagen of 11 humans from the coastal site Cherepakha-13 (Fig. 1) demonstrates relatively high δ^{13}C values, which led to the conclusion that the population of this site consumed a certain amount of millet (Kuzmin et al., 2018). The data agrees with the presence of the two millet crops in the Yankovskaya culture layers of Cherepakha-13.

6.2. Driving forces of millet spread to Primorye

Together, population estimates based on archaeological site data for prehistoric China (Wagner et al., 2013; Hosner et al., 2016) and direct millet ^{14}C dates and their probability distributions (Leipe et al., 2019) suggest that the spread of millet to southern Primorye is connected to a continuous exponential population growth in regions dominated by millet-based agriculture. While during the 4th millennium BCE site

numbers in the Middle and Lower Yellow River region (east of 110°E) were still at relatively low levels, they started to accelerate during the first half of the 3rd millennium BCE (Fig. 6E) when millet cultivation begun to spread to the southernmost part of Primorye, i.e. the coastal plains northeast of the mouth of the Tumen. During the second half of the 3rd millennium BCE, site numbers further increased in the Lower Yellow River region. At the same time, more sites with millet agriculture appeared across the Khanka-Ussuri Plain, the most suitable area for agriculture in southern Primorye. This is also coeval with developments on the Korean Peninsula where millet cultivation increased during the Middle Chulmun period (Lee, 2017), although a mixed foraging-farming subsistence persisted there until the onset of the Bronze Age (ca. 1500 BCE) when full-scale agriculture and a substantial population increase have been reconstructed (Ahn and Hwang, 2015; Oh et al., 2017). This population growth in the two agricultural areas southwest of our study region could have been a reason for immigration of the new culture groups to Primorye as seen in the archaeological data from Zaisanovskaya culture sites.

The cultural developments in the wider Yellow River region are best exemplified by trends in the historical Haidai Region centred over modern Shandong Province. According to the 'Atlas of Chinese Cultural Relics' (Hosner et al., 2016; Wagner et al., 2013), archaeological site numbers in Shandong Province are marked by an unprecedented increase from ca. 3 to 13 sites per century per 10^4 km^2 at 2600 BCE. This high level of site numbers was interrupted by a drop at 2000 BCE and then continued to rise from 1700 BCE until the middle 1st millennium BCE. A recent Bayesian modelling study (Long et al., 2017) based on available radiometric dating evidence re-evaluated the existing chronology for the Haidai Region mainly based on pottery typology and archaeological site stratigraphy. The results demonstrate that the pronounced site increase during the 3rd millennium BCE was apparently linked to the presence of artefacts assigned to three different cultures (Late Dawenkou, Longshan and Yueshi cultures) that, according to conventional stratigraphy, followed each other in the region. The model results suggest that the simultaneous existence of these three cultural complexes started ca. 2800 BCE or even earlier.

However, the cultural developments in North and Northeast China during 4th and 3rd millennia BCE were highly dynamic and new discoveries are changing the picture rapidly. Closer to Primorye than the Haidai and Lower Yellow River regions, the western Liao River region in the south-eastern part of modern Inner Mongolia Autonomous Region and western part of Liaoning Province was the core area of the Hongshan culture (ca. 4700–2900 BCE). Since their discovery, the monumental burial complexes and ritual sites have been interpreted as witnesses to a highly complex agrarian society (Li, 2008) and the five-fold increase in the number of sites compared to the period before seems to confirm this (Liu and Chen, 2012). But with 0.2 sites per century per 10^4 km^2 (Hosner et al., 2016) numbers for the area are, in general, low. Currently it is assumed that the Hongshan society was based on broad-spectrum and regionally diversified subsistence strategies, including millet cultivation. The collapse of Hongshan around 3000 BCE could be another source of migration of millet farmers into the Primorye area.

A first notable (50-fold) increase in site numbers in the Liaoning and Jilin provinces from 0.2 to 9.5 sites per century per 10^4 km^2 (Fig. 6F) is only documented as late as at 2000 BCE, which is associated with the establishment of the Bronze Age Lower Xiajiadian culture (2200–1600 BCE) in the western Liao River region. For Heilongjiang Province, the site data show even lower site numbers during the Bronze Age compared to the Neolithic (Fig. 6G). If we consider that farmers from the Liao River region were involved in the spread of millet to Primorye, this would suggest that it was not primarily linked to increased population concentration in the Liao River region, but to other factors.

A climate shift to cooler and drier conditions less favourable for agriculture is often identified as the main driver of Late Neolithic cultural decline in northern China, such as that of the Hongshan (Liu and Chen, 2012 and references therein). Advancing agropastoralists from the Eurasian steppe introducing West Asian cultural elements (livestock, crops and technologies) to northern China during the Late Neolithic (Anthony, 2007; Warburton, 2011; Allentoft et al., 2015; Hosner et al., 2016; Leipe et al., 2019) triggered tension and conflicts between the newcomers and indigenous farmers. Evidence for unrest and instability is provided by fortifications that appeared during the 3rd millennium BCE in the Ordos region (Liu, 2004) and in the Liao River region during the early 2nd millennium BCE, where they mark the rise of the Lower Xiajiadian culture (Tian, 1993).

Primorye has probably experienced the aftermath of these economic upheavals in the Yellow River region, the ousting of millet farmers and massive immigration to Northeast China. Although the archaeological site numbers documented in the Liaoning and Jilin provinces remain unchanged around the turn of the 4th and 3rd millennium BCE (Fig. 6F), the decline of Neolithic sites in the Heilongjiang Province at 3200 BCE may indicate competition for natural resources with immigrating agropastoralists (Fig. 6G). This scenario would not rule out the involvement of climate change in these processes. It is possible that the continuous long-term decrease in summer monsoon intensity during the middle to late Holocene, which became most pronounced after 2000 BCE (Wang et al., 2005; Dong et al., 2010, Fig. 6K), also recorded in Northeast China (Hong et al., 2001, Fig. 6I; Stebich et al., 2015, Fig. 6J; Tarasov et al., 2006, Fig. 6H) had a negative impact on the grazing grounds in the Eurasian steppe not only since the 3rd millennium BCE (Leipe et al., 2020) but already during the 4th millennium BCE, which started to push steppe agropastoralists towards moister, more productive regions in the southeast occupied by millet farming societies. We hope that the presented discussion will stimulate further research into the direction of the driving forces for the spread of millet cultivation to southern Primorye. To date, neither archaeological nor environmental data from the wider study region is sufficient to resolve this question.

7. Conclusions

Directly dated archaeobotanical records of millet presented in the current paper provide the most robust evidence for the cultivation of this crop between the early 3rd millennium BCE and the late 1st millennium CE. This directly dated millet dataset complements the available unambiguous evidence for an earlier appearance of the crop in Primorye during the 4th millennium BCE. When the first cereal crops, namely broomcorn and foxtail millet, arrived to southern Primorye they had been cultivated as staples by Neolithic societies in northern China already for several millennia. The millet-based ^{14}C dates employed in this study suggest that the crops arrived first in the southernmost part of the study region in the first half of the 3rd millennium BCE during the Late Neolithic Zaisanovskaya period and subsequently spread stepwise to the north and northeast of southern Primorye. Archaeological records show that the appearance of millet was accompanied by a clear change in cultural traditions, suggesting that the crops were part of a 'cultural package' brought by the immigrating population. Although the existing hunter-fisher-gatherer subsistence economy was broadened by the incorporation of millet cultivation, the regional population did not shift to full-scale agriculture until the 1st millennium CE.

In combination with archaeological records and archaeological site data from Chinese provinces, the spatio-temporal distribution of millet dates enables us to discuss likely dispersal routes into the study region and a number of possible drivers, including socio-political instability and climate change. The scarcity of robustly dated archaeological and archaeobotanical records from Northeast China and Korea needs to be addressed in future studies to reconstruct the spatio-temporal patterns of migration and crop dispersal and their underlying driving factors.

Author contributions

Conceptualisation, E.A.S., P.E.T., C.L., M.W.; Material and data collection, E.A.S., C.L., N.A.K., S.V.B., A.V.G., N.A.D., S.A.K., E.B.K., S.S.

M., O.L.M., I.Y.S., D.H., M.W., P.E.T.; Methodology, E.A.S., P.E.T., C.L.; Analysis, E.A.S., P.E.T., C.L.; Writing (original draft), E.A.S., P.E.T., C.L.; Writing (review and editing), E.A.S., C.L., N.A.K., S.V.B., A.V.G., N.A.D., S.A.K., E.B.K., S.S.M., O.L.M., I.Y.S., D.H., M.W., P.E.T.; Visualization, E.A.S., C.L., N.A.K., S.V.B., A.V.G., N.A.D., S.A.K., E.B.K., S.S.M., O.L.M., I.Y.S., P.E.T.

Data availability

All data used to support the findings of this study are available in the paper.

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.

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Appendix A. Supplementary data

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