A 32,000-year pollen record of vegetation, climate dynamics and glacial-interglacial environments of hunter-gatherer populations from Lake Ochaul, Cis-Baikal region of Siberia

Dissertation

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Abstract

The Lake Baikal region (LBR) has been the target of various archaeological and palaeoenvironmental research in the past. Multi-disciplinary and multi-national teams of researchers examine the LBR since 1997 contributing to the Baikal Archaeology Project (BAP). The main goals of the BAP are to investigate hunter-gatherer lifeways in Northern Asia using an individual life histories approach; to develop a robust chronology through intensive radiocarbon dating and Bayesian modelling of the archaeological remains; and to combine archaeological data with the results of high-resolution and accurately dated palaeoenvironmental records. Whereas resolution and number of studies increased over time, there are still large areas that are understudied, not least due to the huge dimension of the LBR. In particular, reconstruction of the last glacial/interglacial vegetation and climate history of the vast Cis-Baikal region outside the Lake Baikal coastal plains are not possible without detailed palaeoenvironmental records with AMS-based age control. Previous palynological studies around Lake Baikal point to the spatial-temporal variability in vegetation development across the LBR due to its large area with complex topography and influence of various elements of the global climate system. Archaeological research also demonstrates some spatial differences in the lifestyle and subsistence strategies of the Neolithic and Bronze Age hunter-gatherers within the LBR. Thus, detailed reconstruction of microregional environments is crucial for better understanding of the evolution of hunter-gatherer cultures. Lakes with continuous sedimentation may serve as natural archives, which preserve multi-proxy records of past environments and have a great potential for the correlation of archaeological and palaeoenvironmental records within geoarchaeological microregions.

This doctoral thesis contributes to the BAP by filling gaps in current knowledge and providing a detailed palaeoenvironmental record of the past 32,000 years obtained from a 7.24-m-long sediment core from Lake Ochaul (54°14’N, 106°28’E; 641 m a.s.l.), a small freshwater lake situated in the Upper Lena microregion of Cis-Baikal, rich in archaeological sites dated from the Upper Palaeolithic to the Bronze and Iron Age. The main results are presented in three peer-reviewed studies, published in international scientific journals. The focus was on two archaeologically and environmentally important time intervals: the (1) Last Glacial Maximum (LGM: ca. 28,000–20,000 years ago) and (2) the Lateglacial and Holocene (ca. 13,500 years ago to today). The respective AMS-dated parts of the Lake Ochaul core were palynologically analysed, and the obtained results were discussed and compared with other records from and outside the LBR to examine spatial-temporal differences of reconstructed environment and climate changes and their driving forces.

The published archaeological data from Cis-Baikal indicates that the region witnessed continuous hunter-gatherer population during the LGM, the climatically harshest part of the Late Quaternary, and therefore may have played an important role in the spread of anatomically modern humans to Northeast Asia and North America. The extent of deforestation during that time is still under discussion. The new pollen and biome reconstruction records from Lake Ochaul show that productive steppe or/and herbaceous tundra dominated this area during the LGM. This type of vegetation and thin snow cover were highly beneficial for large herbivores of the so-called “mammoth fauna” which on the other hand provided regional hunter-gatherer groups with a sufficient amount of food and raw materials for clothes and hunting tools. On the other hand, the LGM pollen record of Lake Ochaul shows continuous presence of boreal trees and shrubs such as birch, spruce, several pine taxa, larch and willow, in proportions that can hardly be explained by far-distant pollen transport. The survival of boreal trees during the LGM and the following spread of taiga forests across Siberia remains one of the long-debated topics in palaeoenvironmental research. This thesis provides well-argued evidence that the relatively moist area around Lake Ochaul was among the glacial refugia, where boreal trees and shrubs persisted the coldest and driest LGM climate interval and from where they quickly spread over the entire LBR during the Lateglacial.

During the Allerød, open taiga forest vegetation was already present around Lake Ochaul. The following Younger Dryas stadial led to a more open forest-tundra landscape with high participation of shrubby and patchy forest associations. The onset of the Holocene (ca. 11,650 cal yr BP) is marked by a further rapid spread of boreal forest vegetation around Lake Ochaul, which occurred about 1000 years earlier than at Lake Kotokel in Trans-Baikal. The Early Holocene warming was interrupted by several rapid oscillations towards colder climate showing the interplay of global insolation, sea level and ice sheet transformations on the regional climate and environments. Temperature and moisture conditions became most favourable during the Middle Holocene (ca. 8000–4200 cal yr BP). During the so-called “Holocene climate optimum”, percentages for boreal tree taxa reached highest values, speaking for densely forested landscapes around Lake Ochaul and a maximal spread of forest vegetation in the LBR. The reconstructed changes in the vegetation cover during the Early and Middle Holocene were associated with a major climate amelioration following a transformation of the atmospheric circulation and a stronger year-round impact of the North Atlantic air masses on the regional climate leading to thicker and longer-lasting snow cover. Those vegetational and climatic transformations along with the extinction of the greater part of the mammoth fauna, one of the main food resources for hunter-gatherer communities, might be a reason for the reported changes in the health conditions and lifeway of the Early Neolithic Kitoi populations, leading to a cultural "hiatus" (ca. 6660–6060 cal yr BP) suggested by the archaeological records from the LBR. The Late Holocene pollen record indicates gradual opening of the forested landscape around Lake Ochaul, which could be related to the gradual decrease in the Northern Hemisphere summer insolation and air temperatures, but also with an intensified human impact in the LBR.

Six AMS radiocarbon dates on large herbivorous animals' bone material from the Ochaul archaeological site located on the northern lake shore indicate that hunting activities around the lake took place during a very long period, with the earliest evidence of the extinct Palaeolithic horse dated to ca. 27,780–27,160 cal yr BP (95% probability range). Other dates indicate deer and elk hunting during the Mesolithic (ca. 8850–8450 cal yr BP), Early, Middle and Late Neolithic (between ca. 6840 and 5490 cal yr BP) and the Iron Age (ca. 2120–1930 cal yr BP). These results demonstrate that despite major environmental transformations during the LGM and Holocene periods, Lake Ochaul and surrounding area remained attractive for large herbivores and for prehistoric hunter-gatherers, who seem to have been present there even during the Middle Neolithic cultural "hiatus", as documented by the AMS-dated zooarchaeological record from the cultural layers of the Ochaul site.

Kurzfassung

Die Region um den Baikalsee (BSR) war bereits in der Vergangenheit Gegenstand verschiedener archäologischer und paläoumweltgeschichtlicher Forschung. Multidisziplinäre und multinationale Forschungsteams des Baikal Archaeology Projects (BAP) untersuchen die BSR seit 1997. Die Hauptziele des BAP sind das Studium von Jäger-Sammler-Lebensweisen in Nordasien, insbesondere der Rekonstruktion von individuellen Lebensgeschichten; das Entwickeln einer robusten Chronologie durch systematische Radiokarbondatierungen organischer Reste und Bayessche Modellierung sowie das Kombinieren von archäologischen Daten mit den Ergebnissen hochauflösender und präzise datierter Paläoumweltaufzeichnungen. Obwohl Auflösung und Anzahl der Studien mit der Zeit zugenommen haben, gibt es nach wie vor große Gebiete, die nicht ausreichend untersucht sind, nicht zuletzt wegen der enormen Größe der BSR. Insbesondere die Rekonstruktion der Vegetations- und Klimageschichte des letzten Glazial/Interglazial-Zyklus der weitläufigen Cis-Baikal Region außerhalb der Küstenebenen des Baikalsees ist nicht ohne detaillierte Paläoumweltaufzeichnungen mit radiokarbonbasierter Alterskontrolle möglich. Frühere palynologische Studien rund um den Baikalsee deuten auf eine räumlich-zeitliche Variabilität der Vegetationsentwicklung innerhalb der BSR aufgrund der komplexen topografischen Bedingungen und Einflüsse verschiedener Faktoren des globalen Klimasystems hin. Archäologische Untersuchungen zeigen ebenfalls einige lokale Unterschiede in den Lebensweisen und Subsistenzsstrategien von neolithischen und bronzezeitlichen Jägern und Sammlern in der BSR. Aus diesem Grund ist eine detaillierte Rekonstruktion von Umweltveränderungen auf mikroregionaler Ebene maßgeblich für ein besseres Verständnis der Entwicklung von Jäger-Sammler-Kulturen. Seen mit kontinuierlicher Sedimentation können als natürliche Archive dienen, welche multi-proxy-basierte Informationen über vergangene Umweltbedingungen enthalten und ein großes Potential für die Korrelation von archäologischen und landschaftsgeschichtlichen Datensätzen innerhalb geoarchäologischer Mikroregionen bieten.

Diese Dissertationsschrift leistet einen Beitrag zum BAP, indem sie Wissenslücken schließt und detaillierte Paläoumweltdaten der letzten 32.000 Jahre präsentiert. Gewonnen wurden die Daten aus einem 7,24 m langen Sedimentkern aus dem Ochaulsee (54°14’N, 106°28’O; 641 m ü.d.M.), einem kleinen Süßwassersee in der Mikroregion der Oberen Lena in der Cis-Baikal Region, die reich an archäologischen Fundstätten vom Jungpaläolithikum bis zur Bronze- und Eisenzeit ist. Die wichtigsten Ergebnisse wurden in drei Peer-Reviewed Studien in internationalen Fachzeitschriften publiziert. Der Fokus lag dabei auf zwei archäologisch und ökologisch wichtigen Zeitintervallen: (1) dem Letzten Glazialen Maximum

(LGM: ca. 28.000–20.000 Jahre BP) und (2) dem Spätglazial und Holozän (vor ca. 13.500 Jahren BP bis heute). Die jeweiligen AMS-datierten Abschnitte des Ochaulsee-Bohrkerns wurden palynologisch analysiert. Anschließend wurden die erhaltenen Ergebnisse diskutiert und mit anderen Datensätzen innerhalb und außerhalb der BSR verglichen, um räumlich-zeitliche Unterschiede der rekonstruierten Umwelt- und Klimaveränderungen und deren Antriebsmechanismen zu untersuchen.

Die publizierten archäologischen Daten aus der Cis-Baikal Region deuten darauf hin, dass die Region während des LGM, dem klimatisch harschesten Abschnitt des Spätquartärs, kontinuierlich Jäger-Sammler-Populationen beherbergte und daher wahrscheinlich eine Schlüsselrolle in der Ausbreitung des anatomisch modernen Menschen nach Nordostasien und Nordamerika spielte. Das Ausmaß des Waldrückganges während dieser Zeit ist nach wie vor umstritten. Die neuen Pollen- und Biomrekonstruktionen vom Ochaulsee zeigen, dass fruchtbare Steppe oder/und Strauchtundra die Gegend während des LGM dominierten. Zusammen mit nur dünner Schneebedeckung im Winter war dieser Vegetationstyp besonders vorteilhaft für große Herbivoren der sogenannten „Mammutfauna“, die wiederum regionale Jäger-Sammler-Gruppen mit ausreichend Nahrung und Rohmaterialien für Kleidung und Jagdwerkzeuge versorgen konnte. Jedoch zeigt das LGM-Pollenprofil des Ochaulsees ein kontinuierliches Vorkommen von borealen Bäumen und Sträuchern wie Birke, Fichte, verschiedene Kieferntaxa, Lärche und Weide in Anteilen, die kaum mit Ferntransport erklärt werden können. Das Überdauern von borealen Baumarten während des LGM und die anschließende Ausbreitung von Taigawäldern über Sibirien gehören nach wie vor zu den am längsten diskutierten Themen der Paläoumweltforschung. Diese Arbeit liefert gut begründete Hinweise darauf, dass die relativ feuchte Gegend um den Ochaulsee zu den glazialen Refugia gehörte, in denen boreale Baum- und Straucharten während der kältesten und trockensten Phasen des LGM überdauern und sich anschließend während des Spätglazials rasch über die gesamte BSR ausbreiten konnten.

Bereits während des Allerøds dominierte offene Taigavegetation die Landschaft um den Ochaulsee. Das anschließende Jüngere Dryas Stadial führte zu einer offeneren Wald-Tundra-Landschaft mit hohem Strauchanteil und eher lückenhaften Waldgesellschaften. Der Beginn des Holozäns (ca. 11.650 Jahre BP) zeichnet sich durch die weitere und schnelle Ausbreitung borealer Waldvegetation um den Ochaulsee aus, welche etwa 1000 Jahre früher als am Kotokelsee in der Trans-Baikal Region auftrat. Die kontinuierliche Erwärmung während des Frühholozäns wurde mehrfach von kurzzeitigen Klimaschwankungen unterbrochen, was den Einfluss des Zusammenspiels von globaler Sonneneinstrahlung, Meeresspiegeländerungen und

Eisschildtransformationen auf das regionale Klima und die Umwelt zeigt. Temperatur- und Feuchtigkeitsbedingungen wurden während des Mittelholozäns (ca. 8000–4200 Jahre BP) vorteilhafter. Während des sogenannten „Holozänen Klimaoptimums“ erreichten die relativen Anteile borealer Baumtaxa die höchsten Werte, was für dicht bewaldete Landschaften um den Ochaulsee und eine maximale Ausbreitung von Waldvegetation in der BSR spricht. Die rekonstruierten Veränderungen der Vegetationsbedeckung während des Früh- und Mittelholozäns stehen im Zusammenhang mit einem erheblichen Klimawandel infolge einer Änderung der atmosphärischen Zirkulation und einem stärkeren, ganzjährigen Einfluss der nordatlantischen Luftmassen auf das regionale Klima, was zu massiverer und länger anhaltender Schneebedeckung führte. Diese Vegetations- und Klimaveränderungen sowie das Verschwinden des Großteils der Mammutfauna, eine der wichtigsten Nahrungsquellen für Jäger-Sammler-Kulturen, könnten Gründe für die Veränderungen des Gesundheitszustandes und der Lebensweise der frühneolithischen Kitoi-Populationen sein, die letztendlich zu einem kulturellen „Hiatus“ (ca. 6660–6060 Jahre BP) führten, wie archäologische Daten aus der BSR nahelegen. Die Pollendaten aus dem Spätholozän deuten auf eine sukzessive Öffnung der bewaldeten Landschaften um den Ochaulsee hin, was mit dem allmählichen Rückgang der sommerlichen Sonneneinstrahlung und der Lufttemperaturen in der nördlichen Hemisphäre aber auch mit einem intensiveren menschlichen Einfluss in der BSR zusammenhängen könnte.

Sechs AMS-Radiokarbondatierungen von Knochenmaterial großer Herbivoren aus der archäologischen Fundstätte Ochaul am Nordufer des Sees deuten darauf hin, dass Jagdaktivitäten in Seenähe während eines sehr langen Zeitraums stattfanden, wobei der früheste Hinweis auf ein ausgestorbenes paläolithisches Pferd auf ca. 27.780–27.160 Jahre BP (95% Wahrscheinlichkeitsspanne) datiert wurde. Weitere Daten weisen auf die Jagd von Rehen, Hirschen und Elchen während des Mesolithikums (ca. 8850–8450 Jahre BP), des frühen, mittleren und späten Neolithikums (zwischen ca. 6840 und 5490 Jahren BP) und der Eisenzeit (ca. 2120–1930 Jahre BP) hin. Diese Ergebnisse zeigen, dass der Ochaulsee und die umliegenden Gebiete trotz großer Umweltveränderungen während des LGM und des Holozäns für große Pflanzenfresser und prähistorische Jäger-Sammler attraktiv blieben, die scheinbar selbst während des mittelneolithischen kulturellen „Hiatus“ anwesend waren, wie AMS-datierte zooarchäologische Daten aus den Kulturschichten der Ochaul-Fundstätte belegen.

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aDNA	ancient DNA
AL	Allerød
AMS	accelerator mass spectrometry
AP	arboreal pollen
a.s.l.	above sea level
BAP	Baikal Archaeology Project
BCE	before common era
BHAP	Baikal-Hokkaido Archaeology Project
BP	before present (i.e. before the year 1950 AD)
cal	calendar
CLDE	cold deciduous forest
cps	counts per second
DBD	dry bulk density
EBA	Early Bronze Age
EM	Early Mesolithic
EN	Early Neolithic
ICP-OES	inductively coupled plasma optical emission spectrometer
kyr	kiloyear
LBR	Lake Baikal Region
LGM	Last Glacial Maximum
LM	Late Mesolithic
LN	Late Neolithic
LP	Late Palaeolithic
MN	Middle Neolithic
NAP	non-arboreal pollen
NGRIP	North Greenland Ice Core Project
NH	Northern Hemisphere
NPP	non-pollen palynomorph
OZ	ostracod zone

P-ED XRF	portable energy-dispersive X-ray fluorescence spectrometry
PBO	Preboreal oscillation
PZ	pollen zone
rpm	rotations per minute
SEM	scanning electron microscope
SiO_2bio	biogenic silica
SPT	sodium polytungstate
STEP	steppe
SZ	sediment zone
TAIG	taiga
TC	total carbon
TIC	total inorganic carbon
TN	total nitrogen
TOC	total organic carbon
TUND	tundra
y	year
YD	Younger Dryas
XRD	X-ray diffraction

1 Introduction

1.1 Preface

The doctoral thesis presented here is a contribution to the ongoing Baikal Archaeology Project (BAP: https://baikalproject.artsrn.ualberta.ca/), which "consists of an international and multi-disciplinary team of scholars with expertise in archaeology, bioarchaeology, ethnoarchaeology, genetics, bio- and geochemistry, and palaeoenvironmental studies" (https://baikalproject.artsrn.ualberta.ca/about/). This team, which consists of senior and young researchers as well as doctoral, master and bachelor students from Canada, Russia, Germany, United Kingdom and several other countries, is exploring prehistoric hunter-gatherer lifeways in Northern Asia and aims to improve the current "understanding of the dynamism, variability, and resilience of prehistoric Holocene hunter-gatherers". The BAP research strategy greatly relies on "what has been called the bioarchaeology of individual life histories approach – a suite of laboratory and macroscopic methods that generate information pertaining to the age, sex, diet, mobility, habitual activities, health and genetic traits of particular persons through the examination of their skeletal remains in conjunction with their archaeological and environmental context" (https://baikalproject.artsrn.ualberta.ca/about/).

However, such detailed reconstructions of individual life histories require comprehensive, comparably high-resolution and accurately dated palaeoenvironmental information, which can be used for the reconstruction of regional landscape development and climate changes and their possible effects on human population dynamics, cultural traditions and subsistence strategies (Weber et al., 2013). Tarasov et al. (2017) summarised the key question raised in the former archaeological and palaeoecological studies as follows: Did climate change directly or indirectly affect hunter-gatherers in the LBR or were changes in the regional archaeological sequence the result of socio-cultural rather than environmental processes? Finding a well-founded answer to this question is particularly important with regard to a documented lack of settlement and mortuary sites in regional archaeological records during the Middle Neolithic in parts of Cis-Baikal (e.g. Weber et al., 2013; Losey and Nomokonova, 2017).

In addition, published pollen records from Lake Baikal and surrounding coastal plains demonstrate significant spatial variations in vegetation dynamics, suggesting spatially complex (i.e. non-universal) reaction of the environments (and human populations) to the millennial-scale and shorter-term climate variability across the vast LBR (e.g. see Bezrukova et al., 2013;

Demske et al., 2005; Kobe et al., 2020; Weber, 2020 for discussion and references). The main obstacles, which challenge robust comparisons with high-resolution bioarchaeological records and an understanding of the potential factors responsible for the reported spatial-temporal differences, are relatively low temporal resolution and poor dating control of available palaeoenvironmental archives (see Tarasov et al., 2017 for discussion and references).

A successful strategy to overcome these obstacles, as demonstrated in the former BHAP research (e.g. Müller et al., 2016; Leipe et al., 2018), is to search for high-resolution environmental archives (e.g. continuously accumulated lake sediment) that are representative of each archaeological macro- and microregion, their detailed (possibly multi-proxy) analyses and robust AMS radiocarbon dating. This strategy has been also applied in the current doctoral project greatly supported by the Social Sciences and Humanities Research Council of Canada, University of Alberta (Edmonton), Freie University Berlin and the project "Individual life histories in long-term culture change: Holocene hunter-gatherers in Northern Eurasia" (SSHRC Partnership Grant № 895-2018-1004).

For this doctoral project, Lake Ochaul (54°14'N, 106°28'E; 641 m a.s.l.), a small freshwater lake situated in the archaeologically and environmentally understudied Upper Lena microregion (Losey and Nomokonova, 2017), ca. 100 km northwest of Lake Baikal (Fig. 1.1), has been selected as the study site. The preliminary investigations at Lake Ochaul in Cis-Baikal revealed a thick layer of bottom sediments, with a potential to provide high-resolution environmental records of the past ca. 40 to 30 cal kyr BP, thus comparable to the well-known and so far, the best-studied palaeoenvironmental archive of Lake Kotokel in Trans-Baikal (Bezrukova et al., 2010; Tarasov et al., 2017). In addition, several archaeological surveys conducted in the area around Lake Ochaul between 1913 and 2016 (Aksyonov, 2009; Peskov, 2016) revealed campsites of the prehistoric hunter-gatherers on the terrace north of the lake and suggested that the sites were discontinuously used by the hunter-gatherer groups possibly since the late Upper Palaeolithic to the Early Bronze Age. The proximity between the archaeological site and the environmental archive of Lake Ochaul offers great potential for the correlation of the respective archaeological and palaeoecological records and for the discussion of human-environmental interactions at a local to regional scale (Kobe et al., 2020).

Pollen analysis of the sediment core recovered from Lake Ochaul was chosen as a key research method in the current project. In a wide range of methods, which are used for reconstructing the environmental setting and the economy and way of life of past human cultures, pollen analysis ranks very highly (Bryant and Holloway, 1983; Dimbleby, 1985). In the LBR, this method was most frequently applied to lake and mire sediments (e.g. see Tarasov et al., 2017 for a review and additional references) and the palynological results were successfully used to reconstruct the Late Pleistocene and Holocene vegetation and climate history (e.g. Tarasov et al., 2009a; Bezrukova et al., 2010). Another focus in the current project was establishing a robust chronology for the analysed core, which allows accurate dating of all palynological and other records generated in this and ongoing studies. For this purpose, 35 sediment samples were selected and AMS dated in the Poznan Radiocarbon Laboratory by Prof. Dr. Tomasz Goslar. In addition to palynological investigation designed and performed by the author of this thesis, a number of other research methods were applied to the sediment core from Lake Ochaul, including sediment lithology and geochemistry, analysis of ostracod and mollusc remains as well as several pilot analyses testing the potential of the sediment and providing additional palaeoenvironmental information, essential for the interpretations of the results. Although, these complementary analyses were performed by the other members of the Lake Ochaul research team, as indicated in the respective publications, the author of this thesis actively participated in the planning and design of these studies, including sample taking, sediment preparation, discussion and interpretation of results, information exchange and data management.

Beside the Introduction and Conclusions chapters, this doctoral thesis consists of three peer-reviewed manuscripts (Kobe et al., 2020; 2022a; 2022b) published in international scientific journals and presenting in detail the main objectives, results and outcome of the current project, as well as extensive supplementary material and tables with the original data. In the published manuscripts, a number of palaeoenvironmental, ecological and archaeological questions have been addressed, aiming at the reconstruction of past vegetation and climate of the study area, the Lake Ochaul history and human-environmental interactions.

The first manuscript “Holocene vegetation and climate history in Baikal Siberia reconstructed from pollen records and its implications for archaeology” (**Chapter 2**) is a review and research paper that contributes to the Archaeological Research in Asia journal's special issue entitled “Middle Holocene hunter-gatherers of Lake Baikal: Integrating individual life histories and high-resolution chronologies”. It provides the first introduction to Lake Ochaul and evaluates the potential of the Och18-II core sediment as a key source of palaeoenvironmental information from the Upper Lena archaeological microregion of Cis-Baikal, which lacks environmental archives with sufficiently high-resolution and robust chronological control. For this purpose, a 160 cm section of the Och18-II core dated to the Lateglacial – Middle Holocene interval (ca. 13.5 to 4 cal kyr BP) was coarsely analysed for pollen and compared with the published well-dated pollen vegetation and climate records from

Lake Kotokel (52°47'N, 108°07'E; altitude 458 m a.s.l.) in Trans-Baikal. This comparison showed some similarities, but also considerable differences in vegetation development in the two subregions of the LBR. Around Ochaul, the landscape was relatively open during the Younger Dryas stadial, but forest vegetation started to spread at the Lateglacial/Holocene transition (ca. 11,650 cal yr BP), thus ca. 1000 years earlier than around Kotokel. While in both regions, taiga forests spread during the Early and Middle Holocene, the marked increase in Scots pine pollen in the Kotokel record after ca. 6800 cal yr BP is not seen at Ochaul, where birch and coniferous taxa, such as Siberian pine, larch, spruce and fir, dominate, indicating different environmental conditions and driving forces in both study regions. However, the pollen data from Ochaul emphasises that the Cis-Baikal area also saw a continuous increase in forest cover and in the proportion of conifers over birch trees and shrubs during the Early–Middle Holocene, which may have contributed to a decrease in the number of large herbivores, the main food resource of the Late Palaeolithic (Tarasov et al., 2021) and Early Neolithic hunter-gatherer groups (Losey and Nomokonova, 2017). This and rather abrupt reorganisation of atmospheric circulation, which affected atmospheric precipitation distribution resulting in thicker and longer-lasting snow cover, may have led to a collapse of Early Neolithic Kitoi populations ca. 6660 cal yr BP followed by a cultural "hiatus" in the archaeological records during the Middle Neolithic phase (ca. 6660–6060 cal yr BP). The results presented in the first manuscript, on the one hand, justified the choice of Lake Ochaul as a valuable palaeoenvironmental archive able to address some of the questions asked by the BAP community and, on the other hand, stressed the importance of sub-regional palaeoenvironmental studies and the need of a representative network of well-dated, high-resolution sediment archives for a better understanding of environmental changes and their potential impacts on the hunter-gatherer populations in the archaeologically defined microregions.

For the second manuscript "Not herbs and forbs alone: Pollen-based evidence for the presence of boreal trees and shrubs in Cis-Baikal (Eastern Siberia) derived from the Last Glacial Maximum sediment of Lake Ochaul" (**Chapter 3**), the Och18-II-4 section spanning the LGM interval was selected and analysed in greater details. There is a strong and long-lasting interest to the vegetation and climate history of Northern Asia and the LBR (see Tarasov et al., 2021 for review and references), as these vast areas witnessed continuous hunter-gatherer habitation during the climatically harshest part of the last glacial and played a key role in the spread of anatomically modern humans to America (e.g. see Tarasov et al., 2021 for discussion and references). A new AMS-dated sedimentary record from Lake Ochaul discussed in the second manuscript covers the interval from ca. 27,850 to 20,400 cal yr BP at ca. 180-year resolution and contributes to a better understanding of the complex spatial vegetation pattern during the LGM. The pollen record indicates the dominance of productive herbaceous vegetation, which supported large herbivorous and carnivorous animal population (i.e. “mammoth fauna”) and their human hunters (Tarasov et al., 2021). Our results show that the Upper Lena was another region in which refugia for arboreal taxa existed and that far-distant transported pollen can be ruled out as the source of the detected AP. Furthermore, comparison of the *Artemisia* and Cyperaceae pollen records from the sites across Eastern Siberia allows to reconstruct moisture and temperature gradients in this region during the LGM and to conclude that moisture availability rather than thermal conditions likely played a decisive role for tree and shrub growth during the coldest stage of the last glacial.

The third manuscript entitled “Lateglacial–Holocene environments and human occupation in the Upper Lena region of Eastern Siberia derived from sedimentary and zooarchaeological data from Lake Ochaul” (**Chapter 4**) provides a high-resolution (260 cm section analysed at 2-cm to 4-cm steps) pollen and NPP records for the entire interval between ca. 13.5 cal kyr BP and the present. This paper reflects the inter-disciplinary spirit of the BAP and combines a palynological approach with other sedimentary geochemical and biological proxies and with results of radiocarbon dating and zooarchaeological analysis of the animal bone samples obtained from cultural layers of the nearby archaeological site Ochaul. In the manuscript, the reconstructions of the postglacial vegetation and lake system development are discussed along with the regional climate dynamics and the hemispheric-scale environmental changes. During the Allerød interstadial the region around Lake Ochaul was dominated by sparse taiga forests. Cooling during the Younger Dryas led to a more open, tundra landscape where trees formed patchy forest stands in climatically favourable environments. This facilitated a rapid spread of forests at the onset of the Early Holocene during which the study region was probably characterised by seasonally dry climate controlled by the interplay of higher insolation, lower global sea levels and remaining ice sheets in the North Atlantic region. After thermal and moisture optimum conditions and a maximum spread of forests during the Middle Holocene, continuous cooling and a trend to more open forests landscapes marked the Late Holocene. These long-term trends were interrupted by several relatively short episodes of change in the vegetation and algal records, which coincide with short-term (centennial-scale) Northern Hemisphere cooling/drying phases. The results show that the regional vegetation reacted sensitively to NH climate oscillations. Six AMS radiocarbon dates of bone material of large herbivorous animals from the Ochaul archaeological site located at the northern shore of the lake provide important information about the prehistoric hunter-gatherers and indicate activities at the site at ca. 27,780–27,160 cal yr BP (95% probability range) as well as during the Mesolithic (ca. 8850–8450 cal yr BP), Early, Middle and Late Neolithic (between ca. 6840 and 5490 cal yr BP) and the Iron Age (ca. 2120–1930 cal yr BP). Our results demonstrate that despite major environmental transformations following the LGM, Lake Ochaul and its surrounding area remained attractive for large herbivores and for prehistoric hunter-gatherers, even during the Middle Neolithic cultural “hiatus” (ca. 6660–6060 cal yr BP) in Cis-Baikal, as documented by the published archaeological records.

1.2 Scientific goals and objectives

The main objectives of this doctoral project were to reconstruct past glacial and interglacial environments of the area around Lake Ochaul, which represents the Upper Lena archaeological microregion of Cis-Baikal, and to address the key question formulated by the BAP team: Did climate change directly or indirectly affect hunter-gatherers in the LBR or were changes in the regional archaeological sequence the result of socio-cultural rather than environmental processes? In order to reach these goals, the high-resolution palynological analysis of the 7.24-m-long Och18-II sediment core spanning about 32,000 years was performed, accompanied by the quantitative biome reconstruction and comparisons of the obtained results with other proxies and with the published regional and global environmental and climatic archives. The overall goal of this project was to obtain a high-resolution and accurately dated palynological record suitable for qualitative and quantitative reconstructions of regional vegetation, climate and human-environmental interactions, as well as for comparison with other high-resolution palaeoenvironmental archives from and outside the LBR and for validation of Earth system modelling experiments.

1.3 Integrated manuscripts

This doctoral thesis is written in a cumulative form and consists of three individual manuscripts (Chapters 2–4) that are published in peer-reviewed scientific journals. Table 1.1 gives an overview of all manuscripts and the author’s contribution. Repetitions are unavoidable since every manuscript represents its own research but with equal or similar regional setting and methodology.

Table 1.1: Overview of the manuscripts including the author's contribution ratio.

Chap.	Title, Authors			Journal, Status of Publication
2	Holocene vegetation and climate history in Baikal Siberia reconstructed from pollen records and its implications for archaeology			Published in *Archaeological Research in Asia* (2020) https://doi.org/10.1016/j.ara.2020.100209
	Franziska Kobe, Elena V. Bezrukova, Christian Leipe, Alexander A. Shchetnikov, Tomasz Goslar, Mayke Wagner, Svetlana S. Kostrova, Pavel E. Tarasov			
	Contribution of F. Kobe:			
	Conception: 75%,	Accomplishment: 60%	Publication: 60%	
3	Not herbs and forbs alone: Pollen-based evidence for the presence of boreal trees and shrubs in Cis-Baikal (Eastern Siberia) derived from the Last Glacial Maximum sediment of Lake Ochaul			Published in *Journal of Quaternary Sciences* (2022, open access) https://doi.org/10.1002/jqs.3290
	Franziska Kobe, Christian Leipe, Alexander A. Shchetnikov, Philipp Hoelzmann, Jana Gliwa, Pascal Olschewski, Tomasz Goslar, Mayke Wagner, Elena V. Bezrukova and Pavel E. Tarasov			
	Contribution of F. Kobe:			
	Conception: 75%,	Accomplishment: 80%	Publication: 65%	
4	Lateglacial–Holocene environments and human occupation in the Upper Lena region of Eastern Siberia derived from sedimentary and zooarchaeological data from Lake Ochaul			Published in *Quaternary International* (2022, open access) https://doi.org/10.1016/j.quaint.2021.09.019
	Franziska Kobe, Philipp Hoelzmann, Jana Gliwa, Pascal Olschewski, Sergey A. Peskov, Alexander A. Shchetnikov, Guzel A. Danukalova, Evgeniya M. Osipova, Tomasz Goslar, Christian Leipe, Mayke Wagner, Elena V. Bezrukova, Pavel E. Tarasov			
	Contribution of F. Kobe:			
	Conception: 80%,	Accomplishment: 70%	Publication: 75%	

1.4 Scientific background

1.4.1 Regional setting of Lake Ochaul

Lake Ochaul (54°14’N, 106°28’E; 641 m a.s.l.) is a small freshwater lake, that is situated in the upper reaches of the Lena River, about 100 km northwest of Lake Baikal (Fig. 1.1). The

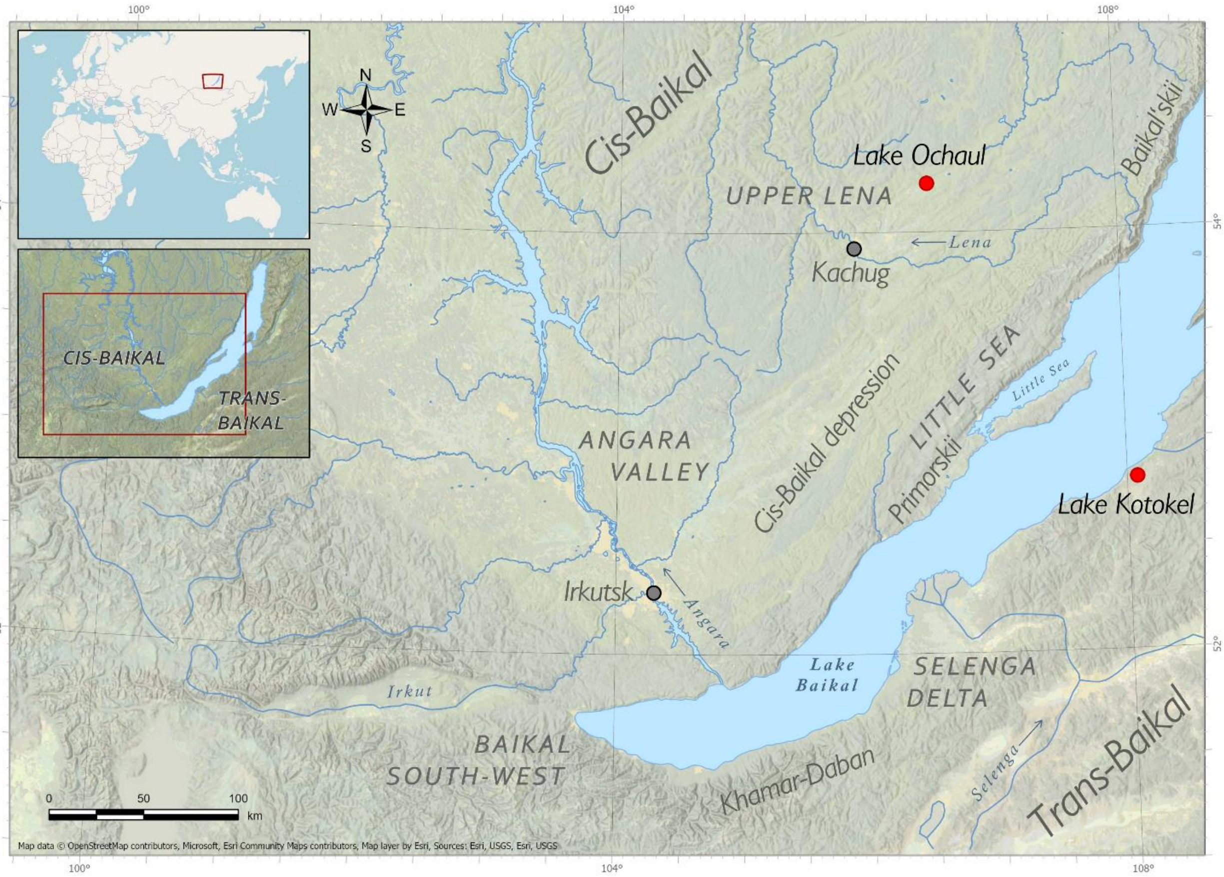

Figure 1.1: Topographic overview map of the Cis-Baikal region with locations of Lake Ochaul (this work) and Lake Kotokel marked (red points) by Karolina Werens, Baikal Archaeology Project.

water surface is about 2.6 km^2 and the catchment area of the lake is about 170 km^2. The lake has a maximum length of ca. 2.7 km and a maximum width of ca. 1.2 km (Boyarkin, 2007) and is rather shallow with a maximum water depth of ca. 2.5 m in the central part (Kobe et al., 2020). Water temperatures of around 0.7 and 14 °C and pH values of ca. 6.6 and 6.1 were measured in March and June, respectively. Densely covered with aquatic vegetation, the banks of Lake Ochaul are low and marshy, especially in the southwest and northeast where the Malaya Anga River, a right tributary of the Bol'shaya Anga, which flows into the Lena River near the city of Kachug ca. 50 km southwest of the lake, crosses the lake. Cryogenic processes play an important role in the formation of the microrelief in the valley. A series of 2–3-m-high palaeoshoreline features that surround the lake in the east, ca. 100–300 m from its modern coastline, indicate that the lake occupied a larger area and was deeper in the past.

The lake catchment is separated from Lake Baikal by the mountain ranges Primorskii and Baikal'skii with the Lena-Angara Plateau bordering the area in the north and west (Kobe et al., 2022b). Lake Ochaul is situated in a trough-shaped valley, that is a part of the Cis-Baikal Depression whereas "Cis-Baikal" describes the region north/northwest of Lake Baikal. The slopes of the valley around Ochaul reach hights up to 850–900 m a.s.l. and therefore 200–250 m above the lake level. Boreal coniferous forests dominate the area with larch, birch and Siberian pine and admixture of spruce and fir and shrubs of the heath family (*Ledum palustre, Vaccinium vitis-idaea, V. uliginosum*) as well as various grass and moss species representing the undergrowth. Whereas Scots pines rarely appear in the catchment area and are not as common as in the Trans-Baikal region, the area south/southwest of Lake Baikal, Larch forests are dominating with abundant birch shrubs (ernik) in the undergrowth (Belov et al., 2002). Climate averages from Kachug show a mean temperature of −25.5 °C in January, 17.1 °C in July, an annual precipitation of 339 mm (https://ru.climate-data.org/) and a period of continuous snow cover of 167 days (Galaziy, 1993).

1.4.2 Palaeoenvironmental background

The palaeoenvironmental background has been summarised in Tarasov et al. (2017). The general knowledge of the vegetational development in the LBR during the Late Pleistocene and Holocene is rather limited. Often, a palynological approach was applied, but qualitative interpretations predominate over objective pollen-based reconstructions of climate and vegetation. Published records are often poorly dated, discontinuous or cover only restricted time intervals (e.g. Demske et al., 2005; Khotinskii 1984; Frenzel et al., 1992; Tarasov et al., 1999; Prentice et al., 2000). Thus, low temporal resolution and insufficient chronological control of pollen archives remain a serious problem. The first pollen-based reconstructions of atmospheric precipitation, temperature of the warmest and coldest month and moisture index were derived from the Bugul'deika site in the southern part of Lake Baikal (Tarasov et al., 2007). Another rather well-studied site is Lake Kotokel situated in the Trans-Baikal subregion (e.g. Bezrukova et al., 2010; Shichi et al., 2009; Tarasov et al., 2009a, 2017; Kostrova et al., 2013, 2016). Both pollen records and the pollen-based palaeoenvironmental reconstructions show somewhat mixed signals for the vegetation and climate developments. The reason for those differences might lay in the large catchment region and complex topography of the LBR. Reasons behind reconstructed spatial-temporal differences in vegetation and climate development need to be better understood. However, this goal cannot be achieved without robustly dated and high-resolution records from different parts of the LBR (Tarasov et al., 2017). Investigating the palaeoenvironmental history of the LBR is also of great importance for archaeological research since possible effects of vegetation and climate dynamics on regional human populations and cultural sequences should always be considered (Weber, 2020). More information about the palaeoenvironmental background can be found in Chapters 2.6.2, 3.6.2 and 4.6.1.

1.4.3 Archaeological background

Weber (2020) reviewed and summarised the results of the archaeological and bioarchaeological research in the Cis-Baikal region (Table 1.2) and discussed how the changes in vegetation and plant and animal resources, the development of bow-and-arrow and fishing techniques might have influenced the evolution of the Holocene hunter-gatherer populations. He suggested that the changes in the archaeological records can hardly be explained by the climate changes only but require thorough analysis of the available environmental and archaeological data.

Table 1.2: Geographic and cultural distribution of Cis-Baikal Middle Holocene cemeteries documented archaeologically. In cases where more than one mortuary tradition was represented at a given location, each was counted as a separate cemetery (Weber, 2020).

Period & mortuary tradition or group	Category	Microregion				
		Angara	Baikal SW	Upper Lena	Little Sea	Total
Late Mesolithic to Early Neolithic, Khin	Cemeteries	6		6	10	22
	Graves	8		12	38	58
	Individuals	8		14	44	66
Early Neolithic, Kitoi	Cemeteries	13	1			14
	Graves	147	99			246
	Individuals	215	159			374
Middle Neolithic	Lack of documented formal cemeteries					
Late Neolithic, Isakovo	Cemeteries	23		1		24
	Graves	94		1		95
	Individuals	124		1		125
Late Neolithic, Serovo	Cemeteries	4		5	10	19
	Graves	19		30	42	91
	Individuals	20		51	70	141
Early Bronze Age	Cemeteries	47	1	12	16	76
	Graves	193	12	65	200	470
	Individuals	211	14	77	230	532
Total	Cemeteries	93	2	24	36	155
	Graves	461	111	108	280	960
	Individuals	578	173	143	344	1238

The LBR is unique in its archaeological history. Unlike other boreal regions, it reveals surprisingly many finds of archaeological cemeteries dated from the Late Mesolithic to the Early Bronze Age. A focus of the BAP was set on the examination of skeletal remains using a range of bioarchaeological methods for reconstructing individual life histories (Zvelebil and Weber, 2013). According to Weber (2020), the driving forces of the evolutionary history of hunter-gatherers are a gradual climate change and environmental trends leading to changes of hunter-gatherer adaptive strategies that can possibly be followed by the appearance of technological, economic and social innovations and diverse hunter-gatherer adaptations and complicated evolutionary trajectories for various environmental settings. Environmental changes, such as the expansion of the forests during the Middle Holocene and the following gradual opening of landscapes influenced the availability and distribution of game and therefore probably had a strong impact on hunter-gatherers. One of the big riddles remains the so-called cultural “hiatus” between ca. 6660–6060 cal yr BP, which followed the collapse of the Early Neolithic Kitoi culture. There are theories (Tarasov et al., 2017) suggesting that the environmental pressure on this population was too strong due to spreading forests and diminishing returns from hunting.

Of great scientific interest is also the Upper Palaeolithic interval between ca. 50,000–11,500 cal yr BP, when harsh glacial climates dominated in Eastern Siberia and scattered hunter-gatherer groups were living in open landscape environments resembling cold steppe and tundra. Nevertheless, the worldwide spread of anatomically modern humans occurred during this time interval and this process is still not sufficiently understood. Tarasov et al. (2021) assumed that after the arrival of anatomically modern humans in the southern part of Siberia about 45,000 years ago, their further spread across the eastern part of Asia was facilitated by the year-round availability of various food resources. Available pollen records (e.g. Müller et al., 2010; Bezrukova et al., 2010; Kobe et al., 2022a) show that the LBR was covered with productive steppe or dry tundra vegetation which was highly beneficial for large herbivorous animals and therefore advantageous for Upper Palaeolithic hunter-gatherers living there. Available climate reconstructions suggest a very continental climate with summers warmer than today and low winter precipitation causing a snow coverage of only small thickness and allowing a year-round grazing for the megafauna (Tarasov et al., 2021).

1.5 Material and methods

1.5.1 Sediment core

In summer 2018, Lake Ochaul (54°13’58.4”N, 106°27’53.8”E) in the Upper Lena microregion of Cis-Baikal was cored by a team of the Institute of Geochemistry (Irkutsk), Siberian Branch of the Russian Academy of Sciences led by Prof. Elena Bezrukova and Dr. Alexander Shchetnikov. Using an UWITEC percussion piston corer and coring platform acquired via the BAP, they recovered a 7.24-m-long sediment core (Och18-II) from the deepest and central part of the lake at a water depth of ca. 2.5 m. The core, consisting of five core sections, was then stored under constantly low temperatures in the storeroom of the Institute of Geochemistry. In March 2019, the tubes were cut in two halves and opened. The sediments were photographed, documented and subsampled for different analyses using the double-L channel (LL-channel) technique after Nakagawa (2007). The sediments of the Och18-II core consist of a partly laminated unit of soft biogenic gyttja (213–0 cm) that is rich in freshwater molluscs and ostracod shells, a transitional layer of laminated silty clay and gyttja (236–213 cm) and a layer of partly finely laminated massive viscous silty clay (724–236 cm).

To improve the quality of the interpretations and to obtain as much information as possible about the lake history and the past local and regional vegetation and climate changes, several other proxies were analysed besides pollen and non-pollen palynomorphs. This includes geochemical (Chapters 3.4.2 and 4.4.2), ostracod (Chapters 3.5.3 and 4.4.5), malacological (Chapter 4.4.6) and zooarchaeological (Chapter 4.4.7) approaches. In the following, the AMS radiocarbon dating and age-depth model construction, the main features of the palynological analysis and the biome reconstruction approach are briefly explained.

1.5.2 AMS radiocarbon dating

A total of 35 bulk sediment samples was sent to the Poznan Radiocarbon Laboratory for accelerator mass spectrometry (AMS) dating to estimate the age of the Och18-II core. The obtained ^{14}C ages suggested continuous accumulation of the recovered core sediment during the past ca. 32,000 years and helped choosing suitable sections for further analyses presented in the respective studies (Chapters 2, 3 and 4). The first coarse results of the AMS dating (Chapter 2) already suggested that the reservoir effect could be a problem in Lake Ochaul since the topmost and therefore surface sample revealed a date of 615±30 ^{14}C yr BP. This assumption was confirmed by using down-core records of short-lived ^{210}Pb and ^{137}Cs isotopes. Then, we subtracted the reservoir age of 600 years from all radiocarbon dates prior to their calibration to calendar ages using OxCal v4.3 (https://c14.arch.ox.ac.uk/oxcal.html; Bronk Ramsey, 1995) and the IntCal20 curve (Reimer et al., 2020). All calibrated ages are presented in calendar ages before present (cal yr BP) whereat "present" stands for the year 1950 AD (Fig. 3.3 and Table 3.1, Chapter 3.4.1 as well as Fig. 4.3 and Table 4.1, Chapter 4.4.1).

1.5.3 Pollen analysis

A total of 124 samples in 2- to 4-cm steps with a weight of 1 or 2 g each were taken from the core sections Och18-II-1, Och18-II-2 and Och18-II-4 for the three palynological studies and treated in the pollen laboratory of the Paleontology Section at the Institute of Geological Sciences, Freie Universität Berlin. Prior to treatment, a *Lycopodium clavatum* spore tablet (Lyco Batch № 483216: 18,583 spores per tablet and Lyco Batch № 050220211: 18407 spores per tablet) was added to each sample following Stockmarr (1971) for later calculations

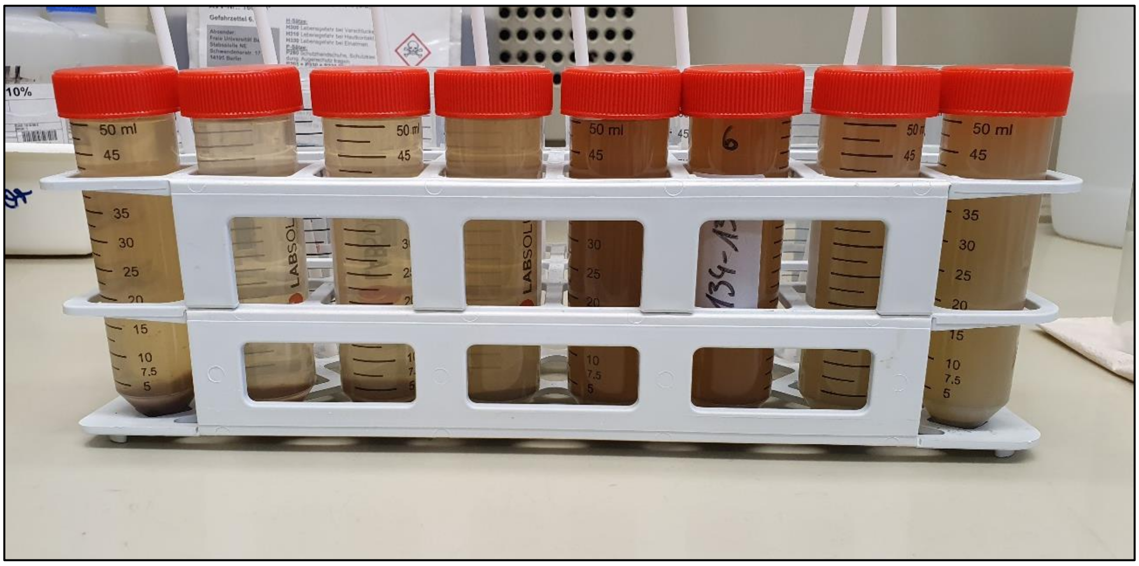

Figure 1.2: Samples after the first low-speed washing. Some samples are already very clear due to low clay content, others are rather dark and murky (Photo by Franziska Kobe).

of pollen and NPP concentrations. For the treatment of sediment samples to extract pollen grains and NPPs, the protocol developed in collaboration with Dr. Christian Leipe and Dr. Stefanie Müller (Leipe et al., 2019) was applied and further explained in this chapter.

At first, ca. 25 to 30 ml of 10% hydrochloric acid (HCl) is added to each sample, stored in 50 ml tubes, to solve carbonates and the calcareous matrix of the *Lycopodium* tablets. Afterwards, the samples are washed twice with distilled water to remove rests of HCl. Then, the sample are treated with 25 ml of 10% potassium hydroxide (KOH) in a hot water bath for 15 minutes to remove humic acids and washed once. To remove clay and other small-sized particles, the samples are repeatedly washed using slow-speed-centrifugation until the supernatant is clear (Fig. 1.2). Although it is more time-consuming, slow-speed-washing is a great alternative to ultrasonic fine-sieving since it is less destructive, especially for already damaged or poorly preserved pollen grains. Now, the samples are transferred to 15 ml tubes and 7 to 8 ml of the heavy liquid sodium polytungstate (SPT) at a density of 2.1 g/cm^3 is added and thoroughly homogenised. After the centrifugation process (15 minutes at a low velocity) is finished, the supernatant, including the pollen and NPP fraction (Fig. 1.3), is moved to 50 ml tubes and washed twice to remove all SPT rests and then, the samples are again transferred to 15 ml tubes.

A big advantage of heavy liquids such as SPT is that they can be recycled and reused multiple times (Fig. 1.4). To do this, the collected supernatants of the previous steps are filtered and carefully heated but not cooked, preferably on a magnetic stirrer, since SPT can be damaged when overheated. Subsequently, the correct density of the SPT (2.1 g/cm^3) can be adjusted by

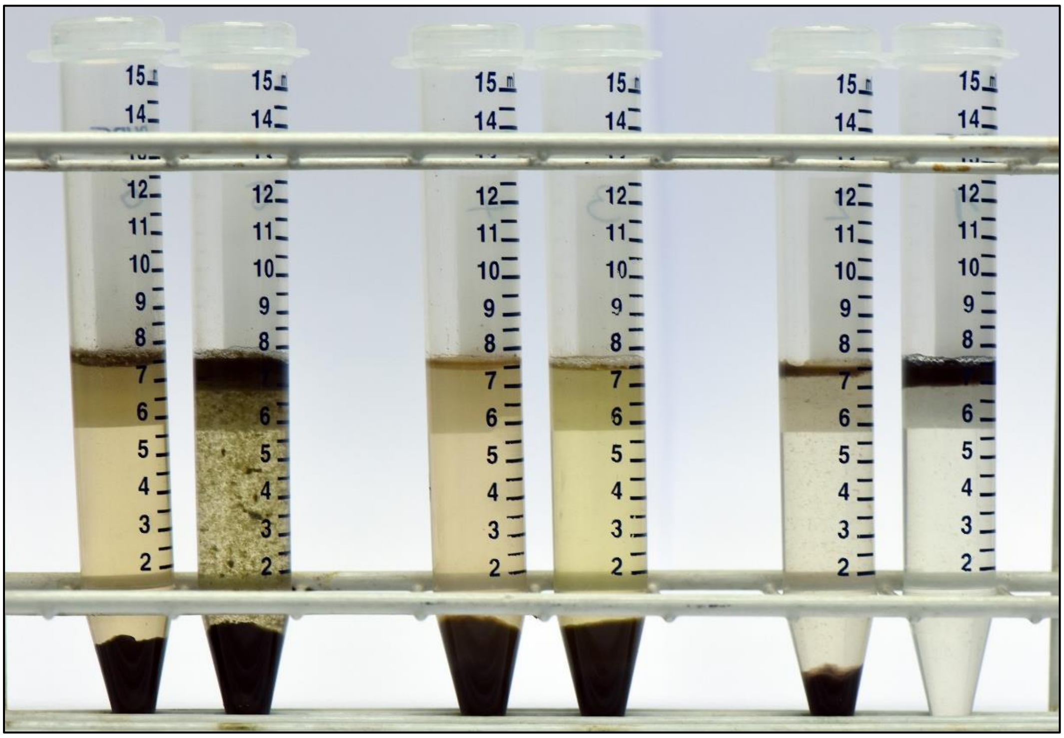

Figure 1.3: Sample after centrifugation with heavy liquid (SPT). The pollen and NPP fraction is visible at the top of the supernatant (Photo by Jan Kersten).

using an areometer or density hydrometer. This process is rather time-consuming and can take several days but also, it can be repeated multiple times. Furthermore, non-toxic heavy liquids like SPT are far less dangerous for humans and the environment than hydrofluoric acid (HF) that is also used to this day for lab treatment of pollen samples.

After dense media separation, the samples are dehydrated by washing with glacial acetic acid and then treated with 3 to 4 ml of acetolysis, a mixture of acetic anhydrite and 95 to 99%

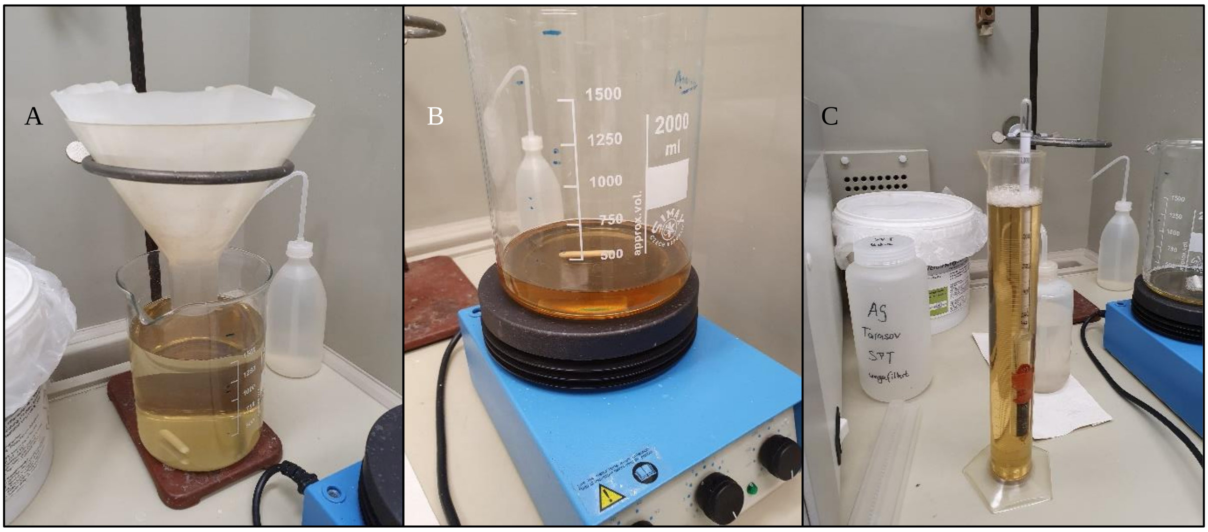

Figure 1.4: SPT under recycling process: (A) Filtering, (B) evaporation and (C) density adjustment (Photo by Franziska Kobe).

sulfuric acid (with a relation of 9:1). The acetolysis admixture is produced by carefully adding sulfuric acid drop by drop to acetic anhydrite to avoid strong reactions. Acetolysis helps to remove organic remains but most importantly, it colours and enlarges pollen grains which helps with the identification. Once the acetolysis admixture is added to the samples, they are heated in a water bath for no more than 3 min. Glacial acetic acid is quickly added to the acetolysis-containing samples to stop the reaction before they are centrifuged and carefully washed thrice. It is important to work fast but concentrated for the whole acetolysis process to avoid damaging the pollen grains. The acetolysis procedure is still under discussion due to the hazardous nature of this chemical solution and the difficulty of obtaining all components for some laboratories or countries. Supernatants of the glacial acetic acid washing, the acetolysis step and at least of the first following washing have to be collected and disposed separately.

Then, the samples are stored in 5 ml tubes with added glycerol under constantly dark and cool conditions (for example in a fridge) to ensure optimal preservation conditions. For the analysis under the microscope, the sample is mixed thoroughly and one drop is added to an object slide ad covered with a coverslip. Pollen grains and NPPs are quantitatively monitored by counting every palynomorph row by row until at least 400 terrestrial pollen grains are reached. Tilia version 1.7.16 software (Grimm, 2011) was then used for calculating relative taxa percentages and for drawing the diagrams with CONISS program for stratigraphically constrained cluster analysis by the method of incremental sum of squares (Grimm, 1987) helping with spotting potential pollen zones.

To expand evaluation possibilities and to broaden the interpretation potential of the results, pollen-based biome reconstruction, introduced by Prentice et al. (1996) has been applied. An advantage of the biome reconstruction method is that it considers the ecology of pollen producing plants and divides the taxa into plant functional types compared to simply interpreting the relative pollen percentages. Taxa that don’t exceed the universal threshold of 0.5% (suggested by Prentice et al., 1996) are excluded from calculations. To increase the importance of minor pollen taxa, square root transformation was applied to the pollen percentage values. When scores of several biomes are equal, the biome with the highest affinity score or the one defined by a smaller number of plant functional types is assigned to each pollen spectrum (Prentice et al., 1996). Plant functional types are assigned to a number of biomes representing major vegetation types on the basis of the modern ecology, bioclimatic tolerance and geographical distribution of pollen-producing plants. This method was successfully used in several global-scale international projects including the BIOME6000 vegetation mapping project (e.g. Prentice et al., 2000) and the Paleoclimate Modelling Intercomparison Project (e.g.

Kageyama et al., 2001) but also in various Siberian pollen datasets (Edwards et al., 2000; Müller et al., 2010; Tarasov et al., 1998b, 2005, 2013a; Binney et al., 2017).

2 Manuscript I

Holocene vegetation and climate history in Baikal Siberia reconstructed from pollen records and its implications for archaeology

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2.1 Abstract

Past research has greatly improved our understanding of palaeoenvironmental changes in the Lake Baikal Region, but at the same time has indicated intra-regional variations in this vast study area. Here we present a new AMS-dated Lateglacial–Middle Holocene (ca. 13,500–4000 cal yr BP) pollen record from Lake Ochaul (54°14'N, 106°28'E; altitude 641 m a.s.l.) situated in the less-studied area of Cis-Baikal and compare reconstructed vegetation and climate dynamics with the published environmental history of Trans-Baikal based on the pollen record from Lake Kotokel (52°47'N, 108°07'E; altitude 458 m a.s.l.). Although both records show comparable major long-term trends in vegetation, there are considerable differences. Around

Ochaul, the landscape was relatively open during the Younger Dryas stadial, but forest vegetation started to spread at the Lateglacial/Holocene transition (ca. 11,650 cal yr BP), thus ca. 1000 years earlier than around Kotokel. While in both regions, taiga forests spread during the Early and Middle Holocene, the marked increase in Scots pine pollen in the Kotokel record after ca. 6800 cal yr BP is not seen in that from Ochaul, where birch and coniferous taxa, such as Siberian pine, larch, spruce and fir, dominate, indicating different environmental conditions and driving forces in both study regions. However, the pollen data from Ochaul emphasises that the Cis-Baikal area also saw a continuous increase in forest cover and in the proportion of conifers over birch trees and shrubs during the Early–Middle Holocene, which may have contributed to a decrease in the number of large herbivores, the main food resource of the Early Neolithic hunter-gatherer groups. This and rather abrupt reorganisation of atmospheric circulation, which affected atmospheric precipitation distribution resulting in thicker and longer-lasting snow cover, may have led to a collapse of Early Neolithic Kitoi populations ca. 6660 cal yr BP followed by a cultural “hiatus” in the archaeological records during the Middle Neolithic phase (ca. 6660–6060 cal yr BP). The results stress the importance of sub-regional palaeoenvironmental studies and the need for a representative network of well-dated, high-resolution sediment archives for a better understanding of environmental changes and their potential impacts on the hunter-gatherer populations in the archaeologically defined microregions.

3 Manuscript II

Not herbs and forbs alone: Pollen-based evidence for the presence of boreal trees and shrubs in Cis-Baikal (Eastern Siberia) derived from the Last Glacial Maximum sediment of Lake Ochaul

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3.1 Abstract

A new accelerator mass spectrometry (AMS)-dated sedimentary record from Lake Ochaul (54°14'N, 106°28'E; 641 m a.s.l.) in Eastern Siberia covers the interval from ca. 27,850 to 20,400 cal yr BP at ca. 180-year resolution and contributes to a better understanding of the complex spatial vegetation pattern during the Last Glacial Maximum (LGM). Non-arboreal pollen taxa are abundant in the pollen assemblages (mean value ca. 92.6%), but boreal trees are represented by all major taxa that grow in the lake catchment today, including *Betula* sect. *Albae*

(0.6–4.8%), *Picea* (0.6–2.8%), *Pinus sibirica* (*Haploxylon* type) (up to 1.5%), *Pinus sylvestris* (*Diploxylon* type) (up to 2%), *Larix* (up to 0.6%) and *Abies* (up to 0.6%). *Betula* sect. *Nanae/Fruticosae* (2–5.2%) and *Salix* (up to 3.2%) are the most representative boreal shrub taxa. Together with existing modern and fossil pollen data from the wider study region the current record provides further evidence for the long-debated presence of boreal trees and shrubs in Eastern Siberia throughout the LGM. Our results show that the Upper Lena was a region in which refugia for arboreal taxa existed and that far-distant transported pollen can be ruled out as the source of the detected arboreal pollen.

4 Manuscript III

Lateglacial–Holocene environments and human occupation in the Upper Lena region of Eastern Siberia derived from sedimentary and zooarchaeological data from Lake Ochaul

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4.1 Abstract

In the current study, different geochemical and biological proxies, including pollen, non-pollen palynomorphs, ostracods and molluscs, from an AMS radiocarbon-dated sediment core from Lake Ochaul (54°14'N, 106°28'E; 641 m a.s.l.) are presented and discussed. Ochaul is a freshwater lake and an archaeological site situated ca. 100 km northwest of Lake Baikal in the upper reaches of the Lena River. The 260-cm-long sedimentary record presented here spans the Lateglacial–Holocene interval, between ca. 13,500 cal yr BP and the present. The reconstructions of the postglacial vegetation and lake system development are discussed along with the regional climate dynamics and the hemispheric-scale environmental changes. During the Allerød interstadial the region around Lake Ochaul was dominated by sparse taiga forests. Cooling during the Younger Dryas led to a more open tundra landscape where trees formed patchy forest stands in climatically favourable environments. This facilitated a rapid spread of forests at the onset of the Early Holocene during which the study region was probably characterised by seasonally dry climate controlled by the interplay of higher insolation, lower global sea levels and remaining ice sheets in the North Atlantic region. After thermal and moisture optimum conditions and a maximum spread of forests during the Middle Holocene, continuous cooling and a trend to more open forests landscapes marked the Late Holocene. These long-term trends were interrupted by several relatively short episodes of change in the vegetation and algal records, which coincide with short-term (centennial-scale) Northern Hemisphere cooling/drying phases. This shows that the regional vegetation reacted sensitively to these climate oscillations. Six AMS radiocarbon dates of bone material of large herbivorous animals from the Ochaul archaeological site located at the northern shore of the lake provide important information about prehistoric hunter-gatherers and indicate that activities at the site took place at ca. 27,780–27,160 cal yr BP (95% probability range) as well as during the Mesolithic (ca. 8850–8450 cal yr BP), Early, Middle and Late Neolithic (between ca. 6840 and 5490 cal yr BP) and the Iron Age (ca. 2120–1930 cal yr BP). Our results demonstrate that despite major environmental transformations following the Last Glacial Maximum, Lake Ochaul and the Malaya Anga River valley remained attractive for large herbivores and for prehistoric hunter-gatherers, even during the Middle Neolithic cultural "hiatus" (ca. 6660–6060 cal yr BP) in Cis-Baikal, as documented by the published archaeological records.

5 Conclusions and future perspective

5.1 Summarising conclusions

This doctoral thesis consists of three multi-proxy studies aiming at reconstructing the last glacial/interglacial environments in the Cis-Baikal region. A 7.24-m-long sediment core from Lake Ochaul (54°14’N, 106°28’E; 641 m a.s.l.) spanning the last 32,000 years delivered a unique archive with detailed information about this region that is rich in archaeological sites but lacking high-resolution palaeonvironmental records with robust age control. With palynological analysis as the main research method, it became possible to reconstruct the vegetation and climate history of the study area and the lake system development with a focus on the LGM and the Lateglacial–Holocene intervals. Pilot studies also demonstrated the potential of several other proxies from the Lake Ochaul sedimentary archive, including sediment geochemistry, ostracod and malacological analyses, providing further important palaeolimnological and palaeoclimatic information and supporting the palynological interpretations. The main results of the current doctoral project are presented in three peer-reviewed articles published internationally and are summarised in Figures 5.1–5.3 as following.

The first article (**Chapter 2**) justifies selection of Lake Ochaul with its prehistoric hunter-gatherer campsites as a representative area of the Upper Lena microregion of Cis-Baikal and tests the potential of the Och18-II sediment core as a valuable archive of the last glacial/interglacial environments. This study presents a coarse-resolution pollen analysis for the Lateglacial to Middle Holocene interval and develops a preliminary age model for this section. The first accurately-dated pollen record from Lake Ochaul with multi-century resolution was used to reconstruct millennial-scale trends in regional vegetation development between 13,500 and 4000 cal yr BP. Further comparison with the Lake Kotokel pollen record representative of Trans-Baikal demonstrates noticeable differences in vegetation composition and forest development of the two major subregions of the LBR and stresses the importance of microregional palaeoenvironmental studies for a better understanding of environmental changes and their potential impacts on the hunter-gatherer populations in the archaeologically defined microregions. The study suggests that a continuous increase in forest cover and in the proportion of conifers over broadleaved trees and shrubs during the Early–Middle Holocene may have contributed to a further decrease in the deer populations, the main food resource of the Early Neolithic hunter-gatherer groups. This and a rather abrupt reorganisation of atmospheric circulation, resulting in thicker and longer-lasting snow cover, may have led to a

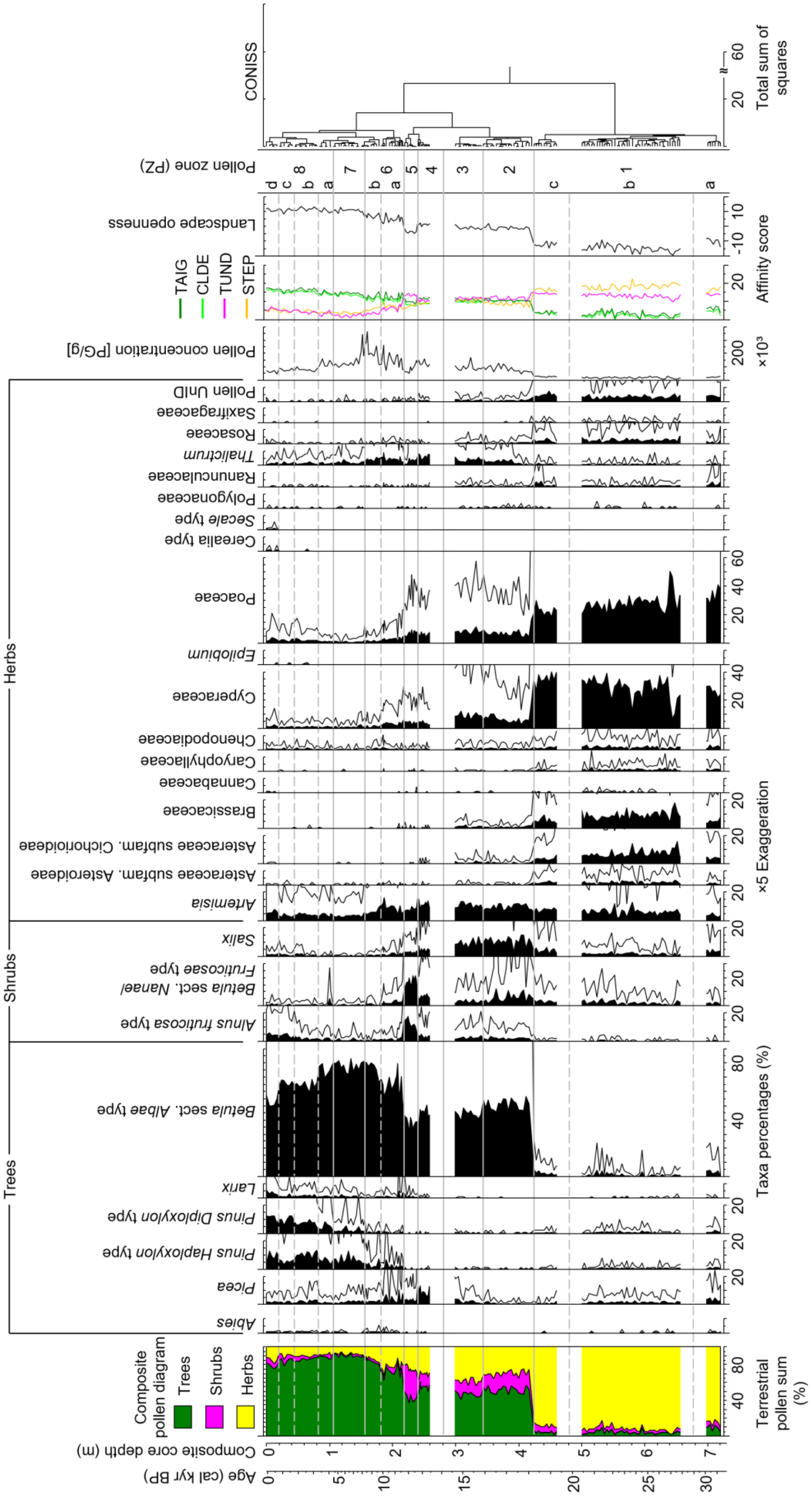

Figure 5.1: Simplified percentage diagram showing results of pollen analysis of the Och18-II sediment core from Lake Ochaul and calculated affinity scores of major regional biomes: taiga (TAIG), cold deciduous forest (CLDE), tundra (TUND) and cool steppe (STEP) as well as the calculated landscape openness and CONISS dendrogram plotted against core depth and age axes.

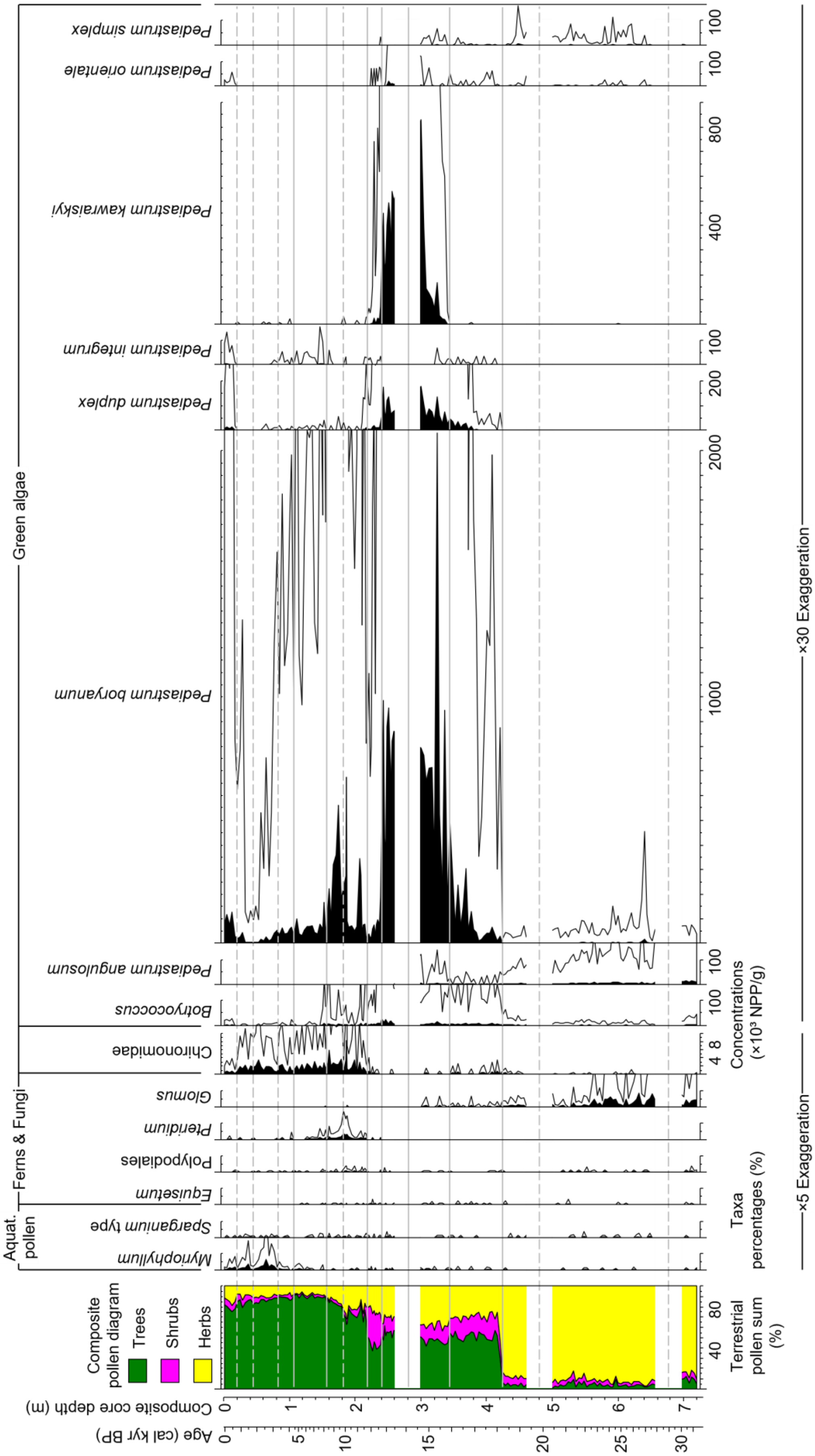

Figure 5.2: Simplified diagram showing aquatic pollen and fern spore percentages and absolute concentrations of counted chironomid and green algae remains in the Och18-II sediment core record from Lake Ochaul plotted against core depth and age axes.

collapse of Early Neolithic Kitoi populations ca. 6660 cal yr BP, followed by a cultural "hiatus" in the archaeological records during the Middle Neolithic phase (ca. 6660–6060 cal yr BP).

The second article (**Chapter 3**) provides the final age model for the entire Och18-II core and contributes to the discussion of the vegetation and climate history of the region during the LGM. Published pollen and plant macrofossil records from the northern and southern part of the taiga zone in Siberia demonstrate that boreal forests – the most characteristic feature of the Eurasian vegetation – quickly established there already during the Lateglacial, suggesting that small tree populations could have survived the generally colder- and drier-than-present glacial period somewhere in the region. However, due to a lack of high-resolution pollen and radiocarbon-dated macrofossil data from the vast central regions of Eastern Siberia, there is no agreement on if and where boreal trees could have survived during the LGM. The new pollen record from Lake Ochaul contributes to a better understanding of the spatially complex vegetation across Eastern Siberia between ca. 28,000 and 20,000 cal yr BP. In line with the published palaeobotanical data from the wider study region, the new record provides further evidence of the productive herbaceous vegetation dominating throughout the LGM, but argues that the Upper Lena was another region in which refugia for boreal tree and shrub taxa existed during that time. The study also demonstrates the use of *Artemisia* and Cyperaceae pollen records for reconstructing moisture and temperature gradients in LGM Eastern Siberia. Thus, regions south/southeast of Lake Baikal (including Trans-Baikal) were warmer and drier than those in the north/northwest (including Cis-Baikal), which explains the presence of trees in the Ochaul area and emphasises that moisture availability rather than thermal conditions likely played a decisive role for tree and shrub growth during the LGM.

The third publication (**Chapter 4**) further tests the sensitivity of the Ochaul vegetation and the lake system to century-scale climate fluctuations and to the Late Holocene cooling and presents a 2-cm-step-resolution palynological record of the Och18-II core, which covers the past 13,500 years. Major pollen composition changes in the Lake Ochaul sediments coincide with temperature changes documented in ice cores from Greenland, proving that the constructed age-depth model is accurate and the obtained pollen data are suitable for a robust reconstruction of postglacial vegetation dynamics around the lake and a discussion of the underlying climate changes. The ratios of tree, shrub and herbaceous pollen and the biome reconstruction demonstrate that during the Allerød interstadial the region around Lake Ochaul was dominated by sparse taiga forests. During the YD, cooling led to the spread of boreal shrubs and dwarf shrubs and a more open, tundra landscape, although forest patches survived in favourable environments, which explains a rapid spread of forests with the onset of the interglacial conditions. In the Early Holocene, the study region was probably characterised by seasonally dry climate, controlled by the interplay of higher insolation, lower global sea levels and remaining ice sheets in the North Atlantic region. During the Middle Holocene, the region saw thermal and moisture optimum conditions and a maximum spread of forests, but the climate continuously cooled during the Late Holocene, paralleled by a trend towards slightly more open landscapes. In addition to these long-term trends, the pollen data and the reconstructed biome scores indicate several relatively short episodes of vegetation change, which coincide with centennial-scale cooling/drying events in the North Atlantic.

The aquatic pollen and NPP records supplemented by sediment geochemistry and pilot analyses of ostracod and mollusc remains from the same core are shown to be suitable for reconstructing the evolution of the Lake Ochaul aquatic system and indicate that the lake did not dry up even during the LGM. This result further suggests that the lake was an important source of fresh water for herbivores and thus an important hunting ground for prehistoric hunter-gatherer groups perhaps since the Palaeolithic. As suggested by AMS dates of zooarchaeological remains from the Ochaul archaeological site, hunter-gatherers were also present in the area during the Middle Neolithic cultural “hiatus” (ca. 6660–6060 cal yr BP) proposed for several other microregions of Cis-Baikal.

5.2 Perspectives

This 3-year doctoral project generated a new high-resolution and accurately dated palaeoenvironmental archive for the Upper Lena microregion of Cis-Baikal based on a 7.24-m-long sediment core from Lake Ochaul spanning the last 32,000 years. On the other hand, the current study highlights the great potential of the lake sedimentary archive for future in-depth research, involving proxies other than pollen (e.g. green algae, ostracods, molluscs, chironomids) and analytical methods (e.g. isotope and aDNA analyses). Another research direction may include the systematic survey and excavation of archaeological sites next to Lake Ochaul in combination with charcoal particle analysis of the lake sediment to gain detailed insights into human occupation and natural fire history during the last glacial/interglacial interval.

The complete results of the palynological analysis presented in Figures 5.1 and 5.2 indicate a few gaps in the records, associated with technical problems during the coring process in summer 2018. A parallel core situated next to Och18-II obtained in summer 2021 will help to close those gaps and extend the published record into the MIS3 interstadial. The still unpublished pollen and NPP records show that another remarkable change occurs within the

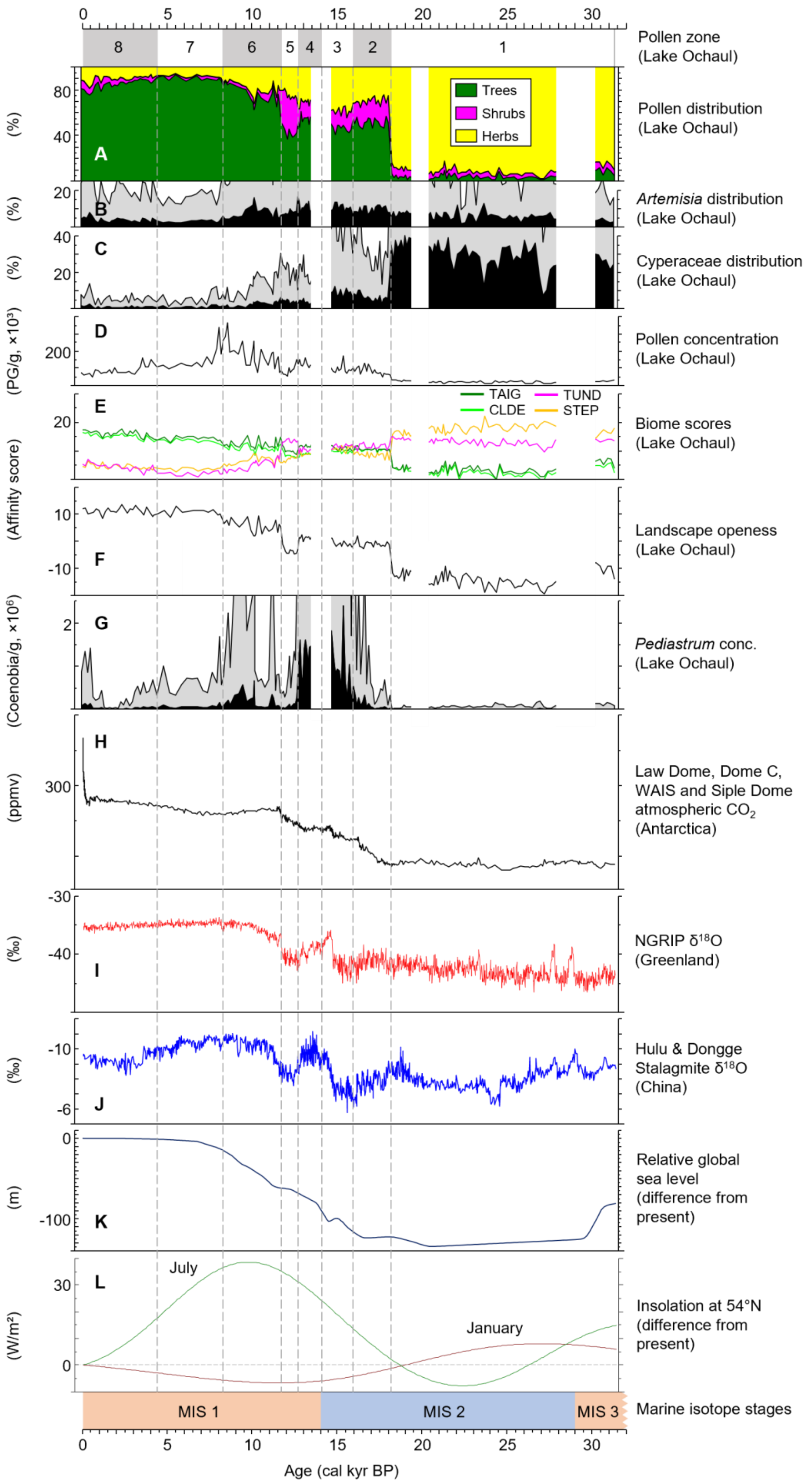
Pollen zone
(Lake Ochaul)
Pollen distribution
(Lake Ochaul)
Trees
Shrubs
Herbs
Artemisia distribution
(Lake Ochaul)
Cyperaceae distribution
(Lake Ochaul)
Pollen concentration
(Lake Ochaul)
TAIG
TUND
CLDE
STEP
Biome scores
(Lake Ochaul)
Landscape openess
(Lake Ochaul)
Pediastrum conc.
(Lake Ochaul)
Law Dome, Dome C,
WAIS and Siple Dome
atmospheric CO2
(Antarctica)
NGRIP δ18O
(Greenland)
Hulu & Dongge
Stalagmite δ18O
(China)
Relative global
sea level
(difference from
present)
Insolation at 54°N
(difference from
present)
July
January
Marine isotope stages
MIS 1
MIS 2
MIS 3
(%)
(PG/g, ×10³)
(Affinity score)
(Coenobia/g, ×10⁶)
(ppmv)
(‰)
(m)
(W/m²)
Age (cal kyr BP)

Figure 5.3: A summary chart showing (A) the percentage distribution of tree, shrub and herb pollen, the contribution of (B) *Artemisia* and (C) Cyperaceae pollen, (D) the terrestrial pollen concentration, (E) the calculated affinity scores for taiga (TAIG), cold deciduous forest (CLDE), tundra (TUND) and steppe (STEP) biomes, (F) the landscape openness and (G) the *Pediastrum* algae concentrations derived from the Och18-II sediment core from Lake Ochaul (this study) and selected palaeoclimate data including (H) the composite Law Dome, Dome C, WAIS and Siple Dome atmospheric CO_2 content (after Bereiter et al., 2015), (I) the NGRIP ice core $\delta^{18}O$ record (after Svensson et al., 2008), (J) the composite stalagmite $\delta^{18}O$ records from Hulu cave and Dongge cave in China (after Cheng et al., 2016), (K) the reconstructed changes in relative global sea level (after Lambeck et al., 2014), the computed mean (F) July and (G) January insolation differences from present at 54°N (after Laskar et al., 2004).

Och18-II-3 section of the core (460–300 cm; ca. 19,250–14,650 cal yr BP). At around 18,000 cal yr BP (420 cm), the AP percentages (mainly *Betula* sect. *Albae*) rise from 5–12% to more than 70% (Fig. 5.1). The green algae *Pediastrum* species composition and concentrations also rapidly change at that time (Fig. 5.2). A similar change in the Lake Kotokel pollen record of Trans-Baikal occurred at least 2000 years later and was extended in time and less pronounced (Bezrukova et al., 2010; Tarasov et al., 2017). What caused this difference between Cis-Baikal and Trans-Baikal? Comparison to several other high-resolution climate proxies, including oxygen isotope records from the Greenland ice (Fig. 5.3I) and Chinese stalagmites (Fig. 5.3J), the global sea level curve (Fig. 5.3K) and the atmospheric CO_2 content (Fig. 5.3H) demonstrate that rapid changes in the Ochaul pollen and biome records (Fig. 5.3A-F) occur during an interval of moderate changes in these records and coincide with the time when the summer and winter insolation at 54°N latitude reached modern values (Fig. 5.3L). Although an earth system and vegetation modelling experiment (Prentice and Jolly, 2000) suggests that insolation-induced Lateglacial climate amelioration and rising atmospheric CO_2 values had a positive effect on tree growth and forest spread, the timing and underlying mechanism behind the early birch spread around Lake Ochaul have to be addressed in future research.

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7 Appendix

7.3 Newly generated records

7.3.1 Pollen data

Pollen data of all 124 analysed and published sediment samples is provided in Table 7.2 and 7.3 including sample ID, sample core depth (cm), sample age (cal yr BP), total terrestrial pollen sum, pollen concentration (grains/g) and list of counted taxa.

Table 7.2: Pollen data list with Sample ID, core depth, age, sum of all terrestrial pollen, calculated pollen concentration and taxa list for all analysed tree (T) and shrub (S) taxa.

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	**Sum terrestrial pollen**	**Pollen concentration (grains/g)**	*Abies*	*Picea*	*Pinus Haploxylon* type	*Pinus Diploxylon* type	*Larix*	*Betula* sect. *Albae* type	Other trees	*Alnus fruticosa* type	*Betula* sect. *Nanae/Fruticosae* type	*Salix*	Other shrubs
					T	T	T	T	T	T	T	S	S	S	S
II-1/0-1	0.5	-47	513	71,677	1	8	22	65	29	296	0	23	3	8	0
II-1/4-5	4.5	117	426	57,365	1	8	55	52	13	213	0	25	2	3	0
II-1/8-9	8.5	281	432	64,741	1	4	39	54	20	216	0	17	7	6	1
II-1/12-13	12.5	446	464	70,676	1	9	35	58	14	234	0	21	3	3	0
II-1/16-17	16.5	610	414	47,490	1	6	50	30	10	226	0	18	4	5	1
II-1/20-21	20.5	774	474	88,083	2	9	33	47	7	304	0	19	5	11	1
II-1/24-25	24.5	939	446	83,717	0	8	27	45	5	302	0	18	1	4	0
II-1/28-29	28.5	1103	452	67,196	1	3	16	26	5	305	0	24	2	7	0
II-1/32-33	32.5	1267	432	75,027	1	9	26	44	5	279	0	24	4	3	0
II-1/36-37	36.5	1432	402	74,704	1	8	20	50	12	256	0	13	4	2	1
II-1/40-41	40.5	1596	602	91,696	1	5	36	74	4	403	0	17	2	3	1
II-1/44-45	44.5	1761	476	69,650	0	5	33	41	9	307	0	20	3	5	0
II-1/48-49	48.5	1925	402	100,951	1	5	40	24	4	264	0	10	3	7	0
II-1/52-53	52.5	2089	526	76,966	1	13	52	33	9	333	0	16	3	8	0
II-1/56-57	56.5	2254	405	76,021	1	10	45	30	7	259	0	5	3	7	0
II-1/60-61	60.5	2418	525	76,819	1	8	44	42	11	351	0	12	4	1	0
II-1/64-65	64.5	2582	426	73,300	1	3	53	32	7	266	0	10	4	2	0
II-1/68-69	68.5	2747	450	80,407	1	15	52	46	10	268	0	4	3	1	0
II-1/72-73	72.5	2911	509	68,542	2	10	38	38	6	349	0	8	0	4	0
II-1/76-77	76.5	3075	602	63,562	1	19	69	49	14	380	0	10	7	4	0
II-1/80-81	80.5	3240	509	84,453	2	17	67	23	4	336	0	10	3	0	1
II-1/84-85	84.5	3404	500	105,585	0	7	33	18	4	389	0	7	1	0	0
II-1/88-89	88.5	3569	446	159,385	1	4	23	13	4	355	0	3	2	1	0
II-1/92-93	92.5	3733	537	103,949	1	8	44	45	8	372	0	10	0	3	0
II-1/96-97	96.5	3897	467	105,832	2	5	31	31	7	336	0	11	2	1	0
II-1/100-101	100.5	4062	410	147,978	0	5	17	22	4	305	0	8	22	1	0
II-2/2-3	102.5	4144	546	137,112	0	7	19	28	3	418	0	4	11	4	0
II-2/6-7	106.5	4374	403	104,013	1	2	27	7	7	323	0	5	0	0	1
II-2/10-11	110.5	4751	506	119,025	1	7	38	8	9	403	0	2	1	1	0
II-2/14-15	114.5	5115	480	94,892	1	3	17	10	3	392	0	9	4	1	0
II-2/18-19	118.5	5466	414	113,138	2	7	42	6	11	317	0	2	3	1	0
II-2/22-23	122.5	5805	399	125,671	1	5	18	14	6	314	0	2	4	2	0
II-2/26-27	126.5	6134	538	116,252	1	8	37	29	6	397	0	4	3	2	2
II-2/30-31	130.5	6452	489	110,818	0	14	63	7	5	352	0	3	2	0	1
II-2/34-35	134.5	6761	657	131,280	0	12	30	14	5	544	0	6	3	1	0
II-2/38-39	138.5	7061	437	108,277	0	11	40	5	7	324	0	12	2	0	0

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	**Sum terrestrial pollen**	**Pollen concentration (grains/g)**	*Abies*	*Picea*	*Pinus Haploxylon* type	*Pinus Diploxylon* type	*Larix*	*Betula* sect. *Albae* type	Other trees	*Alnus fruticosa* type	*Betula* sect. *Nanae/Fruticosae* type	*Salix*	Other shrubs
					T	T	T	T	T	T	T	S	S	S	S
II-2/42-43	142.5	7352	418	165,270	0	6	23	11	6	331	0	5	3	1	0
II-2/46-47	146.5	7635	425	121,504	0	12	27	22	1	318	0	2	5	2	0
II-2/50-51	150.5	7911	489	216,359	0	7	25	7	4	390	0	6	2	2	1
II-2/52-53	152.5	8046	492	338,624	1	14	18	10	3	396	0	2	3	1	1
II-2/54-55	154.5	8179	586	181,494	1	9	25	7	3	476	0	2	3	1	0
II-2/56-57	156.5	8311	433	259,563	3	2	11	9	1	339	0	3	4	1	0
II-2/58-59	158.5	8441	652	281,770	3	15	24	1	3	527	0	6	1	1	0
II-2/60-61	160.5	8569	547	363,032	4	4	14	3	2	433	0	2	6	2	0
II-2/62-63	162.5	8695	585	190,720	1	14	24	8	3	454	0	5	8	4	0
II-2/66-67	166.5	8944	527	204,026	1	11	5	4	1	424	0	1	8	4	0
II-2/70-71	170.5	9187	550	182,512	1	13	9	0	1	432	0	9	5	3	1
II-2/74-75	174.5	9424	537	255,874	1	10	11	6	5	402	0	6	1	6	0
II-2/78-79	178.5	9656	537	116,036	6	17	39	9	5	356	0	7	0	4	0
II-2/82-83	182.5	9883	561	115,834	1	13	5	2	7	383	0	10	5	4	1
II-2/85-86	185.5	10,049	653	224,717	3	8	6	0	6	423	0	7	14	9	1
II-2/86-87	186.5	10,104	502	259,130	4	17	4	2	2	287	0	6	16	3	0
II-2/87-88	187.5	10,159	491	136,183	1	21	5	1	3	282	0	8	11	6	1
II-2/90-91	190.5	10,321	569	71,930	5	41	38	8	9	344	0	5	9	3	1
II-2/94-95	194.5	10,534	494	208,636	0	2	5	2	5	346	0	7	9	5	0
II-2/98-99	198.5	10,742	403	156,020	2	22	13	0	2	247	0	9	7	9	0
II-2/102-103	202.5	10,946	434	115,215	1	12	2	1	3	283	0	3	17	10	2
II-2/106-107	206.5	11,146	888	185,412	3	12	22	3	4	632	0	5	36	8	0
II-2/108-109	208.5	11,245	626	190,704	1	14	5	2	1	499	0	12	13	1	0
II-2/110-111	210.5	11,343	473	95,541	1	48	9	3	23	271	0	8	12	4	2
II-2/112-113	212.5	11,439	520	144,226	0	18	1	0	4	316	0	14	15	13	1
II-2/114-115	214.5	11,535	474	166,195	0	10	11	4	4	334	0	12	14	6	1
II-2/116-117	216.5	11,630	409	76,772	0	31	7	5	15	221	0	26	15	8	0
II-2/118-119	218.5	11,724	477	85,232	1	15	0	0	18	212	0	70	48	17	0
II-2/120-121	220.5	11,817	461	62,531	0	15	1	0	13	196	0	68	61	14	0
II-2/122-123	222.5	11,910	452	61,761	1	17	0	0	2	186	0	73	75	12	0
II-2/124-125	224.5	12,001	490	56,557	0	12	0	0	5	184	0	88	80	15	1
II-2/126-127	226.5	12,092	431	53,395	0	12	0	1	8	138	0	59	85	13	0
II-2/128-129	228.5	12,182	456	99,692	0	18	0	0	2	192	0	52	67	16	1
II-2/130-131	230.5	12,271	432	72,981	0	11	1	0	3	171	0	47	69	10	0
II-2/132-133	232.5	12,359	386	91,962	0	17	0	0	5	128	0	45	83	9	0
II-2/134-135	234.5	12,447	443	98,003	0	10	0	0	3	162	0	54	81	12	0
II-2/136-137	236.5	12,534	427	123,983	0	10	0	0	2	164	0	45	92	7	0
II-2/138-139	238.5	12,620	396	147,177	0	13	0	1	2	153	0	31	71	16	0
II-2/140-141	240.5	12,705	493	120,545	3	67	1	0	4	184	0	12	37	6	0
II-2/142-143	242.5	12,790	428	147,287	0	41	0	0	1	163	0	17	18	33	1
II-2/144-145	244.5	12,874	572	116,807	0	77	0	2	2	271	0	20	33	13	0
II-2/146-147	246.5	12,957	489	113,589	1	30	1	0	2	222	0	24	35	27	3
II-2/148-149	248.5	13,040	559	126,682	0	53	0	0	1	260	0	19	35	23	0
II-2/150-151	250.5	13,122	487	158,771	1	43	0	0	3	222	0	10	38	26	1
II-2/152-153	252.5	13,203	616	127,190	1	45	1	2	0	296	0	23	41	19	1
II-2/154-155	254.5	13,284	526	111,076	0	29	1	0	3	266	0	10	47	22	0
II-2/156-157	256.5	13,364	448	101,527	0	29	2	1	2	191	0	16	30	24	1
II-2/158-159	258.5	13,443	524	118,750	0	67	1	0	1	229	0	22	29	22	0
II-4/0-1	500.5	20,428	348	17,864	0	3	0	0	0	2	0	1	12	6	0
II-4/4-5	504.5	20,544	342	15,582	0	2	3	1	0	1	2	1	14	8	0

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	**Sum terrestrial pollen**	**Pollen concentration (grains/g)**	*Abies*	*Picea*	*Pinus Haploxylon* type	*Pinus Diploxylon* type	*Larix*	*Betula* sect. *Albae* type	Other trees	*Alnus fruticosa* type	*Betula* sect. *Nanae/Fruticosae* type	*Salix*	Other shrubs
					T	T	T	T	T	T	T	S	S	S	S
II-4/8-9	508.5	20,659	402	23,345	0	3	0	2	0	3	1	0	6	5	0
II-4/12-13	512.5	20,775	377	12,738	0	6	1	2	0	6	0	0	8	8	0
II-4/16-17	516.5	20,890	408	14,808	1	6	1	0	1	1	2	3	12	6	1
II-4/20-21	520.5	21,006	363	21,554	0	5	1	1	0	4	1	0	13	5	0
II-4/24-25	524.5	21,121	302	18,461	0	4	1	3	0	15	0	0	4	4	1
II-4/28-29	528.5	21,237	355	8915	0	10	2	3	0	3	1	3	14	6	0
II-4/32-33	532.5	21,352	317	12,376	0	7	5	5	0	13	1	3	17	5	1
II-4/36-37	536.5	21,468	324	17,856	0	3	1	1	0	1	1	3	8	6	0
II-4/40-41	540.5	21,583	372	21,469	0	5	3	5	0	12	2	1	7	5	1
II-4/44-45	544.5	21,699	364	23,325	0	5	1	3	0	6	0	0	13	9	0
II-4/48-49	548.5	21,918	419	15,635	0	7	6	6	0	12	3	3	16	14	0
II-4/52-53	552.5	22,137	316	22,372	0	4	1	0	1	0	0	1	14	1	0
II-4/56-57	556.5	22,356	345	21,514	0	6	2	2	0	4	1	3	3	7	1
II-4/60-61	560.5	22,574	435	13,165	0	7	2	9	0	3	1	3	6	6	0
II-4/64-65	564.5	22,793	417	14,511	2	9	4	4	1	8	0	1	9	6	0
II-4/68-69	568.5	23,012	343	20,366	0	3	1	2	0	3	1	0	6	7	0
II-4/72-73	572.5	23,231	319	13,412	0	8	4	3	1	2	0	1	1	8	0
II-4/76-77	576.5	23,450	355	23,730	0	4	0	3	0	2	0	0	7	9	0
II-4/80-81	580.5	23,669	393	12,723	0	5	4	2	0	1	0	1	8	11	0
II-4/84-85	584.5	23,887	387	8665	0	10	2	4	0	0	0	1	11	8	0
II-4/88-89	588.5	24,106	410	12,409	0	4	1	2	0	1	0	0	6	8	0
II-4/92-93	592.5	24,325	359	24,527	0	2	1	2	0	2	0	0	7	2	0
II-4/96-97	596.5	24,544	447	13,102	2	8	4	8	1	17	1	0	11	5	0
II-4/100-101	600.5	24,763	330	22,169	0	5	0	3	0	0	1	0	9	3	0
II-4/104-105	604.5	24,982	320	17,804	0	4	1	5	0	0	0	1	2	3	0
II-4/108-109	608.5	25,200	510	28,546	0	8	1	4	1	4	0	1	7	4	2
II-4/112-113	612.5	25,419	423	20,155	0	8	1	0	1	6	1	0	9	1	0
II-4/116-117	616.5	25,638	385	23,229	1	4	1	1	0	0	0	2	8	7	0
II-4/120-121	620.5	25,857	347	25,793	1	4	0	0	1	2	1	0	4	3	0
II-4/124-125	624.5	26,076	305	11,696	0	2	4	2	0	1	0	2	6	4	1
II-4/128-129	628.5	26,295	338	9723	0	7	1	1	0	5	0	0	2	9	0
II-4/132-133	632.5	26,513	392	10,034	0	8	3	1	1	1	2	1	4	8	0
II-4/136-137	636.5	26,732	351	28,359	2	5	3	1	1	1	0	1	2	2	0
II-4/140-141	640.5	26,951	383	21,235	0	5	1	1	0	1	0	1	0	1	0
II-4/144-145	644.5	27,170	397	11,748	1	4	1	0	0	2	1	1	1	1	0
II-4/148-149	648.5	27,389	373	7421	0	3	1	1	1	6	0	1	4	9	0
II-4/152-153	652.5	27,608	322	10,880	0	7	2	2	2	3	1	1	12	1	0
II-4/156-157	656.5	27,826	305	14,646	0	6	2	1	0	4	0	0	9	4	0

Table 7.3: Pollen data list with Sample ID, core depth, age, and taxa list for all analysed herb taxa (H) and unidentified pollen grains.

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Artemisia*	Asteraceae subfam. Asteroideae	Asteraceae subfam. Cichorioideae	Brassicaceae	Cannabaceae	Caryophyllaceae	Chenopodiaceae	Cyperaceae	*Epilobium*	Poaceae	Cerealia type	*Secale* type	Polygonaceae	Ranunculaceae	*Thalictrum*	Rosaceae	Saxifragaceae	Other herbs	Pollen UnID
			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	
II-1/0-1	0.5	-47	25	1	0	0	1	0	5	8	0	8	1	1	0	0	2	4	0	2	3
II-1/4-5	4.5	117	24	1	1	0	1	0	2	5	0	8	3	1	1	0	4	0	0	2	0
II-1/8-9	8.5	281	23	0	1	0	0	0	5	8	0	18	0	1	0	1	6	3	0	1	0
II-1/12-13	12.5	446	37	1	1	0	1	0	3	13	0	16	0	5	0	1	4	2	1	1	1
II-1/16-17	16.5	610	26	1	0	0	0	0	3	6	1	10	3	1	0	0	8	1	0	2	0
II-1/20-21	20.5	774	17	0	0	0	0	1	3	2	0	7	0	0	0	0	5	1	0	0	0
II-1/24-25	24.5	939	11	0	0	0	0	1	3	5	0	12	0	0	0	0	3	0	0	1	0
II-1/28-29	28.5	1103	23	1	0	0	0	0	6	2	0	12	0	0	1	2	11	2	0	3	0
II-1/32-33	32.5	1267	16	3	0	0	0	0	1	4	0	6	0	0	0	0	5	0	1	1	0
II-1/36-37	36.5	1432	12	1	0	0	0	0	3	5	1	4	0	0	0	1	4	1	0	3	0
II-1/40-41	40.5	1596	15	0	0	0	0	0	1	9	0	17	0	0	1	2	9	0	0	2	1
II-1/44-45	44.5	1761	18	0	0	1	0	0	3	4	0	14	0	0	0	0	11	0	0	2	0
II-1/48-49	48.5	1925	16	0	0	0	0	0	6	4	0	14	0	0	0	0	3	0	0	0	0
II-1/52-53	52.5	2089	28	0	0	0	0	0	2	5	0	14	0	0	0	2	6	1	0	0	1
II-1/56-57	56.5	2254	19	1	0	0	0	0	2	3	0	5	0	0	0	1	5	1	0	1	0
II-1/60-61	60.5	2418	25	0	0	0	0	1	2	5	1	8	0	0	0	0	8	0	0	1	0
II-1/64-65	64.5	2582	18	0	0	0	0	0	6	6	1	9	1	0	0	0	7	0	0	0	0
II-1/68-69	68.5	2747	17	0	0	2	0	0	4	3	0	9	0	0	0	1	11	1	0	2	1
II-1/72-73	72.5	2911	17	2	0	0	0	0	4	9	0	10	0	0	1	2	8	1	0	0	2
II-1/76-77	76.5	3075	23	1	0	0	0	0	1	6	0	11	0	0	0	0	6	0	0	1	0
II-1/80-81	80.5	3240	17	0	0	0	0	0	3	6	0	11	0	0	0	2	4	1	1	1	0
II-1/84-85	84.5	3404	14	0	0	1	0	0	2	5	0	7	0	0	1	0	8	1	0	2	1
II-1/88-89	88.5	3569	22	0	0	0	0	0	1	3	0	4	0	0	0	1	9	0	0	0	1
II-1/92-93	92.5	3733	26	0	0	0	0	0	2	7	0	7	0	0	0	0	4	0	0	0	0
II-1/96-97	96.5	3897	17	0	0	0	0	0	6	7	0	5	0	0	0	1	5	0	0	0	0
II-1/100-101	100.5	4062	11	0	0	0	0	0	1	5	0	5	0	0	0	0	4	0	0	0	0
II-2/2-3	102.5	4144	28	0	0	0	0	0	4	6	0	4	0	0	0	0	8	1	0	1	1
II-2/6-7	106.5	4374	14	0	0	0	0	0	1	3	0	5	0	0	0	0	6	0	0	1	0
II-2/10-11	110.5	4751	12	1	0	0	0	0	1	8	0	7	0	0	0	0	7	0	0	0	0
II-2/14-15	114.5	5115	16	1	1	0	0	0	2	1	0	4	0	0	0	0	13	1	0	0	2
II-2/18-19	118.5	5466	11	0	0	0	0	0	2	4	0	0	0	0	1	0	5	0	0	0	0
II-2/22-23	122.5	5805	10	0	0	0	0	1	0	2	0	3	0	0	0	0	17	0	0	0	0
II-2/26-27	126.5	6134	18	2	0	0	0	0	1	6	0	7	0	0	0	0	13	0	0	2	5
II-2/30-31	130.5	6452	17	1	1	0	0	0	4	6	0	3	0	0	0	0	10	0	0	0	1
II-2/34-35	134.5	6761	24	0	0	0	0	0	0	3	0	4	0	0	0	1	6	3	0	1	0
II-2/38-39	138.5	7061	18	2	0	0	0	0	0	5	0	3	0	0	0	0	6	2	0	0	1
II-2/42-43	142.5	7352	15	0	0	0	0	0	4	2	0	3	0	0	0	0	5	0	0	3	0
II-2/46-47	146.5	7635	17	0	0	0	0	0	1	9	0	4	0	0	1	0	4	0	0	0	0
II-2/50-51	150.5	7911	12	1	0	0	0	0	1	12	0	5	0	0	0	1	9	4	0	0	0
II-2/52-53	152.5	8046	16	0	0	0	0	0	1	5	0	5	0	0	1	0	13	1	0	1	0
II-2/54-55	154.5	8179	28	0	0	0	0	0	1	7	0	7	0	0	0	1	15	0	0	0	1
II-2/56-57	156.5	8311	26	0	0	0	0	0	1	7	0	12	0	0	0	1	11	1	0	1	2
II-2/58-59	158.5	8441	31	0	0	0	0	0	2	7	0	5	0	0	0	1	23	2	0	0	2
II-2/60-61	160.5	8569	25	1	0	0	0	0	3	13	0	10	0	0	0	0	25	0	0	0	0
II-2/62-63	162.5	8695	28	0	0	0	0	0	3	5	0	7	0	0	0	1	20	0	0	0	0
II-2/66-67	166.5	8944	33	0	0	1	0	0	1	4	0	6	0	0	0	0	21	2	0	0	2
II-2/70-71	170.5	9187	32	0	0	0	0	0	7	11	0	11	0	0	0	0	15	0	0	0	1

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Artemisia*	Asteraceae subfam. Asteroideae	Asteraceae subfam. Cichorioideae	Brassicaceae	Cannabaceae	Caryophyllaceae	Chenopodiaceae	Cyperaceae	*Epilobium*	Poaceae	Cerealia type	*Secale* type	Polygonaceae	Ranunculaceae	*Thalictrum*	Rosaceae	Saxifragaceae	Other herbs	Pollen UnID
			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	
II-2/74-75	174.5	9424	33	0	0	0	0	0	8	8	0	5	0	0	0	2	31	1	0	1	0
II-2/78-79	178.5	9656	51	2	0	0	0	0	3	5	0	7	0	0	0	1	24	1	0	0	0
II-2/82-83	182.5	9883	63	0	1	0	0	0	5	15	0	12	0	0	0	0	31	0	0	3	0
II-2/85-86	185.5	10,049	78	3	1	0	0	0	14	16	0	18	0	0	0	0	37	6	0	3	2
II-2/86-87	186.5	10,104	77	0	0	0	0	2	3	18	0	7	0	0	0	3	46	3	0	2	1
II-2/87-88	187.5	10,159	79	1	0	0	0	0	7	16	0	16	0	0	0	0	29	2	0	2	2
II-2/90-91	190.5	10,321	48	1	0	0	0	0	5	23	0	10	0	0	0	2	15	1	0	1	2
II-2/94-95	194.5	10,534	46	3	0	0	0	0	4	17	0	14	0	0	0	0	25	3	0	1	0
II-2/98-99	198.5	10,742	43	0	0	0	0	0	2	14	0	12	0	0	0	1	16	4	0	0	0
II-2/102-103	202.5	10,946	44	1	0	0	0	0	2	12	0	14	0	0	0	0	20	5	0	2	3
II-2/106-107	206.5	11,146	64	0	0	0	0	0	8	19	0	30	0	0	0	0	36	3	0	3	1
II-2/108-109	208.5	11,245	29	0	0	1	0	0	3	10	0	5	0	0	1	1	26	2	0	0	1
II-2/110-111	210.5	11,343	36	0	0	3	1	0	1	19	0	20	0	0	1	0	10	1	0	0	3
II-2/112-113	212.5	11,439	56	2	0	0	0	0	1	21	0	21	0	0	0	0	31	5	0	1	1
II-2/114-115	214.5	11,535	27	0	0	0	0	0	5	16	0	10	0	0	1	0	12	3	0	4	1
II-2/116-117	216.5	11,630	22	1	0	1	0	0	2	19	0	19	0	0	1	1	11	2	0	2	2
II-2/118-119	218.5	11,724	31	0	0	0	0	0	1	29	0	23	0	0	0	0	8	2	0	2	1
II-2/120-121	220.5	11,817	32	1	0	4	0	0	3	22	0	26	0	0	0	1	4	0	0	0	2
II-2/122-123	222.5	11,910	33	0	0	0	1	0	1	21	0	21	0	0	1	0	3	3	0	2	0
II-2/124-125	224.5	12,001	38	0	0	0	0	0	0	21	0	31	0	0	1	2	9	3	0	0	2
II-2/126-127	226.5	12,092	30	0	0	0	0	1	2	22	0	35	0	0	0	0	21	2	0	2	1
II-2/128-129	228.5	12,182	34	0	1	2	0	0	3	22	0	28	0	0	0	0	15	1	0	2	3
II-2/130-131	230.5	12,271	43	0	0	0	0	1	2	11	0	42	0	0	0	2	16	1	0	2	2
II-2/132-133	232.5	12,359	34	1	1	0	0	0	4	15	0	20	0	0	0	1	16	2	0	5	1
II-2/134-135	234.5	12,447	36	1	0	1	0	2	2	20	0	40	0	0	0	1	14	1	0	2	2
II-2/136-137	236.5	12,534	37	0	0	0	0	0	2	13	0	35	0	0	0	0	16	2	0	2	0
II-2/138-139	238.5	12,620	35	1	0	0	3	0	3	17	0	29	0	0	0	1	17	1	0	2	0
II-2/140-141	240.5	12,705	83	1	0	1	0	0	5	10	0	42	0	0	0	1	32	0	0	4	1
II-2/142-143	242.5	12,790	62	0	1	0	0	0	3	21	0	26	0	0	0	1	36	3	0	1	5
II-2/144-145	244.5	12,874	46	0	5	0	0	0	3	28	0	29	0	0	0	1	41	0	0	1	3
II-2/146-147	246.5	12,957	53	0	0	0	0	1	1	20	0	38	0	0	1	1	21	3	0	5	2
II-2/148-149	248.5	13,040	60	3	5	1	0	1	4	33	0	34	0	0	0	0	24	2	0	1	5
II-2/150-151	250.5	13,122	56	0	0	0	0	0	3	17	0	33	0	0	0	1	30	1	0	2	1
II-2/152-153	252.5	13,203	81	1	6	3	0	0	1	22	0	29	0	0	1	2	40	0	0	1	4
II-2/154-155	254.5	13,284	61	0	2	0	1	0	6	20	0	28	0	0	0	1	28	0	0	1	3
II-2/156-157	256.5	13,364	64	1	1	2	0	0	2	13	0	30	0	0	0	0	35	1	1	2	3
II-2/158-159	258.5	13,443	49	1	3	1	0	0	2	14	0	39	0	0	0	3	39	1	0	1	2
II-4/0-1	500.5	20,428	24	6	21	44	0	0	8	123	0	74	0	0	0	3	2	17	1	1	11
II-4/4-5	504.5	20,544	28	9	22	18	1	5	9	117	0	83	0	0	0	3	2	11	2	0	10
II-4/8-9	508.5	20,659	20	4	26	48	3	2	15	127	0	118	0	0	0	4	2	13	0	0	15
II-4/12-13	512.5	20,775	17	6	20	30	0	0	5	140	0	114	0	0	0	3	4	4	3	0	18
II-4/16-17	516.5	20,890	34	4	29	36	1	12	5	137	0	99	0	0	0	4	1	9	1	2	7
II-4/20-21	520.5	21,006	25	6	21	26	0	2	7	137	0	95	0	0	0	3	1	8	0	2	4
II-4/24-25	524.5	21,121	18	1	23	15	0	1	10	100	0	92	0	0	2	0	0	6	1	0	11
II-4/28-29	528.5	21,237	19	8	19	23	3	5	7	113	0	93	0	0	0	4	4	13	1	1	4
II-4/32-33	532.5	21,352	26	6	17	27	0	2	5	99	0	75	0	0	0	1	0	2	0	0	6
II-4/36-37	536.5	21,468	28	5	16	26	1	3	5	112	0	92	0	0	0	2	1	5	1	3	12
II-4/40-41	540.5	21,583	26	7	18	27	2	3	8	147	0	77	0	0	1	0	2	9	1	3	8
II-4/44-45	544.5	21,699	16	5	20	28	1	2	13	105	0	118	0	0	2	0	3	8	4	2	16
II-4/48-49	548.5	21,918	23	14	44	38	1	7	7	88	0	101	0	0	0	6	1	17	1	4	13

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Artemisia*	Asteraceae subfam. Asteroideae	Asteraceae subfam. Cichorioideae	Brassicaceae	Cannabaceae	Caryophyllaceae	Chenopodiaceae	Cyperaceae	*Epilobium*	Poaceae	Cerealia type	*Secale* type	Polygonaceae	Ranunculaceae	*Thalictrum*	Rosaceae	Saxifragaceae	Other herbs	Pollen UnID
			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	
II-4/52-53	552.5	22,137	39	6	15	27	1	1	7	97	0	78	0	0	0	2	4	11	1	4	7
II-4/56-57	556.5	22,356	7	8	22	42	0	3	5	113	0	100	0	0	1	3	1	7	0	4	14
II-4/60-61	560.5	22,574	11	3	31	26	1	8	9	156	0	137	0	0	1	1	2	7	1	4	13
II-4/64-65	564.5	22,793	32	13	33	40	0	3	9	118	0	113	0	0	0	1	1	10	0	0	10
II-4/68-69	568.5	23,012	23	9	17	28	1	5	4	111	0	97	0	0	0	1	4	10	4	6	9
II-4/72-73	572.5	23,231	8	8	19	48	0	3	7	100	0	82	0	0	0	2	0	14	0	0	11
II-4/76-77	576.5	23,450	27	8	22	20	0	6	1	105	0	126	0	0	0	0	1	8	3	3	18
II-4/80-81	580.5	23,669	53	11	57	50	1	5	7	50	0	102	0	0	0	3	5	14	2	1	11
II-4/84-85	584.5	23,887	24	5	29	41	0	5	6	99	0	119	0	0	0	4	2	11	2	4	16
II-4/88-89	588.5	24,106	31	1	28	41	0	8	9	111	0	134	0	0	0	2	4	16	1	2	13
II-4/92-93	592.5	24,325	24	10	34	29	2	5	6	97	0	120	0	0	0	3	2	8	0	3	11
II-4/96-97	596.5	24,544	28	12	53	41	1	8	7	96	0	131	0	0	0	1	3	8	0	1	12
II-4/100-101	600.5	24,763	16	2	21	22	0	3	7	115	0	105	0	0	3	5	0	7	3	0	17
II-4/104-105	604.5	24,982	16	3	17	34	0	2	10	110	0	100	0	0	0	0	1	8	2	1	10
II-4/108-109	608.5	25,200	35	3	34	39	2	4	6	181	0	144	0	0	1	4	8	15	2	0	16
II-4/112-113	612.5	25,419	22	8	45	43	2	3	10	111	0	128	0	0	0	6	2	15	0	1	5
II-4/116-117	616.5	25,638	25	8	27	44	1	3	7	113	0	114	0	0	0	1	7	6	4	1	8
II-4/120-121	620.5	25,857	10	5	32	41	0	3	10	96	0	118	0	0	0	2	1	10	2	1	9
II-4/124-125	624.5	26,076	17	5	19	23	0	6	1	118	0	81	0	0	0	3	0	7	1	2	11
II-4/128-129	628.5	26,295	18	9	32	45	0	3	6	106	0	79	0	0	1	3	2	8	0	1	12
II-4/132-133	632.5	26,513	28	8	37	46	0	10	5	127	0	81	0	0	0	3	1	15	0	2	7
II-4/136-137	636.5	26,732	20	5	23	30	0	0	2	130	0	100	0	0	0	3	4	13	0	3	9
II-4/140-141	640.5	26,951	25	8	25	18	0	6	8	71	0	200	0	0	1	3	0	8	0	0	11
II-4/144-145	644.5	27,170	25	7	47	58	0	3	6	30	0	193	0	0	0	2	1	13	0	0	17
II-4/148-149	648.5	27,389	26	14	43	70	0	7	2	41	0	123	0	0	1	2	1	13	3	1	21
II-4/152-153	652.5	27,608	27	8	52	37	0	2	7	70	0	74	0	0	0	3	1	6	1	3	7
II-4/156-157	656.5	27,826	15	4	16	27	0	2	7	74	0	107	0	0	0	3	2	18	4	0	14

7.3.2 NPP data

NPP data of all 124 analysed and published sediment samples is provided in Table 7.4 including sample ID, sample core depth (cm), sample age (cal yr BP) and list of counted aquatic pollen grains, spores and other NPPs and calculated Chironomidae and green algae concentrations.

Table 7.4: NPP data list with Sample ID, core depth, age, and taxa list for all analysed aquatic pollen grains (Aq), Fern spores (spo), other non-pollen palynomorphs (NPP) and green algae (ALG). Chironomidae and all green algae are displayed as calculated concentrations (conc.).

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Myriophyllum*	*Sparganium* type	*Equisetum*	Polypodiales	*Pteridium*	*Glomus*	Chironomidae (conc.)	*Botryococcus* (conc.)	*Pediastrum angulosum* (conc.)	*Pediastrum boryanum* (conc.)	*Pediastrum duplex* (conc.)	*Pediastrum integrum* (conc.)	*Pediastrum kawraiskyi* (conc.)	*Pediastrum orientale* (conc.)	*Pediastrum simplex* (conc.)
			Aq	Aq	spo	spo	spo	NPP	NPP	ALG	ALG	ALG	ALG	ALG	ALG	ALG	ALG
II-1/0-1	0.5	-47	2	0	0	0	0	0	419	699	0	77,266	5868	2934	0	838	0
II-1/4-5	4.5	117	1	1	0	0	0	0	673	808	0	116,615	12,523	4444	0	404	0
II-1/8-9	8.5	281	6	0	0	0	2	0	450	599	0	74,332	8392	1648	0	599	0
II-1/12-13	12.5	446	4	0	0	0	0	0	762	914	0	125,359	12,033	2589	0	1828	0
II-1/16-17	16.5	610	7	1	0	1	0	0	229	0	0	27,416	688	344	0	344	0
II-1/20-21	20.5	774	1	0	0	1	0	0	743	0	0	20,813	0	0	372	0	0
II-1/24-25	24.5	939	4	1	0	0	1	0	1877	0	0	26,091	0	0	0	0	0
II-1/28-29	28.5	1103	7	0	0	0	0	0	1338	149	0	43,707	0	0	0	0	0
II-1/32-33	32.5	1267	5	2	0	0	0	0	2258	174	0	4168	0	0	0	0	0
II-1/36-37	36.5	1432	15	1	0	0	0	0	743	0	0	2787	0	0	0	0	0
II-1/40-41	40.5	1596	3	1	0	0	0	0	1980	0	0	4417	0	0	0	0	0
II-1/44-45	44.5	1761	2	1	0	1	1	0	1756	0	0	3219	0	0	0	0	0
II-1/48-49	48.5	1925	3	0	0	0	0	0	2009	0	0	5022	0	0	0	0	0
II-1/52-53	52.5	2089	7	0	0	1	0	0	3512	146	0	3219	0	0	0	0	0
II-1/56-57	56.5	2254	10	1	0	0	0	0	1877	0	0	17,644	0	0	0	0	0
II-1/60-61	60.5	2418	15	0	0	0	0	0	878	293	0	10,096	439	0	293	0	0
II-1/64-65	64.5	2582	30	1	0	0	0	0	1893	172	0	25,121	860	0	0	0	0
II-1/68-69	68.5	2747	8	0	0	1	0	0	1787	179	0	9113	0	0	179	0	0
II-1/72-73	72.5	2911	17	2	0	1	0	0	1751	135	0	17,640	135	135	0	0	0
II-1/76-77	76.5	3075	14	1	0	0	0	0	739	317	0	40,650	317	634	0	0	0
II-1/80-81	80.5	3240	2	1	0	0	1	0	498	332	0	52,928	332	332	0	0	0

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Myriophyllum*	*Sparganium* type	*Equisetum*	Polypodiales	*Pteridium*	*Glomus*	Chironomidae (conc.)	*Botryococcus* (conc.)	*Pediastrum angulosum* (conc.)	*Pediastrum boryanum* (conc.)	*Pediastrum duplex* (conc.)	*Pediastrum integrum* (conc.)	*Pediastrum kawraiskyi* (conc.)	*Pediastrum orientale* (conc.)	*Pediastrum simplex* (conc.)
			Aq	Aq	spo	spo	spo	NPP	NPP	ALG	ALG	ALG	ALG	ALG	ALG	ALG	ALG
II-1/84-85	84.5	3404	5	0	0	1	0	0	2112	0	0	33,787	634	634	211	0	0
II-1/88-89	88.5	3569	2	0	0	0	1	0	2502	357	0	60,752	0	1787	0	0	0
II-1/92-93	92.5	3733	2	1	0	1	0	0	1161	194	0	37,553	0	387	0	0	0
II-1/96-97	96.5	3897	2	1	0	0	0	0	453	0	0	41,925	227	680	0	0	0
II-1/100-101	100.5	4062	0	0	0	0	0	0	1805	0	0	58,108	0	0	722	0	0
II-2/2-3	102.5	4144	0	0	0	0	5	0	1004	753	0	66,045	502	1004	0	0	0
II-2/6-7	106.5	4374	1	0	0	1	0	0	1032	258	0	32,004	258	0	0	0	0
II-2/10-11	110.5	4751	3	0	0	0	0	0	2117	0	0	98,560	0	1882	0	0	0
II-2/14-15	114.5	5115	4	0	0	1	0	0	988	0	0	38,945	395	0	0	0	0
II-2/18-19	118.5	5466	2	0	1	0	0	0	2460	0	0	32,247	273	273	0	0	0
II-2/22-23	122.5	5805	0	0	0	0	0	0	945	0	0	54,489	315	1575	0	0	0
II-2/26-27	126.5	6134	2	1	1	1	2	0	2593	216	0	69,362	648	1729	0	0	0
II-2/30-31	130.5	6452	1	1	0	0	1	0	2040	453	0	68,440	0	1133	0	0	0
II-2/34-35	134.5	6761	1	2	0	0	2	0	1199	200	0	70,735	599	999	0	0	0
II-2/38-39	138.5	7061	0	0	0	0	1	0	3221	248	0	43,360	496	991	0	0	0
II-2/42-43	142.5	7352	0	0	0	0	1	0	1186	0	0	39,143	0	0	0	0	0
II-2/46-47	146.5	7635	0	2	0	0	6	0	2001	0	0	78,620	858	5146	0	0	0
II-2/50-51	150.5	7911	3	2	1	2	2	0	1327	2212	0	57,961	442	3097	0	0	0
II-2/52-53	152.5	8046	0	0	0	1	2	0	2753	6883	0	165,870	1377	0	0	0	0
II-2/54-55	154.5	8179	0	0	1	1	7	1	1239	2478	0	56,988	310	0	0	0	0
II-2/56-57	156.5	8311	0	1	0	1	1	0	2398	2398	0	76,130	0	0	0	0	0
II-2/58-59	158.5	8441	0	0	0	0	2	0	2593	5618	0	154,282	0	0	0	0	0
II-2/60-61	160.5	8569	0	3	0	0	9	0	5973	5973	0	221,005	0	1991	0	0	0
II-2/62-63	162.5	8695	0	0	0	1	4	0	1956	978	0	96,175	652	652	0	0	0
II-2/66-67	166.5	8944	1	0	1	0	4	0	2710	774	0	320,170	0	0	0	0	0
II-2/70-71	170.5	9187	0	1	1	2	5	0	2323	664	0	360,046	0	0	0	0	0
II-2/74-75	174.5	9424	0	2	0	0	6	0	2382	4765	0	561,778	1906	0	0	0	0
II-2/78-79	178.5	9656	0	0	1	0	10	0	3673	1296	0	180,860	0	0	0	0	0
II-2/82-83	182.5	9883	0	1	0	2	20	0	619	1652	0	226,919	1032	0	1032	0	0

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Myriophyllum*	*Sparganium* type	*Equisetum*	Polypodiales	*Pteridium*	*Glomus*	Chironomidae (conc.)	*Botryococcus* (conc.)	*Pediastrum angulosum* (conc.)	*Pediastrum boryanum* (conc.)	*Pediastrum duplex* (conc.)	*Pediastrum integrum* (conc.)	*Pediastrum kawraiskyi* (conc.)	*Pediastrum orientale* (conc.)	*Pediastrum simplex* (conc.)
			Aq	Aq	spo	spo	spo	NPP	NPP	ALG	ALG	ALG	ALG	ALG	ALG	ALG	ALG
II-2/85-86	185.5	10,049	0	1	0	5	17	0	3441	2753	0	274,271	0	1032	0	0	0
II-2/86-87	186.5	10,104	0	0	1	4	15	0	8259	1549	0	674,150	0	0	0	0	0
II-2/87-88	187.5	10,159	0	0	0	2	15	1	1387	832	0	88,477	0	0	0	0	0
II-2/90-91	190.5	10,321	0	2	0	2	10	0	1011	253	0	63,840	506	0	0	0	0
II-2/94-95	194.5	10,534	1	0	0	1	3	0	1689	1689	0	70,953	0	0	0	0	0
II-2/98-99	198.5	10,742	0	0	0	3	1	0	3484	0	0	50,716	0	0	0	0	0
II-2/102-103	202.5	10,946	1	1	1	0	1	0	0	531	0	66,899	531	0	531	0	0
II-2/106-107	206.5	11,146	0	1	0	2	7	0	2923	2506	0	344,934	0	0	0	0	0
II-2/108-109	208.5	11,245	0	1	0	2	7	0	1523	7007	0	277,222	0	0	0	0	0
II-2/110-111	210.5	11,343	0	0	0	3	3	0	808	808	0	43,024	1010	0	0	0	0
II-2/112-113	212.5	11,439	0	0	1	1	1	0	1664	555	0	75,441	4438	0	0	0	0
II-2/114-115	214.5	11,535	0	1	0	2	4	0	1052	5259	0	77,137	4207	1052	0	0	0
II-2/116-117	216.5	11,630	0	2	0	1	3	0	563	7321	0	27,030	9385	939	939	0	0
II-2/118-119	218.5	11,724	0	1	1	1	0	0	357	1608	0	27,875	6611	1072	1072	0	0
II-2/120-121	220.5	11,817	1	1	0	0	0	0	814	3120	0	36,488	3527	678	2170	0	0
II-2/122-123	222.5	11,910	0	0	1	0	0	0	0	3416	0	22,546	3416	956	1503	0	0
II-2/124-125	224.5	12,001	2	0	0	0	0	0	115	4155	0	26,547	5540	577	2424	2424	0
II-2/126-127	226.5	12,092	0	0	3	0	1	0	372	2602	0	59,094	11,769	0	5079	0	0
II-2/128-129	228.5	12,182	0	2	0	0	0	0	0	4810	0	75,644	19,895	0	24,704	2405	0
II-2/130-131	230.5	12,271	1	0	1	0	0	0	169	1689	0	33,787	8785	0	6589	0	0
II-2/132-133	232.5	12,359	0	0	0	0	0	0	238	5480	0	77,667	11,197	0	10,483	2382	0
II-2/134-135	234.5	12,447	0	0	0	0	0	0	221	9734	0	95,791	10,619	664	26,547	664	0
II-2/136-137	236.5	12,534	0	1	1	0	0	0	0	8420	0	78,978	9872	581	20,616	2613	0
II-2/138-139	238.5	12,620	0	1	1	1	1	0	0	6690	0	188,060	32,706	1115	72,102	2230	1115
II-2/140-141	240.5	12,705	0	0	0	0	0	0	0	25,429	0	499,785	57,705	0	258,206	0	0
II-2/142-143	242.5	12,790	0	0	0	0	0	0	0	15,486	0	984,899	174,818	0	449,777	0	0
II-2/144-145	244.5	12,874	0	0	0	3	0	0	0	14,090	0	424,550	75,761	0	231,573	0	0
II-2/146-147	246.5	12,957	1	1	1	1	0	0	0	24,158	0	383,042	52,962	0	248,780	697	0
II-2/148-149	248.5	13,040	1	4	0	0	0	0	0	14,504	0	877,933	120,790	0	401,801	4532	0

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Myriophyllum*	*Sparganium* type	*Equisetum*	Polypodiales	*Pteridium*	*Glomus*	Chironomidae (conc.)	*Botryococcus* (conc.)	*Pediastrum angulosum* (conc.)	*Pediastrum boryanum* (conc.)	*Pediastrum duplex* (conc.)	*Pediastrum integrum* (conc.)	*Pediastrum kawraiskyi* (conc.)	*Pediastrum orientale* (conc.)	*Pediastrum simplex* (conc.)
			Aq	Aq	spo	spo	spo	NPP	NPP	ALG	ALG	ALG	ALG	ALG	ALG	ALG	ALG
II-2/150-151	250.5	13,122	0	0	0	0	0	0	0	6520	0	955,557	135,297	0	493,917	18,583	0
II-2/152-153	252.5	13,203	1	2	0	1	0	0	0	13,421	0	801,134	103,239	0	454,251	14,453	0
II-2/154-155	254.5	13,284	0	1	0	0	0	0	211	16,471	0	650,405	62,506	0	315,911	6757	0
II-2/156-157	256.5	13,364	1	0	0	0	0	0	227	10,651	0	819,918	72,066	0	538,907	9292	0
II-2/158-159	258.5	13,443	0	1	1	0	0	0	0	4986	0	861,163	77,505	0	501,741	6119	0
II-4/0-1	500.5	20,428	0	0	0	0	0	6	0	205	1489	1745	0	0	0	0	1181
II-4/4-5	504.5	20,544	0	0	0	0	0	1	46	364	3189	1959	0	0	0	182	1230
II-4/8-9	508.5	20,659	0	0	1	0	0	1	0	348	2091	2091	0	0	0	116	1103
II-4/12-13	512.5	20,775	0	0	0	0	0	2	0	237	1554	743	0	0	0	101	473
II-4/16-17	516.5	20,890	1	0	0	1	0	4	0	327	2178	1125	0	0	0	73	871
II-4/20-21	520.5	21,006	0	0	0	0	0	1	0	356	2791	1544	0	0	0	0	891
II-4/24-25	524.5	21,121	0	0	2	0	0	0	0	428	2934	856	0	0	0	183	1712
II-4/28-29	528.5	21,237	0	1	0	1	0	0	25	251	3491	1708	0	0	0	0	2888
II-4/32-33	532.5	21,352	0	1	0	0	0	8	78	156	4021	1913	0	0	0	0	625
II-4/36-37	536.5	21,468	0	0	0	0	0	2	0	551	3086	1929	0	0	0	110	1819
II-4/40-41	540.5	21,583	0	0	0	1	0	3	0	519	3347	1385	0	0	0	0	1039
II-4/44-45	544.5	21,699	0	0	0	0	0	2	0	833	4678	3076	0	0	64	0	897
II-4/48-49	548.5	21,918	1	3	0	0	0	6	37	336	4179	3023	0	0	0	0	1530
II-4/52-53	552.5	22,137	1	0	0	2	0	4	0	708	4389	2195	0	0	0	71	566
II-4/56-57	556.5	22,356	0	0	0	0	0	2	62	811	2869	1372	0	0	0	0	312
II-4/60-61	560.5	22,574	0	0	0	1	0	13	0	484	4146	2784	0	0	0	91	182
II-4/64-65	564.5	22,793	0	0	0	1	0	22	0	487	6542	1288	0	0	0	0	348
II-4/68-69	568.5	23,012	0	0	0	0	0	5	0	238	2672	1009	0	0	0	0	416
II-4/72-73	572.5	23,231	0	0	0	0	0	8	0	168	4835	1135	0	0	0	252	252
II-4/76-77	576.5	23,450	1	1	0	0	0	3	0	602	3743	2005	0	0	0	334	401
II-4/80-81	580.5	23,669	0	1	0	1	0	21	0	550	4047	1845	0	0	0	842	2558
II-4/84-85	584.5	23,887	0	0	0	0	0	21	0	112	4321	1119	0	0	0	90	179
II-4/88-89	588.5	24,106	0	0	0	0	0	28	0	182	4600	1937	0	0	0	91	454
II-4/92-93	592.5	24,325	0	0	0	0	0	16	0	342	7310	5056	0	0	0	478	3758

Sample ID (Och18-…)	**Depth (cm)**	**Age (cal yr BP)**	*Myriophyllum*	*Sparganium* type	*Equisetum*	Polypodiales	*Pteridium*	*Glomus*	Chironomidae (conc.)	*Botryococcus* (conc.)	*Pediastrum angulosum* (conc.)	*Pediastrum boryanum* (conc.)	*Pediastrum duplex* (conc.)	*Pediastrum integrum* (conc.)	*Pediastrum kawraiskyi* (conc.)	*Pediastrum orientale* (conc.)	*Pediastrum simplex* (conc.)
			Aq	Aq	spo	spo	spo	NPP	NPP	ALG	ALG	ALG	ALG	ALG	ALG	ALG	ALG
II-4/96-97	596.5	24,544	1	1	0	0	0	24	117	322	8881	2521	0	0	0	0	410
II-4/100-101	600.5	24,763	0	1	1	0	0	8	0	336	6718	3695	0	0	134	202	1814
II-4/104-105	604.5	24,982	0	0	0	0	0	5	56	278	3505	1447	0	0	0	723	1168
II-4/108-109	608.5	25,200	0	0	0	0	0	3	0	336	3134	1959	0	0	0	168	2015
II-4/112-113	612.5	25,419	0	0	1	1	0	21	48	810	3907	1668	0	0	0	191	1096
II-4/116-117	616.5	25,638	0	0	0	0	0	4	0	362	5008	2715	0	0	0	0	2594
II-4/120-121	620.5	25,857	0	0	0	0	0	8	223	520	4757	4088	0	0	0	0	2899
II-4/124-125	624.5	26,076	1	0	0	1	0	10	38	153	3643	2378	0	0	0	0	307
II-4/128-129	628.5	26,295	0	1	0	0	0	17	0	144	3452	2014	0	0	0	0	115
II-4/132-133	632.5	26,513	0	2	0	0	0	37	0	128	2022	2227	0	0	0	0	77
II-4/136-137	636.5	26,732	0	0	0	0	0	6	0	566	8726	5817	0	0	0	485	162
II-4/140-141	640.5	26,951	0	0	0	1	0	5	0	665	3049	15,136	0	0	0	832	1331
II-4/144-145	644.5	27,170	0	0	0	1	0	16	0	296	3225	3876	0	0	0	0	0
II-4/148-149	648.5	27,389	0	2	0	0	0	22	0	60	2069	836	0	0	0	139	99
II-4/152-153	652.5	27,608	0	0	0	0	0	29	0	169	2196	304	0	0	0	0	0
II-4/156-157	656.5	27,826	0	0	0	0	0	15	0	96	6290	1873	0	0	0	0	0

7.3.3 Biome data

Biome score data of all 124 analysed and published sediment samples derived from terrestrial pollen data is provided in Table 7.5 including sample ID, sample core depth (cm), sample age (cal yr BP) and affinity scores for cold deciduous forest biome, taiga biome, steppe biome and tundra biome and calculated landscape openness.

Table 7.5: Biome score data list with Sample ID, core depth, age and affinity scores for cold deciduous forest biome (CLDE), taiga biome (TAIG), steppe biome (STEP) and tundra biome (TUND) and calculated landscape openness.

Sample ID (Och18-...)	**Depth (cm)**	**Age (cal yr BP)**	Cold deciduous forest (CLDE)	Taiga (TAIG)	Steppe (STEP)	Tundra (TUND)	Landscape openness
II-1/0-1	0.5	-47	16.28	17.33	4.38	5.46	11.86
II-1/4-5	4.5	117	16.04	17.22	4.07	4.79	12.43
II-1/8-9	8.5	281	16.39	17.02	6.35	6.95	10.07
II-1/12-13	12.5	446	15.06	16.25	5.39	5.85	10.40
II-1/16-17	16.5	610	15.56	16.51	5.42	5.82	10.69
II-1/20-21	20.5	774	15.93	17.12	3.85	4.99	12.13
II-1/24-25	24.5	939	15.07	16.21	3.79	4.76	11.45
II-1/28-29	28.5	1103	13.99	14.44	5.90	4.67	8.54
II-1/32-33	32.5	1267	14.75	16.01	4.02	4.92	11.10
II-1/36-37	36.5	1432	15.10	16.33	3.44	3.89	12.43
II-1/40-41	40.5	1596	14.37	14.92	3.93	4.03	10.88
II-1/44-45	44.5	1761	15.33	16.11	5.02	5.11	11.00
II-1/48-49	48.5	1925	15.30	16.14	5.05	5.40	10.75
II-1/52-53	52.5	2089	15.49	16.90	4.45	5.01	11.89
II-1/56-57	56.5	2254	16.04	17.46	3.72	3.66	13.73
II-1/60-61	60.5	2418	14.96	15.96	4.07	3.60	11.89
II-1/64-65	64.5	2582	15.01	15.46	5.19	4.19	10.27
II-1/68-69	68.5	2747	15.41	17.08	5.05	2.75	12.03
II-1/72-73	72.5	2911	14.87	16.10	4.49	3.96	11.60
II-1/76-77	76.5	3075	15.77	17.42	3.66	4.23	13.19
II-1/80-81	80.5	3240	14.20	15.88	3.84	3.68	12.04
II-1/84-85	84.5	3404	13.56	14.51	3.51	2.60	10.99
II-1/88-89	88.5	3569	13.21	13.84	3.95	1.53	9.89
II-1/92-93	92.5	3733	15.20	16.20	3.42	3.29	12.78
II-1/96-97	96.5	3897	14.39	15.16	4.20	3.15	10.96
II-1/100-101	100.5	4062	13.41	14.25	3.03	5.11	9.14
II-2/2-3	102.5	4144	13.04	13.93	4.04	3.34	9.89
II-2/6-7	106.5	4374	13.60	13.60	3.57	2.12	10.03
II-2/10-11	110.5	4751	13.73	14.68	3.28	2.00	11.40
II-2/14-15	114.5	5115	12.30	12.62	3.70	2.28	8.91
II-2/18-19	118.5	5466	14.25	15.35	2.32	1.15	13.03
II-2/22-23	122.5	5805	13.58	14.47	3.91	1.25	10.56
II-2/26-27	126.5	6134	14.00	15.00	3.95	2.43	11.05
II-2/30-31	130.5	6452	13.62	15.17	3.82	1.47	11.35
II-2/34-35	134.5	6761	12.91	14.05	2.74	0.95	11.31
II-2/38-39	138.5	7061	13.33	14.74	3.29	2.71	11.45
II-2/42-43	142.5	7352	13.51	14.45	3.75	1.73	10.70
II-2/46-47	146.5	7635	13.22	14.73	3.14	2.73	11.60

Sample ID (Och18-...)	**Depth (cm)**	**Age (cal yr BP)**	Cold deciduous forest (CLDE)	Taiga (TAIG)	Steppe (STEP)	Tundra (TUND)	Landscape openness
II-2/50-51	150.5	7911	12.55	13.49	3.81	2.96	9.69
II-2/52-53	152.5	8046	12.27	13.79	3.83	1.73	9.96
II-2/54-55	154.5	8179	11.76	12.76	4.36	1.67	8.40
II-2/56-57	156.5	8311	11.48	11.92	5.28	3.65	6.65
II-2/58-59	158.5	8441	10.74	12.08	4.33	1.95	7.75
II-2/60-61	160.5	8569	10.32	11.21	5.19	3.29	6.03
II-2/62-63	162.5	8695	12.07	13.45	4.61	3.50	8.84
II-2/66-67	166.5	8944	10.66	11.92	5.03	2.87	6.89
II-2/70-71	170.5	9187	9.87	11.25	5.90	4.13	5.35
II-2/74-75	174.5	9424	12.03	13.22	6.30	3.18	6.91
II-2/78-79	178.5	9656	12.89	15.31	6.21	2.87	9.10
II-2/82-83	182.5	9883	10.15	11.49	7.40	4.97	4.09
II-2/85-86	185.5	10,049	10.22	11.06	9.02	5.85	2.04
II-2/86-87	186.5	10,104	8.39	10.64	8.68	5.51	1.96
II-2/87-88	187.5	10,159	9.39	11.34	8.85	6.48	2.49
II-2/90-91	190.5	10,321	12.21	15.43	6.03	4.69	9.40
II-2/94-95	194.5	10,534	10.46	10.46	7.81	6.02	2.65
II-2/98-99	198.5	10,742	10.74	12.98	7.35	7.02	5.63
II-2/102-103	202.5	10,946	9.81	11.29	7.54	6.76	3.75
II-2/106-107	206.5	11,146	10.45	11.34	6.79	5.79	4.55
II-2/108-109	208.5	11,245	9.44	10.75	4.47	4.04	6.28
II-2/110-111	210.5	11,343	11.63	14.73	6.17	6.85	7.88
II-2/112-113	212.5	11,439	9.72	11.45	8.12	8.19	3.26
II-2/114-115	214.5	11,535	11.69	12.95	6.37	6.83	6.13
II-2/116-117	216.5	11,630	12.18	14.82	5.72	9.40	5.42
II-2/118-119	218.5	11,724	10.20	11.82	5.62	13.04	-1.22
II-2/120-121	220.5	11,817	9.56	11.21	6.37	13.25	-2.04
II-2/122-123	222.5	11,910	7.86	9.68	5.53	13.51	-3.83
II-2/124-125	224.5	12,001	8.36	9.74	6.55	14.09	-4.34
II-2/126-127	226.5	12,092	8.37	9.88	7.38	14.50	-4.61
II-2/128-129	228.5	12,182	8.16	10.00	7.11	13.21	-3.21
II-2/130-131	230.5	12,271	8.03	9.44	7.89	12.92	-3.48
II-2/132-133	232.5	12,359	7.95	9.92	7.65	13.26	-3.34
II-2/134-135	234.5	12,447	7.92	9.23	7.28	14.01	-4.79
II-2/136-137	236.5	12,534	7.21	8.55	7.43	13.15	-4.60
II-2/138-139	238.5	12,620	8.04	9.72	8.53	13.30	-3.58
II-2/140-141	240.5	12,705	7.44	11.38	10.02	8.91	1.36
II-2/142-143	242.5	12,790	8.76	11.76	9.75	10.85	0.90
II-2/144-145	244.5	12,874	8.17	11.76	8.06	9.57	2.19
II-2/146-147	246.5	12,957	8.92	11.29	8.16	11.48	-0.20
II-2/148-149	248.5	13,040	8.65	11.63	8.55	10.66	0.98
II-2/150-151	250.5	13,122	9.22	12.10	8.51	10.36	1.74
II-2/152-153	252.5	13,203	8.48	11.09	8.76	9.65	1.44
II-2/154-155	254.5	13,284	9.30	11.53	8.47	10.01	1.52
II-2/156-157	256.5	13,364	8.66	11.09	8.89	10.45	0.64
II-2/158-159	258.5	13,443	8.48	11.97	8.85	10.19	1.78
II-4/0-1	500.5	20,428	1.41	1.96	18.02	13.07	-16.06
II-4/4-5	504.5	20,544	1.97	2.29	18.51	14.05	-15.90
II-4/8-9	508.5	20,659	1.28	1.73	18.28	12.54	-16.55
II-4/12-13	512.5	20,775	2.22	3.22	15.94	14.23	-12.72
II-4/16-17	516.5	20,890	0.95	1.90	18.13	13.48	-16.23
II-4/20-21	520.5	21,006	1.72	2.67	16.48	13.79	-13.81
II-4/24-25	524.5	21,121	3.68	4.57	15.89	13.48	-11.32

Sample ID (Och18-...)	**Depth (cm)**	**Age (cal yr BP)**	Cold deciduous forest (CLDE)	Taiga (TAIG)	Steppe (STEP)	Tundra (TUND)	Landscape openness
II-4/28-29	528.5	21,237	2.51	4.02	19.14	14.09	-15.12
II-4/32-33	532.5	21,352	4.87	6.17	15.32	14.08	-9.15
II-4/36-37	536.5	21,468	1.14	1.77	16.68	14.06	-14.91
II-4/40-41	540.5	21,583	3.98	4.87	15.91	12.66	-11.04
II-4/44-45	544.5	21,699	2.97	3.87	16.68	14.59	-12.81
II-4/48-49	548.5	21,918	5.06	6.11	19.51	13.13	-13.40
II-4/52-53	552.5	22,137	0.00	0.84	18.44	12.24	-17.61
II-4/56-57	556.5	22,356	2.59	3.69	16.66	13.08	-12.98
II-4/60-61	560.5	22,574	2.57	3.62	15.59	13.58	-11.98
II-4/64-65	564.5	22,793	3.40	4.66	18.05	12.52	-13.38
II-4/68-69	568.5	23,012	2.17	2.81	18.56	14.18	-15.76
II-4/72-73	572.5	23,231	3.16	4.54	17.87	11.77	-13.33
II-4/76-77	576.5	23,450	1.93	2.70	16.48	14.14	-13.77
II-4/80-81	580.5	23,669	2.19	3.03	22.09	11.13	-19.06
II-4/84-85	584.5	23,887	1.93	3.35	18.30	13.00	-14.95
II-4/88-89	588.5	24,106	1.18	1.82	18.59	12.79	-16.78
II-4/92-93	592.5	24,325	0.00	0.00	19.08	11.90	-19.08
II-4/96-97	596.5	24,544	4.29	5.39	18.96	11.96	-13.57
II-4/100-101	600.5	24,763	1.26	2.21	17.26	14.52	-15.04
II-4/104-105	604.5	24,982	1.63	2.47	16.74	12.45	-14.27
II-4/108-109	608.5	25,200	1.64	2.64	17.49	12.45	-14.85
II-4/112-113	612.5	25,419	0.95	2.13	19.46	11.73	-17.33
II-4/116-117	616.5	25,638	1.14	1.85	18.62	13.73	-16.77
II-4/120-121	620.5	25,857	0.86	1.64	18.30	12.50	-16.67
II-4/124-125	624.5	26,076	2.11	2.42	16.66	13.79	-14.24
II-4/128-129	628.5	26,295	2.40	3.62	18.77	11.93	-15.14
II-4/132-133	632.5	26,513	1.77	3.00	19.18	11.98	-16.18
II-4/136-137	636.5	26,732	0.86	2.13	17.60	12.37	-15.47
II-4/140-141	640.5	26,951	0.00	0.89	19.16	11.28	-18.26
II-4/144-145	644.5	27,170	0.00	0.71	20.29	9.40	-19.59
II-4/148-149	648.5	27,389	2.34	2.89	19.97	11.28	-17.08
II-4/152-153	652.5	27,608	1.58	2.85	19.38	11.01	-16.53
II-4/156-157	656.5	27,826	2.11	3.29	18.47	13.81	-15.18

7.4 List of publications

Main-authorship:

Kobe, **F**., Bittner, M.K., Leipe, C., Hoelzmann, P., Long, T., Wagner, M., Zibulski, R., Tarasov, P.E., 2019. Lateglacial and early Holocene environments and human occupation in Brandenburg, eastern Germany. Geography, Environment, Sustainability 12, 132–147: https://doi.org/10.24057/2071-9388-2018-50.

Kobe, **F**., Bezrukova, E.V., Leipe, C., Shchetnikov, A.A., Goslar, T., Wagner, M., Kostrova, S.S., Tarasov, P.E., 2020. Holocene vegetation and climate history in Baikal Siberia reconstructed from pollen records and its implications for archaeology. Archaeological Research in Asia 23, 100209: https://doi.org/10.1016/j.ara.2020.100209.

Kobe, **F**., Leipe, C., Shchetnikov, A.A., Hoelzmann, P., Gliwa, J., Olschewski, P., Goslar, T., Wagner, M., Bezrukova, E.V., Tarasov, P.E., 2022a. Not herbs and forbs alone: Pollen-based evidence for the presence of boreal trees and shrubs in Cis-Baikal (Eastern Siberia) derived from the Last Glacial Maximum sediment of Lake Ochaul. Journal of Quaternary Science 37, 868–883: https://doi.org/10.1016/j.quaint.2021.09.019.

Kobe, **F**., Hoelzmann, P., Gliwa, J., Olschewski, P., Peskov, S.A., Shchetnikov, A.A., Danukalova, G.A., Osipova, E.M., Goslar, T., Leipe, C., Wagner, M., Bezrukova, E.V., Tarasov, P.E., 2022b. Lateglacial–Holocene environments and human occupation in the Upper Lena region of Eastern Siberia derived from sedimentary and zooarchaeological data from Lake Ochaul. Quaternary International 623, 139–158: https://doi.org/10.1016/j.quaint.2021.09.019

Co-authorship:

Leipe, C., Müller, S., Hille, K., Kato, H., **Kobe**, **F**., Schmidt, M., Seyffert, K., Spengler III, R., Wagner, M., Weber, A.W., Tarasov, P.E., 2018. Vegetation change and human impacts on Rebun Island (Northwest Pacific) over the last 6000 years. Quaternary Science Reviews 193, 129–144: https://doi.org/10.1016/j.quascirev.2018.06.011.

Leipe, C., **Kobe**, **F**., Müller, S., 2019. Testing the performance of sodium polytungstate and peat sediment samples. Quaternary International 516, 207–214: https://doi.org/10.1016/j.quaint.2018.01.029.

Schwamborn, G., Hartmann, K., Wünnemann, B., Rösler, W., Wefer-Roehl, A., Pross, J., Schlöffel, M., **Kobe**, **F**., Tarasov, P.E., Berke, M.A., Diekmann, B., 2020. Sediment history mirrors Pleistocene aridification in the Gobi Desert (Ejina Basin, NW China). Solid Earth 11, 1375–1398: https://doi.org/10.5194/se-11-1375-2020.

Tarasov, P.E., Savelieva, L.A., **Kobe**, **F**., Korotkevich, B.S., Long, T., Kostromina, N.A., Leipe, C., 2021. Lateglacial and Holocene changes in vegetation and human subsistence around Lake Zhizhitskoye, East European midlatitudes, derived from radiocarbon-dated pollen and archaeological records. Quaternary International (in press): https://doi.org/10.1016/j.quaint.2021.06.027.

7.5 Curriculum vitae

Due to data protection regulations, the curriculum vitae is not included in the online version of this doctoral thesis.

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7.6 Declaration

Berlin, January 2021

I hereby declare that I wrote this doctoral thesis on my own and that all used sources are properly acknowledged. This thesis has not been previously submitted to the Freie Universität Berlin or any other institution.

Franziska Kobe