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Extreme events and the spread of Uralic languages

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ABSTRACT

In this paper we present novel aspects concerning the possible connection between the 4.2 ka climatic event and the early spread of Uralic languages from western Siberia to North-East Europe. We discuss different reasons for the divergence of Proto-Uralic and the spread of the Uralic languages, and propose a scenario where the 4.2 ka climatic event and the early spread of Uralic languages is connected via three themes: 1) habitat changes, 2) animal husbandry and 3) trade. Our arguments are based on analysis of linguistic evidence of Proto-Uralic cultural vocabulary, early contacts with Indo-Iranian, as well as loanwords from unknown sources that might be connected to animal husbandry and trade of metals in the Seima-Turbino network.

1. Introduction

In the search for a holistic view of the human past one interweaves the information obtained in the fields of linguistics, archaeology and genetics. Human past has not, however, happened in a vacuum but is connected to the surrounding world – the environment. When hoping to understand how the world as we see it today has taken shape, one also needs to consider the environmental factors – such as climate – and their role in shaping the past. Connection between climatic factors and the spread of languages has been suggested for example for Bantu (Bostoen et al. 2025a, 2025b, this special issue), Transeurasian (Robbeets and Leipe, 2025, this special issue), Sino-Tibetan (Deng and d'Alpoim Guedes, 2026, this special issue), Aleut (Berge et al., 2025, this special issue) and Uralic languages (Grünthal et al., 2022a; Honkola et al., 2013; Saarikivi, 2022). The early divergences of the Uralic family have been connected both to the Holocene Thermal Maximum and the cooling climate phase after it (Honkola et al., 2013) while Grünthal et al. (2022a) more specifically connects the early spread of Uralic to the time frame of the 4.2 ka climatic event. In addition, the northward spread of Uralic languages has been connected to the warmer climatic phase after 9th century AD (Saarikivi, 2022). In this paper we present novel aspects concerning the possible connection between the 4.2 ka climatic event and the early spread of Uralic languages.

Uralic languages are spoken in a vast geographical area in northern Eurasia (Fig. 1). Of ca. 40–50 Uralic languages, only Finnish, Estonian and Hungarian have the status of a national language; the rest are spoken as minority languages in Norway, Sweden, Estonia and Russia. Some languages attested in the 19th-20th century have already become extinct and some languages that have been fragmentarily or indirectly attested in place names and medieval sources became extinct already during the medieval spread of Russian. According to the current view Proto-Uralic started to diverge ca. 4000 years ago. The spread was a fast one and took place mainly westwards from the Uralic homeland, which according to the most recent view was located in the eastern side of the Urals (see Section 2.1).

The spread of Uralic languages has previously been connected to the spread of the transcultural Seima-Turbino (ST) phenomenon (Kallio, 2006; Häkkinen, 2009: 45–51; Parpola, 2012: 158–162, 2022; Nichols, 2021; Grünthal et al., 2022a; Vesakoski et al., 2025), which has been characterized as a transcultural network of bronze traders (see Section 4.3.1). Most of the ST artefacts have been dated to 4200–3900 BP (Marchenko et al., 2017) coinciding with the current view of the divergence of Proto-Uralic (Grünthal et al., 2022a; Kallio, 2006). There is also a spatial match as the most important ST sites are located along the east-west river network (Irtysh - Kama - Oka), which is also the area to where the Uralic proto-languages have been situated (Fig. 2; Saarikivi, 2022). Nichols and Rhodes (2018: 59–60) suggest that the spread of Finno-Ugric languages (i.e. excluding the spread of Samoyedic) needs to be explained by their dominant role in the east-west trade network including the trade of for example metal items and furs. This trade took place along the same river network where ST operated; they call it the Fur Road (Nichols and Rhodes, 2018: 60).

More complex models concerning the factors contributing to the early Uralic spread have also been presented. These models include

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climate change as the ultimate inducer of events. In Honkola et al. (2013) the emphasis is on the Holocene Thermal Maximum and the cooling phase after that which supposedly affected speaker populations via the carrying capacity of the environment. Their quantitative phylogeny gave a notably older date for the Proto-Uralic divergence (ca. 5300 BP) than what is nowadays the consensus (ca. 4000 BP). Due to this their matching of climatic events and the spread of Uralic languages may be seen as outdated.

In Grünthal et al. (2022a; reviewed in Nichols, 2021) the focus is on events that took place around the current view of the time of the Proto-Uralic divergence (ca. 4000 BP), that is, the 4.2 ka climatic event, the concurrent ST phenomenon and contacts with the speakers of Indo-Iranian. The authors suggest that the drought brought by the 4.2 ka climatic event to the steppe and continental interiors – together with bubonic plague and salmonella – affected more the herding and farming populations speaking Indo-European languages than Uralic hunter-fishers living in the forest-steppe. Due to the population decline of the Indo-European speakers, Uralic-speakers were able to prosper and get a firm foothold in certain locations in the area (Grünthal et al., 2022a; Nichols, 2021). This chain of reasoning provides a possible explanation of what made Uralic spread possible and why Uralic languages were able to stay in this territory. It does not, however, explain what *induced* the early spread of Uralic languages. Instead Grünthal et al. (2022a) suggest that "– early Uralic speech spread rapidly along the waterborne trade network north of the steppe, expanding as part of the same interregionalization as ST." Nichols (2021) summarizes this in the following way: "The 4.2 ka event and its effects on the various Indo-European-speaking societies provided just such an occasion, weakening preexistent economies, expanding trade economies and networks, and triggering the Uralic spread." In this paper we discuss potential inducers of the early Uralic spread.

The 4.2 ka climatic event was a major Holocene climate episode recognized since early studies with reductions in monsoon precipitation and increases in aridity in Mesopotamia, the Aegean, Egypt, the Levant, and parts of China (Singh, 1971; Cullen et al., 2000; DeMenocal, 2001; Weiss et al., 1993; Ran and Chen, 2019) (Fig. 3a). The 4.2 ka event should not, however, be viewed as a global drought event. Previous literature reviews (Booth et al., 2005; Railsback et al., 2018; Helama, 2024) show that wet conditions seem to have prevailed towards higher latitudes (Fig. 3b-c), over a wide spread of sites in central/northern Europe and sub-Saharan Africa. In addition, cold conditions have been reported – albeit less frequently than hydroclimatic anomalies (Helama, 2024). A specific characteristic of the 4.2 ka climatic event is that the reconstructed conditions are commonly connected to collapses or at least transformations of cultures, especially inside the traditional study region, where the cultural responses are seen to reflect deficits in water supply (Cullen et al., 2000; DeMenocal, 2001; Weiss et al., 1993; Ran and Chen, 2019). The published evidence for cultural linkages, especially those often correlating on-site archaeological evidence with off-site climate records, have, however, been contested (Jaffe et al., 2019). It is emphasised that the research confusing such correlations with monocausal narrative may fail to recognize the more complex behaviour of human populations (Jaffe et al., 2021).

Contacts with Indo-Iranian have played a central role in the study of early spread of Uralic (Carpelan and Parpola, 2001; Grünthal et al., 2022a; Häkkinen, 2023b; Kallio, 2006; Parpola, 2012, 2022); these contacts are the earliest uncontroversial contact episode between Indo-European and Uralic. The earliest Indo-Iranian loanwords were not borrowed to Proto-Uralic but to Common Uralic i.e. a continuum of Uralic dialects after the Uralic protolanguage had already diverged (Grünthal et al., 2022a). This argument is based on an observation that the number of Indo-Iranian loans varies between different branches of

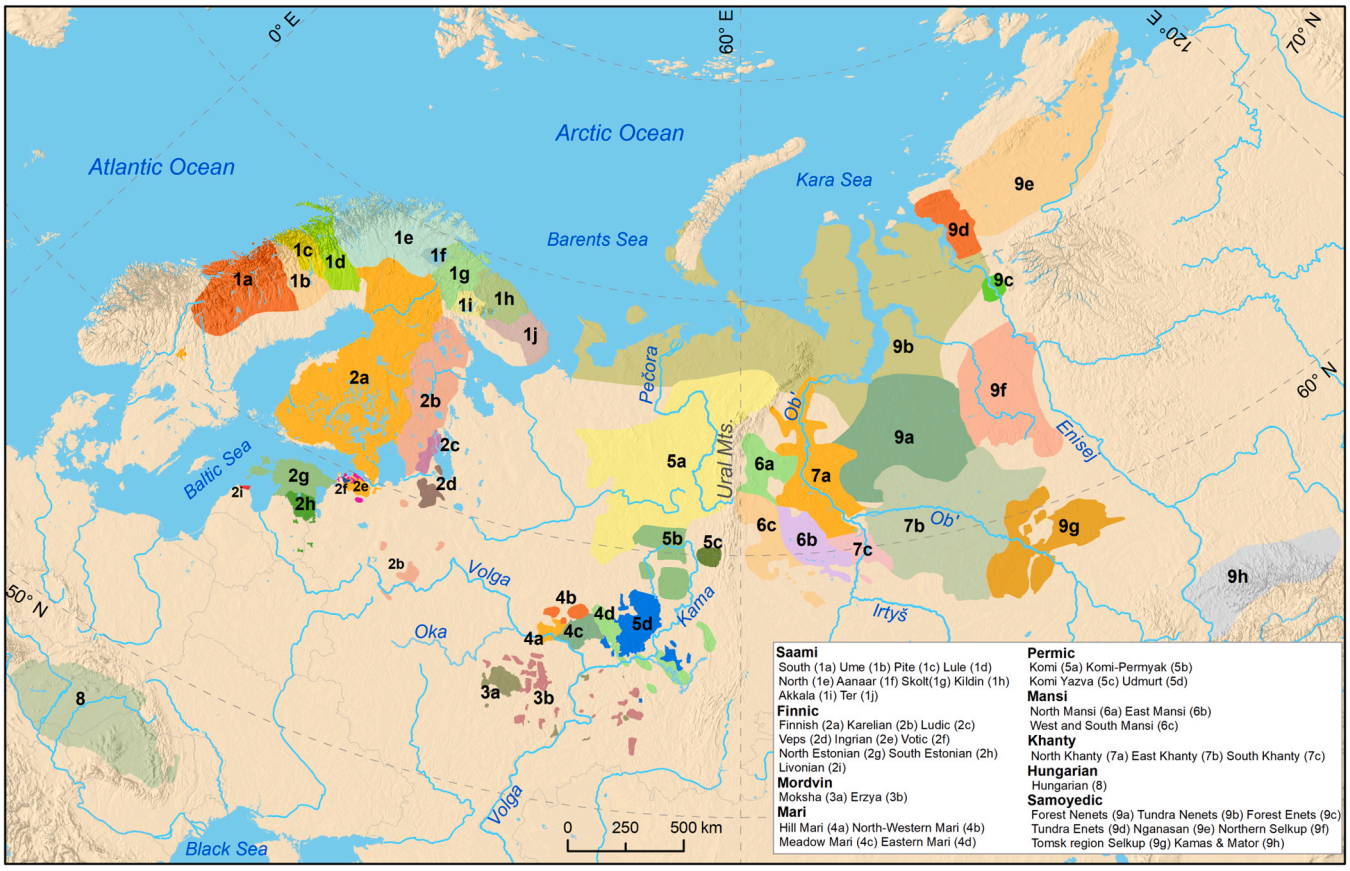

Fig. 1. Uralic languages at the beginning of the 20th century and the main branches to which they belong to. Map produced by Timo Rantanen in the URHIA project (Rantanen et al. 2021, 2022).

Uralic and that there are phonological discrepancies in the early loans in different Uralic languages (Grünthal et al., 2022a). The contacts with Indo-Iranian have been irreplaceable in the search of an absolute time for the Proto-Uralic divergence as Proto-Indo-Iranian can be more securely dated thanks to the old written evidence of Iranian and Indo-Aryan, the earliest of which dates to before 3000 BP (cf. Kümmel, 2020); according to the current view the divergence of Proto-Uralic took place ca. 4000 BP (Grünthal et al., 2022a; Kallio, 2006).

In this paper we study the possible connection between the 4.2 ka climatic event and the early spread of Uralic languages. We take a closer look at the climate data connected to this event in the geographical area relevant to the Uralic spread, that is, the southern part of the Eurasian forest zone and the steppe south from it. We discuss the possible effects of this event on the ecology and hydrology in the forest zone and in the areas south from it; what kind of changes it induced in forest, steppe and desert ecosystem services and how these changes potentially contributed to the early spread of Uralic. All this is reflected with up-to-date information about Indo-Iranian loanwords in Uralic languages. We discuss the possible cultural influences that can be inferred from the loanword material and present new arguments concerning the stratigraphy of some loanwords.

2. Early spread of Uralic

2.1. Proto-Uralic

2.1.1. Cultural vocabulary

Linguistic palaeontology is one of the few linguistic methods that can contribute to reconstructing the culture and possibly the geographic settings of the Proto-Uralic speakers (cf. Fox, 1995). It also is frequently used in discussions of the history of different language families. It has, however, often been noted that reconstructing the vocabulary of a protolanguage spoken thousands of years ago always gives a fragmentary picture (Clackson, 2013; Mallory, 2001: 355; Kallio, 2006: 8; see Holopainen, 2022 and Vigh, 2024 for different viewpoints on Uralic linguistic palaeontology). Despite its limitations, it is worth taking into account what information the reconstructed vocabulary holds in the search of the Uralic homeland. It is to be noted that the earlier presentations like the one by Häkkinen (2001) are based on the partly outdated material of UEW.

According to the current view ca. 300 words can be reconstructed to Proto-Uralic (Aikio, 2022: 23). Among other words, these include words to describe both the local environment and the culture of the speakers. Reconstructed words related to the environment include names of certain trees (such as *kojwV ‘birch’, *kuwsi ~ *kowsi ‘spruce’, *d’e̮mi ‘bird cherry’) and different kinds of animals: small mammals (*ćijili ‘hedgehog’, *šiŋiri ‘mouse’), birds (such as *lunta ‘goose’), fish species (*säwnä ‘Cyprinus (?)’, *särkV ‘Leusiscus (?)’) and insects (e.g. *kuńći ‘ant’). Animal names include also fur animals; we will discuss these in Section 4.1.1. There are also words such as *orkV ‘valley, riverbed’ and *ćud’a ‘rime/glaze ice’ to describe the landscape.

Considering cultural vocabulary there are words describing the use of fire (such as *peji- ‘to cook’, *lämi ‘broth, soup’, *japći- ‘to roast on a fire’); words for *jeŋsi ‘bow’, *ńeli ‘arrow’ and related technology, probably connected with hunting; words related to fishing (such as *kalimV ‘net’, *woča ‘fishing weir’); words for other tools (*pata ‘clay

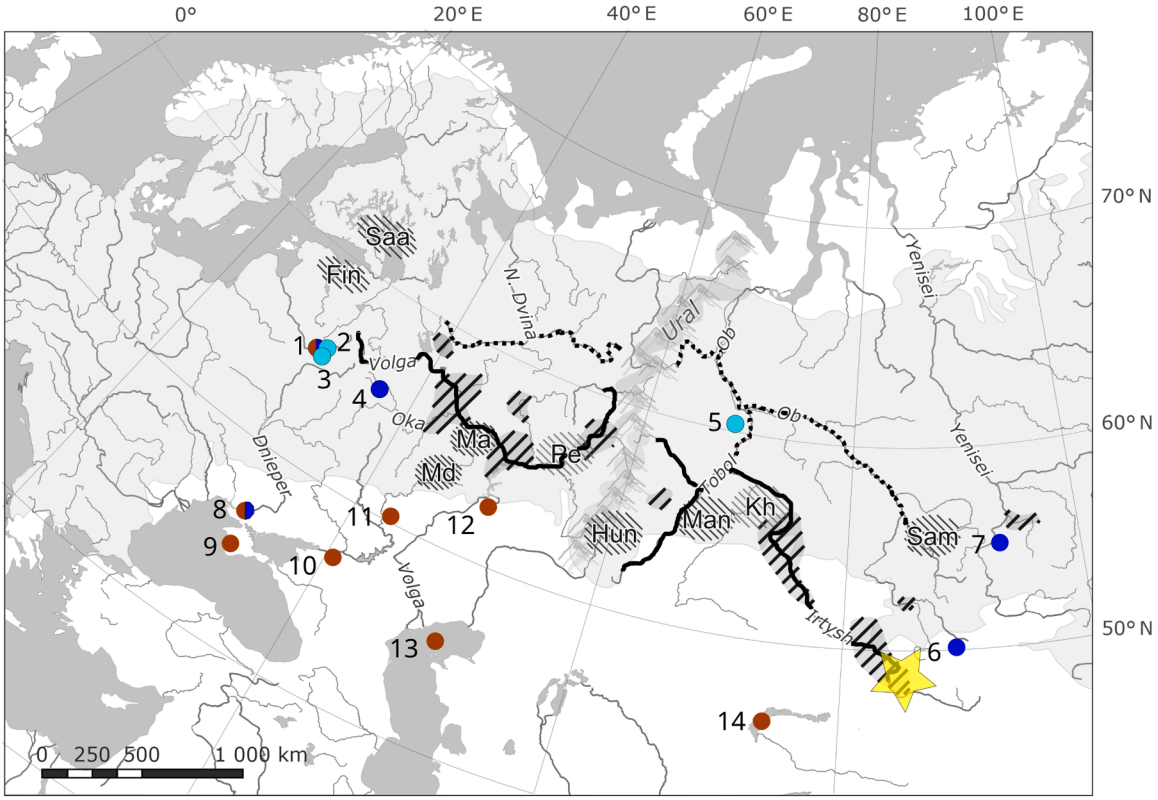

Fig. 2. The effects of the 4.2 ka climatic event in northern Eurasia. Coloured circles indicate locations from which there is palaeoclimatic proxy data concerning the 4.2 ka climatic event. Colour coding: cyan = wet; blue = cold; brown = dry. More information about the climate conditions in these locations is provided in Table 1 (for locations 1–7) and in Table 2 (for locations 8–14). Yellow star indicates the suggested location of origin of the ST phenomenon (Marchenko et al., 2017 and references therein). The base map is the same used in Nichols (2021) and Grünthal et al. (2022a) showing recent and modern forest zone (light shaded band; tundra to north, steppe to south), the suggested speaker areas of different Uralic proto-languages (finer hatching with labels: Fin = Finnic, Saa = Saami, Ma = Mari, Md = Mordvin, Pe = Permic, Hun = Hungarian, Man = Mansi, Kh = Khanty, Sam =Samoyed; the locations of the hatched areas of Fin, Md, Ma, Pe and Sam differ from those given in Grünthal et al., 2022a), major ST sites (upward coarse parallel hatching) and major travel and trade routes (heavy line along rivers = southern route; heavy dotted lines = northern route).

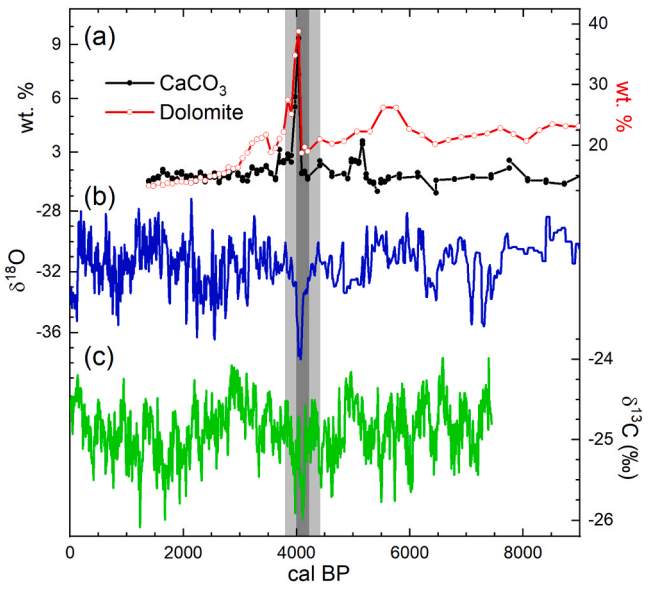

Fig. 3. Characterisation of the 4.2 ka climatic event (a) as a classical site of the Gulf of Oman where increases in dolomite % wt. and $CaCO_3$% wt. indicate aeolian activity (Cullen et al., 2000), (b) in the Mt Logan in Yukon as a peak of less negative $\delta^{18}O$ indicative of increased moisture (Fisher et al., 2008), (c) in the northern European tree-ring $\delta^{13}C$ chronology where the isotopic enrichment likely occurred during wet/overcast conditions (Helama and Oinonen, 2019). Dark and light grey shading show the timeframes of the 4.2 ka event characterised either as a short (4.2–4.0 ka) or long (4.4–3.8 ka) episode, respectively.

pot', *äjmä 'needle'); some words related to transportation (*suksi 'ski', *suxi- 'to row'); a handful of words related to mythology or shamanism (including some uncertain etymologies, such as *nojta 'shaman' with irregular reflex of the *o vowel in the Mansi cognate, cf. Zhivlov, 2014: 137). Interesting terms also include numerals ('one' to 'seven') and kinship terms (such as *käliw 'in-law'). For example, a number of terms for relatives like 'in-laws' can be reconstructed, as well as word for 'mother', but no words for siblings (for the reconstruction of Proto-Uralic kinship system see Metsäranta et al., 2025).

There are many words that cannot be reconstructed to Proto-Uralic and the loss of words due to later borrowings is a natural phenomenon in languages, especially as great time depth is concerned. It should be noted that words can be replaced also due to taboo. For example, no Proto-Uralic words for 'bear' or 'elk' can be reconstructed, even though it is quite natural to assume that such animals would have been known to Proto-Uralic speakers. Especially the names for 'bear' in later Uralic languages show frequent replacement because of taboo, due to the high importance of bear in the traditional religion and folklore (Bakró-Nagy, 1979; Piha, 2022).

Finally, despite there are always risks in making inferences from absent words (as absence of evidence is not evidence of absence), it is worth noting that no terms for domestic animals can be reconstructed to Uralic protolanguage. There is also a complete absence of words related to maritime environment or culture (Grünthal et al., 2022a; Kallio, 2006).

2.1.2. *Location of "homeland"*

The reconstructed vocabulary (discussed in Section 2.1.1) points to an inland hunter-fisher society, living in the northern taiga zone. It is also clear that the spread of Uralic varieties (Saami, Samoyed, Khanty) to tundra happened much later (Saarikivi, 2022; Abondolo and Valijärvi, 2023: 5–6). While the majority of the Uralic sub-branches are connected to the forest zone, Ugric (Hungarian, Khanty and Mansi) is an exception to this as it has long been assumed that the linguistic ancestors of the Ugric speakers at some point of prehistory adopted equestrian nomadism and lived in a steppe environment (see Section 2.2.3). The Hungarian speakers continued to live as nomads in the steppe regions until the early mediaeval times.

Despite the consensus concerning the location of Proto-Uralic in the northern boreal forest, there are differing views about on which side of the Ural Mountains Proto-Uralic was spoken. Homeland in the Volga-Kama region in the European part of modern-day Russia (see e.g., Salminen, 2001) as well as a homeland in the western Siberia (see e.g., Janhunen, 2009, 2014) have been the two candidates that have been supported. In recent years, the eastern homeland has received more support from areal linguistics and multidisciplinary research (Abondolo and Valijärvi, 2023; Grünthal et al., 2022a; Németh and Vigh, 2021; Nichols, 2021; Vigh, 2024; Metsäranta et al., 2025). Recently also other non-western locations have been suggested for the Proto-Uralic homeland. Häkkinen (2023b) supports homeland around the Ural mountains (i.e. slightly to the west from western Siberia), while Vesakoski et al. (2025) suggest that Proto-Uralic was spoken in Altai-Sayan mountain region (i.e. more east from western Siberia). Nevertheless, in both cases the views concerning the spread of the Uralic languages do not significantly differ from other recent research (for this see Section 2.2.1).

2.2. *From Proto-Uralic to Common Uralic*

2.2.1. *The early spread*

The initial spread of the Uralic languages from western Siberia to large parts of northern Eurasia seems to have been a fast process; Salminen (2001, 2002) has noted that the difficulties in reconstructing intermediary protolanguages connecting different branches of the family can be explained with a fast spread, and the presence of early Indo-Iranian loanwords with skewed spread and phonological discrepancies also points to this conclusion (see also Kallio, 2006). Indo-Iranian loanwords are also the ones which are used to date the divergence of Proto-Uralic to ca. 4000 years ago (Grünthal et al., 2022a; Kallio, 2006) as Uralic cultural vocabulary is not very helpful in this task. The recent research on Uralic spread (such as Nichols, 2021; Grünthal et al., 2022a) fits Salminen's initial ideas. Furthermore, research connecting linguistics with archaeology (such as Lang, 2020) suggests that early forms of Finnic and Saami reached the Baltic Sea area ca. 3000 BP, ca. 2500 BP the latest (summarized in Pesonen et al., 2025). Thus although it is difficult to precisely determine the early speech areas of Uralic, the current research presents a picture of early varieties of Uralic being spoken in a chain-like formation over the central parts of northern Eurasia during the Bronze Age as a result of a rapid spread (Fig. 2).

Grünthal et al. (2022a) use the term *Common Uralic* to describe the early continuum of Uralic varieties that took part in the initial spread. It is technically a matter of terminology how the early varieties are called, but it is clear that when Uralic spread over this huge region, one cannot speak of *Proto-Uralic* anymore, as the reconstructed protolanguage commonly denotes the last variety that existed before the initial divergence. *Common Uralic* can be used as a term describing the already diverged varieties of Proto-Uralic, but it is essential to keep in mind that it was not necessarily a continuum of mutually intelligible Uralic dialects, but the term simply describes the different post-Proto-Uralic varieties that were in contact with Indo-Iranian (and possibly with other, unknown donor languages; Indo-Iranian loans are discussed in Section 4.2.2). The role of Samoyed is particularly interesting. It is the only group that spread to the east after the divergence of Proto-Uralic and there is only a small number of Indo-Iranian loanwords in this branch. This shows that it was only marginally connected with the other branches during the so-called Common Uralic period.

2.2.2. *Contacts with Indo-Iranian*

Different views on the beginning of the Indo-Iranian contacts with Uralic languages have been advocated in recent literature. While there is little doubt that early loans were borrowed from Proto-Indo-Iranian, it is disputed whether the earliest influences reached Proto-Uralic already

(as assumed by, e.g., Rédei, 1986; Holopainen, 2019, and recently by Häkkinen, 2023b) or whether already the earliest loans were borrowed into a continuum of Uralic dialects ("Common Uralic"), after the Uralic protolanguage had already diverged (see Section 2.2.1). While it has been clear for decades that some of the earliest loans show irregularities that point to parallel borrowing into the already separated Uralic varieties (such as Metsäranta, 2023; Zhivlov, 2023; Holopainen and Aikio, 2023), it now seems that there are next to no early loans that could be unambiguously reconstructed to Proto-Uralic. Those few cases that do not show major phonological irregularities show skewed distribution within Uralic, which can be interpreted as evidence for parallel borrowing (as argued by Grünthal et al., 2022a). It should also be stressed that according to the most recent research on Indo-Iranian prehistory (Palmér, 2025), the linguistic predecessors of Proto-Indo-Iranian arrived to Central Eurasia through a western route in Eastern Europe, putting the earliest phases of Indo-Iranian relatively far from the suggested Proto-Uralic homeland. Thus our view is that the first Indo-Iranian contact was not with Proto-Uralic but Common Uralic instead. As a result, these contacts with Indo-Iranian have nowadays the primary role in dating the divergence of Proto-Uralic (see Section 1). It is also commonly accepted that the Uralic languages have been influenced by different prehistoric stages of Indo-Iranian at different times. The earliest loans represent a very archaic stage of (Proto-)Indo-Iranian, and there are later Iranian loans in most branches of the Uralic family; especially the Permic languages and Hungarian feature a large number of clearly late Iranian loans (see Holopainen, 2019; Metsäranta, 2020).

Words reconstructable to Proto-Indo-Iranian paint a picture of a society with social hierarchy, pastoral means of subsistence, horse breeding, wheeled vehicles, beekeeping, mythology and trade (see e.g., Carpelan and Parpola, 2001; Palmér, 2025: 227–228). Considering the old age of the borrowings, a notable number of loanwords have been borrowed to Uralic from different stages of Indo-Iranian; our focus here is on the earliest loans that display phonological features pointing to early borrowing and that are found widely in the Uralic languages. Although some early Indo-Iranian loans such as the words for 'hammer' and 'rope', are more difficult to tie to specific cultural influences, from the perspective of this paper particularly interesting are the possible names for metals, tools and technology as well as the terms possibly referring to apiculture and domestic animals as these terms may be connected to cultural features which contributed to the early spread of Uralic. These etymologies will be addressed in Sections 4.2.4 and 4.3.2.

Examples of loanwords that are clearly early and also point to important cultural influences are the word for 'hundred': PU (?) *ćęta 'hundred' (> Finnish *sata*, North Saami *čuohti*, Erzya Mordvin *śado*, Mari *šüδö*, Hungarian *száz*, West Mansi *šętˇ*, North Khanty *sat*) ← PIIr *ćatám (> Sanskrit *śatám*, Avestan *satəm*) id.; the word shows aberrant *š in Mansi instead of the expected Proto-Mansi *s, which has been interpreted as a sign of a separate borrowing into Pre-Mansi (see Zhivlov, 2023); a similar case of irregularity is the word for 'thousand' in Permic and Mansi, borrowed from Indo-Iranian *ǰhasra-. The word for 'slave', borrowed from the Indo-Iranian ethnonym: Proto-Uralic (?) *orja 'slave' (> Finish *orja*, Erzya Mordvin *ura* 'slave, servant', Udmurt *var* 'servant') ← Proto-Indo-Iranian *ārya- 'Aryan', cf. Sanskrit *árya-*; the word for 'merchandise', Uralic *wosa (?) ← PIIr *wosaH, which likewise shows aberrant cognate in Mansi, pointing to parallel borrowing (Holopainen, 2024: 52–55); and the word for 'lord' (Mordvin *azor*, ansi *ōtər*), borrowed from Indo-Iranian *(H)asura- 'lord, god'.

2.2.3. Loanwords from unknown sources

In addition to loanwords from known sources, in recent research it has been convincingly argued that all the Uralic languages display loanwords (probable substrate words or Wanderwörter) from unknown languages (Aikio, 2015b; Holopainen, 2023b). Such words include the words for 'metal' (Fi *vaski* etc.; see Section 4.3.2) and 'sheep' (Fi *uuhi* etc.; see Section 4.1.2). These words are important for the spread of the Uralic languages as such, but they cannot be used in the reconstructions of *Proto-Uralic* culture and homeland.

Relevant for our research are the probable substrate words in both "Ugric" and "Finno-Permic" languages. There is a group of horse-related cultural vocabulary (such as Hungarian *ló* 'horse' ~ East Mansi *lo* ~ East Khanty *loγ*, Hungarian *nyerëg* 'saddle' ~ East Mansi *naγər* ~ East Khanty *nöγər*) limited to Ugric languages (see Holopainen, 2023b for a recent overview). This vocabulary has been borrowed from some unknown source (or sources). The Ugric languages also adopted some Indo-Iranian loans probably at the same time as the equestrian vocabulary was acquired (see Section 4.2.2).

While the Ugric languages were in contact with unknown languages of the steppe, the so-called Finno-Permic languages acquired substrate vocabulary related to agriculture, flora and fauna from unknown languages of eastern Europe (Aikio, 2015b: 44–47). These words are discussed in Section 4.1.2.

3. The 4.2 ka climatic event

The spatial pattern of the 4.2 ka climatic event has been described as a pattern of "cool poles, dry tropics" (Mayewski et al., 2004). It has also been formally ratified by geologists as the boundary between the Middle- and Late-Holocene (Walker et al., 2018) (Fig. 4a). This boundary was later dated to 4.14 ka by an isotopic tree-ring record collected from sites downwind to the North Atlantic (Helama and Oinonen, 2019). The development of the event is typically characterized either as a short (4.2–4.0 ka) or long (4.4–3.8 ka) episode (Fig. 4b), and it is frequently discussed in the context of longer-term Holocene climate variations (Helama, 2024). Despite the palaeoclimate evidence from multiple continents (Booth et al., 2005; Railsback et al., 2018; Helama, 2024), critical views have also been expressed (Wanner et al., 2008; Parker and Harrison, 2022; McKay et al., 2024). In short, the criticism mainly concerns the putative global spread of the event. That is, even the critical views accept that palaeoclimate datasets do indicate significant climate excursions around 4200 years ago, but while doing so they do not concur with anomalies in large, coherent spatial regions (McKay et al., 2024).

Considering the 4.2 ka event was not a global drought event necessitates discussing its impacts on prehistoric societies on similarly restricted spatial climate patterns (Nan et al., 2025). Accordingly, we focus on climate records from sites more relevant to our study region. A recent review of palaeoclimate evidence topical to this age (Helama, 2024) included only seven (out of the 317) papers roughly covering the domain of Eurasia we are interested in here (Fig. 2). Further, up-to-date literature shows data from two more papers published in 2023–2024. This evidence is itemised in Table 1. These studies show a variety of indications that have likely taken place around the region of interest. The results cannot be summarised in one or two parameters. What seems to be frequently observed, however, is the change in both thermal and hydroclimatic indications. First, several studies refer to colder conditions, which can also be inferred from the increase of tundra biome and decreasing arboreal pollen percentage. Second, increase in moisture is indicated by rising water levels and increased paludification, possibly also by peat humification (Fig. 2; Table 1). According to age estimates, the indicated phase may have lasted from 200 to 700 years. However, many of the papers reported the date of the event simply with mid-point, such as 4.2 ka.

Overall, the studies conducted in the region of interest seem to agree with previous review papers, suggesting that the climate during the 4.2 ka event went through a phase of cooling and hydroclimatic perturbations. The duration of the event in this region cannot be described as short or long, although the simplified reporting of the dates limits the value of this interpretation. An interesting finding is that, in contrast to the drought what is generally accepted based on the climatic records from the sites of monsoon precipitation i.e., the key region of the 4.2 ka event, the studies appear to demonstrate increases in water supply at least to the northwesternmost sites included in this comparison (Fig. 2). Again, this concurs with the previous findings of poleward increases in

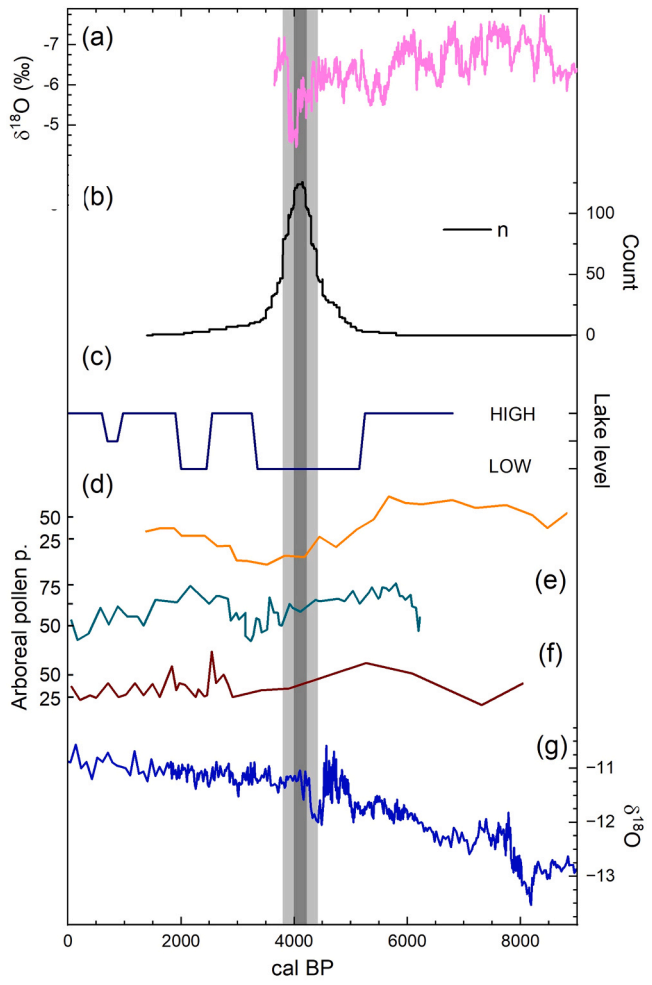

Fig. 4. Palaeoclimatic evidence of the 4.2 ka event described (a) in the $\delta^{18}O$ chronology from Mawmluh Cave speleothem (northeast India) (Berkelhammer et al., 2012) ratified as the Global Stratotype Section and Point for the lower boundary of the Late Holocene Age/Stage (Walker et al., 2018), (b) as a temporal distribution of dating placements of the event as collected from of 317 papers with palaeoclimatic/palaeoenvironmental evidence of the 4.2 ka event (Helama, 2024), and (c) a composite record of relative lake levels of Lake Balkhash (southern Kazakhstan), modified after Krementski (1997). Arboreal pollen percentages from (d) Orgeev in Moldova, (e) Lipigi in Don Valley (f) and Mokhovoe in Kazakhstan, digitised from Kremenetski (2003), representing a west-east transect through the forest-steppes and steppes. (g) A stalagmite $\delta^{18}O$ curve from southern Ural Mountains indicative of colder winter temperatures between 4.6 and 4.2 ka (Baker et al., 2017). Dark and light grey shading show the timeframes of the 4.2 ka event characterised either as a short (4.2–4.0 ka) or long (4.4–3.8 ka) episode, respectively.

moisture, at least as reported for the European continent.

This evidence can be compared with those presented by Kremenetski (2003) and Krementski (1997) who compiled Russian palaeoclimatic literature with records from northern Siberia to steppes of Ukraine, Southern Russia and Kazakhstan. Based on this literature, the climate became colder and more continental between 4.5 and 3.5 ka especially in the northern Siberia but, in contrast to humidity that was reported from the western/northern sites, considerably drier in the southern parts of the region (the south of western Siberia and Kazakhstan). The phase of arid climate evident in the steppe and forest-steppe belts in the Ukraine, southern Russia and Kazakhstan is generally characterising the region between 5200 and 3800 BP (Table 2); this points towards the drier climatic phase coeval to the 'long' 4.2 ka climatic event. According to these reviews, continentality and aridity represented conditions close to modern ones (despite this was not seen in all locations Fig. 4c). Forested areas were decreased (Fig. 4d-f), ranges of broadleaved trees reduced, and steppes around the studied sites became more xeric (see also Demkin et al., 1997; Kremenetski et al., 1997). Topically, the colder conditions in the region of the southern Ural Mountains were more recently confirmed by negative excursion of stalagmite isotopes between 4.6 and 4.3 ka (Fig. 4g) (Baker et al., 2017) and thus at least partially overlapping the 4.2 ka event.

Overall, considerable palaeoclimatic efforts have focused on the 4.2 ka event. Unfortunately, the most recent literature seems to concentrate on sites mainly beyond the region of our interests, that is China and India, which generally demonstrate drier conditions formed under monsoonal climate. The westernmost part of our study region seemingly indicates strengthening of moisture-carrying midlatitude westerlies, their influences further east being hypothetically modified in winter by large-scale air pressure patterns over Siberia (Perşoiu et al., 2019). Eventually this led to colder and drier conditions in the eastern part of our study region, as recorded from the southern Ural Mountains to central Mongolia (Baker et al., 2017; Bliedtner et al., 2023; Karachurina et al., 2023).

Considering that this region belongs to the upstream source areas of River Irtysh, it is conceivable that the 4.2 ka event did also affect the river runoff and thus indirectly the riverine societies depending on the corresponding ecosystem services. Following modern-day hydroclimate estimations (Zhang et al., 2017), the palaeoclimate evidence of increased aridity and colder summer climate would indicate considerably reduced runoff from the Altai mountains during the 4.2 ka event, where glaciers are indeed known to have advanced between 6.0 and 3.0 ka (Nazarov et al., 2012), potentially reinforcing the interpretation of a long-term reduction in downstream water supply over that period. Moreover, the recent Irtysh River runoff appears to be fed by the moisture-carrying midlatitude westerlies (Chen et al., 2016). In a longer perspective, also this mechanism could be linked to the reduced water supply from the upstream headwaters during the 4.2 ka event, via the atmospheric blocking pattern hypothesised to have led to the coeval drought in the region (Perşoiu et al., 2019). Interestingly, contrasting hydroclimatic conditions may have compensated for the reduced runoff in more western and northern sites where the 4.2 ka event was wetter, making these sites more favourable for riverine settlements depending on sufficient water supply.

In any case, the climate of the 4.2 ka event ought not to be considered uniform over wide regional scales and not invariable through its multicentennial interval, during which drier and wetter episodes may have alternated in central Asia (Wolff et al., 2017). Again, these findings concur with those describing the 4.2 event either as a long (multi--centennial to near-millennial) or short (bicentennial) episode, that may have been punctuated with multiple phases of even more anomalous climatic conditions (Helama, 2024).

4. Potential factors contributing to the Uralic spread

4.1. *In the forest zone*

4.1.1. *Changes in forest ecosystem services*

Based on evidence from linguistic palaeontology the Proto-Uralic homeland was located in or near the Eurasian boreal forest zone (i.e. taiga) (see Section 2.1) characterized by evergreen coniferous forests. Several large rivers run through the forested landscape such as Ob and its tributaries (e.g. Irtysh and Tobol) and Volga and its tributaries (e.g. Oka and Kama) creating a travel route between east and west (Fig. 2). Most likely this route has been used for transportation and trading of for, example, furs since prehistoric times, due to which Nichols and Rhodes (2018: 59) call it the Fur Road. Nevertheless, it was only the ST phenomenon (see Section 4.3.1) that made this route visible as metal items preserve notably better than items made of organic matter (Nichols and Rhodes, 2018: 59).

Taiga is the ecological environment for several species, which have

Table 1
Characterisation of the 4.2 ka event in sites relevant to the study region (Helama, 2024), itemised by the first (FY), mid (MD) and/or last year (LY) of climatic or environmental change in kiloyears, latitude (LA) and longitude (LO) of the site, and the indication given in the original paper (within parentheses our interpretation of this indication). Numbers in the # column refer to the numbers in Fig. 2.

#	Site	FY	MD	LY	LA	LO	Indication	Reference
1	W Russia		4.2		55.63	31.53	Cold and arid	(Mroczkowska et al., 2021)
2	W Russia		4.2		55.63	31.55	Increase in water level	(Mazurkevich et al., 2020)
3	W Russia		4.2		55.63	31.53	Higher water level	(Wieckowska-Lüth et al., 2021)
4	W Russia	4.5			55.82	37.92	Paludification and peat deposition probably associated with a sharp cooling, changes in moisture and groundwater levels	(Mazei et al., 2023)
5	W Siberia		4.2		60.90	68.66	Increased peat humification (= increase in moisture)	(Tsyganov et al., 2021)
6	Altai Mts.	4.3		3.8	50.53	87.70	Increases of tundra biome	(Karachurina et al., 2023)
7	S Siberia		4.1		55.93	92.95	Cooling	(Columbu et al., 2023)
-	E Siberia	4.2		4.0	54.23	106.47	Cooling and decreasing arboreal pollen percentage	(Kobe et al., 2022)
-	SE Siberia		4.4		56.05	130.55	Decrease in arboreal pollen percentage (= cooling)	(Courtin et al., 2021)

Table 2
Palaeoclimatic data collected by Kremenetski (2003) from literature representing sites from the steppe and forest-steppe belt of Eurasia, focussing here on indications relevant to the 4.2 ka event. In the impact column within parenthesis is our interpretation about the impact in certain, more specific geographic locations. Numbers in the # column point to the numbers in Fig. 2.

#	Area	Start cal BP	End cal BP	Impact
	Moldova & Ukraine	4800	4000	Forest covering river valleys reduced. Steppe more arid.
8	• Kardashinskoe			(cold & dry)
9	• Lake Saki	4125	3700	(dry)
	Don Basin	4700	4000	Arid and continental climate.
10	• Razdorskoe			(dry)
	Southern Russia	4800	4000	Phase of maximum aridity. Reduced forest area.
11	• Lipigi			(dry)
	South Russian & forest steppes	5200		Climate drier and more continental. Pine forests reduced.
12	• Buzuluk			(dry)
13	**Caspian Sea**	4350	3950	Regression of the Caspian Sea (dry)
	Kazakhstan	5200	3900	Arid climate
14	• Lake Balkhash	4990		Regression in Lake Balkhash (dry)

been hunted for their fur; some of them also for their meat. These include animals such as pine marten, red fox, European beaver, red squirrel, brown bear and mountain hare (Kirkinen, 2019: 31, 55). In addition to being a valuable animal for its meat and fur, European beaver was also valuable for castoreum, an oily glandular secretion, with which beavers mark their territorial boundaries (Kirkinen, 2019: 55). It has been used for medical purposes and in perfumes for millennia and indeed, castoreum contains e.g. salicylic acid which is the active ingredient in aspirin (Müller-Schwarze, 2011: 42).

Names for several fur animals can be reconstructed to Proto-Uralic. These are at least *ńoma 'hare', *ńukiś 'marten' and *ora 'squirrel' as well as possibly *majaka 'beaver' (which lacks cognates in Ugric and Samoyedic, however). As noted in the Section 2.1.1., the names of 'bear' and 'elk' might have been lost due to taboo, due to their probable high importance in mythology and culture of the Uralic speaking taiga populations. This suggests that speakers of Proto-Uralic were living in the same ecological environment as these animals, especially as also several other environmental terms can be reconstructed to Proto-Uralic (see Section 2.1.1). This group of names for fur animals may perhaps also be indicative of the possibility that speakers of Proto-Uralic participated in the fur trade. In fact, it has been suggested that speakers of Uralic could have had a dominating role in the trade network as that could explain the vast spread of the languages (Nichols and Rhodes, 2018: 60).

Among the fur animals listed above, beaver is of special interest. In addition to being a source for fur, meat and castoreum, it is a keystone species meaning that its impact on its ecological community is disproportionately large relative to its abundance. Beavers create habitats for plants, animals and people by removing trees and damming up water (Müller-Schwarze, 2011: 135). The Beaver ponds provide habitats for example to mammals such as mink, raccoon, white-tailed deer, bear and moose, to birds including different species of waterfowls and to fish species including pike and salmon (Müller-Schwarze, 2011: 138–142). For humans the beaver meadows have been favourable sites to start agriculture as the areas are flat, the soil is fertile and majority of the trees have already been cut down (Müller-Schwarze, 2011: 142–143). For their own habitat, the most important thing is water. They also need woody vegetation for the winter – North American beavers prefer aspen, those in Europe willow – but otherwise the beaver is quite flexible in what they eat, as long as the food supply is reliable (Müller-Schwarze, 2011: 118–143).

Here we propose a scenario in which the 4.2 ka climatic event affected the hydroclimatic conditions and runoff of the river systems, for example that of Irtysh and its tributaries (see Section 3). While this perhaps did not have a significant effect on the runoff of the largest river streams, the effect could have been notable with smaller side streams – the potential habitats of beavers. This possibly led beavers to move to more favourable habitats. As a keystone species their departure from one location to another likely had an effect on many other species including mammals, birds and fish. Once this group of animals moved to more favourable habitats, it potentially gave a reason also to humans to change their location; this is because most likely at least some of these animals were consumed by local hunter-fisher populations - perhaps also the speakers of Proto-Uralic.

4.1.2. *Non-Uralic farming populations*

The western Uralic languages (Finnic, Saami, Mordvin, Mari and Permic, in traditional terminology "Finno-Permic"; see Section 2.2.3) display a number of shared words that probably form a layer of substrate borrowings; the words such as Finnish *vehnä* 'wheat', Erzya Mordvin *viš*, East Mari *wiste*, West Mari *wištə* 'spelt' or Erzya Mordvin *čuž*, East and West Mari *šož* 'barley', Komi *ćuž* 'malt' display irregular phonological relations and consonant clusters atypical for Uralic vocabulary (Aikio, 2015b: 44–47). Many of the words belong to the semantic field of agriculture, some also to cattle breeding and animal husbandry more

generally.

We suggest that this layer of borrowings can be connected with Uralic speakers accommodating into environmental conditions: the linguistic ancestors of the western branches of Uralic adopted some form of animal husbandry (and agriculture?) when spreading west of the Urals.

In the following, we discuss the word for 'sheep', which possibly belongs to this layer, as well as two terms for 'cow'. The absolute chronology of this substrate layer has not been discussed in research so far. In addition to the animal terms discussed below, the layer of substrate loans includes terms like 'wheat', 'walnut', 'lime tree' and 'threshing cabin'. It should be stressed that further research will likely shed more light on many of the details of these substrate words, and we cannot exclude the possibility that the words represent several layers of borrowings. However, it seems quite plausible to assume that the words have been borrowed in the context of new cultural innovations.

Uralic (?) *owčV ~ *uwčV 'sheep' (cf. Aikio, n.d.) is an important but problematic term in this context. An Indo-European etymology has been suggested by Koivulehto (1991) but this has not found wide support. Koivulehto assumes a borrowing from Indo-Iranian *(H)awiš 'sheep' (< PIE *$h_2$owis) but this does not explain the affricate reflexes in Mordvin and Ob-Ugric (see below). Also, as the allegedly Proto-Uralic word shows clearly irregular reflexes, Koivulehto's idea of a borrowing into Proto-Uralic is clearly obsolete. Koivulehto also mentions the Proto-Iranian form *āwi-čī- (in Koivulehto's reconstruction; cf. EWAia, 1986), and it would be tempting to derive the Uralic words from this Iranian form. However, this derivation is based on scarce modern East Iranian data and it is unlikely that this formation would have existed in Proto-Indo-Iranian (Martin Kümmel, p.c.).

The vowel correspondences between the alleged cognates denoting 'sheep' in Uralic are irregular. Because of this, Aikio (2015b: 45) listed this word among the "agricultural" substrate words (see above). However, the presence of similar words in Ob-Ugric makes this etymology more problematic than the clear cases of substrate loans in the western languages. This kind of a distribution that stretches also eastwards is interesting: it is possible that the word for 'sheep' was borrowed very early into disintegrating and spreading Uralic dialects before the clearly western substrate words (such as Finnish *vehnä*, Erzya Mordvin *viš* etc.) discussed above. Interestingly, the word for 'flour' in the Permic languages and Mansi, recently discussed by Holopainen (2024: 55–56), likewise shows a similar kind of more "easterly" distribution. Thus it could perhaps also be a substrate loan borrowed from a lost source; it might be possible to find further examples of substrate words shared by the "western" and "eastern" branches of the family.

Concerning the problematic phonology of the 'sheep' word, Finnish *uuhi* points to earlier *Vwši, as Finnic *h* cannot reflect PU *č (Sammallahti, 1999: 76; Aikio, 2015a: 4–5). There are different possibilities to explain the Finnic *uu* vocalism: both < *ow, *uw seem to be regular according to modern views on Uralic historical phonology (Aikio, 2012: 241–243). Mordvin E *utśa*, M *učа*, on the other hand, points to old *č, making it impossible to derive the Finnic and Mordvin cognates regularly from a common source. The alleged Mari cognate *užγa* 'sheepskin' is rather borrowed from Permic (Metsäranta, 2018: 108–109). Proto-Permic *ʒž would probably fit a reconstructions *owši or *uwši, so formally Finnish *uuhi* could be cognate with the Permic word. The Proto-Permic vocalism points to *u (or *o next to labial consonants), and *ž can regularly reflect intervocalic *š or *č (Zhivlov, 2023). On the other hand, the Ob-Ugric "cognates" are also quite problematic: PMs *āš, PKh *āč (Zhivlov, 2006: 136–137); this vowel correspondence between Khanty and Mansi is not found in reliable Uralic etymologies but is typical of loanwords (Zhivlov, 2023: 149).

Another interesting term but with far more limited distribution is the word for 'cow' in Finnic (Finnish *lehmä*, Estonian *lehm* etc.). Erzya Mordvin *liś'me*, the formal cognate of the Finnic word, denotes 'horse'. It has been noted by Aikio (2015b: 45) that the Finnic and Mordvin words belong to the so-called agricultural substrate. This is a plausible idea, but it is difficult to determine whether this would have been borrowed into the predecessors of Finnic and Mordvin at the same time as the word for 'sheep' discussed above. It is difficult to assess what would have been the original meaning of the source word.

The word for 'cow' in Mordvin, Mari and Permic is also a possible substrate borrowing (Aikio, 2014: 128 footnote 1). In UEW, a noun *uskalV 'cow' is reconstructed to account for Mordvin *skal*, Mari *əškal*, *uskal* and Udmurt *iskal*, *skal* 'cow', but as the irregular variation of the word-initial vowel cannot be accounted for based on regular sound laws, it has been noted by Aikio that the words probably reflect borrowings from an unknown source, with diverging substitutions of the word-initial consonant cluster *sk-. This is a plausible idea, and it would indeed be interesting to connect the borrowing of this word for 'cow' to the layer of other animal terms discussed above (which according to our knowledge has not been done before), but the phonological problems require further research.

4.2. South of the forest zone

4.2.1. Changes in steppe ecosystem services

In search of factors contributing to the Uralic spread, we need to consider not only the conditions in the supposed living area of the Uralic speakers, the forest zone, but also the conditions in the closeby areas. The forest taiga borders in the south to Eurasian Steppe, a treeless grassland plain, which stretches across the Eurasian landmass. It has been suggested that this was the area where speakers of Indo-Iranian were living (Parpola, 2022; Palmér, 2025). Speakers of Indo-Iranian were in contact with speakers of Uralic for as long as two millennia evidenced by many layers of (Indo-)Iranian loanwords; for the purpose of this paper the early loanwords are the most relevant ones (see Sections 1 and 2.2.2).

During the Early Bronze Age (ca. 5000 BP) western, central and eastern steppe differed in their economic strategies. People living in western and eastern steppes practiced pastoralism with cattle, sheep/goats and horses, but especially in the east this was supplemented by game and fish; in the north of central steppe horse was central to their subsistence (Frachetti, 2008: 44–46). This changed at the beginning of the Middle Bronze Age (ca. 4500 BP) when there was a steppe-wide transition to mobile pastoralism. In the western and eastern steppe this meant intensification of pastoralist economies and reduction in the utilization of wild animals; in the central steppe this was the start of pastoralism with cattle and sheep/goats. This transition is described as "one of the first and most dramatic transitions of economic strategy across the Eurasian steppe" being a potential sign of increased connections between areas (Frachetti, 2008: 47).

For steppe pastoralists the most important thing is the availability of pastureland to ensure the growth of their herds. To ensure this, their life revolves around observing the environmental conditions and the seasonal changes in them. The changes in these conditions are notable in the steppic regions as they are located in the continental climate area, which is defined by notable changes especially in temperature; low precipitation and humidity is characteristic throughout the year (Frachetti, 2008: 73, 75, 77).

During the 4.2 ka climatic event the steppe became drier (see Section 3, Fig. 2, Table 2). Notably the dry period recorded from the steppe is coeval with the long 4.2 ka event, i.e. a period of 4400–3800 BP. Variation is, however, seen both in conditions and in the animal compositions of the herds (Frachetti, 2008: 48). Indeed, it has been suggested that the pastoralist herd compositions were at least partly environmentally determined (Bendrey, 2011). For example, sheep and goats are more adapted to hot and dry environments while cattle are in need of more water and pastures with better quality (Bendrey, 2011 and references therein). Thus it may be that the 4.2 ka climatic event did not mean a catastrophe to everyone living in the steppe as suggested also by an example from southeastern Kazakhstan (Frachetti, 2008: 38). This emphasizes the possibility of resilience also among pastoralists and not

only among hunter-fishers as discussed by for example Grünthal et al. (2022a). All this does not, however, exclude the possibility that some groups speaking Indo-Iranian did move close to the southern Urals due to the drought caused by the 4.2 ka climatic event as suggested by Grünthal et al. (2022a).

With this we would like to add complexity to the scenario given in Grünthal et al. (2022a) concerning the effect of the 4.2 ka climatic event to pastoral groups speaking Indo-Iranian. Furthermore, we would like to raise a possibility that Uralic speakers got at least some cultural influence concerning animal husbandry from speakers of Indo-Iranian (see also Section 4.1.2.) which perhaps furthered their spread in the western side of the Urals. This chain of reasoning consists of three components. First, there supposedly was a discrepancy in subsistence strategies between steppe pastoralists and hunter-fishers of forest zone during the very early phase of the Uralic spread. Second, it has been suggested that the people of the Textile Ware culture – who most likely practiced animal husbandry – spoke Uralic languages in the western side of the Urals (Nichols, 2021). Finally, there are Indo-Iranian loanwords related to animal husbandry in Uralic. These loanwords are inspected in the following section.

4.2.2. *Indo-Iranian loanwords related to animal husbandry*

A number of early Indo-Iranian loanwords are connected to animal husbandry. The words show varying distribution within Uralic, which is the case with other early loans as well; this fits the idea that the contact occurred between Common Uralic and Proto-Indo-Iranian that spread initially from west to east (cf. Palmér, 2025). One of the most well-known examples that can be connected to animal husbandry is the word for 'horn', which formally goes back to Proto-Uralic *ćarwi and is reflected by Finnish *sarvi*, North Saami *čoarvi*, Erzya Mordvin *śuro*, Mari *šur*, Komi, Udmurt *śur*, Hungarian *szarv*, borrowed from Proto-Indo-Iranian *ćrwā (> Avestan *sruuā* 'horn'). The affricate *ć shows that the borrowing is quite early (Holopainen, 2019 with further references). While 'horn' obviously could have denoted the 'horn' of a wild animal, other words in this category support the idea that this is also connected to animal husbandry. The Proto-Indo-Iranian word for 'boar', *warā́jha-, was also borrowed into the predecessors of Finnic and Mordvin; Finnish *oras* denotes 'castrated boar', Moksha Mordvin *urəź* denotes boar more generally but also the meaning 'castrated boar' is found there, so it is probable that the word has been borrowed in the context of animal husbandry.

The words for 'pig, piglet' in Finnic, Mordvin and Permic should also be mentioned here, although it has now been convincingly suggested that Finnic *porsas is rather borrowed from Proto-Balto-Slavic (Kallio, 2025). Mordvin *purcos* and Udmurt *parś*, Komi *porś* are more difficult to interpret but might be from Indo-Iranian instead. Similarly, the words for 'udder' in Finnic (Fi *udar*, *utare*), Mordvin (*odar*) and Mari (*waδar*, *woδar*) have different possible Indo-European sources (the Finnic word can also be from Germanic; see Holopainen, 2019 with references), but from the point of view of cultural influences, it is plausible that these Uralic words represent borrowings from Indo-Iranian *(H)ūdhar- 'udder' (> Sanskrit *ūdhar-*).

Proto-Indo-Iranian *dhaHinu- 'cow' (> Sanskrit *dhenú-* id.) has also probably been borrowed into Uralic, although the etymology has been criticized by Jakob (2023). Finnish *tiine* 'pregnant (animal)' and Mari *tüjüž* id. can formally reflect *tejniš, which could be borrowed from the Indo-Iranian word, although a Baltic or Balto-Slavic source is also possible, especially as the Baltic cognate of the Indo-Iranian word displays the meaning 'pregnant (of animals)' (Holopainen, 2019: 276–277). A more secure borrowing is *wVrta- (*wirta-) 'to raise, nurture' in Mari (*urδe-*, *wurδe-*) and Permic (Komi *verd-*, Udmurt *vord-*). The words are probably parallel borrowings from Indo-Iranian *Hwardh- 'to raise, nurture' (Holopainen, 2019: 311–312).

Finally, the word for 'kidney' in Mari (*wärγə*, *werγə*) and (*vẹrk*) Komi, from Indo-Iranian *wrtka- 'kidney' (Holopainen, 2019: 319–321), can also have been borrowed in the context of animal husbandry, although the issue remains somewhat unclear.

The Ugric words also display some interesting Indo-Iranian loans that can be connected with cultural influence, in this case related to equestrian nomadism, notably Common Ugric (?) *oćtVrV 'whip' ← Proto-Indo-Iranian *aštrā 'whip, stick' (Holopainen 2023b) and Khanty *wə̄rəs 'horse hair' (Holopainen, 2019: 318: the latter might also be a later loan from Iranian). In Hungarian, the words *tej* 'milk' (← Indo-Iranian *dhāyas- 'refreshment; milk') and *tehén* 'cow' (← Indo-Iranian *dhaHinu- 'cow') are also relatively early loans, but it is unclear if they were borrowed at the same time as the word for 'whip' (Holopainen, 2019; Katz, 2003). It should also be noted that the word for 'reindeer' in several Uralic languages might be borrowed from Proto-Iranian *patsu- 'cattle', but as these borrowings are clearly from *Iranian* and thus relatively late, it cannot be connected to early cultural influences; see Holopainen (2019: 184, 196).

In addition to animal husbandry, possible influences connected to agriculture can be seen in the borrowing of the Indo-Iranian word *yawa- 'grain' to several western Uralic languages, but it is unclear how old borrowing events we are dealing with. Finnic *jüwä < *jewä is possibly from Balto-Slavic (Holopainen, 2019: 103–105; Kallio, 2025). Also, the Finnic word for 'food, provisions', Proto-Finnic *eväs (> Finnish *eväs* etc.), has been recently argued to be an Indo-Iranian loan from Proto-Indo-Iranian *(H)awasam (> Sanskrit *avasám* 'provisions, food') or its "Pre-Proto-Indo-Iranian" predecessor (Holopainen, 2024: 59–60), but it is difficult to determine in what kind of cultural context this word has been borrowed.

4.2.3. *Changes in desert ecosystem services*

In desert ecosystems low rainfall and high temperature are the factors that limit the growth and distribution of organisms and populations. In this barren environment the fertile oases, which have a water supply throughout the year, are favourable habitats to many species including humans. And indeed, these areas have played a significant role in the world's history, especially that of Eurasia; many early empires were located there, and areas such as Mesopotamia have been important for example in the development of agriculture.

During the 4.2 ka climatic event drought increased for example in the deserts of Middle East and Central Asia (Helama, 2024). This drought has been connected to the collapse of the Akkadian empire, which was dependent on rain-fed agriculture (Cullen, et al., 2000). It has also been suggested that intensifying drought had a role in the establishment of the Bactria-Margiana Archaeological Complex (BMAC) (ca. 4250–3700 BP) when people were moving to a more reliable water supply (Anthony, 2008: 421). BMAC, also known as Oxus Civilization, was part of an extraordinary exchange network ranging from the Mediterranean in the west to Indus river in the east and northern steppe in the north (Lyonnet and Dubova, 2021: 7; Anthony, 2008: 393). Perhaps the key to the success of BMAC during the 4.2 ka climatic event was the exchange network as an increase in long-distance trade during a climatic downturn is also seen in more recent (ca. 600 BP) material from North America (Vehik, 2002).

The potential relevance of BMAC to the spread of early Uralic comes from two factors related to these vast networks. First, as BMAC was in contact with supposedly Indo-Iranian speaking Sintasha (Lubotsky, 2001; Palmér, 2025), it cannot be excluded that some influences from BMAC also reached speakers of Uralic via their contacts with Indo-Iranian, despite this may be difficult to prove. Second is the spread of the lost-wax technique in bronze casting supposedly from BMAC to ST (Anthony, 2008: 444). With the lost-wax technique one can make very detailed and fine metal objects; something which is characteristic for the ST items (see Section 4.3.1). As the utilization of the lost-wax method was unique to ST metalsmiths in northern Eurasia, one may question whether the ST phenomena would have existed in the first place if they had not adopted this method.

In lost-wax technique beeswax plays an important role as the model of the item is made of wax. During the production of the metal item this

model is covered with a mold with holes. When the mold is heated, the melted wax runs out through the holes and the molten bronze can be poured in. It is to be noted that a temperature of 900–1100 °C is needed to melt bronze. Thus a sufficient amount of firewood is also needed in the process; bellows and turf were also possibly used in this process to increase the heat (Lang, 2007: 115–117). Interestingly, three terms related to beeswax are Indo-Iranian loanwords in Uralic. We discuss these below.

4.2.4. Beeswax-related Indo-Iranian loanwords in Uralic

Earlier, when the Uralic homeland was situated in the Volga area, the bee-related Indo-Iranian loanwords were considered as a sign that alongside these words Uralic speakers obtained also cultural innovations related to beekeeping from speakers of Indo-Iranian (Salminen, 2001: 393). This inference holds also now when the Uralic homeland is situated to western Siberia. This does not either hamper the possibility that the beeswax was used in lost-wax casting (see Section 4.2.3); instead it perhaps gave another reason for the people to practice apiculture.

Common Uralic *mekši 'bee' (> Fi *mehi-läinen*, Md E *mekš*, Ma *mükš*, Ko *moš*, Ud *muš*, Hu *méh*) ← PIIr *makš (<? *mekš) 'fly, bee' > Sanskrit *makṣ* (EWAia, 1986) is one of the examples of possible "Pre--Proto-Indo-Iranian" loans, with Uralic *e pointing to retained Proto--Indo-European *e. The phoneme *š points to an Indo-Iranian donor, as does the fact that Indo-Iranian *makš does not have a good Proto--Indo-European etymology (see Holopainen, 2019; Van Sluis, 2022 for discussions of the background of the Indo-Iranian word). The distribution of the word in Uralic is quite wide, but the word is missing from Ob-Ugric and Samoyed. The Uralic cognates are formally regular, with the exception of Meadow Mari *mükš* (< Proto-Mari *mükš) that shows an unexpected full vowel instead of the reduced *ŭ that is the regular reflex of Proto-Uralic *e in Mari (Aikio, 2014). This might point to separate borrowing of the word into Pre-Mari or perhaps into the possibility that the Mari word could be an early loan from Pre-Proto-Permic.

Proto-Uralic or Common Uralic *meti 'honey' ← PIIr *mádhu < Pre-IIr *médhu 'honey' is a well known loanword (Holopainen, 2019 with references). Because of the *e-vocalism, also other Indo-European sources are possible (cf. Simon, 2020), although the Proto--Indo-European word probably did not originally denote 'honey' but some kind of 'honeywine', and the meaning 'honey' developed in some branches only (Indo-Iranian, Tocharian and Balto-Slavic; Anthony, 2008: 90–95; EWAia, 1986: 302-303; Adams, 2013: 494). Because the word for 'bee' was borrowed from Indo-Iranian, it is plausible to assume that *meti was borrowed similarly from that branch, especially as evidence for early contacts with other early Indo-European branches is quite poor (Grünthal et al., 2022a, see also Holopainen, 2024). The word *meti has regular cognates in many branches, but it is missing from Samoyed, Ob-Ugric and Saami. This situation can be interpreted in two ways: the word could have been lost in these branches, but it is also possible that the borrowing occurred into central branches/dialects of diverging Uralic only and never reached the varieties spoken in the eastern and northern fringes of the Uralic speech area. This interestingly fits the often repeated idea that honeybees were unknown in prehistoric Siberia (cf. Salminen, 2001: 393).

In addition to these more widespread loans, it has been noted by Carpelan and Parpola (2001: 122–126) as well as Katz (2003: 224) that an Indo-Iranian term for 'beeswax', Proto-Indo-Iranian *ćišta- attested in Sanskrit compound *mádhu-śiṣṭa-*, was borrowed into Uralic. This word is found in Mordvin (Erzya Mordvin *šta*, Moksha Mordvin *kšta*), Mari (Hill Mari *šəštə*, Meadow Mari *šište*), and Permic (Komi *śiś*, Udmurt *śuś*), and traditionally it has been reconstructed into Proto-Finno-Ugric as *šićtV or *šikćtV (cf. UEW: 785–786). It is obvious, however, that the consonantal and vowel relations between the alleged cognates is irregular (Holopainen 2023a: 326) and the word cannot have been borrowed into a common protolanguage (Proto-Uralic or any disputed intermediary protolanguage) but it has to reflect early parallel borrowings (as seems to be the case with the early loanwords into Uralic in general).

The loans denoting beeswax seem to be quite old because the Mari and Permic words point to an Indo-Iranian donor that had word-initial *ć (rather than later Iranian *ts or *s), so despite the 'beeswax' word being found only in three branches of Uralic in the west, the borrowing into these Uralic varieties must have taken place quite early, similarly to the other Proto-Indo-Iranian loanwords. Carpelan and Parpola (2001) argued that the word for 'beeswax' is borrowed from Proto-Indo-Aryan, because no cognate of the noun *ćikšta- is found in the Iranian branch. However, as this noun is originally a verbal adjective formed from the root 'to leave' (Werba, 1997: 195), it can be supposed that this formation could have existed already in Proto-Indo-Iranian (cf. Holopainen, 2019). The idea of Proto-Indo-Aryan loanwords in Uralic has not found support in general (Holopainen, 2019; Kümmel, 2020).

4.3. Across the Eurasia

4.3.1. Seima-Turbino transcultural phenomenon

The ST phenomenon is special due to its vast geographical coverage ranging from the eastern Altai-Sayan mountain area – the likely location of origin of the phenomenon (Fig. 2) – to Finland and the Baltics in the west (Chernykh, 2008; Marchenko et al., 2017 and references therein). This extensive area covers both steppe and taiga zones and various different archaeological cultures (Chernykh, 2008). It is nowadays dated to ca. 4200–3900 BP, Trans-Ural and western Siberian sites being older than those in the western side of the Urals (Marchenko et al., 2017). This largely coincides both with the suggested time and the direction of the early Uralic spread (Grünthal et al., 2022a). The main ST sites are located along the east-west river network (Fig. 2), and it has been suggested that the ST items spread via this route (Grünthal et al., 2022a).

Characteristic ST items are bronze objects, mainly weapons such as spearheads, celts and knives/daggers often decorated with a horse figure (Shaw and Jameson, 1999; Marchenko et al., 2017). These items were "among the most technically and aesthetically refined weapons in the ancient world" (Anthony, 2008: 443–444). One of the methods they used to produce these fine items was lost-wax casting (see Section 4.2.3); specifically the decorations of knife/dagger handles were made with this method (Anthony, 2008: 444). ST items appeared suddenly in the archaeological material suggesting a rapid spread of the phenomena (Chernykh, 2008). Furthermore, there are no known ST settlement sites (Chernykh, 2008). All this has led to the suggestion that people producing ST items and distributing them were metallurgists and horse riders who simultaneously with mobile hunter-gatherers from the western Siberian taiga moved northwestwards. Alternatively, it has been suggested that it was the new bronze technology, instead of people, moving (hypotheses summarized in Vesakoski et al., 2025). In any case, the group of people involved in ST was genetically very diverse including also an individual with a high percentage of an ancestry component that has been connected to speakers of Uralic languages (Zeng et al., 2025).

From the ST material, an eastern and a western variant can be identified, the Ural mountains being the divider. For example, in the east there are a larger number of casting molds while in the west the number of the items and the variation in them is greater (Childebayeva et al., 2024: S2 and references therein). In addition, the amount of tin used to make the bronze items increase towards the east (Childebayeva et al., 2024: S2); in the west arsenical bronze – the older alternative to produce bronze items – is more common (Anthony, 2008: 418, 447). The tin deposits are globally rather rare, but one of those exists in upper Irtysh also pointing towards a likely location of origin of the ST phenomenon (Anthony, 2008: 444).

The early spread of the Uralic languages has been connected to ST (see Section 1). As metal objects have a central role in ST, we will now turn our focus to the metal terms in Uralic languages. These have been discussed earlier for example in Grünthal et al. (2022a, 2022b). Here we point out some problematic details in the reconstruction of the alleged Proto-Uralic metal term (Finnish *vaski* and its cognates) and discuss

other possible Proto-Uralic metal terms that have been suggested in etymological research. It should be noted immediately that the lexical evidence for Proto-Uralic or Common Uralic metallurgy is very scarce (Häkkinen, 2001; Kallio, 2006; Aikio, 2022), and because that we have rather limited possibilities to investigate the possible lexical influences from the languages of the ST people(s) in Uralic metal terms. However, some interesting observations can be made.

4.3.2. Uralic metal terms

The most interesting word here is the one word for 'metal' that has been traditionally reconstructed to Proto-Uralic (UEW; Kallio, 2006). Already Kallio (2006) noted that this word, reconstructed as *wäśkä by him, might be connected to the ST traders. Kallio argued that both Saami (N) *veaiki* (< PSaa *veaškē) and the Samoyed cognates (Nganasan *basa*, Tundra Nenets *yesya* etc. < PSam *wäsa) regularly point to *wäśkä. Kallio's idea of Seima-Turbino connections of PU *wäśkä is interesting, but Aikio (2015b: 42) has since noted that the word is hardly a Proto-Uralic etymon but rather we are dealing with a Wanderwort that has been borrowed separately to early varieties of Uralic or diffused through the early varieties of Uralic. Aikio notes that the Proto-Samoyed word *wäsa shows disharmonic shape that cannot reflect any Proto-Uralic vowel combination regularly. This irregularity is interestingly similar to the irregularity found in many early Indo-Iranian loans in Common Uralic. Despite the attempts in Grünthal et al. (2022b) to defend the traditional Uralic etymology, the severe irregularities in several branches of the family force us to support Aikio's (2015b) conclusions.

Other sources for this metal term have also been suggested, but they have not found acceptance. A Tocharian origin (parallel borrowings into Uralic from the Proto-Tocharian source that yielded Tocharian A *wäs*, Tocharian B *yasa*) has been suggested by Blažek (2011: 127). This etymology is, however, rather unlikely, especially in the light of Kallio (2004) who assumes that the Tocharian word is borrowed from Uralic (early form of Samoyed) to Tocharian, as the etymology of Tocharian A *wäs*, B *yasa* is disputed (probably this is not inherited from Indo-European; Adams, 2013).

Häkkinen (2023a: 102–104) has suggested that this word could also be found in a Proto-Uralic compound denoting 'tin' or 'lead': he reconstructs Proto-Uralic *ä(j)sVn-weć(k)V on the basis of Udmurt *uzveś* 'tin', and South Mansi *ɛtküš* 'lead' (found also in other Mansi dialects). Although Häkkinen is probably right in assuming that the Udmurt and Mansi words are somehow connected, phonological irregularities between both parts of this alleged compound show that these two words cannot be true cognates. Due to the limited distribution of this metal term in the Permic and Ob-Ugric branches that have been situated next to each other since prehistoric times, a borrowing between the two branches or a parallel loan from some lost source might explain the similarity between these words. In any case, we can conclude that a Proto-Uralic compound *ä(j)sVn-weć(k)V cannot be reconstructed, and the assumption of Uralic metal name *ä(j)sV remains speculative and uncertain. Because of this, Häkkinen's (2023a: 105–106) idea that *ä(j)sV is a loan from Indo-Iranian *Háyas- 'copper' (> Sanskrit *áyas-* id.) is likewise quite unlikely.

Another interesting metal term is the word for 'tin', reconstructed as *wolnɜ (UEW: 581), and reflected by Mari (East) *wulno*, (West) *wulnə̑* 'tin' (< Proto-Mari *wulnə; Aikio, 2014: 151), Hungarian *ón* 'tin', Mansi (East, North, South) *ålen*, (W) *olən* 'silver; money' (< Proto-Mansi *alnə; Zhivlov, 2006: 102; it is commonly assumed that the meaning 'silver' in Mansi is secondary), Khanty (Vakh dialect) *olnə* 'tin', (Vasjugan dialect) *olna* 'lead', South Khanty (*χănt*) *utən* 'tin' (< Proto-Khanty *alnā; Zhivlov, 2006: 102). This could theoretically be considered another candidate for a PU metal name, but this word likewise shows problematic correspondences: at least Khanty vocalism is irregular according to Aikio (p.c.), meaning that the word cannot go back even to Proto-Ugric. As a result, these words have to be loans from some (unknown) source.

As the words for 'tin' discussed above are found only in the Ugric languages and Mari, contrary to the other metal term *wVćkV that has "cognates" in all the branches of the family, it is not at all certain that this word can be connected with the Seima-Turbino phenomenon. However, from the point of view of the Seima-Turbino connections, it is interesting that bronze mixed with tin was used in Seima-Turbino sites east of the Ural mountains. From this it would be tempting to assume that the words for 'tin' in Hungarian, Khanty, Mansi and Mari have been borrowed in connection with the Seima-Turbino network.

In connection with the metal terms and Seima-Turbino, Kallio's (2006) idea that Proto-Uralic *weŋći 'knife' was borrowed into Indo-Iranian as *wāćī- 'axe, pointed knife' (> Sanskrit *vāśī-*, Avestan *vāsī-* 'pointed knife') should be commented on. This etymology should be rejected, however. The phonological irregularities between the alleged cognates in Finnic (Fi *veitsi*), Hungarian *vés* 'carve', Khanty V *wäńť-* 'cut' and Komi *vęź-* 'to cut diagonally' make the reconstruction of a noun 'knife' to Proto-Uralic unlikely, and it is doubtful if these words have any kind of etymological relation with one another.

5. Conclusion

In this paper we propose a variety of possible ways of how the 4.2 ka climatic event and the early spread of Uralic languages could be connected. These are summarized in Fig. 5. These pathways include events that took place in the forest zone, i.e. where the speakers of Uralic languages were living, and those that took place south from it, i.e. the area where groups with which people speaking early Uralic had contacts with lived. In addition, we discuss ST phenomenon, the influence of which ranged across Eurasia.

The 4.2 ka climatic event had different effects on the forest zone and south from it; taiga became wetter and cooler while steppe and desert became drier. These affected the ecology and hydrology in each environment, which again caused changes in their respective ecosystem services. Considering the forest environment, we propose a scenario where the 4.2 ka climatic event potentially affected the living habitats of beavers, a keystone species and an important animal for fur, meat and castoreum. Changes in the occurrence of beavers had cascading effects to the rest of the ecosystem, eventually also affecting human populations, which perhaps spoke Uralic languages. The changes in ecosystem services affected both subsistence and economy (i.e. trade) and potentially pushed people to move. While it has been suggested that Uralic speakers were the trade managers etc. of the fur trade, we do not, however, see objections to the possibility that some groups of Uralic speakers would have also been the ones hunting the fur animals. Search for both fur and food animals could have thus been potential contributors to the initial push that made speakers of western Uralic languages to move west from western Siberia.

Uralic languages have got lexical influence concerning animal husbandry from at least two sources, from non-Uralic farming populations living in the forest zone in the west side of the Urals and from Indo-Iranian speakers living in the steppe. Both of these populations were likely affected by the 4.2 ka climatic event; intriguingly also the steppe-wide transition to mobile pastoralism coincides with the long 4.2 ka event. Signs of animal husbandry appear in the archaeological material connected to speakers of Uralic languages in the western side of Urals (i.e. Textile Ware) after the suggested time of the early Uralic spread. We thus propose a scenario in which speakers of Uralic languages were in contact with these two non-Uralic farming groups, and adopted the cultural innovation of animal husbandry alongside the loanwords. This cultural innovation potentially contributed to the later success of the groups speaking Uralic languages in the western side of the Urals.

Trade and the ST network have been overarching themes in many earlier papers concerning the early spread of Uralic languages and indeed, we also see that these most likely had a role in the early spread of Uralic languages. Trade – including long-distance trade – could have been the way to cope with environmental changes; it could have also led to the transmission of the lost-wax technique – an essential part of the ST

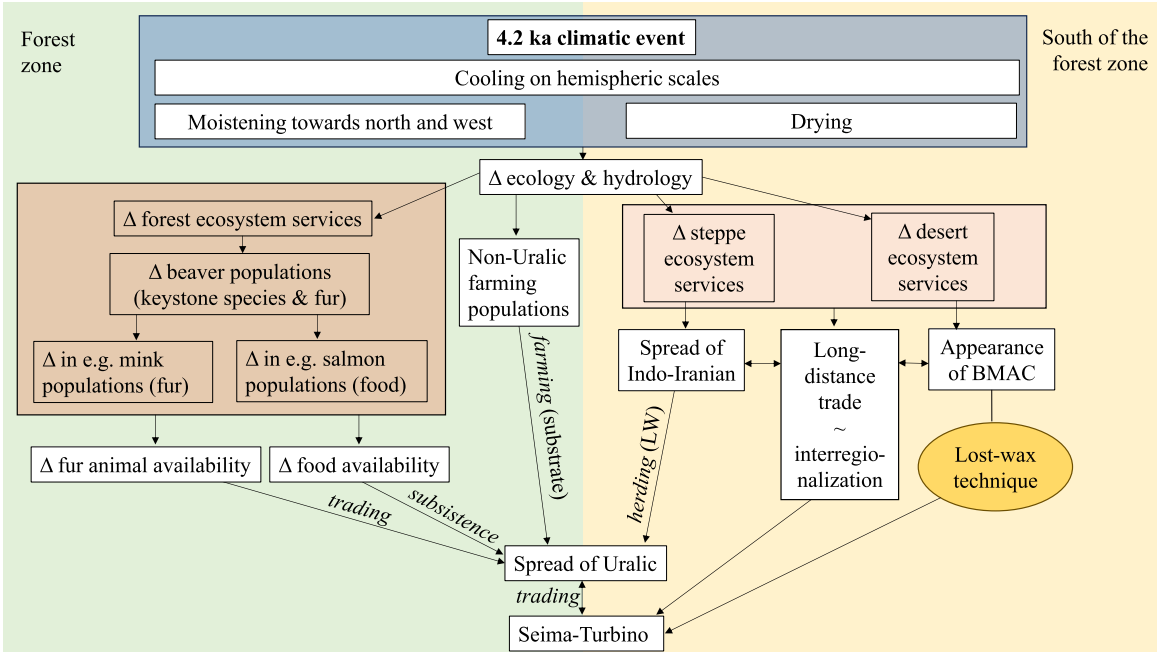

Fig. 5. Summary of different factors that potentially contributed to the Uralic spread. Events that took place in the forest zone are presented on the left side of the figure (light green background), those south of the forest zone in right (light yellow background).

phenomenon – from Central Asia to the northern steppe. The people involved in ST were genetically very diverse and, among others, most likely also involved speakers of both Uralic and Indo-Iranian languages. It thus potentially provided a multilingual context in which ideas and knowledge – and also perhaps languages – spread effectively.

In sum, we propose a scenario where the 4.2 ka climatic event and the early spread of Uralic languages is connected via three themes: 1) habitat changes, 2) animal husbandry and 3) trade. The linguistic evidence of Proto-Uralic cultural vocabulary, Indo-Iranian loans and loanwords of unknown origin is quite difficult to interpret as such, but taken together, the different layers of etymologies fit quite well with the external evidence described above. We hope that we also managed to show that a more detailed investigation of some issues (such as metal terms and some disputed Uralic etymologies) can lead to different interpretations of prehistory.

At the core of this paper are the novel insights about the possible connections between the 4.2 ka climatic event and the early spread of Uralic languages. While doing this we emphasize the difficulty to prove – but similarly also to disprove – these connections as several levels of uncertainties are embedded in a topic covering such a large geographical area in such a deep time. We discuss several contributing factors and causal chains, yet we cannot hope to be exhaustive as the processes that led to the early spread of Uralic languages have certainly been more complex than what we can present in this paper. Nevertheless, by presenting some novel ideas concerning the spread and highlighting the likely complexity of the process, we wish to increase the understanding concerning the early stages of the Uralic language family.

CRediT authorship contribution statement

Sampsa Holopainen: Conceptualization, Investigation, Methodology, Writing – original draft & editing. **Terhi Honkola:** Conceptualization, Investigation, Methodology, Visualization, Writing – original draft & editing. **Samuli Helama:** Conceptualization, Investigation, Methodology, Visualization, Writing – original draft & editing.

Declaration of Competing Interest

The authors have no competing interests

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Data Availability

All the data used in this paper has been previously published.

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