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# Timing and cultural-environmental context of the spread of barley to and within northern East Asia

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ABSTRACT

While the introduction of wheat into early full-scale farming systems of northern China has received much research attention over the past two decades, few studies have looked at when and how the cultivation of barley, which is better adapted to colder climates, spread across East Asia. New radiocarbon ($^{14}C$) dates obtained from archaeological barley grains together with material evidence suggest that the crop was introduced to Primorye (Russia's border region with China and North Korea) no later than the 2nd century BCE, although an earlier arrival sometime between the 4th and 3rd centuries BCE seems possible. From Primorye, the crop probably spread further eastward to Hokkaido. The combined archaeological and chronological evidence suggests that barley-cultivating cultural groups may have migrated to southern Primorye from areas to the west or from southern Liaoning/north-western Korea, which rules out a dispersal via the northern Eurasian steppes or the Japanese archipelago. We propose that a combination of cultural and climatic factors was the driving force behind this migration. While we identify the eastward expansion of the Warring State of Yan around 300 BCE as the primary driver that pushed barley-cultivating populations to migrate, it seems possible that long-term cooling and drying less favourable for farming during 1000–300 BCE added to the political unrest at the northern and eastern boundaries of the Chinese Warring States, or may even have amplified their policies of territorial expansion.

## 1. Introduction

The spread of the West Asian domesticates wheat (*Triticum* spp.) and barley (*Hordeum vulgare*) into eastern Eurasia was a long-term process and had strong influence on existing subsistence economies and agricultural systems (Deng et al., 2020; Leipe et al., 2017; Li and Dong, 2018; Long et al., 2018; Sergusheva and Vostretsov, 2009; Tang et al., 2021). Although huge progress has been made in understanding early agricultural trajectories, it is still difficult to assess differences and commonalities in the spread of both crops across this vast region. While wheat and barley appear together in many archaeobotanical records from eastern Eurasia (Lister et al., 2018) and some scholars analysed their spread on the assumption that they were largely synchronous (Stevens et al., 2016), other studies postulated that their dispersal was distinct (Liu et al., 2017). Studies on the eastward spread (including timing and routes) of West Asian crops have mainly focused on China and are strongly biased towards wheat (e.g., Barton and An, 2014; Betts et al., 2014; Chen et al., 2020; Dodson et al., 2013; Flad et al., 2010; Long et al., 2018; Stevens et al., 2016), which is partly due to the fact that in northern China the cultigen had already become a staple by the second half of the 1st millennium CE (Zhou and Garvie-Lok, 2015) and later rose to equal or greater importance compared to the indigenous foxtail (*Setaria italica*) and broomcorn (*Panicum miliaceum*) millets (Lu et al., 2019).

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Bayesian chronological modelling of wheat-based $^{14}$C dates (Long et al., 2018) suggests that the crop first arrived in the lower Yellow River (2800–2300 BCE) and then in its upper (2000–1800 BCE) and middle (1700–1550 BCE, each period given as 68.3 % probability ranges) reaches. While in the highlands of the upper Yellow River, the earliest directly dated evidence of barley cultivation (2140–1960 BCE) from the Xiasunjiazhai archaeological site (Liu et al., 2017; Fig. 1a) corresponds with that of wheat, the oldest dated barley grain (900–790 BCE) from the lowlands of the lower Yellow River from the Zhaogezhuang archaeological site (Liu et al., 2017; Fig. 1b) postdates the modelled wheat arrival by up to two millennia (Liu et al., 2017; Long et al., 2018). This suggests that, among others, climatic conditions could have been an important factor determining the spread of barley. Being more cold-tolerant than other cereal crops (Ullrich, 2014), barley was likely preferred at higher altitudes and latitudes. A representative example is the spread of agriculture onto the Tibetan-Plateau, which was particularly promoted by the cultivation of barley (Ma et al., 2022; Tang et al., 2021) and enabled permanent human settlement of this harsh, high-altitude environment (Chen et al., 2015).

Despite the differences in the spatiotemporal pattern of early barley

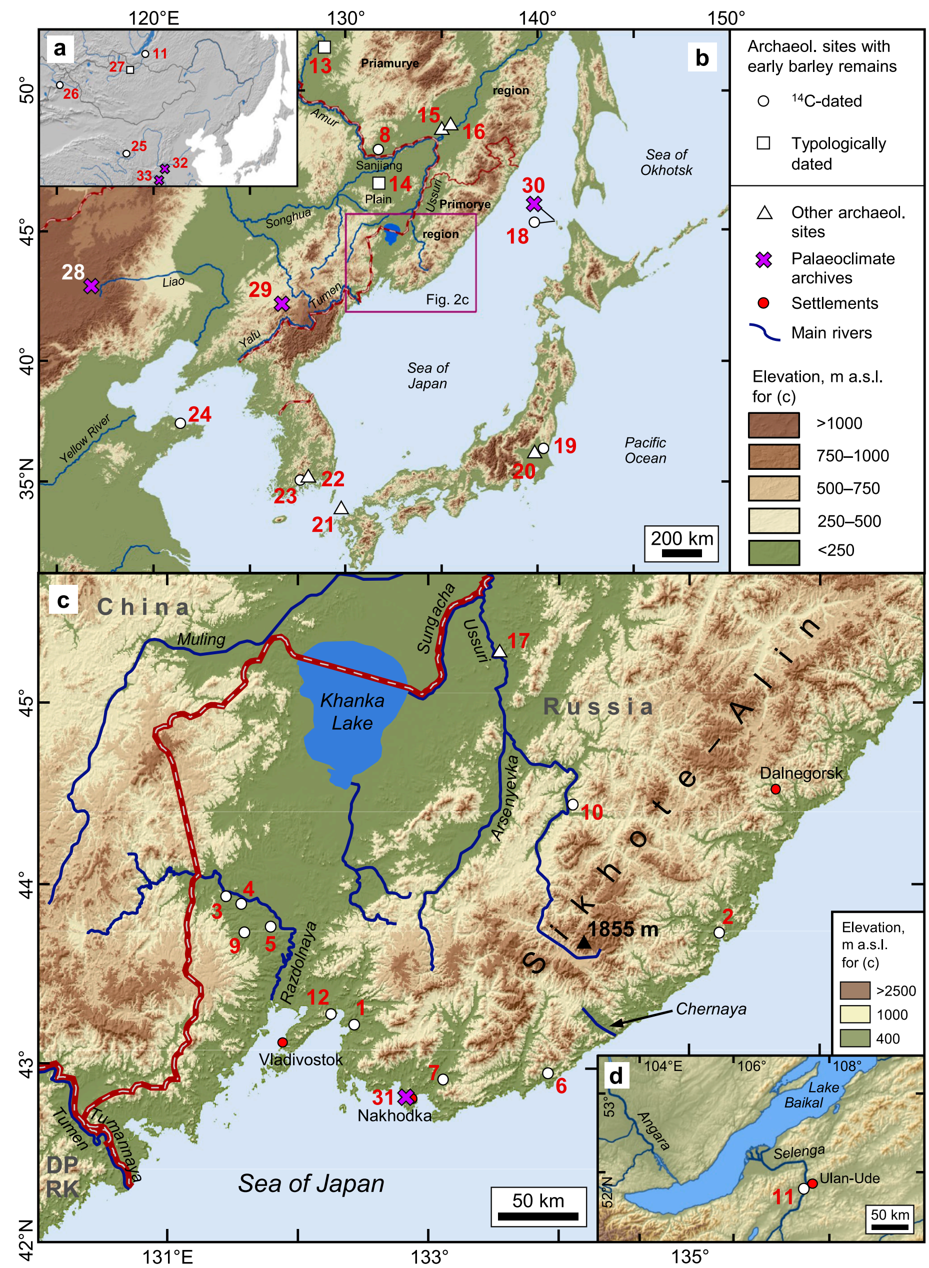


Fig. 1. Map compilation showing (a) part of northern East Asia and detailed maps of (b) the Priamurye and Primorye regions, (c) southern Primorye and (d) southern Trans-Baikal with archaeological sites with directly AMS $^{14}$C-dated naked barley grains obtained in this study (white circles, nos. 1–11, Table 1) together with other directly and non-directly dated (white squares) early barley records and archaeological sites (white triangles) as well as locations of palaeoclimate proxy records (purple crosses) mentioned in the discussion. Sites are numbered as follows: 1 – Malaya Podushechka; 2 – Sinie Skaly; 3 – Chernyatino; 4 – Sinel'nikovo-1 fortified settlement; 5 – Borisovka-3; 6 – Shelomaev Klyuch; 7 – Zolotaya Dolina-2; 8 – Osinovoe Ozero; 9 – Abrikosovskoe settlement; 10 – Koksharovskoe-1 walled town; 11 – Ivolga; 12 – Cherepakha-13; 13 – Chernigovka-5; 14 – Fenglin; 15 – Amursky Sanatorium; 16 – Petropavlovka-5; 17 – Glazovka-gorodishche; 18 – Hamanaka-2; 19 – Funakuba; 20 – Takeda Ishidake; 21 – Karakami; 22 – Pyeonggeodong; 23 – Sangchon B; 24 – Zhaogezhuang; 25 – Xiasunjiazhai; 26 – Tongtian Cave; 27 – Egiin Gol; 28 – Dali Lake; 29 – Sihailongwan Maar Lake; 30 – Kushu Lake; 31 – Gniloe Lake; 32 – Dongshiya Cave, 33 – Sanbao Cave. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and wheat cultivation, the study by Liu et al. (2017), considering exclusively China, remains the only one, which has addressed in particular the eastward dispersal of barley based on directly dated archaeobotanical remains. Another approach was taken by Lister et al. (2018), who analysed genetic data of accessions of extant landraces to investigate barley cultivation spread across Eurasia. As already suggested for wheat (e.g., Barton and An, 2014; Dodson et al., 2013; Zhao, 2009), the same authors outline evidence for the northern Eurasian steppe as a possible dispersal route for barley to East Asia. Although archaeobotanical studies indicate that barley could have played an important role in mixed subsistence economies and early cropping systems at the northern limits of early agricultural East Asia (Leipe et al., 2017, 2018; Sergusheva, 2019; Sergusheva and Vostretsov, 2009; Yamada, 1995), this has not been attested and it is still unclear when and how the crop appeared and spread in these regions, which is partly due to the limited number of archaeobotanical records available. This also applies to regions east of the Yellow River, including the Liao River region, the Korean Peninsula and the Japanese archipelago (Fig. 1b), where macrobotanical evidence for the earliest barley cultivation remains scarce (Endo and Leipe, 2022; Lee, 2017; Shoda et al., 2021).

A comparatively well-studied region in terms of early agricultural developments is southern Primorye (Fig. 1c) in the Russian Far East, on the border with China and North Korea, where archaeobotanical records in combination with direct $^{14}$C dating (Leipe et al., 2019; Sergusheva et al., 2022) have provided detailed insights into the beginning of agriculture based on the cultivation of broomcorn and foxtail millet in the first half of the 3rd millennium BCE (Sergusheva and Vostretsov, 2009). Since then, the populations of southern Primorye were characterised by a mixed subsistence economy mainly based on millet cultivation, hunting, fishing and gathering, a pattern that remained largely unchanged for at least the next two millennia. The introduction of barley into the crop repertoire of southern Primorye farmers along with soybean (*Glycine* max) and hemp (*Cannabis sativa*) took place in the second half of the 1st millennium BCE (Sergusheva and Vostretsov, 2009), which marks a period of material cultural and technological transformations and diversity (Popov et al., 2019). So far, no direct $^{14}$C dating of remains of these new crops has been carried out and discussed in a wider archaeological context, hampering discussion of the underlying driving forces of this fundamental change in subsistence systems of Primorye and the neighbouring Amur River region (Fig. 1b).

Here we present a new set of accelerator mass spectrometry (AMS) $^{14}$C dates derived from archaeological barley grains representing different cultural contexts and sites across southern Primorye and the Amur River region. To further substantiate early evidence of barley cultivation in the eastern Eurasian steppes and explore possible relationships with the crop's appearance in the southern Russian Far East, we also report AMS $^{14}$C dates of cereal grains recovered from the fortified Xiongnu settlement of Ivolga in Trans-Baikal, south of Lake Baikal (Fig. 1d). Our new results, combined with a review of archaeobotanical, archaeological and palaeoclimate records from northern East Asia, are used to examine possible routes and driving forces of the spread of barely and its agricultural and cultural impacts on the region.

## 2. Archaeological cultural background

The introduction of barley in Primorye (Fig. 1c) falls into a period, which is marked by the appearance of various new cultural traditions that show relationships with metal producing societies and/or use of metal objects or metallurgy (Fig. 2). The appearance of metal items in the region marks a relatively long period (end of 3rd–middle of 1st millennium BCE), during which finds of both bronze and iron objects are rare (Belova and Sidorenko, 2020; Yanshina, 2004). More often found are polished stone artefacts that imitate bronze objects (e.g., spearheads, daggers and jewellery) that were commonly used in regions of metallurgic tradition (Andreeva, 2005; Tabarev, 2014). Such imitation of metal items is also known from the Korean Peninsula and Japan. During the early stages of the Mumun (1500–100 BCE) and Yayoi (10th century BCE–250 CE) periods, people produced polished stone daggers that were replicas of bronze prototypes (Hudson, 2022; Leipe et al., 2020a). This demonstrates the peripheral location of these regions within the East Asian Bronze Age sphere at that time.

The more widespread use of iron in southern Primorye begins from the second half of the 1st millennium BCE (Tabarev, 2014; Yanshina, 2004; Yanshina and Klyuev, 2005; Zhushchikhovskaya, 2008), although iron objects are still rarely recorded in Yankovskaya cultural layers and most of them date to the late phase of this culture (Klyuev and Gridasova, 2013; Nikitin, 2017). Based on the available $^{14}$C dates, most studies place the beginning of the Yankovskaya period between 1000 and 800 BCE and its end in south-eastern Primorye between 300 and 100 BCE and in south-western Primorye (Khasansky District) to the 1st century CE (Popov et al., 2019; Sergusheva and Vostretsov, 2009; Vostretsov, 2006; Zhushchikhovskaya and Nikitin, 2019). Archaeological sites are distributed between the mouth of the Tumannaya River and the mouth of the Chernaya River (Fig. 1c). Most sites are located along the coastline, while some are located further inland close to rivers. With more than 200 discovered to date, Yankovskaya culture settlement sites are the most abundant of all prehistoric cultures in Primorye and document a considerable population increase during this period. The Yankovskaya people had a mixed subsistence economy including riverine and coastal fishing, gathering of wild edible plants, hunting of wild game (e.g., Manchurian red deer, roe deer and elk), breeding of pigs and dogs and crop cultivation. The focus was probably on the exploitation of marine food resources, as the zooarchaeological records suggest. Archaeobotanical records, which are only available for the later Yankovskaya cultural context, demonstrate the presence of agriculture (Sergusheva and Moreva, 2017; Vostretsov, 2005).

Around the middle of the 1st millennium BCE, sites of the Krounovskaya culture (represented to date by about 80 settlement sites), appeared in the continental parts of Primorye near Khanka Lake and the middle reaches of the Razdolnaya River (Vostretsov, 2013). Available

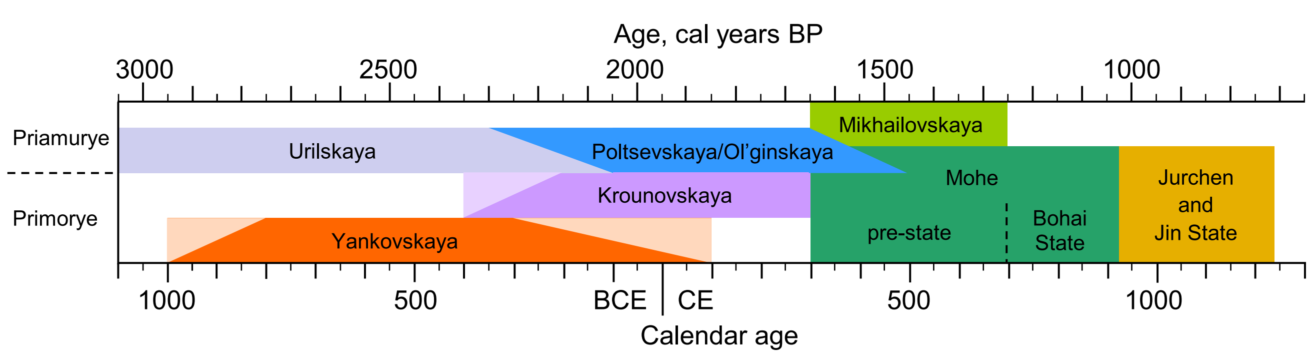


**Fig. 2.** Chronologies of archaeological cultures dating between 1000 BCE and 1000 CE in Primorye and Priamurye mentioned in the text. Light-coloured triangles indicate when there are different assumptions about the start and end of a period or when there are differences at sub-regional level.

records suggest that Krounovskaya groups relied on crop cultivation and animal husbandry, including pigs, dogs, cattle and horses, as well on hunting, fishing and gathering (Andreeva, 2005; Sergusheva and Vostretsov, 2009; Vostretsov, 1996, 2005). Iron items appear more frequently in Krounovskaya cultural layers than in Yankovskaya cultural layers (Brovko et al., 2018). The spread of the Krounovskaya culture in southern Primorye coincides with a phase of considerable population dynamics, during which Yankovskaya site numbers declined sharply and part of their population migrated further inland and settled in riverine environments (Vostretsov, 2005, 2013). In the 2nd and 1st centuries BCE, some Krounovskaya groups started to migrate eastwards and south-eastwards to coastal areas mainly inhabited by Yankovskaya people. These processes probably led to the assimilation and displacement of the remaining Yankovskaya populations (Sergusheva and Vostretsov, 2009; Vostretsov, 2005). At the same time, the region saw a general population decline (Vostretsov, 1999).

The population dynamics in the late 1st millennium BCE were further complicated by the southward expansion of Poltsevskaya culture populations from the Amur River region into the middle reaches of the Ussuri River (Fig. 1b) about 300–200 BCE. This culture increasingly expanded into the southern and south-eastern parts of Primorye (Dyakova and Sidorenko, 2024; Kolomiets, 2005), practising arable farming, animal husbandry and hunting, fishing and gathering (Sergusheva et al., 2022). Archaeological records illustrate an increase in the number of iron tools and weapons such as socketed axes, knives and arrowheads, as well as improvement in production quality (Dyakova and Sidorenko, 2024; Kolomiets et al., 2002). The end of the culture is dated to 400–800 CE, but various aspects of its chronology, origin and relationships remain debated (Dyakova and Sidorenko, 2024; Kolomiets, 2005; Yanshina, 2013).

The Early Middle Ages in Primorye are represented by the Mohe culture, whose settlement sites date from the end of the 3rd/beginning of the 4th century to the 8th century CE. In the 8th century, Bohai sites appeared in the west and south of Primorye, marking the beginning of early statehood in the medieval history of Primorye. With the expansion of the Bohai State (698–926 CE), the acculturation of the indigenous Mohe by immigrating Bohai populations began. At the same time, elements of the Mohe culture were preserved in the material culture of the Bohai people of Primorye for a long time (Boldin, 1996; Kim, 2020). Pre-state Mohe populations were comprised of different tribal groups, with a concentration of sites in the fertile southern parts of the Khanka Lake lowlands (Piskareva, 2013). The subsistence economy was also based on agriculture, animal husbandry and foraging. Archaeobotanical records suggest that crop cultivation, mainly based on millet and barley, was on a small scale during the early phase of the Mohe period, but became more important and diversified in later periods (Piskareva et al., 2019). During the Bohai State period, crop cultivation and animal husbandry formed the subsistence base of the Bohai society in Primorye. The Khitan Empire was destroyed by the Jurchens, descendants of the Bohai people, who established the Jin Empire (1115–1234 CE), which extended across the territories of north-eastern China, North Korea and parts of Primorye.

## 3. Material and methods

Three $^{14}$C dates on barley grains from Primorye have been published so far. The earliest conventional date (2620 ± 75 $^{14}$C BP, SOAN-7767) comes from the Malaya Podushechka settlement site. This date was obtained from a bulk sample of carbonised grains found in the filling of a vessel of the Yankovskaya culture (Sergusheva, 2010). At the settlement site Sinie Skaly, grains of naked barley were found in the fill layers of an Iron Age dwelling assigned to the Krounovskaya culture and conventionally dated to 2190 ± 90 $^{14}$C BP (SOAN-7766) (Sergusheva, 2010). The only AMS $^{14}$C date on naked barley comes from the Shelomaev Klyuch site of the Krounovskaya culture and shows an age of 2083 ± 40 $^{14}$C BP (IAAA 32077) (Sleptsov et al., 2006). Calibration of these dates yields the following calendar ages (95.4 % probability range): 974–518 BCE, 406 BCE–9 CE and 337 BCE–13 CE. The 95.4 % probability ranges of the calibrated dates show that the grains of the SOAN-7767 sample are at least 169 to 163 years older than the two AMS-dated grains (Poz-89788, 2155 ± 30 $^{14}$C BP; Poz-89790, 2135 ± 30 $^{14}$C BP; Table 1) from the same barley grain cluster from Malaya Podushechka. The older age of the bulk grain sample is likely due to contamination, such as from adhering organic soil components. We have therefore excluded this date from further discussion of the barley chronology. The calibrated age range of SOAN-7766 is similar to that (351–53 BCE) of the AMS-derived date Poz-89792 on a barley grain from the same fill layers at Sinie Skaly. However, due to the large error range (±90) of the uncalibrated $^{14}$C date, the uncertainty range of SOAN-7766 is much larger. Following Walker (2005), we did not consider this dating in the current study to maximise the precision of our barley chronology.

To examine the chronology of the early cultivation of barley in southern Primorye and the Middle Amur River region, we selected 13 charred barley grains (Fig. 3) from available archaeobotanical assemblages for AMS $^{14}$C dating (Table 1). The dated grains originate from eleven archaeological sites (Fig. 1b and c) representing the interval between the Yankovskaya culture period and the Middle Ages Bohai State. To determine the age of early cereal cultivation at the Ivolga site (Fig. 1d), six samples of charred grains of naked ($n = 2$) and hulled ($n = 2$) barley, bread wheat ($n = 1$) and broomcorn millet ($n = 1$) were chosen for AMS $^{14}$C dating (Table 1; Fig. 3). The dated barley samples consisted of a single grain each. To reach a sufficient mass of carbon for successful dating of the broomcorn millet sample, three caryopses were combined. All newly obtained and published dates used in the discussion were calibrated to calendar ages using OxCal v4.4 (Bronk Ramsey, 1995) and the IntCal20 curve (Reimer et al., 2020). All calibrated $^{14}$C ages mentioned in the text are given as 95.4 % confidence intervals unless otherwise stated. Taxonomic identification of cereal grains selected for AMS $^{14}$C dating was based on geometric morphometric traits of the caryopses referring to information from identification keys (e.g., Cappers and Bekker, 2013; Fuller and Weisskopf, 2014; Jacomet, 2006; Zohary and Hopf, 2000), reference collections and atlases (e.g., Cappers and Neef, 2012; Neef et al., 2012).

## 4. Results and interpretation

The 95.4 % calibrated probability ranges of 13 barley grains from southern Primorye and the Middle Amur River span between 381 BCE and 1210 CE (Table 1, Fig. 4). The four oldest barley grains are from the Malaya Podushechka, Sinie Skaly and Zolotaya Dolina archaeological sites (Fig. 1c) representing Iron Age cultural layers and have similar age ranges, i.e. between 355 and 346 BCE and 55–51 BCE. With 160 BCE–22 CE, the calibrated age range of the barley grain (Poz-89791) from Krounovskaya cultural context of Shelomaev Klyuch is slightly younger than the four specimens from Malaya Podushechka, Sinie Skaly and Zolotaya Dolina.

Eight dates are associated with Middle Ages cultural layers. Their calibrated ages span between 550 and 1210 CE. The five oldest dates in this cluster are from the sites Borisovka-3, Chernyatino, Sinie Skaly and the Sinel'nikovo-1 fortified settlement and represent Mohe cultural layers. All of the dates show similar calibrated ages ranging between 550 and 647 CE. The barley grain from the northernmost analysed site, Osinovoe Ozero, on the Middle Amur River has a calibrated age range 671–876 CE dating to the regional Troitskiy variant of the Mohe culture. Slightly younger (772–974 CE) is the barley grain from the Abrikosovskoe site in the lower Razdolnaya River valley, representing the

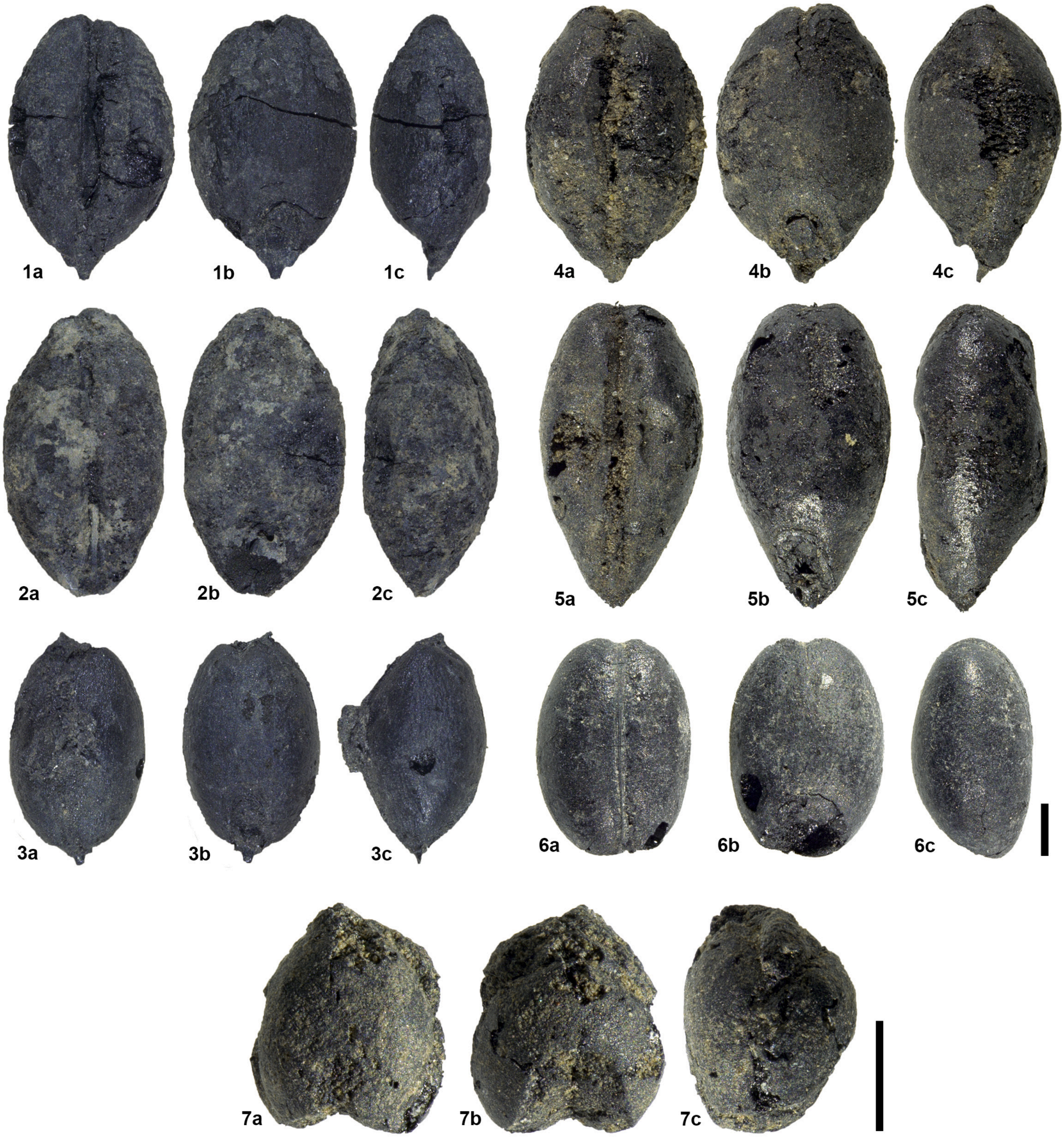


**Fig. 3.** Photographs of selected $^{14}$C-dated (see Table 1 for results) charred barley, wheat and millet grains from different archaeological sites (see Fig. 1b–d for locations): 1 – naked barley, Malaya Podushechka site, Poz-89788; 2 – naked barley, Shelomaev Klyuch site, Poz-89791; 3 – naked barley, Sinie Skaly site, Poz-89796; 4 – naked barley, Ivolga site, Poz-121664; 5 – cf. hulled barley, Poz-121583, Ivolga site; 4 – bread wheat, Ivolga site, Poz-121581; and one of three $^{14}$C-dated (Poz-122294) broomcorn millet grains, Ivolga site. All grains are shown in ventral (a), dorsal (b) and lateral (c) views. Scale bars = 1 mm.

Bohai State period in this region. The youngest barley grain with an age range of 1035–1210 CE comes from cultural layers of the Koksharovskoe-1 walled town and represents the post-Bohai period, i.e. the time after the fall of the Bohai State and before the formation of the Jin Empire (Klyuev and Belova, 2024).

The calibrated ages of the dated cereal grains from the Ivolga site in Trans-Baikal range between 194 BCE and 117 CE (Table 1, Fig. 4). Regarding the median ages, the oldest sample in this set is the naked barley grain from the bottom of ash pit 11 with a calibrated age range of 194 BCE–5 CE. The 95.4 % confidence intervals of all calibrated $^{14}$C dates fall within the conventional age range of the Xiongnu period (Di Cosmo, 2004).

**Table 1**
Conventional and calibrated (Reimer et al., 2020) $^{14}$C ages of 13 charred naked barley (*Hordeum vulgare* var. *nudum*) grains from eleven archaeological sites in southern Primorye and the Middle Amur River (southern Priamurye) and charred grains of naked barley, hulled barley (*Hordeum vulgare* var. *vulgare*), bread wheat (*Triticum aestivum*) and broomcorn millet (*Panicum miliaceum*) from the Ivolga settlement site in the Trans-Baikal region. The archaeological cultural context from which the grains were recovered is given for each dating. If not stated otherwise, one cereal grain was used per dating. See Fig. 1b–d for location of sites.

| Lab ID | Dated material | Archaeological site | Archaeological culture | Conventional age ($^{14}$C BP) | Calibrated 95 % age range (BCE/CE) | Calibrated median age (BCE/CE) |
|---|---|---|---|---|---|---|
| southern Primorye and Middle Amur River | | | | | | |
| Poz-89788 | *H. vulgare* var. *nudum* | Malaya Podushechka | Yankovskaya | 2155 ± 30 | 355–55 BCE | 192 BCE |
| Poz-89792 | *H. vulgare* var. *nudum* | Sinie Skaly settlement | Yankovskaya | 2145 ± 30 | 351–53 BCE | 175 BCE |
| Poz-89790 | *H. vulgare* var. *nudum* | Malaya Podushechka | Yankovskaya | 2135 ± 30 | 349–51 BCE | 157 BCE |
| Poz-89802 | *H. vulgare* var. *nudum* | Zolotaya Dolina-2 | Krounovskaya | 2130 ± 30 | 346–51 BCE | 149 BCE |
| Poz-89791 | *H. vulgare* var. *nudum* | Shelomaev Klyuch | Krounovskaya | 2055 ± 30 | 160 BCE–22 CE | 55 BCE |
| Poz-89793 | *H. vulgare* var. *nudum* | Borisovka-3 | Mohe | 1480 ± 30 | 550–644 CE | 594 CE |
| Poz-89803 | *H. vulgare* var. *nudum* | Chernyatino-2 | Mohe/Bohai State | 1435 ± 30 | 580–655 CE | 622 CE |
| Poz-89794 | *H. vulgare* var. *nudum* | Chernyatino-5 | Mohe | 1425 ± 30 | 586–659 CE | 625 CE |
| Poz-89796 | *H. vulgare* var. *nudum* | Sinie Skaly settlement | Bohai State | 1405 ± 30 | 598–665 CE | 637 CE |
| Poz-89801 | *H. vulgare* var. *nudum* | Sinel'nikovo-1 fortified settlement | Mohe | 1390 ± 30 | 601–673 CE | 647 CE |
| Poz-89795 | *H. vulgare* var. nudum | Osinovoe Ozero | Mohe | 1255 ± 30 | 671–876 CE | 737 CE |
| Poz-89799 | *H. vulgare* var. *nudum* | Abrikosovskoe settlement | Bohai State | 1170 ± 30 | 772–974 CE | 863 CE |
| Poz-89800 | *H. vulgare* var. *nudum* | Koksharovskoe-1 walled town | post-Bohai State | 920 ± 30 | 1035–1210 CE | 1111 CE |
| Trans-Baikal | | | | | | |
| Poz-121581 | *T. aestivum* | Ivolga settlement | Xiongnu | 2085 ± 30 | 194 BCE–5 CE | 97 BCE |
| Poz-122294 | *P. miliaceum* (3 grains) | Ivolga settlement | Xiongnu | 2080 ± 30 | 175 BCE–8 CE | 92 BCE |
| Poz-122282 | *H. vulgare* var. *nudum* | Ivolga settlement | Xiongnu | 2050 ± 30 | 159 BCE–26 CE | 47 BCE |
| Poz-121665 | cf. *H. vulgare* var. *vulgare* | Ivolga settlement | Xiongnu | 2045 ± 30 | 154 BCE–58 CE | 40 BCE |
| Poz-121583 | cf. *H. vulgare* var. *vulgare* | Ivolga settlement | Xiongnu | 2025 ± 30 | 103 BCE–76 CE | 13 BCE |
| Poz-121664 | *H. vulgare* var. *nudum* | Ivolga settlement | Xiongnu | 1985 ± 30 | 44 BCE–117 CE | 33 CE |

## 5. Discussion

### 5.1. Early barley cultivation in Primorye

The available archaeobotanical records combined with the results of direct $^{14}$C dating (Fig. 4) of barley grains from the oldest cultural contexts suggest that the crop appeared in southern Primorye most likely in the 2nd century BCE or slightly earlier. The results suggest that barley was used during this time by populations of the Yankovskaya and Krounovskaya cultures. It is not clear from these data which culture (or cultures) was the first to use barley. Additional inferences can be drawn by combining the available archaeobotanical with archaeological records. The few archaeobotanical records from Yankovskaya cultural layers indicate that only broomcorn and foxtail millet were cultivated in the early phase of this culture, which pre-dates the current barley finds (Sergusheva, 2022a). A good example of this is provided by the archaeobotanical records from the multi-layered Cherepakha-13 site (Fig. 1c). The crop component of the older records associated with early Yankovskaya occupation (first half of 1st millennium BCE) contain only the two millets (Sergusheva and Moreva, 2017). This suggests that Yankovskaya people continued the farming traditions of the Late Neolithic Zaisanovskaya (4300/3500–1600 BCE) populations (Sergusheva et al., 2022). Furthermore, given the focus on the exploitation of marine resources, a preference for a diverse crop package seems less likely. On the other hand, the crop remains from the younger cultural layers of Cherepakha-13, associated with Krounovskaya occupation and dated to the second half of the 1st millennium BCE, contain also one seed identified as barley and one seed identified as soybean (Sergusheva and Moreva, 2017). However, both seeds are poorly preserved and could not be identified with absolute certainty. As they were recovered from the same depositional context, both crop remains are likely of the same age as a directly dated sample of three foxtail millet grains (Poz-107955, 2210 ± 30 $^{14}$C BP), which have a calibrated age of 377–178 BCE (Sergusheva et al., 2022).

The broader spectrum of crops and domestic animals suggests that food production played a more important role in the subsistence economy of Krounovskaya populations than among Yankovskaya populations. Besides barley, the Krounovskaya groups also cultivated broomcorn and foxtail millet, soybean, hemp and possibly Japanese barnyard millet (*Echinochloa esculenta*) (Sergusheva and Moreva, 2017; Sleptsov et al., 2006, 2008; Yanushevich et al., 1990) and were likely full-scale farmers (Sergusheva and Vostretsov, 2009; Vostretsov, 2005). It is most likely that barley was first cultivated in southern Primorye by Krounovskaya people and was then adopted by Yankovskaya people and perhaps other groups through cultural interactions, which remain, however, poorly understood to date. This is in agreement with Yankovskaya cultural records, which show an increase in iron objects in the second half of the 1st millennium BCE (Sergusheva, 2022a). Iron tools were probably obtained by exchange with Krounovskaya people, who possessed more iron objects than members of the Yankovskaya culture (Brovko et al., 2018). Possibly, the adoption of barley and soybean cultivation (i.e. crop diversification) by the Yankovskaya promoted the migration of part of their population further inland and a stronger reliance on crop cultivation and less on wild food resources (Andreeva et al., 1986; Sergusheva, 2022a).

Assuming that barley arrived in Primorye with the Krounovskaya people, it may have arrived together with soybean and before the start of broader-scale cultivation, as suggested by the directly dated barley grains (Fig. 4). Given the lower boundaries of the calibrated ages of the two oldest wood charcoal-based $^{14}$C dates with an acceptable error range (i.e. less than ± 100 years) from Krounovskaya context, the culture existed in Primorye from about 400 BCE (Popov et al., 2019). Zhushchikhovskaya (2018) places the beginning of the Krounovskaya period between 400 and 200 BCE. The oldest crop-based $^{14}$C dates associated with the Krounovskaya culture are those of the three foxtail millet grains (377–178 BCE) from Cherepakha-13 (Sergusheva et al., 2022), which are linked with the barley from the same stratigraphic context. Both calibrated age ranges are similar and suggest that the dated crops most likely grew before the end of the 3rd century BCE. Although the currently available evidence suggests that the emergence of the Krounovskaya culture and barley cultivation in Primorye coincides, supporting the hypothesis of an introduction of the crop by demic diffusion, a spread by cultural diffusion cannot be ruled out. A solid estimate of the beginning of the Krounovskaya period and barley cultivation, which requires further research and direct $^{14}$C dating of cultural remains, could clarify this.

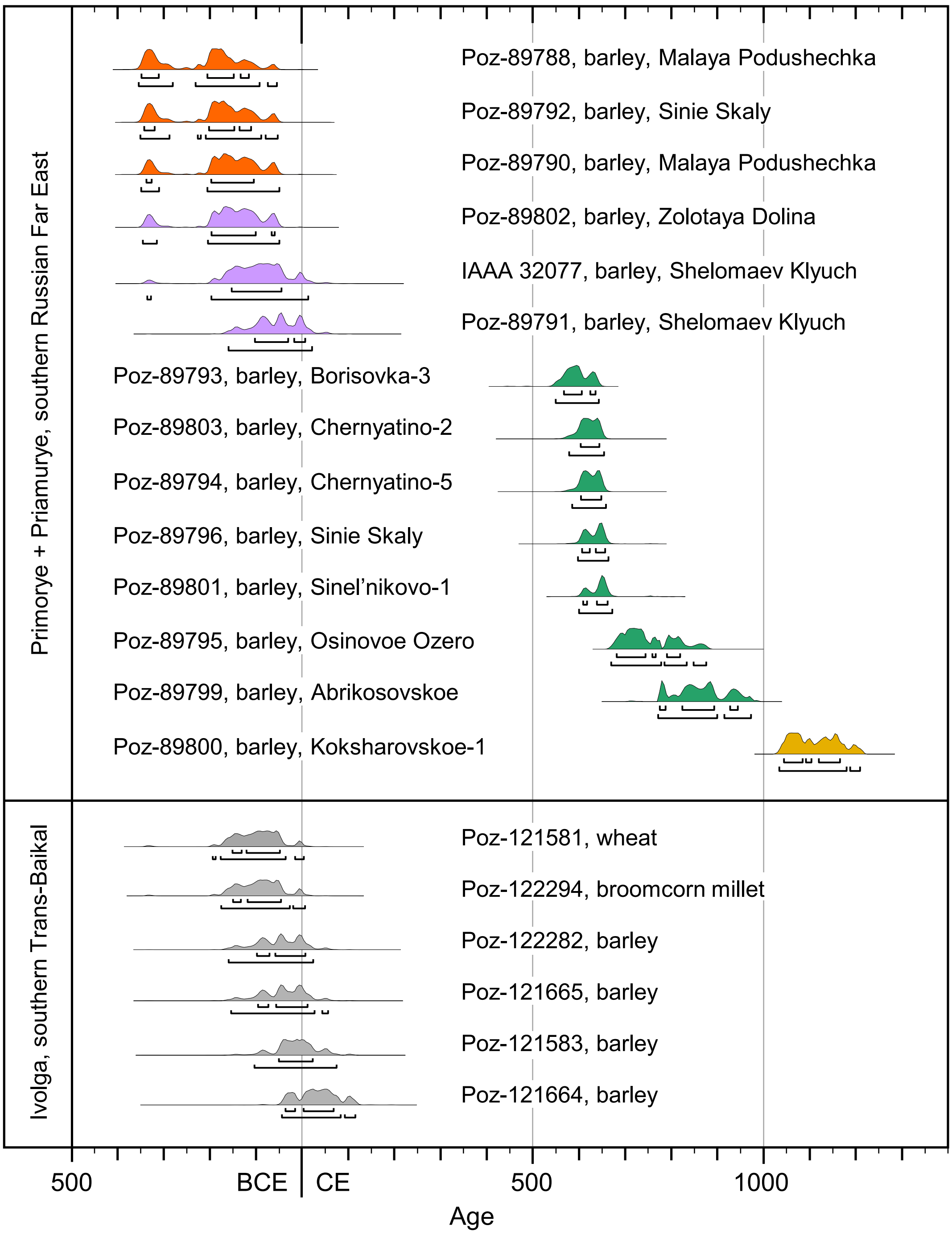


**Fig. 4.** Posterior probability distribution (coloured silhouettes) with 95.4 % (lower square brackets) and 68.3 % (upper square brackets) confidence levels of calibrated ages of the 13 newly obtained and the one existing (Sergusheva, 2010) AMS $^{14}C$-dated charred naked barley grains from archaeological sites (see Fig. 1b and c for locations) in southern Primorye and Priamurye as well as the six newly obtained AMS $^{14}C$ dates on cereal grains from the Xiongnu period fortified settlement of Ivolga (Fig. 1d) in southern Trans-Baikal (Table 1). Archaeological cultural background of the dated barley grains from Primorye and Priamurye are given in Table 1 and are indicated by silhouette colours as following: orange – Yankovskaya culture; violet – Krounovskaya culture; green – Mohe culture/Bohai State; yellow – post-Bohai State. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### *5.2. Early barley cultivation in neighbouring regions and its routes to Primorye*

To identify the routes by which barley cultivation spread to the Primorye region and to understand the underlying mechanisms, it is necessary to examine what is known about the crop's appearance and use in neighbouring regions. There are only few studies so far that focus on the spatiotemporal spread of barley to and within East Asia (Lister et al., 2018; Liu et al., 2017). Most studies concentrated on the arrival of wheat in China and its dispersal routes (e.g., Betts et al., 2014; Chen et al., 2020; Dodson et al., 2013; Flad et al., 2010; Long et al., 2018; Lu et al., 2019; Zhao, 2009), as this West Asian crop played a more important role in cropping systems of early agricultural societies in most parts of the region. Since wheat and barley co-occurred in many places in East Asia, it makes sense to include early records of wheat in the discussion of the arrival of barley to Primorye.

#### 5.2.1. Arrival via the eastern Eurasian steppe

Given the location of Primorye at the north-eastern limits of early agricultural East Asia, an arrival of barley via the steppe zone of southern Siberia and Mongolia seems plausible (Lister et al., 2018). A route via the northern steppes and the Hexi Corridor has been also discussed for the introduction of wheat to northern China (Dodson et al., 2013; Flad et al., 2010; Zhao, 2009). Verifying this dispersal route for the arrival of barley in Primorye is challenging, as there are only very few archaeobotanical records available from southern Siberia, Mongolia, the Amur River region and the Northeast China Plain. Datasets of stable carbon isotope ($\delta^{13}C$) ratios of human remains used to identify shifts in $C_3$ versus $C_4$ plant consumption suggest that millet cultivation arrived to northern Mongolia and Trans-Baikal from the west, i.e. from the Altai region or Minusinsk Basin in southern Siberia, via agropastoral networks (Ventresca-Miller et al., 2023). The earliest evidence of millet consumption from the Minusinsk Basin dates to the Bronze Age between 1400 and 1300 BCE (Svyatko et al., 2021). Human bone $\delta^{13}C$ data from further southeast suggest that millet was part of the diet in the Early Iron Age during 700–500 BCE in the Tuva region of southern Siberia (Murphy et al., 2013) and during 900–400 BCE in the Great Lakes Depression in western Mongolia (Wilkin et al., 2020). Assuming that cereal cultivation spread to the fertile Minusinsk Basin from somewhere south of the Altai Mountains, where millet, barley and wheat had been cultivated since ca. 3000 BCE, as evidenced by archaeobotanical records from Tongtian Cave in western Xinjiang (Zhou et al., 2020; Fig. 1a), it is likely that also both West Asian crops were part of the agropastoral economy of the isotopically investigated individuals. Further east, in north-central Mongolia, human $\delta^{13}C$ records show that increased $C_4$ plant consumption began during the Xiongnu period, beginning in the 3rd century BCE. This is supported by the oldest records of plant macroremains available from the southern Siberian and Mongolian steppes recovered from Xiongnu period burial, seasonal camp and settlement sites such as Egiin Gol (Fig. 1a) (see Honeychurch et al., 2023 for a detailed review). In addition to millet, they also contain caryopses of wheat and barley, which is the earliest, though yet not directly dated, evidence of the two crops in these regions. Recent archaeobotanical investigations at the fortified Ivolga settlement site (Fig. 1d) recovered charred grains of broomcorn millet, foxtail millet, free-threshing wheat and hulled and naked barley (Sergusheva et al., 2019, 2020). The $^{14}C$ datings of a subset of these cereal assemblages (Fig. 4) are the first to be directly obtained from crop remains from Xiongnu cultural context and confirm their use in the Trans-Baikal region by 200–1 BCE. The so far earliest finds of barley in the Amur River region (Priamurye) appear together with broomcorn and foxtail millet grains in strata of the early Middle Ages Mikhailovskaya culture at the Chernigovka-5 site (Fig. 1b). The site, located in the lower reaches of the Zeya River, a left tributary of the Amur River, is dated to the 6–7th centuries CE (Sergusheva, 2022b). The similarity of the calibrated age (671–876 CE, Fig. 4) of the directly dated barley grain from Osinovoe Ozero (Fig. 1b) with the chronology of Chernigovka-5 probably implies the simultaneous presence or introduction of barley at both sites.

Given this spatiotemporal pattern of the arrival of barley and other cereal crops in the eastern Eurasian steppes and the Amur River region, it appears unlikely that the earliest barley in Primorye arrived via a northern steppe route. Comparison with the probability distributions of the calibrated ages of the barley from Ivolga (Fig. 4) suggests that the crop arrived in Primorye several decades to one century earlier. In addition, the existing archaeobotanical records from north of the Amur River, although still sparse and rarely directly dated, do not support that barley was introduced to Primorye via this region (Sergusheva, 2022b).

#### 5.2.2. Arrival via the Japanese archipelago

Another possible route of barley transmission to Primorye is via the Japanese archipelago. As in other parts of East Asia, research on the development and spread of agriculture in Japan has focused on the earliest millet-rice-based farming systems, and evidence for the timing of the arrival and spread of barley and wheat cultivation remains limited (Endo and Leipe, 2022; Shoda et al., 2021). The Hokkaido region in northern Japan, which was home to complex hunter-fisher-gatherer populations until the middle of the 19th century CE (Crawford, 2011; Weber et al., 2013), provides the oldest solid evidence of barley use on the Japanese archipelago. This comprises a single directly $^{14}C$-dated barley grain (Poz-91171, 2220 ± 30 $^{14}C$ BP) from the Hamanaka-2 archaeological site (Müller et al., 2016) on Rebun Island (Fig. 1b) in northern Hokkaido (Leipe et al., 2018). The grain's calibrated age (375–203 BCE) and its archaeological find context associates it with the early phase of the Epi-Jomon period (300 BCE–600 CE) in the Hokkaido region (Abe et al., 2016). The Hamanaka-2 barley shows a close temporal connection with the dated barley grains from the Krounovskaya and Yankovskaya cultural layers (Fig. 5) from across the Sea of Japan. Thus, the barley recorded in Primorye could have been transmitted via the Yayoi cultural sphere (Kyushu, Shikoku and Honshu Island regions). Unlike Hokkaido, the latter region experienced the shift from foraging to full-scale agriculture, mainly based on mixed millet-rice cultivation, during the Early–Middle Yayoi period (10th century–1 BCE).

It has been assumed that wheat and barley arrived and spread between Kyushu and northern Honshu either together with rice and millet at the beginning or at a later stage of the Yayoi period (e.g., Crawford, 2011; de Boer et al., 2020; Habu, 2014; Kanaseki and Sahara, 1976; Kaner and Yano, 2015; Nakayama, 2010; Sakamoto, 1996). However, $^{14}C$ dating of seeds from Yayoi cultural layers has shown that they represent contamination from younger periods (e.g., Inada et al., 2023; Kunikita et al., 2020; Kunikita et al., 2023). To date, there are no securely dated records of barley and wheat macroremains or seed impressions in pottery associated with the Yayoi period (10th/4th century BCE–250 CE) (Endo and Leipe, 2022). The earliest unambiguous evidence for the use of wheat in Japan comes from the Karakami site on Iki Island (Nagasaki Prefecture), located in the Tsushima Strait between the Korean Peninsula and Kyushu Island (Fig. 1b), and is based on a caryopsis directly $^{14}C$-dated (PLD-11631, 1860 ± 20 $^{14}C$ BP) to 127–233 CE (Rekihaku Database of Radiocarbon Dates, https://www.rekihaku.ac.jp). However, the associated cultural record shows affinities with contemporaneous ones from the Korean Peninsula, suggesting that the recovered wheat is more likely related to Three-Kingdom Korea (1st century BCE–7th century CE) than to Late Yayoi period (ca. 1–250 CE) Japan (Nagasaki Prefectural Board of Education, 1995; Oksbjerg, 2007). With a calibrated $^{14}C$ age (TKA-23707, 1560 ± 21 $^{14}C$ BP) of 433–567 CE (Kunikita et al., 2021), the oldest directly dated wheat grain from mainland Japan (Takeda Ishidake site, Ibaraki Prefecture, Fig. 1b) falls into the Middle (400–475 CE) or Late (475–710 CE) Kofun period. Even younger (706–884 CE) is the so far oldest $^{14}C$-dated barley grain (TKA-23952, 1219 ± 21 $^{14}C$ BP) recovered at the Funakuba archaeological site (Fig. 1b) in the same prefecture (Inada et al., 2023). The available archaeobotanical and $^{14}C$ data suggest that in the Yayoi period wheat and barley, if cultivated at all, were of little importance during this early phase of agricultural development. The currently limited direct dating evidence indicates that wheat and barley were incorporated into the existing crop repertoire during the Middle–Late Kofun period. Larger assemblages of charred wheat and/or barley grains from the Osaka Plain (Shoda et al., 2021) and central and northern Tohoku (northern Honshu Island) (Ota et al., 2023) typologically dated to the late 5th and 8th centuries CE, respectively, support this scenario. If correct, the adoption and growing importance of both West Asian crops after the Early Kofun period may have been related to contemporaneously increasing cultural influence from the Korean Peninsula. This is evident from archaeological records (Hudson et al., 2020; Mizoguchi, 2013; Rhee et al., 2022; Rhee et al., 2007) as well as ancient (Cooke et al., 2021) and modern (Liu et al., 2024) human genomics, and was accompanied by agricultural intensification and population increase (Leipe et al., 2024). Consequently, it seems more likely that the Epi-Jomon barley was introduced to Hokkaido from the Northeast Asian mainland rather than from the southern part of Japan. The same origin has been proposed for the naked

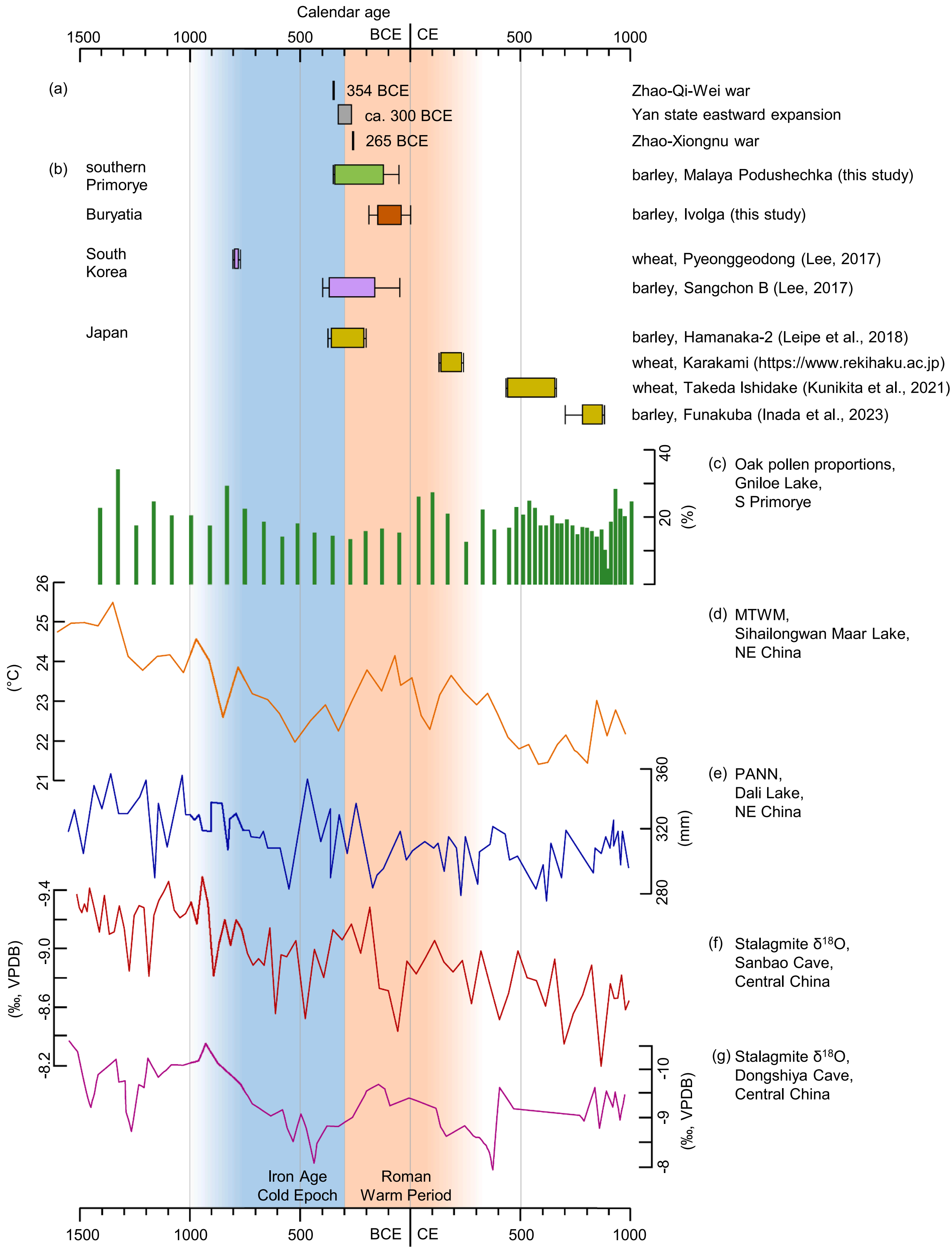


**Fig. 5.** Figure compilation showing (a) outstanding events of military conflict in the north-eastern Chinese Warring State domain documented in written sources; (b) the 95.4 % (whiskers) and 68.3 % (bars) confidence intervals of calibrated age ranges of $^{14}$C-dated barley and wheat remains from the regions discussed in this study; (c) the oak pollen proportions of the LG sediment core pollen sequence from Gniloe Lake (43.43°N, 133.55°E, 3 m a.s.l.; Fig. 1c) as a proxy for changes in summer temperature (Lyashchevskaya et al., 2023); (d) the pollen-based reconstructions of the mean temperature of the warmest month (MTWA) from Sihailongwan Maar Lake (42.29°N, 126.60°E, 797 m a.s.l., Fig. 1c), Changbai Mountains, NE China (Stebich et al., 2015); (e) the pollen-based reconstructions of annual precipitation (PANN) from Dali Lake (43.15°N, 116.35°E, 1226 m a.s.l., Fig. 1c), NE China (Xiao et al., 2015); (f) the stalagmite $\delta^{18}O$ record SB43 from Sanbao Cave (31.67°N, 110.43°E, 1900 m a.s.l., Fig. 1a), Central China (Dong et al., 2010); and (g) the stalagmite $\delta^{18}O$ record DSY1 from Dongshiya Cave (33.78°N, 111.57°E, 840 m a.s.l., Fig. 1a), Central China (Zhang et al., 2018).

barley used by Okhotsk culture (5th–10th century CE) groups in northern Hokkaido. By contrast, hulled barley, which was preferentially used by Early–Middle Satsumon culture (8th–10th century CE) groups in central and southern Hokkaido, has been suggested to have spread from Honshu Island (Leipe et al., 2017; Yamada, 1995; Yamada and Tsubakisaka, 2008). A spread of barley from a northerly gene pool in the Russian Far East to Hokkaido is also supported by genetic analyses of barley accessions from different regions in Eurasia (Lister et al., 2018).

*5.2.3. Arrival via Liaoning/the Korean Peninsula*

To the Korean Peninsula, barley was supposedly introduced together with rice and wheat at the beginning of the Mumun period around 1500 BCE (Crawford and Lee, 2003; Lee, 2016). Bayesian modelling of $^{14}$C dates directly obtained from archaeological rice remains from South Korea dates the arrival of the crop to ca. 1700–1200 BCE (Leipe et al., 2020b). This estimate is mainly determined by the calibrated age (1436–1116 BCE) of the oldest available $^{14}$C-dated rice grain (SNU 08–305, 3040 ± 60 $^{14}$C BP) from the Gyodong archaeological site (Ahn, 2010). The idea that rice, barley and wheat were jointly introduced grounds on their co-occurrence in Early (1500–800 BCE) and Middle (800–400 BCE) Mumun cultural layers at many sites (Lee, 2016). However, this hypothesis still needs to be tested by direct age determination. The oldest directly dated wheat (Pyeonggeodong site, UCI67222, 2585 ± 20 $^{14}$C BP) and barley (Sangchon B site, S01302, 2200 ± 80 $^{14}$C BP) grains have calibrated age ranges of 805–772 BCE and 401–47 BCE, respectively (Lee, 2017 and references therein), which fall within the Middle and Late (400–100 BCE) Mumun periods. Lee et al. (2023) note that wheat and barley start to occur more frequently in archaeobotanical records dating to the Proto-Three Kingdoms (100 BCE–300 CE) and Three Kingdoms (300–668 CE) periods. More widespread wheat and barley cultivation started only slightly later, or even around the same time that rice became a staple crop in the Early Iron Age (300–100 BCE) (Kim, 2015; Lee et al., 2023). Lee et al. (2023) associate the increasing importance of rice and wheat with the introduction of iron tools by the end of the Late Mumun period. Although the limited number of directly dated wheat and barley records from the prehistoric Korean Peninsula are not sufficient to draw final conclusions about their arrival time, the available evidence shows a clear temporal relationship between the increasing importance of rice, wheat and barley and the age of the barley grains from Iron Age southern Primorye (Fig. 5d). In addition, the occurrence of early iron objects in the north-western Korean Peninsula, mainly in the area north of the Chongchon river (Yi, 2015), and in Krounovskaya cultural layers also coincide. These findings suggest that barley may have spread to Primorye from a south-western direction, possibly from or via Liaoning or the north-western Korean Peninsula.

Assuming that barley cultivation was introduced to southern Primorye by farmers from or via Liaoning/the north-western Korean Peninsula, they could have migrated along the Tumannaya (Tumen) River valley (Fig. 1b). The latter has also been identified as the most likely route for the spread of millet cultivation from Liaoning in the first half of the 3rd millennium BCE during the Late Neolithic Zaisanovskaya period based on the spatiotemporal distribution of directly dated archaeological millet grains (Sergusheva et al., 2022). This is consistent with the scenario that the introduction of barley cultivation is linked to the arrival of Krounovskaya populations (see discussion in section 5.1.). The earliest Krounovskaya sites are located west of Khanka Lake and in the middle reaches of the Razdolnaya River (Fig. 1c) (Vostretsov, 2013). Krounovskaya culture sites have also been recorded in China between the middle reaches of the Tumannaya River and the areas west of Khanka Lake, where they are associated with the Tuanje culture (Vostretsov, 2005). Since the chronologies of these sites are ambiguous, an arrival from the areas west of Khanka Lake seem also possible.

There is currently no archaeological or archaeobotanical evidence indicating that the Krounovskaya culture spread into southern Primorye via the Songhua River and the Sanjiang Plain (Fig. 1b). A flotation-based archaeobotanical investigation (Zhao, 2021) of deposits from one dwelling at the Fenglin archaeological site (Fig. 1b), associated with the Guntuling culture on the Sanjiang Plain, provides the only available evidence for crop cultivation during the Early Iron Age in the Songhua River region. The 2349 identified crop remains represent foxtail millet (~69 %), broomcorn millet (~5 %), barley (~5 %) and soybean (~22 %), which, except for the absence of wheat, corresponds to the crop package associated with Krounovskaya farmers (Sergusheva and Vostretsov, 2009; Yanushevich et al., 1990). The recovered crops, attributed to the Guntuling period and dated between the 2nd century BCE and 2nd century CE or even 4th century CE (Sobolev, 2021), have not been directly dated. Additional evidence of crop cultivation from the wider region pre-dating the turn of the eras comes from deposits of the Poltsevskaya culture, which shows cultural affinities with the Guntuling (Sobolev, 2021). Cultural layers at the two archaeological sites Amursky Sanatorium and Petropavlovka-5 in the Amur River valley near the confluence of the Ussuri River (Fig. 1b) dated to the 3rd–1st centuries BCE were studied (Sergusheva, 2023). The only cultigen contained in the archaeobotanical records from both sites is millet. The same crop is exclusively contained in the plant remain records obtained by flotation from Poltsevskaya period storage cellars at the Glazovka-gorodishche site (Kolomiets et al., 2002) in the middle reaches of the Ussuri River northeast of Khanka Lake (Fig. 1c). One of the millet grains has been directly dated (Sergusheva et al., 2022), yielding an age (386–103 BCE) very similar to that of the oldest dated barley grains from Krounovskaya and Yankovskaya cultural contexts (Fig. 4).

## 5.3. Driving forces behind the spread of barley to Primorye

*5.3.1. Cultural factors*

The period from the end of 3rd to the middle of 1st millennium BCE in Primorye and the Amur River region was a phase of unprecedented cultural dynamics and human migration. In Primorye, new populations associated with the Margaritovskaya culture arrived by the end of the 3rd millennium BCE. They were soon followed by other populations, associated with archaeological sites such as Chernyatino-2, Kharinskaya and Elizavetovka-1, by the beginning of the 1st millennium BCE (Kuzmin et al., 2005; Popov et al., 2019). There is evidence that at the same time immigrants related to the Urilskaya culture had already introduced iron and cast iron, and probably also their production, to the middle reaches of the Amur River (Nesterov, 2022). During the 1st millennium BCE, the region witnessed the emergence of new cultures, including Yankovskaya, Krounovskaya and Poltsevskaya, which partly co-existed and introduced new domesticates and technologies. According to archaeological evidence, the groups of the Krounovskaya culture were the first full-scale farmers to fundamentally change the subsistence economy of the region. Our findings confirm that barley cultivation spread across the region no later than the 2nd century BCE. There is evidence that a combination of climatic and cultural factors may have been the driving force behind this process.

In China, the decline of central power of the Zhou dynasty began with the loss of their homeland in the Wei River region to expanding agropastoralists from the East Asian steppes and the eastward shift of their capital to Luoyang in 771 BCE (Shaughnessy, 1999; Shelach-Lavi, 2015). At the same time, the regional states, which had once been installed by the Zhou rulers, gained increasing economic and military strength, leading to growing independence from the central Zhou court (Li, 2024; Shaughnessy, 1999). This was paralleled by increasing competition for natural and human resources and regional hegemony among the states, which culminated during the Warring States period (475–221 BCE), when expansionist policies began to affect also the north-eastern frontier regions and caused the dispersal of local populations (Rhee et al., 2022).

Yan (1046–222 BCE), the north-easternmost state, was centred around its capital Ji (now Beijing) and bordered by the Bohai Sea. Due to its own quest for power and territorial expansion and its position between rival states in the west and south and non-Zhou cultural groups and polities in the north and east, the history of Yan was marked by military conflicts on multiple fronts. According to Chinese written sources, Yan expanded north-eastward and eastward around 300 BCE. Through its north-eastward expansion, probably as far as present-day Chifeng, Yan annexed part of the homeland of nomadic tribes summarised by contemporaneous writers as Donghu (Byington, 2016). To the east, Yan conquered part of the homeland of a neighbouring polity, which by the Chinese of the time were called Choson (Logie, 2019; Yi, 2015) and perhaps occupied the region around the Liaodong Peninsula and the north-western part of the Korean Peninsula (Byington, 2019). Some scholars argue that the Yan conquest shifted the border to the Choson beyond the Liaodong Peninsula up to somewhere close to the Yalu River (Fig. 1b), although this interpretation of the early Chinese chronicles remains controversial (Byington, 2009, 2019). This eastward expansion of Yan caused migration from Liaoning to the Korean Peninsula (Yi, 2015 and references therein) and perhaps also to the north.

Migration from Liaoning to the Korean Peninsula is also evidenced by the spread of Jeomtodae pottery (Miyamoto, 2022; Yi, 2015). The appearance of Jeomtodae pottery is linked with the introduction of Iron and pinpoints the start of the Early Iron Age at around 300 BCE (Rhee et al., 2022; Yi, 2015), which, in turn, marks the beginning of more widespread wheat and barley cultivation and the increasing importance of rice (Kim, 2015; Lee et al., 2023). Miyamoto (2016) notes that the Jeomtodae pottery is not associated with rice, but with millet and wheat cultivation, indicating that crop preferences were not uniform and differed between indigenous farmers and newcomers. Further unrest around the Bohai Sea was fueled by the rivalry between Yan and the state of Qi (1046–221 BCE), which controlled the lower Yellow River reaches and the Shandong Peninsula. Mutual invasions and short-lived conquests at the beginning of the 3rd century BCE (Fu, 2023) likely contributed to migrations, possibly from the Shandong Peninsula across the Bohai Sea to the Liaodong Peninsula and beyond.

Cultural interaction between dynastic Chinese polities and nomadic tribes and chiefdoms of the East Asian steppes, which often manifested themselves in armed conflict, are probably also the reason for the adoption of crop cultivation by the Xiongnu. Especially the Warring States of Yan and Zhao (403–228 BCE) and the agropastoral state of Cheshi in the Turfan Basin (Li et al., 2013; Tarasov et al., 2019), whose territories bordered the northern steppes, were involved in warfare with nomadic tribes, but also in cultural interactions and trade relations (Juliano, 1991). Perhaps the Xiongnu sought to secure food supplies in times of war, when trade and exchange was impossible or at least more complicated. After major military defeats against the Zhao state and the Qin empire in the middle and late 3rd century BCE, the Xiongnu confederation prospered during the interregnum (206–202 BCE) between the Qin and Han dynasties when China was affected by civil war and also adopted Han cultural features and agricultural techniques (Bentley, 1993). In the late 3rd century BCE, the Xiongnu empire expanded its territory into different directions. To the east, the Xiongnu defeated the nomadic confederation of the Donghu in eastern Mongolia and the greater Northeast China Plain region. To the north, they occupied territories of nomadic tribes in southern Siberia, including the areas south of Lake Baikal (Parzinger, 2006). A witness of the later expansion is the Ivolga settlement, which attests for a diverse set of crops, including millet, barley and wheat (Sergusheva et al., 2020), that was grown there sometime between 200 and 1 BCE (Fig. 4). It seems plausible that crop cultivation was introduced to allow and maintain self-sufficient military outposts, such as Ivolga, dispersed across a vast area with varying climatic conditions.

### 5.3.2. *Environmental factors*

While archaeological records provide materialistic evidence for cultural trajectories and interactions, it is much more difficult to identify and verify influence of climate and environmental change on human behaviour if no corresponding written sources are available. Palaeoclimate records indicate that there was a general long-term trend toward cooler and drier conditions in northern China during the Late Holocene (Herzschuh et al., 2019; Liu et al., 2015; Tarasov et al., 2019). Examination of proxy records of temperature and precipitation from the continental Northeast Asian monsoon domain show the following trends around the time of barley arrival in Primorye. The SB43 stalagmite $\delta^{18}O$ record from the Sanbao Cave (Dong et al., 2010; Fig. 5f), located in western Hubei Province (Fig. 1a), shows a trend toward reduced precipitation during the first half of the 1st millennium BCE. This trend is confirmed by the $\delta^{18}O$ record of the DSY1 stalagmite from the Dongshiya Cave (Zhang et al., 2018; Fig. 5g), located further north in western Henan Province (Fig. 1a). A corresponding moisture development is illustrated by the quantitative pollen-based reconstruction of annual precipitation (Xiao et al., 2015; Fig. 5e) from Dali Lake, located close to the modern north-western limit of the East Asian summer monsoon domain in Inner Mongolia (Fig. 1b). The assumption that this drying trend is related to climate cooling is supported by a pollen-based reconstruction of summer temperature (Stebich et al., 2015; Fig. 5d) based on a robustly dated (varve counting) sediment sequence (Schettler et al., 2006) from the Sihailongwan Maar Lake in the Changbai Mountains region (Fig. 1b). The cooling/drying trend in the stalagmite $\delta^{18}O$ records and the temperature record from Sihailongwan was interrupted by a climate reversal from ca. 400 BCE to 100/1 BCE (Fig. 5). However, the precipitation and temperature levels increased only slightly and remained below the levels of the 2nd millennium BCE. An exception is the pollen-based reconstruction from Dali Lake, which indicates a re-increase in precipitation already around 500 BCE. This temporal deviation may be due to the less robust chronology of the latter record in the respective depth range (Wen et al., 2017) compared to the ones from the Dongshiya and Sanbao caves and Sihailongwan. A general trend toward lower temperatures, suggested for southern Primorye in a well-dated pollen record (Lyashchevskaya et al., 2023; Fig. 5c) from Gniloe Lake (Fig. 1c) between 1300 and 300 BCE (Lyashchevskaya et al., 2023), was interrupted for a short time around 800 BCE. In this record as well, the renewed increase in oak pollen after 300 BCE was weak and only intensified at the beginning of the 1st millennium CE. A similar climatic trend is also indicated by the RK12 pollen record from Kushu Lake on Rebun Island in northern Hokkaido (Leipe et al., 2018; Fig. 1b). After a phase of low oak pollen proportions around 600–400 BCE, the values increase again.

This climate cooling period is remarkably coherent with a cold climate phase recognised in palaeoclimate records from the North Atlantic region often referred to as the Iron Age Cold Epoch or the Sub-Atlantic Cold Period. Commonly dated to 900–300 BCE (Fig. 5) (Behringer, 2010), it preceded the Roman Warm Period (300 BCE–300 CE, Fig. 5) (Clauzel et al., 2020). Analogies with the North Atlantic region have also been identified for the latter Late Holocene centennial-scale climate oscillation in the East Asian monsoon region (Ji et al., 2005; Leipe et al., 2024), which may be explained by climatic teleconnections or common hemispheric- to global-scale forcing factors. The trend toward cooler and drier conditions less favourable for arable farming may have been an additional factor that added to, or even amplified, the Chinese Warring States' policies of territorial expansion and the resulting unrest and migrations. This scenario is consistent with the eastward expansion of Yan toward areas closer to the monsoon moisture source and thus more suitable for crop cultivation. Noteworthy is that this Yan state expansion coincides with the southward movement of Celtic tribes from their homelands in France, Germany and Austria into northern Italy and the Balkan Peninsula around 300 BCE (Dáithí, 2003). Sirocko (2013) correlates these European cultural expansions and migrations to a phase of weak solar activity around 300 BCE (Kromer and Friedrich, 2007; Zielhofer et al., 2017), which probably led to cooler winters and a high risk of (extreme) flooding in Europe.

We hypothesise that the combination of the outlined political, cultural and climatic factors triggered the migration of farmers, with a broad crop package including barley, to southern Primorye. It is possible that the new immigrants were affected by the eastward and north-eastward expansion of the Yan state and/or the conflicts within the Qi territory, or that these events kicked off a domino effect that resulted in the movement of other neighbouring populations. Although other crops such as rice and wheat could have been known to the Early Iron Age farmers, the available archaeobotanical evidence from Krounovskaya and Yankovskaya cultural contexts suggests that millet and barley were preferred, likely due to the fact that they are better adapted to cooler climate conditions and a shorter growing period (Ullrich, 2014).

Although archaeobotanical records cannot prove it beyond a doubt, it seems plausible that barley was cultivated as a summer crop alongside millet, rather than as a winter crop. Written records document that summer cropping of barley was practiced in the 1st millennium BCE in central and eastern China (Liu et al., 2017). In addition, DNA studies of extant barley landraces from across Eurasia show that varieties lacking sensitivity to increasing daylength – making them suitable for spring sowing – are concentrated in north-eastern China, northern Japan and Primorye (Jones et al., 2016; Lister et al., 2009; Lister et al., 2018). The latter studies conclude that the development of non-daylength sensitive barley was an adaptation to cooler climate conditions in northern latitudes. The preference of naked over hulled barley in early cropping systems in Primorye and northern Japan (Leipe et al., 2017; Lister et al., 2018) is likely not determined by climatic conditions. Hulled forms are more cold-tolerant and drought-resistant, although the latter trait may not be relevant for the two regions that receive plenty of rainfall during the warm season. The decisive reasons for preferring naked barley could be that processing of the harvest is much easier. The husks shed easily during threshing, which was perhaps an attractive trait for populations that still relied heavily on foraging. In addition, naked barely has a higher nutritional value and energy content than hulled barley (e.g., Jood and Kalra, 2001; Huang et al., 2003; Shvachko et al., 2021; Šterna et al., 2017).

## 6. Conclusions

According to the cultural context of available archaeological barley remains, the crop appeared in southern Primorye during the Early Iron Age (ca. 500 BCE–300 CE), when the region experienced the emergence of several new cultures. Spatiotemporal examination of Early Iron Age archaeological records revealed that barley cultivation was most likely introduced by Krounovskaya culture groups migrating to southern Primorye, where there were already populations practicing millet cultivation. Direct AMS $^{14}$C dating of barley grains suggests the crop occurred by the 2nd century BCE. However, this could have happened as early as the 4th century BCE, assuming that the introduction of barley cultivation coincides with the appearance of Krounovskaya groups. However, the available $^{14}$C dates are not yet sufficient to resolve this issue or to exclude the possibility of cultural diffusion of barley cultivation.

Additional archaeobotanical investigations are also required to explore the role of wheat cultivation in Early Iron Age southern Primorye. So far, wheat has been reported in only one archaeobotanical record, and available data suggest that barley was probably more important than wheat, which may reflect the better adaptation of barley to cold climates or another, cultural-historical background. We conclude that the appearance of barley, along with other new crops, marks the beginning of full-scale agriculture and a first diversification of cropping systems after almost two millennia of mixed foraging and millet-based farming.

The set of archaeological and archaeobotanical evidence shows that barley was likely introduced from the neighbouring regions south and/or west of Primorye and not from the Japanese archipelago or via routes crossing the northern Eurasian steppes. Instead, our results corroborate the hypothesis that barley arrived in northern Japan directly from Primorye. However, further research is needed to reconstruct the routes of barley dispersal and whether it was via the Razdolnaya River from the west and/or via the Tumen River from south-western directions. Directly derived $^{14}$C dates on barley in the current and previous studies prove that the crop spread over a large area, arriving in southern Primorye, northern Japan and Trans-Baikal during the second half of the 1st millennium BCE, possibly within a period of only three centuries.

Our findings suggest that the spread of the Krounovskaya culture (and barley cultivation) to southern Primorye could have been a response to unrest and military conflict in the course of the expansionist policy of the Warring State of Yan. One factor that drove the Warring States' policy of territorial expansion for procurement of natural and human resources may have been the Late Holocene long-term climate cooling and drying trend, which was superimposed by centennial-scale climate deterioration around 1000–300 BCE, associated with the Iron Age Cold Epoch. The prolonged cooling and the decline of natural food resources, combined with relatively high population numbers and the growing challenges for securing food supplies, may have driven migrations and shifts in subsistence economies, resulting in a further spread of barley across northern East Asia.

## CRediT authorship contribution statement

**Christian Leipe:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Elena A. Sergusheva:** Writing – review & editing, Writing – original draft, Resources, Investigation. **Martine Robbeets:** Writing – review & editing, Writing – original draft. **Patrick Wertmann:** Writing – review & editing, Investigation. **Nikolay N. Kradin:** Writing – review & editing, Resources. **Mayke Wagner:** Writing – review & editing, Funding acquisition. **Pavel E. Tarasov:** Writing – review & editing, Project administration, Methodology, Funding acquisition.

## 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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## Data availability

Data is provided in Article

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