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Environmental Changes and Human Impacts on Landscapes near Medieval Steklyanukha-2 Fortress in Russia from Early Iron Age to Modern Times

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Abstract: The development of landscapes in one of the most populated river basins of the southern Russian Far East was studied using pollen and diatom data. The study sites were a multi-layered mountain fortress, Steklyanukha-2, and an Upper Holocene high floodplain sequence of the Steklyanukha River. Buried soil from the fluvial section acts as an environmental archive of the time in which people from the Yankovskaya archeological cultures settled in the river basin. The soil was formed under conditions of decreasing water supply in the valley and prolonged droughts. Findings of pollen *Fagopyrum* and *Urtica* signal economic activity in the Early Iron Age. Floodplain lake sediments accumulated from 1.6 to 0.5 kyr, when the valley was actively developed during the Middle Ages. There are signals of the development of secondary birch and oak forests. In the cultural layer of the fortress and lake sediments formed in the Middle Ages, *Ambrosia* and *Xanthium* pollens were found and are reliable evidence of agricultural activity in the valley. The pollens of plants typically seen in human-disturbed areas were also found. Indirect evidence of human activity includes non-pollen palynomorphs. The study of diatoms in a depression near a rampart confirmed the archaeologists' assumption that it was used as a water reserve. Pollen spectra from surface soils reflect agricultural activity in the river basin since the second half of the 19th century. The largest amount of pollen of alien and synanthropic plants and weeds, as well as spores of pathogenic fungi and fire indicators, were found here.

Keywords: ancient agriculture; mountain fortress; humidity changes; pollen; diatoms

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1 Introduction

To understand the ways in which the appearance of humans has transformed the biosphere on a global scale, it is important to know the different regional histories of land use and assess how different Holocene land use models have influenced the development of ecosystems (Ellis et al., 2013; Chen et al., 2015a). In the Far East, the development of early land use, which included a specific fire regime, may have had an impact on the landscapes since the mid-Holocene. Southern Primorye is one of the most developed regions of the Russian Far

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East. Geosystems here have been transformed to varying degrees during economic activity, with large areas occupied by agricultural lands and secondary forests (Krasnopeev and Rosenberg, 2005). The region was sparsely populated until the middle of the 19th century, although the transformation of natural geosystems has ancient roots; the first farmers in Southern Primorye appeared in the Neolithic (Vostretsov, 2009). Farmers resettled from inland regions to the seacoast for multiple reasons, including cooling during the Middle to Late Holocene (Vostretsov, 2006; 2013). In the early Middle Ages, Primorye was part of the Bohai State, and agriculture became one of its leading types of land use (Shavkunov, 1994; Astashenkova et al., 2018). Labor tools associated with arable farming have been found at agricultural sites of the Bohai time. There is also evidence of a steady increase in the production of cultivated plants that includes seeds from 14 types of cultivated plants, such as millet, cereals, legumes, oilseeds, vegetables, and technical crops (Sergusheva, 2012).

Despite an extensive investigation of landscape development in Southern Primorye during periods of Holocene climatic changes (Korotky et al., 1997; Anderson et al., 2017; Razjigaeva et al., 2017, 2019, 2021a) and paleogeographical studies of archaeological sites (Verkhovskaya, 1996; Korotky, 2009; Vostretsov, 2013; Sergusheva et al., 2016), human impacts on landscapes within settlements and nearby territories remain poorly understood. Work is needed to better understand the development of regional ecosystems in the context of global climatic change (Novenko et al., 2019; Chen et al., 2022). One method for elucidating human impacts on landscapes is pollen analysis (Verkhovskaya, 1996; Tarasov et al., 2006; Korotky, 2009; Nosova et al., 2014; Hunt et al., 2018; Rudenko and Novenko, 2019). Pollen criteria for identifying the anthropogenic transformation of vegetation have received much attention (Alexandrovski et al., 1991; Novenko, 2016; Sergusheva et al., 2016; Novenko et al., 2019, Chen et al., 2022; Zhang et al., 2022); however, this issue has not been sufficiently addressed for the Russian Far East. Prior research from Primorye emphasized that when studying ancient human habitation in the region it is important to analyze data collected at archaeological sites and in nearby natural areas (Korotky, 2009).

The purpose of this article is to identify the signs of anthropogenic impacts on landscapes against the background of their natural dynamics during Late Holocene climatic changes in one of the agricultural regions of Primorye, the Shkotovka River Basin. This area was the scene of agriculture and occupation since the Neolithic period, and settlement was especially active in the early Iron Age and the Middle Ages. Natural environments at this time changed greatly, there were warmer and colder periods, prolonged droughts alternated with periods of frequent floods. The role of the first settlers in the transformation of the vegetation are poorly studied. Are there bioindicator signs of the development of agriculture in antiquity? What was the main driver leading to changes, whether it was always only natural factors that determined the landscape development? Are there signs of human influence on vegetation changes? Results record natural palaeoenvironmental changes, as well as human land use and its impact upon the local vegetation.

2 Materials and Methods

2.1 Study area

The Shkotovka River Basin in the southern Russian Far Eastwas one of the most populated areas in the Middle Ages (Krushanov, 1991). There are several ancient settlements in the mountains and the valley (Astashenkova et al., 2018). The fortress Steklyanukha-2 is located on Boytsovaya Mountain (absolute height 204 m) between the Steklyanukha and Shkotovka river valleys, about 15 km from the sea. The site is multi-layered, with the early stage of settlement dating back to the Early Iron Age. It was most likely settled by representatives of the Yankovskaya archaeological culture (9th–4th centuries BC. E.), based on pottery remains at the site. The next stage was the Mohe culture (6th–7th centuries C. E.) where there are signs of the presence of representatives of the Bohai time (8–10th centuries C. E.); the settlement was most likely built by the Jurchens (12th–13th centuries C. E.). At the top of the mountain, there is a well-preserved stone-soil rampart bordering the southern and western walls of the settlement (Piskareva et al., 2021). Approximately 1.5 km to the southwest in the valley, there is a well-preserved large settlement, Steklyanukha-1 (Sainbar), which is also a multi-layered site. People have lived here since the Early Iron Age (Yankovskaya culture) and the settlement was built during the Bohai and Jin states (Alexandrov, 1985). Modern active development of the area began during the second half of the 19th century (Busse, 1898); one of the richest Chinese settlements was located in the Shkotovka River basin in the 19th century (Budishchev, 2016).

2.2 Study methods

Landscape reconstructions were based on a multi-proxy study of three sections within the fortress Steklyanukha-2, where excavations were carried out in 2020 (Piskareva et al., 2021). For paleogeographic purposes, a matrix between stones composing the rampart wall was sampled, as well as buried soil (up to 20 cm thick) under the rampart and surface soil (7 cm thick) (section 320). The second excavation was inside the settlement (section 520) and included a thin (11 cm) cultural layer, the underlying buried soil (5 cm thick), and slope deposits represented by sandy loam with debris. For these sections, pollen analysis was performed. In the southern part of the settlement, we sampled the bottom of the depression (section 620) that was supposedly used by ancient people as a water reservoir. These samples were taken for diatom analysis and included the soil profile with buried soil (total thickness of 35 cm) and the underlying sandy loam (5 cm) with rock debris. To obtain the longest history of landscape development, a sequence of Upper Holocene fluvial deposits was sampled on the high floodplain of the Steklyanukha River. We describe natural outcrops on the right side of the river, 3.6 km from the confluence of the Shkotovka River and 0.5 km from the fortress Steklyanukha-2 (Fig. 1).

The samples used for pollen analyses were treated using a heavy liquid of 2.2 g/cm^3 density (Pokrovskaya, 1966). Relative significance was calculated for three groups, namely: pollen of trees and shrubs (AP); herbs and dwarf shrub pollen (NAP); and spores. The percentages of individual taxa were calculated for the groups AP and NAP, and separately for spores. The presence of microcharcoals and burnt cells of herbs were noted. Tilia program v. 2-0-41 (Grimm, 2004) was used as a basis for constructing a pollen diagram. Non-pollen pa-

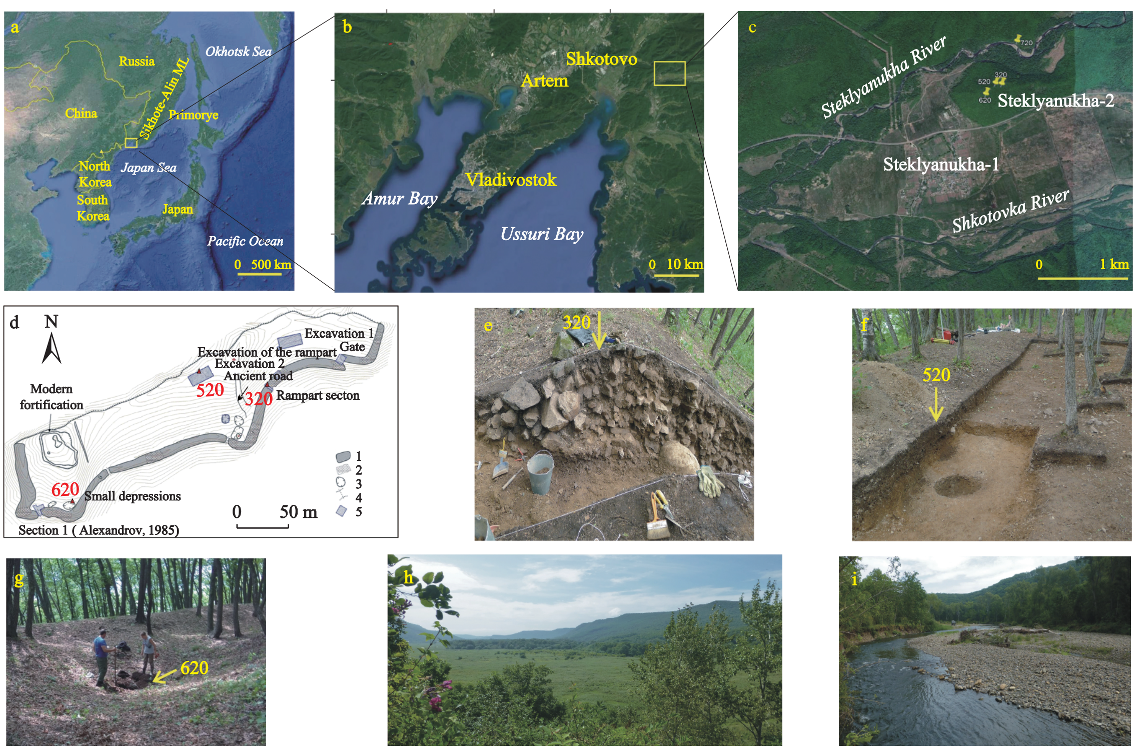

Fig. 1 Study area and location of the Steklyanukha-2 fortress and Steklyanukha River valley in Primorye, Russian Far East. a. Location of the study area within a region of Asia; b. Location of the study area within South Primorye; c. Location of the fortress Steklyanukha-2 and study areas; d. the Steklyanukha-2 fortress scheme (Piskareva et al., 2021) with sampling sites: 1, eastern wall; 2, stone wall; 3, depression; 4, break of the wall; 5, excavation; e. section of the rampart (320); f. excavation 2 with culture layer (section 520); g. depression (section 620); h. Steklyanukha River valley low course (view from the fortress); i. Steklyanukha River (view from section 720)

lynomorphs were also identified.

The diatom analysis was performed following a standard procedure (Gleser et al., 1974). Diatom species were identified under an Axioscop microscope at 1000 × magnification. The taxonomic composition of diatoms and their ecological characteristics were identified following Krammer and Lange-Bertalot (1986; 1988; 1991).

Radiocarbon dating was performed in the Institute of Earth Sciences, St. Petersburg State University. The radiocarbon dates were calibrated into calendar dates using OxCal 4.4.1 software and an IntCal20 calibration curve (Ramsey, 2017;2021; Reimer, 2020).

3 Results

3.1 Sections in the fortress Steklyanukha-2

Soil was found under the rampart wall (Fig. 1e) and dated to ^{14}C 4200 ± 110 yr B. P., 4720 ± 160 cal yr B. P., LU-9982 was obtained from the upper part of the paleosol. AP prevailed in the pollen spectra (Fig. 2). The dominant pollens were *Betula* (up to 69% in total) and *Corylus* (up to 64%).

Broadleaved pollens (*Quercus*, *Ulmus*, *Juglans*, *Fraxinus*) were present in small amounts (up to 8.3%). Coniferous pollens (*Pinus* s/g *Haploxylon*) were sporadic. Pollens of diverse shrubs (*Eounymus*, *Alder*, *Duschekia*, *Myrica* and *Betula ovalifolia*) were found. NAP was represented by genera typical of dry habitats (*Artemisia* and other Asteraceae, Chenopodiaceae), including *Guldenstedtia*, which is typically found in very dry places. Single pollens of aquatic plants (*Numphaea*, *Nymphoídes*) and sedges were found. Tartary buckwheat pollen (*Fagopyrum tataricum*, 2 grains) was also found. The content of spores, mainly ferns, did not exceed 2%.

In the rampart matrix, the amount of AP decreased. The role of broadleaved taxa (mainly *Quercus*, up to 19%) increased, and the proportion of *Corylus* was greatly reduced (< 14.5%). Wormwood (*Artemisia*) pollen dominated among the NAP, and herb pollen became more diverse. Important findings were pollens of *Am-*

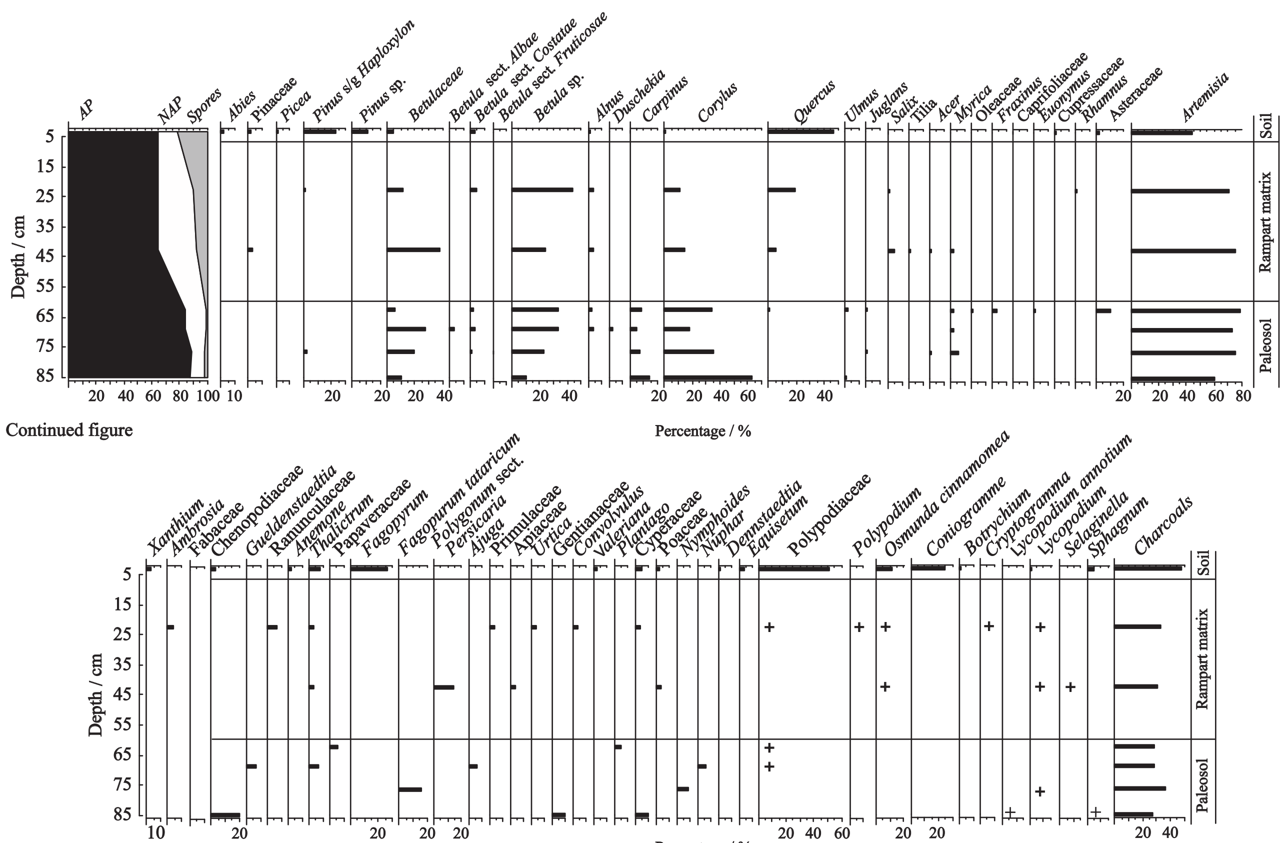

Fig. 2 Pollen diagram of the section of the fortress wall of Steklyanukha-2 (section 320) in Primorye, Russian Far East. +, Single grains

brosia, *Urtica*, and *Polygonum* sect. *Persicaria*. Spores of ferns including *Osmunda* and *Cryptogramma*, typical for rocks, and *Lycopodium* were present. A large number of microcharcoals were found. The surface soil on the rampart included a moderate abundance of AP. Pollen of *Quercus* prevailed. *Pinus* s/g *Haploxylon* pollen was present at increased proportions with the source being Korean pine (*Pinus koraiensis*). Among NAP, 10 pollen grains of common buckwheat (*Fagopyrum esculentum*) and *Xanthinum* pollen were found. A large number of spores, including of various ferns (*Osmunda*, *Coniogramme*, *Dennstaedtia*, *Botrychium*), and single spores of *Equisetum* and *Sphagnum* were also found.

In the excavation site 2 inside the fortress, the pollen spectra from the sandy loams at the base of the section and from the buried soil under the cultural layer included mainly AP (up to 65%) (Fig. 3). Birch pollen dominated (up to 66%). Broad-leaved pollens were represented by a small amount of *Tilia*, *Acer*, and Oleaceae. There was a single detection of coniferous pollen. In NAP (up to 20%) *Artemisia* predominated, and *Xanthium* was found. Non-pollen palynomorphs included spores of fungi *Byssothecium circinans*, *Leucopholiota lignicola*, and *Savoryella*. There were also rotifers and microcoals.

The cultural layer contained rich pollen spectra. In AP, along with a predominance of *Betula* (up to 67.0%), the proportion of *Quercus* (22.0%) and other broad-leaved trees (*Ulmus, Juglans, Tilia, Fraxinus*, *Corylus,* Oleaceae) increased. Coniferous pollen included *Pinus* s/g *Haploxylon* and *P.* s/g *Diploxylon*, with the source being *Pinus densiflora*. The amount and variety of NAP increased (up to 33.0%). Important finds included pollen of Solanaceae (up to 15.4%), *Xanthium*, and Papaveraceae. An abundance of sedge pollen (Cyperaceae, 22.0%) and a single *Typha* were found in the top layer. Microcharcoals were found. Among non-pollen palynomorphs, spores of pathogenic fungi (*Pleurophragmium*,

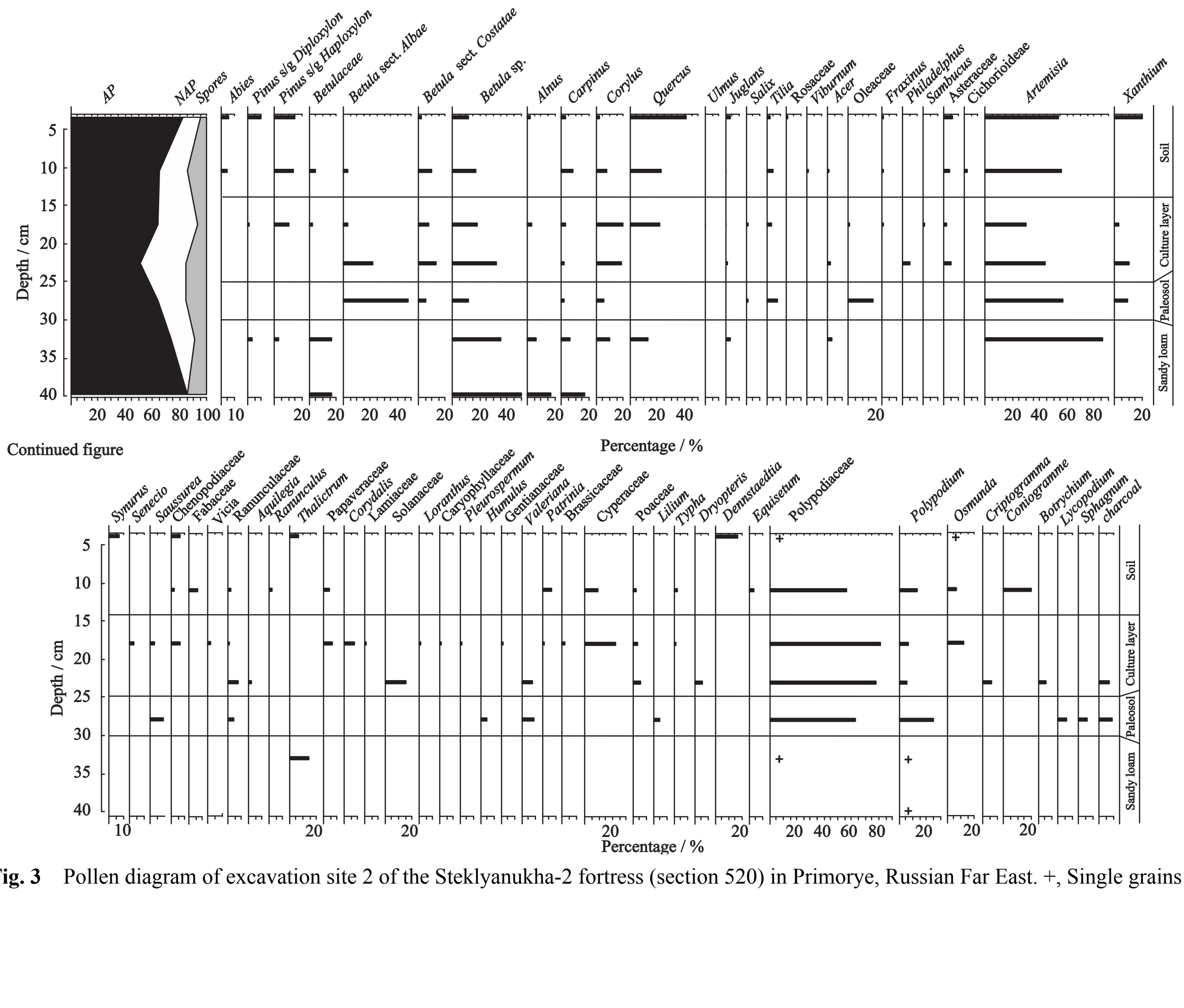

Fig. 3 Pollen diagram of excavation site 2 of the Steklyanukha-2 fortress (section 520) in Primorye, Russian Far East. +, Single grains

Caeumannomyces, Xylariaceae, *Bactrodesmium*) and coprophilic fungi *Delitshia* were found. Pollen spectra from the surface soil included a large amount of *Quercus* (up to 41.0%). There was much coniferous pollen (*Pinus* s/g *Haploxylon*, up to 14.0%; *P.* s/g *Diploxylon*, 9.0%, *Abies*, up to 6.0%). NAP became less diverse. Non-pollen palynomorphs were represented by spores of the fungi *Gelasinospora, Glomus, Caeumannomyces, Leucopholiota lignicola*, and *Zygnema* cells, as well as black mold spores *Mitteriella* and *Zizyphus*.

In the southern part of the fortress, two small depressions were found near the rampart. We sampled the soil profile (section 620) at the bottom of a larger depression (Fig. 1g). All samples contained single soil diatoms such as *Hantzschia amphioxys*, and *Pinnularia borealis* was the most common. *Caloneis aerophila*, inhabiting mainly wet stones and rocks, was also found. Diatoms that were found and are typical in aquatic environments included planktonic *Aulacoseira distans*, *A. italica*, *A. granulata*, *A. granulata* var. *angustissima*, *Cyclotella meneghiniana*, fouling *Epithemia porcellus*, *E. gibba*, *Ulnaria ulna*, *Fragilariforma nitzschioides*, and benthic *Pinnularia viridis*.

3.2 Section of the high floodplain of the Steklyanukha River

In section 720 of the river terrace, buried soil (20 cm thick) lies on fluvial pebbles (total thickness up to 90 cm). In the paleosol, the taxonomic composition of diatoms was poor (29–34 taxa) and benthic species prevailed (up to 61.3%). Soil diatoms such as *Hantzschia amphioxys*, *Luticola mutica*, *Pinnularia borealis*, and *P. obscura* dominated (up to 51.4%). The content of acidophilic diatoms was low (< 1%). The upper part of the soil had a ^{14}C date of 2170 ± 100 yr B. P., 2160 ± 140 cal yr B. P., LU-9983.

The pollen spectra from the paleosol (Fig. 4, Unit 1) included a high content of NAP (up to 67.8%). Among AP, *Betula* dominated (up to 65.4%) and broadleaf pollen reached 17.3%. Conifers included pollen of Korean pine (up to 13.3%) and sporadic *Abies.* Pollen of plants typical for floodplains (*Alnus*, up to 21.0%, *Salix*, *Ribes*, Cornaceae) was abundant. Pollen of juniper (Cupressaceae, up to 13.8%) and *Spirea* came from the slopes.

Fig. 4 Pollen diagram of high floodplain deposits of Steklyanukha River (section 720) in Primorye, Russian Far East. Units: 1, paleosol; 2, floodplain; 3–4, floodplain lake; 5, floodplain; 6, soil; +, single grains

Among NAP, genera typical for dry habitats (*Artemisia*, up to 71.2%, Chenopodiaceae, up to 22.4%) predominated. Representatives of humid habitats (Cyperaceae, Ranunculaceae, Polygonaceae, Apiaceae) were small in number. Single pollens of buckwheat (*Fagopyrum*), nettle (*Urtica*, up to 3.3%), and hop (*Humulus*) were found. Spores were represented mainly by ferns and club-moss. Non-pollen palynomorphs included spores of fungi *Cercophora, Glomus*, and *Gelasinospora*. There were many microcharcoals in the upper part of the soil. Rotifers (*Rotatoria*) were also found.

In the floodplain sandy loams and loams (Unit 2), 50 taxa of diatoms were found. Epiphytes prevailed (83.6%). Lacustrine-rheophilic *Cocconeis placentula, Gomphonema grunowii*, *Reimeria sinuata* and *Cymbella tumidula* dominated. Species were found that are typical for fluvial environments (Aleshinskaya, 1968) including *Hannaea arcus* (4.1%), *Meridion circulare* (1.8%), and *Didymisphenia geminate*. These species prefer flowing, well-aerated waters and can remain on the bottom at high flow rates. Twenty-five taxa of diatoms were found in the overlying loams (Unit 3). Species of different ecological groups were present, including typical rheophiles and soil diatoms. The assemblage is typical for river valleys with frequent floods. There were single pollen and spores. The amount of AP increased in Unit 3 (up to 40.8%). Birch pollen was found less (up to 40.8%) along with broadleaved taxa (up to 16.3%). *Abies* pollen was likely brought from the upper part of the basin during floods. Among NAP, the proportion of *Artemisia* decreased. *Sphagnum* and *Equisetum* were identified among spores. Non-pollen palynomorphs included spores of the fungi *Bryophytomyces* that infect *Sphagnum* mosses.

Peaty loams (Unit 4) accumulated in the waterlogged flood lake. The sediments contained up to 45 diatom taxa and the content of benthic species reached 59.8%. The role of epiphytes, including rheophilic species, remained quite high (up to 46.6%). The acidophile *Pinnularia schroederi*, which inhabits mainly oligotrophic waters, dominated. *Placoneis elginensis*, *Surirella minuta*, *S. angusta* and *Pinnularia subcommutata*, which prefer mesotrophic and mesotrophic-eutrophic waters, reached ≥ 4%. Species typical for small lakes, such as *Pinnularia acrosphaeriae*, *Nitzschia hybrida*, *Neidium ampliatum* and *Frustulia vulgaris,* were present. Soil diatoms such as *Hantzschia amphioxys*, *Pinnularia borealis* and *Luticola mutica* were also found; the highest content of these species (up to 22.2%) was recorded in the base, indicating a drier environment. The sample for ^{14}C date 1670 ± 60 yr B. P., 1560 ± 80 cal yr B. P., LU-9985 was obtained from the lower part of the layer; 480 ± 100 yr B. P., 490 ± 100 cal yr B. P., LU-9984 was obtained from the upper part.

In Unit 4, AP pollen reached 52.8%. The amount of birch and broadleaf pollen increased (up to 24%). *Ephedra* pollen was found in the sample with a peak of birch pollen (60.7%). NAP was more varied. There was an abundance of *Thalictrum* pollen that is typical of dry floodplain meadows. Pollen of water walnut (*Trapa*) was found. The pollen of *Ambrosia*, *Urtica* and *Potentilla* was found in the sediments formed ~920–700 cal yr B. P.. The number of spores reaches 22.8%. *Sphagnum* spores were often found. Non-pollen palynomorphs were represented by spores of the fungi *Entorrhiza, Glomus*, and *Valsaria*. Rotifers were found.

The upper part of the section (Unit 5) was composed of floodplain deposits that formed during the Little Ice Age. At the base, against the background of high soil diatom content (33.6%), a large number of epiphytes were found (53.4%), such as *Gomphonema grunowii*, *Reimeria sinuata*, *Cocconeis placentula*, *Meridion circulare*. The epiphyte contents increased up to 71.2% in the top layer, while the proportion of soil species decreased to 17.6%. The role of acidophiles increased (4.7%).

In the base of Unit 5, there was a layer of sandy loam with clay admixture that formed during a strong flood. A small amount of birch pollen, *Artemisia*, and spores of ferns and club moss were found. In NAP, the pollen of *Rhus* and *Diphylleia*, typical for damp and shady places, appeared. Above, in the humus sand, NAP prevailed (up to 57.0%). In AP, coniferous pollen was represented mainly by *Pinus koraiensis* (up to 25.0%) and *P. densiflora* (up to 10.0%). Among NAP, the amount of *Artemisia* pollen decreased, and the pollen of hygrophilous plants (Cyperaceae, Ranunculaceae) was present at increased proportions. Pollen of *Senecio*, *Polygonum* sect. *Persicaria* appeared. Pollen of apophytes such as *Urtica*, *Cirsium* and *Ambrosia* were found. In the upper layer the proportion of Cichorioideae increases. Microparticles of charcoal were found.

In the surface soil (Unit 6), the content and diversity of AP increased. Wind drift coniferous pollen from the Shkotovskoe plateau became more active and was recorded by an increase in coniferous (*Pinus koraiensis*, *Abies* and *Picea*) pollen proportion. The content of *Pinus densiflora* pollen sharply decreased in the top (from 13.7% to 2.5%). The quantity and variety of broad-leaved pollen slightly increased. Allochthonous pollen of *Tsuga* and *Firmiana* were found. In NAP, *Artemisia* pollen increased towards the top layer and there was more pollen from moisture-loving plants, especially sedges (up to 26.4%). The pollen of *Nymphoides*, an aquatic plant brought from floodplain lakes, appeared. Each sample contained *Ambrosia* and *Xanthium* pollen. There was a lot of Cichorioideae pollen. Common buckwheat pollen was found at the base. Pollen of *Rumex* and *Hyoscyamus* (up to 2.3%) appeared. The composition of spores became more diverse. Fern spores that prefer rocky habitats (e.g., *Woodsia* on open cliffs, *Blechnum* on shaded cliffs) appeared. In the forest cover, there was more *Dryopteris* (9.2%). Among non-pollen palynomorphs, spores of pathogenic fungi (*Clasterosporium*, *Curvularia*, *Cercophora*) and *Gelasinospora* were found. Charcoals were found throughout the section.

4 Discussion

Biostratigraphic data indicate both the dynamics of natural landscapes that were controlled by climatic changes in the late Holocene, and the long-term presence of humans in the Shkotovka River Basin (Fig. 5). Signals of human influence on the landscapes were found not only in the cultural layer within the fortress and rampart matrix but also in the buried soils that formed before the construction of the mountain fortress Steklyanukha-2 and in the natural section of the high floodplain of the Steclyanukha River. Pollen records from the study sections show that the valleys of the Steklyanukha and Shkotovka rivers have been repeatedly inhabited since the Early Iron Age, confirming the results of archaeological work in the multilayered sites of Steklyanukha-1 and Steklyanukha-2 (Alexandrov, 1985; Piskareva et al., 2021).

As in other archaeological sites (Korotky, 2009), the sections at the fortress Steklyanukha-2 include a small amount of pollen and spores. The findings of the pollen of plants that accompany human activities and a number of non-pollen palynomorphs can both, directly and indirectly, confirm the presence of ancient humans by showing that there was a human impact on the natural landscapes. In the high floodplain section formation of pollen spectra strongly depended on fluvial environments, previously shown by Korotky (2002) and Mokhova (2020) for other river basins of Primorye. Small amounts of pollen and spores in some layers can be explained by their formation during high flood activity. As in other river basins of Primorye, the studied deposits include allochthonous pollen brought from the upper reaches of the river, mostly by water transport.

Comparison between the fortress and the natural sec-

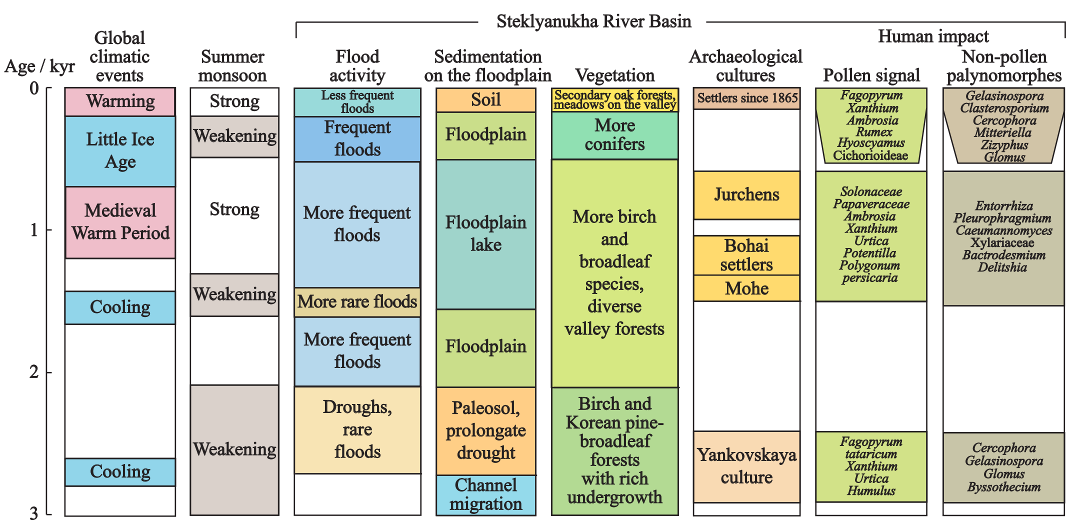

Fig. 5 Summary of the Late Holocene environmental changes in Shkotovka River Basin of Russian Far East with human impact and archaeological cultures (Piskareva et al., 2021), global climatic changes (Wanner et al., 2011), Asian Summer monsoon intensity (Li et al., 2011; Chen et al., 2015b)

tion makes it possible to characterize the development of natural landscapes as a background against the activities of ancient people and is important for understanding ancient land use and human influences on the landscape.

4.1 Landscape development before the construction of the fortress (Early Iron Age)

The territory of the Shkotovsky District of the Primory began to be populated during the Neolithic, but the most common sites of the Early Iron Age are of the Yankovskaya and Krounovskaya archaeological cultures (Khorev, 1978; Klyuev et al., 2008). Both archaeological cultures are present in the vicinity of settlements in Steklyanukha-1 and Steklyanukha-2. Evidence of these cultures was also found in the valley settlement of Steklyanukha-1. At the mountain fortress Steklyanukha-2, only fragments of pottery from the Yankovskaya archaeological culture were found (Alexandrov, 1985; Piskareva et al., 2021). Pollen data from buried soils found at the Steklyanukha-2 site and in the section of the high floodplain of the Steklyanukha River reflect the development of the landscapes of the Steklyanukha River basin before the construction of the fortresses.

The buried soil under the fortress rampart was apparently formed during a cooling period at the boundary of the Middle–Late Holocene (~4720 ± 160 cal yr B. P.) and marks the state of the territory before the arrival of the builders of the fortress. At that time, birch forests with an abundance of hazel were widespread. Euonymus also grew in the forest undergrowth. The pollen of shrub alder, gristle, and oval-leaved birch was possibly transferred from the swampy areas of the Shkotovskoe plateau (Razjigaeva et al., 2017) or from river valleys. Alder pollen could also have been brought in from the valley. Herbaceous taxa typical of dry slopes of the hill and rocky habitats prevailed.

An interesting finding is the single pollen from herbaceous plants living in a swamp or in an aquatic environment (Cyperaceae, Numphaea, *Nymphoídes*) found among pollen of plants that prefer dry habitats. Such a contrast within mountainous environments may indicate vigorous activity on the slopes of the Boytsovaya Mountain (i.e., water and soil were brought in). Tartary buckwheat pollen (*Fagopyrum tataricum*) was also found at this location. At present, it is considered a weed in crops and grows along roadsides, on embankments, and in disturbed places. Unlike common buckwheat (*F. esculentum*), this species is more frost-hardy and has been used as a grain crop in China since the middle Holocene (Hunt et al., 2018). Archaeobotanical evidence indicates buckwheat cultivation in northern China started around 5500 cal yr B. P.; its first distribution was recorded at 5000–4000 cal yr B. P., the second 1600–1000 cal yr B. P. and around 4000 cal yr B. P. buckwheat emerged in Japan (Hunt et al., 2018). Manchuria was located on the periphery of the supposed center of the original cultivation of buckwheat (Ohnishi, 1998). Evidence of the cultivation of buckwheat in Manchuria in the Middle Ages has been found. The first pollen evidence of buckwheat cultivation in the Changbai Mountains region was dated to the first half of the 9th century C. E. (Makohonienko et al., 2008). Wind transport of *Fagopyrum* pollen is not active, and its presence in pollen spectra is interpreted as the presence of agricultural crops in the immediate vicinity of the study area in the past. Small charcoals found in the paleosols indicate frequent fires.

The buried soil in the floodplain section corresponds to a period of decreased humidity in the Late Holocene. Evidence of dry conditions is the domination of soil diatoms that reflect a gradual decrease in flood intensity and the development of soil-forming processes; the low content of acidophiles typical of bog environments confirms this. A long dry period, which began during the cooling of 2800–2600 cal yr B. P., was also evident in other river basins of South Primorye. Buried soil of similar age (^{14}C-date 2110 ± 80 yr B. P., 2100 ± 110 cal yr B. P., LU-8854) was found in the floodplain sections of the Razdolnaya River valley near the Starorechenskoye fortress (Razjigaeva et al., 2021a). This period of prolonged droughts is correlated with the global cold event that was accompanied by a decrease in moisture in East Asia (Wanner et al., 2011). Data for South Primorye and Northeastern China show that the summer monsoon was weak during this time (Li et al., 2011; Chen et al., 2015b; Razjigaeva et al., 2021b).

Findings of *Rotatoria* in the buried soil in the high floodplain of the Steklyanukha River confirm that, despite the dry conditions, floods occurred periodically. The passage of floods is also evidenced by a large number of *Lycopodium* spores, which were likely brought by water flows from the upper reaches of the river from the dark coniferous forest belt.

Pollen spectra from the buried soil correspond to the development of Korean pine-broadleaf and birch forests with rich undergrowth (*Corylus*, *Syringa*, *Physocarpus*). It is possible there were areas in the valley occupied by open birch forests. In addition to alder, the floodplain also had willow, currant, fieldfare, and dogwood. Ferns were common in the forest cover. Juniper and spiraea grew on the steep slopes. Forb meadows were widespread. Wet habitats occupied a limited area on the floodplain. Findings of buckwheat pollen (*Fagorirum*) and nettle pollen (*Urtica*, up to 3.3%) may be a signal of anthropogenic activity in the Early Iron Age. Hop pollen (*Humulus*) was also found, which is considered a species confirming the close habitation of humans (Makohonienko et al., 2008). In pollen from the surface soils of human-disturbed areas of Northeast China, *Humulus* pollen is characteristic of wastelands (Li et al., 2012). An important finding of *Cercophora* spores that cause disease in both wild and cultivated soybeans. The tradition of growing soybeans in China has a history of over 3000 yr. Domesticated soybean was found in South Korea that was dated to about 2720–2380 cal yr B. P. (Lee et al., 2011). The buried soil findings include those of the spores *Gelasinospora*, a fungus that settles in burnt-out areas that can be a sign of human impact. The abundance of microcharcoals could be associated with anthropogenic fires in the valley. Findings of spores of the fungus *Glomus* indicate soil erosion (Miehe et al., 2009), as a result of the activities of ancient people.

Pollen spectra from the sandy loam and the buried soil under the cultural layer within excavation 2 inside the fortress (Fig. 1g) show that birches were widespread in the forest and hazel was widespread in the undergrowth. Among broadleaf trees, linden, maple, and lilacs were common. Coniferous pollen was brought from the upper mountains. *Xanthium* pollen in buried soil could be washed out from the cultural layer. In general, the composition of pollen spectra is similar to the spectra obtained from the buried soil under the rampart. The presence of humans is indirectly indicated by spores *Byssothecium circinans,* a fungus that lives on both woody substrates and an important forage crop, alfalfa. Spores of the edible woody fungus *Leucopholiota lignicola*, as well as *Savoryella*, that grow on decaying wood, were also found.

Our data confirm the instability of climatic conditions during the Early Iron Age: extreme droughts combined with rare severe floods. Changes in agroclimatic conditions led to repeated migration of the agricultural population within Eastern Manchuria and Primorye (Vostretsov, 2013).

4.2 Development of landscapes during the Middle Ages (Mohe, Jurchen)

The Shkotovka River Basin was actively populated in the Middle Ages. In the valleys and low mountains, there are a number of settlements (Astashenkova et al., 2018; Piskareva et al., 2021). The archaeological site of Steklyanukha-2 is a mountain fortress that is 0.6 km from Steklyanukha-1, where the main economic activity occurred.

The Steklyanukha-2 settlement is surrounded by a stone-soil rampart (500 m long) (Figs. 1e, 1f) that runs along the flattest area on the mountain top. The northern part is outlined by inaccessible sheer cliffs (up to 7 m high). The gently sloping area inside the fortress may be the remains of an ancient road. The area was actively used during the Mohe times. It has been established that the construction of the fortress took place in the Middle Ages, but the main fortifications were built later than the Mohe period, presumably during the Jurchen times. Currently, there are no data on the exact age of the fortress (Piskareva et al., 2021). Archaeological data show that the peak of the population of fortress Steklyanukha-2 was in the early Middle Ages, as it correlates with the Mohe archaeological culture (6th–7th centuries C. E.); ceramics and household waste of this age were found (Piskareva et al., 2021).

According to pollen data from the high floodplain section, it can be assumed that the development of the river basin was accompanied by the felling of coniferous trees as well as fires and, as a result, secondary birch forests appeared. Large amounts of *Thalictrum* pollen are not typical for the natural pollen spectra (Korotky, 2002). The abundance of this pollen was noted for sediments formed from 1560 to 700 cal yr BP. Pollen spectra from floodplain loams reflect a well-developed valley forest. Diatom data indicate that humidity increased. There was a large amount of horsetail on the floodplain, along with *Sphagnum* mosses.

The composition of diatoms indicates that the flood lake was formed from 1560 cal yr BP to 490 cal yr BP in the valley near the fortress. At some points, the lake dried up completely. Pollen spectra from lacustrine deposits reflect mainly local vegetation rather than pollen spectra from alluvial facies (Korotky, 2002; Mokhova, 2020). In the vegetation of the lower belt of the Sikhote-Alin, there were more birches and broadleaf trees, especially during the Medieval Warm Period. There were more walnuts (*Quercus*) and elms (*Ulmus*) in valley forests and hazels on the mountain slopes. In the valley, forb meadows were widely developed. The water-nut *Trapa* grew in the floodplain lake.

The signal for the human impact during the Mohe period is nettle pollen (*Urtica*), an apophyte that is widespread around settlements. Findings of the spores of the fungus *Entorrhiza*, which develops on rush (*Juncus*), may serve as an indirect sign of the widespread use of this plant for weaving mats. Pollen data from the cultural layer (excavation 2) and rampart matrix are evidence of landscape development in the late Middle Ages during the construction and use of the fortress. Pollen spectra from the cultural layer show widespread development of birches and broad-leaved trees (oak (*Quercus*), elm, walnut, linden (*Tilia*), ash (*Fraxinus*), and lilac (*Syringa*)). The composition of the undergrowth was varied (hazel, euonymus, sweet syringa). The role of Korean pine in coniferous-broadleaved forests increased. Pollen of *Pinus densiflora* was wind-blown. The increase in the role of broad-leaved plants in the forest vegetation indicates Medieval warming, which was also demonstrated in the southern Russian Far East (Razjigaeva et al., 2018). The abundance of birch pollen and the presence of *Ephedra* pollen in flood plain lake sediments suggest drier conditions during ~1130–920 cal yr B. P.. A warmer and drier phase around 1200–935 cal yr B. P. was also recorded in the peat bog section on the Shkotovskoe Plateau (Razjigaeva et al., 2017). The increase in the amount and diversity of NAP in the cultural layer confirms that the forest on the slope of the Boytsovaya Mountain, facing the valley and the settlement of Steklyanukha-1, was partially demolished in the Middle Age (Piskareva et al., 2021).

The cultural layer includes pollen of *Xanthium*, which is a ruderal annual plant. The pollen of this plant was also found at the Starorechenskoye fortress (Razjigaeva et al., 2021a). In China, *Xanthium strumarium* appeared around 2100 cal yr B. P. (Makohonienko et al., 2008; Chen and Hind, 2011). Findings of *Xanthium* pollen are interpreted as evidence of increased agricultural activity (Jia, 2005). The spread of *Xanthium strumarium* in Manchuria in the late Holocene suggests an increase in human activity or a change in land use. This plant grows in segetal and ruderal habitats, on roadsides and riverbanks, and is classified primarily as a weed of cultivated fields (Makohonienko et al., 2008). The abnormally high content of Solanaceae pollen and the presence of poppies (Papaveraceae) in the pollen spectra may also indicate human habitation. The abundance of pollen of swamp plants such as Cyperaceae and *Typha* is unusual for forest pollen spectra on the mountain. It can be assumed that these plants were used for household needs, such as for making mats, bedding, and other uses.

An indirect signal of human habitation is spores of pathogen funguses from the cultural layer. We found spores of mold (*Pleurophragmium*, *Gaeumannomyces*) that develops on cereals and *Xylariaceae* that lives on leaves, seeds, and fruits. *Bactrodesmium* grows on deciduous wood and bark (oak, ash), and also lives on spruce needles. Perhaps people cut and used spruce branches. Spores of coprophilous fungus *Delitshia* indicate the presence of domestic animals in the fortress. This conclusion is confirmed by horse bones in the cultural layer of excavation-2 (Piskareva et al., 2021).

In general, the data obtained for the cultural layer are similar to the spectra from the rampart matrix. The matrix is represented by a mixture of slope deposits and different age soils: buried soil and soil at the time of the fortress construction, along with the contribution of broadleaf trees in the forest. The finding of nettle (*Urtica*) and *Ambrosia* pollen in the matrix indicate human influence. *Ambrosia* is a paleoinvasive species and its pollen was found in some archaeological sites in Primorye (Verkhovskaya and Esipenko, 1993; Kudryavtseva et al., 2018). Kornyushenko also found *Ambrosia* pollen in the cultural layer of the Starorechenskoe fortress (Razjigaeva et al., 2021a). In the Steklyanukha-2 fortress, we also found pollen of *Polygonum* sect *Persicaria*; some researchers consider *Polygonum persicaria* as an indicator of agriculture (Nosova et al., 2014).

Microcharcoals found in the cultural layer and the rampart matrix indicate frequent fires on the mountain. Traces of fires in the fortress were also described during archaeological work (Piskareva et al., 2021). In the flood plain lake sediments formed in ~920–700 cal. B. P., *Ambrosia* pollen was found. It is evidence of agricultural activity during the Jurchen times. In the sediments accumulated at the beginning of the Little Ice Age, pollen of *Urtica* and *Potentilla* were also found. In modern flora, the genus *Potentilla* includes species that grow near human settlements. The pollen of plants such as *Potentilla anserina* is typical for secondary habitats and is considered evidence of the existence of pastures in the Holocene (Miehe et al., 2009). Findings of spores of the fungus *Glomus* indicate increased erosion, which could be due to trampling and grazing (Miehe et al., 2009). The spores of the *Valsaria* fungus, which infects apple trees and nuts, are indirect evidence that humans may have been actively harvesting in the Middle Ages.

In the southern part of the fortress near the rampart, two depressions were found that were presumably used for the storage of drinking water (Piskareva et al., 2021). The diatom composition is a mixture of species with different ecological preferences. There are species characteristic of both aquatic habitats (stagnant and flowing waters: lakes, ponds, swamps, rivers, streams, springs) and subaerial habitats with a constantly or periodically moistened substrate (moist rocks and stones, moss cushions and soils). The presence of lacustrine-rheophilic species may indicate that people could have brought water from the river to the fortress.

4.3 Dynamics of landscapes during the Little Ice Age

The Little Ice Age in Primorye was characterized by high moisture, watering of river valleys, and frequent floods. This is confirmed by the data obtained in the study of the floodplain sediments of the Steklyanukha River. The composition of diatoms in the floodplain loam at the top of the section shows that the deposits accumulated under the conditions of the increasing influence of river waters. There are signs of waterlogging in the floodplain. At the base of the floodplain unit, a layer of sandy loam that formed during a strong flood was found. The first half of the Little Ice Age was especially cold (Razjigaeva et al., 2021b). The role of conifers, represented by Korean pine and *Pine densiflora* increased in forests. Wet biotopes became widespread on the floodplain. Pollen of Sakhalin-Japanese species (*Diphylleia*, *Rhus*), absent in the modern flora of Primorye, was found. Rare species of modern flora *Cyclophorus linqua* grew on the rocks.

Cold and humid conditions were unfavorable for developing the territory. There were apparently separate small settlements. Oak became more widespread at the beginning of the Little Ice Age. It is possible that secondary oak forests occupied some areas in the basin. A combination of apophyte plant pollens, such as those of *Urtica*, *Cirsium*, and *Ambrosia*, in the floodplain deposits is evidence of people's presence in nearby areas. The proportion of chicory (Cichorioideae) pollen also increases.

4.4 Signs of human impact on modern landscapes

The modern stage of the development of the Shkotovsky District began in 1865 when the Shkotovo (originally Tsemukhinskaya Sloboda) settlement was formed (Arseniev, 2020). For the next 18 yr, it was the only settlement between Vladivostok City and the Olga Village (Kolyagin, 2012). The active development of this part of Primorye began at the turn of the 19th and 20th centuries. (Gorchakov et al., 2017). The Steklyannaya village (now Steklyanukha) appeared in 1905 and the settlers were from the Chernigov Province. In 1919 Korean settlers founded the Sainbar village nearby (Kolyagin, 2012). Agriculture was the main land use. The settlers used a one-field system of field cultivation where they sowed wheat for 3–6 yr in a row and then beans and buckwheat on the depleted soil; they were also engaged in truck farming, gardening, and beekeeping.

Pollen spectra from the surface soil inside the fortress (excavation 2), as well as from the soil on the rampart and soil on the floodplain, reflect the development of secondary oak forests. The coniferous-broadleaf forests were actively destroyed by settlers in the second half of the 19th when the forests were actively cut and burned out. Korean settlers fired twice a year, once in spring and once in autumn to prepare the land for agriculture (Arseniev, 2020). There is less hazel in the underbrush. The diversity of grass cover also decreased. There was a drift of pollen from Korean pine-broadleaved forests of the low mountains. The pollen of dark conifers (spruce and fir) was brought from the Shkotovskoe Plateau. The distribution of *Pinus densiflora* pollen, contents of which sharply decreases along the section, confirms its wider distribution in the territory before its development by settlers from the central part of the Russian Empire (Budishchev, 2016). Pine was actively used for construction in the pre-revolutionary period (Busse, 1898); however, at present, this pine is absent in the surrounding areas.

The largest number of taxa indicating human activity were found in the surface soils. Among NAP in the soil within the fortress, buckwheat pollen was found along with an abundance of wormwood pollen. Common buckwheat pollen could have been brought in from fields located in river valleys. Buckwheat has been used since the end of the 19th century not only as grain but also for the development of virgin lands. It was usually the first crop used to sow virgin lands (Busse, 1898) as it loosens the soil and prevents the development of weeds. Pollen of the alien plant *Xanthium* was found. Frequent fires near the fortress are indicated by the presence of spores of the fungus *Gelasinospora* that develop on burnt substrates. The finding of *Glomus* spores indicates soil erosion. Spores of the black molds *Mitteriella* and *Zizyphus*, which infect buckthorn plants, were also seen (Gautam and Avasthi, 2016).

In the surface soil of the floodplain, each sample contained pollen of invasive plants *Ambrosia* and *Xanthium*. There is a high abundance of chicory pollen, a sign of human activity. Pollen of common buckwheat found at the base also points to agriculture. We found pollen of sorrel (*Rumex*) that is considered as a synanthropic plant (Makohonienko et al., 2008; Rudenko and Novenko, 2019). Pollen of henbane (*Hyoscyamus*, up to 2.3%), which often grows near dwellings, on wastelands and garbage heaps, near cattle wintering grounds, on pastures, and along roads, is evidence of proximity to housing. The allochthonous pollen *Tsuga* and *Firmiana* in the surface soil was probably transferred from the south (Japan or China). Pollen *Tsuga* could have come from the Changbai Mountain region where there is artificial planting of this tree (Makohonienko et al., 2008).

Signs of human activity in the valley include the spores of the pathogenic fungi *Clasterosporium*, which causes disease in wild and cultivated stone fruit trees; *Curvularia*, which causes leaf spots; *Cercophora*, the causative agent of soy and rice diseases; and the fungus *Gelasinospora*, an indicator of fires. The occurrence of frequent fires is also evidenced by the findings of microcharcoals.

5 Conclusions

Pollen data within the fortress Steklyanukha-2 and from the natural fluvial sequence differ in their AP and NAP ratios. In the floodplain deposits, the content of NAP increases and corresponds to the presence of open spaces and the development of meadow communities in the valley. A large amount of pollen was transported from rocky habitats, including the northern slope of Boytsovaya Mountain. The fluvial sequence record several stages of valley development during periods of different moisture availabilities. Under conditions of decreased watering and long periods of droughts, buried soil was formed, and the age of this paleosol is estimated more than 2.0 kyr. The paleosol is a paleoarchive of environmental change and human impact on the landscape during the appearance of the Yankovskaya Culture. Flood plain lake sediments accumulated from 1.6 to 0.5 kyr, when the valley was actively developed in the Middle Ages. The hydrological activity of the river increased notably during the Little Ice Age when floods became much more frequent. Pollen data from the fortress reflect forest vegetation of the lower mountain belt. The fortress was surrounded by broadleaf and Korean pine-broadleaf forests that developed during the warmer climate (the Medieval Warm Period). In general, pollen data show a limited extent of cutting and deforestation.

Human impacts are recorded in the deposits of the fluvial section and on the site of the Medieval mountain fortress, located at a distance of 0.6 km from the main settlement, where economic activity was concentrated. We found pollen of plants that were used by people for agriculture, household needs, as well as adventive species. Signals of development in the lower part of the valley in the Early Iron Age were found in the floodplain sequence. Indirect signs of human presence include the findings of nettle pollen, buckwheat, and non-pollen palynomorphs, as well as fungus-pathogens of plants (soybeans), that people could collect. The active settlement of the valley during the Mohe period was most likely accompanied by the felling of coniferous and deciduous forests, fires, and the emergence of secondary birch and oak forests.

The data obtained for the cultural layer and the rampart matrix show that the vegetation surrounding the settlement corresponded to warmer conditions than those in which the buried soils were formed. *Ambrosia* and *Xanthium* pollen were found in the cultural layer of the settlement and the flood plain lake sediments that formed in the Middle Ages and are reliable evidence of agricultural activity in the valley. There is also the pollen of apophytes (nettle, cinquefoil) that are, as a rule, widespread in human-disturbed areas. The abnormal content of individual taxa among NAP also indicates their use by humans: nightshades, poppies, and agricultural crops, came from China, and sedges and cattails were used for household needs. The increased content of NAP from the cultural layer may indicate partial deforestation in the upper part of the hill to provide a better view. The study of diatoms from the soil profile of the depression showed that such pits were used to store water, including water brought from the river.

The largest number of pollen taxa indicating human activity were found in surface soils, both in the fortress and on the high floodplain. Pollen data reflect the development of secondary oak forests and active agriculture within nearby river valleys that began in the 19th century. Pollens of invasive plants (ragweed, cocklebur, henbane) and apophytes (sorrel) and fire indicators were found here, as well as spores of pathogenic fungi, including the causative agent of soybean and rice diseases.

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