University of Groningen

Bringing Home Animals

Junno, Aripekka Oskari

DOI:
[10.33612/diss.134868900](https://doi.org/10.33612/diss.134868900)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2020

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):
Junno, A. O. (2020). *Bringing Home Animals: Final-Stage Jomon and Okhotsk Culture Food Technologies*. [Thesis fully internal (DIV), University of Groningen, Stockholm University]. University of Groningen.
<https://doi.org/10.33612/diss.134868900>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

rijksuniversiteit
 groningen

Stockholm
University

Bringing home animals: Final-stage Jomon and Okhotsk Culture food technologies

PhD thesis

to obtain the degree of PhD of the
University of Groningen
on the authority of the
Rector Magnificus Prof. C. Wijmenga
and in accordance with
the decision by the College of Deans

and

to obtain the degree of PhD of
Stockholm University
on the authority of the
Deputy Vice President for Human Science Prof. E. Wåghäll Nivre
and in the accordance with
the decision by the College of Deans

Double PhD degree

This thesis will be defended in public on
Monday 26 October 2020 at 19.45 hours

by

Aripekka Oskari Junno

born on 22 January 1986
in Tampere, Finland

Supervisors

Prof. P.D. Jordan

Dr. S. Isaksson

Co-supervisors

Prof. H. Kato

Assessment Committee

Prof. D.C.M. Raemaekers

Prof. A.-L. Schallin

Prof. M. Skandfer

Prof. B. Fitzhugh

university of
 groningen

Stockholm
University

Bringing Home Animals: Final-Stage Jomon and Okhotsk Culture Food Technologies

Aripekka Oskari Junno

Abstract

In this thesis, organic residues preserved in ancient pottery are used to reconstruct diversity and change in the foodways of Late Holocene hunter-gatherer communities in coastal northern Hokkaido (1750 BCE–1250 CE). The Late Holocene period of this region is very dynamic, and characterised by numerous migrations and cultural replacements. The research into these processes has generally focused on typological variation in pottery, which is a device each of the period's different cultures made widespread use of. This thesis takes a novel approach, and uses pottery residue analysis to investigate long-term patterns of continuity and change in cooking practices, employing the concept of cuisine to interpret the results. In particular, the Okhotsk Cultures (400–1100 CE) form a central focus of the thesis, and their complex animal cosmology, diverse subsistence and multifaceted household activities offer a rich context in which to examine changing foodways.

The primary goal is understanding long-term and “macro-scale” patterns of continuity and change, and this also requires improving existing chronological frameworks, which largely rely on pottery typologies rather than radiocarbon dating. Refining and improving existing chronologies therefore forms the second goal of the thesis. The third goal is to examine foodways at a more contextual “micro-scale”. This involves studying how pottery use was organised within the domestic space of a single Okhotsk Culture long-house, and how these practices were informed by social relations and the cosmology of human-animal interactions.

The present thesis consists of an extended introduction, which sets the research in a wider regional and culture-historical setting, and also presents the main methods, concepts and approaches. The central research question is whether the close association between use of pottery and the processing of aquatic resources, which was established by the Early Holocene, does in fact persist into these Late Holocene cultures. The core of the thesis tackles this question by presenting five journal articles, which focus on the archaeological sites of Hamanaka 2, Kafukai 1 and 2, and Menashidomari. The overall results indicate that this older pattern was starting to break down, and that a range of new and more diverse cooking practices was emerging. The thesis also demonstrates that these important shifts in cuisine can also be tied into much higher-resolution chronological frameworks using new methods and approaches. Finally, the “micro-scale” analysis of container function within a single household suggests that some sort of symbolic distinction was made between different sources of foods.

Keywords: organic residue analysis, lipid, stable isotope, cuisine, Okhotsk Cultures, Jomon, Hokkaido, pottery, radiocarbon dating, chronology, marine reservoir effect, household, coastal archaeology

Acknowledgements

The best part of this research has without a doubt been the amazing people I've had the chance to meet and spend time with. What would my life be had I not had the chance to meet them? It would certainly not have been possible to conduct this research without the help and continued support from my colleagues and friends in the Netherlands, Sweden, Japan, Russia, and many other countries I was fortunate enough to visit during the past three and a half years. Thank you!

Then, I want to highlight how fantastic it has been to work with all three of my supervisors during the past years. The support I received from Peter Jordan, my main supervisor at the Arctic Centre, University of Groningen, and Sven Isaksson, my supervisor at the Archaeological Research Laboratory of Stockholm university, as well as Hirofumi Kato, my third supervisor at the Centre for Ainu and Indigenous Studies of Hokkaido University, was unwavering from the first day, and I can say that I have learned a great deal from all of you. You all spent considerable time tutoring me in the Netherlands, Sweden and Japan and I hope I will be able to make the most of what you have passed on to me. Peter was very enthusiastic about the project since day one, and having access to his insights and vision had a massively positive influence on my work. Also, I very much enjoyed traveling and attending conferences with Peter in Russia, Japan and Canada, always discussing and debating about archaeology and new ideas for research.

Sven showed a Samurai-level patience in teaching me a whole new craft – well, that's how Sven regards laboratory work and organic residue analysis, and I agree with him – which I was not familiar with before this project. Working with Sven in the laboratory and learning new things about ancient lipids and different analytical techniques was definitely one of the highlights of the past few years, and I know that I want to continue learning more and improving my skills in this 'craft' in the future.

Hirofumi I had actually already met before the project started, when he was visiting Helsinki in 2015. During this project, I visited Japan a number of times and each visit was organized by Hirofumi, who was always ready to arrange meetings with different collection managers across Hokkaido, and if need be, accompany me on the road to make sure I could collect the samples I needed. I was also lucky to have the chance to excavate with Hirofumi

on several occasions and learn countless things about Japan and the Japanese archaeology in the process. Therefore, needless to say that I certainly hope that I can continue working together with Hirofumi, Sven and Peter in the future. Thank you all very much!

I am also very thankful for the opportunity to take part in the Horizon2020, European Union's Framework Programme for Research and Innovation, and conducting research within the European Training Network. I am very grateful to our ArchSci project management and host institutions for organizing all the workshops and training modules. I wish to thank the universities of York and Copenhagen, and especially Matthew Collins, Hannes Schröder and Oliver Craig – who was the chair in my supervisory meetings – for their help and support in my research and training.

ArchSci2020 was a very special project for me, and I think also for the other fourteen PhD researchers – Manon Bondetti, Özge Demirci, Jack Dury, Tatiana Feuerborn, Alison Harris, Maiken Hemme Bro-Jørgensen, Theis Jensen, Xénia Keighley Weber, Mariana Muñoz-Rodriquez, Madison Llewellyn, Jonas Niemann, Anne Katrine Runge, Eden Slidel and Anne-Marijn Snaaijer-van Spelde – at the four universities in York, Copenhagen, Stockholm and Groningen. It was great conducting research, attending workshops and hanging out with all of you, thank you!

In Sweden, I wish to thank my colleagues at the Archaeological Research Laboratory in Stockholm, Kerstin Lidén, Gunilla Eriksson, Mikael Lundin, Anders Gotherström, Vasiliki Papakosta, Lena Holmquist, Maria Wojnar-Johansson, Anna Hofman, Hans Ahlgren, Aikaterini Glykou and Markus Fjällstrom, for their fantastic support and help during my secondment year.

In the Netherlands, I want to express my gratitude to my colleagues at the Arctic Centre and the Groningen Institute of Archaeology at the University of Groningen, Maarten Loonen, Annette Scheepstra, Frits Steenhuisen, Marjolein Admiraal, Sean Desjardins, Matilda Siebrecht, Eirik Haug Røe and Erwin Bolhuis, for their great help and invaluable moral support throughout the project.

In Japan, I am extremely thankful to my colleagues at the Center for Ainu and Indigenous Studies at the Hokkaido University, including Yu Hirasawa and Akiko Maeda, for their invaluable contributions to my research. Special recognition must also be given to Tetsuya Amano, Masaki Eda and Hiroko Ono at the Hokkaido University Archaeological

Museum, Christian Leipe of the Nagoya University, Takamune Takabatake at the Esashi Archaeological Museum, Satoru Yamada at the Kitami City Archaeological Museum, and Alexander A. Vasilevsky and Vyacheslav A. Grishchenko at the Sakhalin State University, who were all kind enough to provide their expertise and access to the local research materials. Especially Hiroko Ono and Tetsuya Amano were always willing to help me with everything related to research, and counting on their support and experience was very important and welcome for a young researcher like me. I also wish to thank Shinya Shoda of the Nara National Research Institute for Cultural Properties for advising me and providing options to continue my research in Japan. I also wish to thank Masuo Sugihara of the Esashi City for his important help in the collection and transportation of samples from the Menashidomari site. In addition, I give my thanks to the Rebun Field School teams of 2016, 2018 and 2019, led by Hirofumi Kato, Yu Hirasawa and Ren Iwanami, for their work in collecting and documenting materials used for this study. In addition, I wish to thank Takao Sato, Amanda Gomes, Gabrielle Hughes, Erin Gamble and Liou Bing for their support and help during the Rebun excavations and during my time in Sapporo. Also, I wish to thank Takase Katsunori of the Hokkaido university and Ben Fitzhugh of the University of Washington, for finding the time to discuss my research while in Sapporo.

Likewise, I am very thankful to Ferran Borrell of IMF-CSIC in Barcelona, for his invaluable advice and mentoring throughout my career in archaeology. Special thanks also go to my fellow ArchSci students Jack Dury, Özge Demirci and Madison Llewellyn for their continued support during the project, it has been great working with you! Also, I wish to thank Manon Bondetti, also one of the ArchSci students, for her help with methodological questions throughout the project. I wish to also thank Alexander N. Popov and Andrei V. Tabarev, from the Far Eastern Federal University of Vladivostok and Novosibirsk University, respectively, for organizing two brilliant international symposia in Vladivostok in 2018 and 2019. I also want to extend my thanks and appreciation to Andrzej W. Weber of the University of Alberta for his help during the 2016 Rebun FS and 2017 SAA Conference in Vancouver.

Also, I wish to give my thanks to Markku Oinonen, Heli Etu-Sihvola, Laura Arppe, Antti Lahelma, Kristiina Mannermaa, Miikka Tallavaara, Mika Lavento and Petro Pesonen of the University of Helsinki, as well as Anna-Kaisa Salmi from the University of Oulu, and

Päivi Onkamo and Outi Vesakoski of the University of Turku for their great support in the years past. In addition, I wish to thank Pete Hommel for his great help during the Rebun Field School in 2019, where also Jordan Ballard, Carol Ellick and Joe Watson were kind enough to help me with my experimental work. I also wish to thank my close friends Tuuli Kasso of the University of Copenhagen, and Adrià Breu Barcons of the Universitat Autònoma de Barcelona for their support and help with research during the past years. I would also like to thank Joan Anton Barceló of the Universitat Autònoma de Barcelona, who has had a major influence on my research dating back to my time in Catalonia almost ten years ago. I also wish to thank the Stockholm University Faculty of Geosciences, especially Anna Hagglund, Heike Siegmund and Henry Holmstrand for their assistance in managing the analytical instruments required for this study, as well as Cecilie Toudal Pedersen of Copenhagen University for her support on matters concerning ArchSci and the organization of workshops. I also wish to thank Åsa Larsson for her efforts and important feedback as my opponent during the Final Seminar in Stockholm.

Finally, the most important of all is of course my mom, Tiina, who has supported and motivated me every step of the way, every day, throughout my whole life. You are an inspiration to me and it is easy to pursue new and challenging things in life because I know that you always have my back. Thank you, mom!

List of Papers

1. **Junno, A., Isaksson, S., Hirasawa, Y., Kato, H. & Jordan, P.D.** (2020). Evidence of increasing functional differentiation in pottery use among Late Holocene maritime foragers in northern Japan. *Arch. Research in Asia*, 22, 100194. <https://doi.org/10.1016/j.ara.2020.100194>
2. **Junno, A., Dury, J.P.R., Leipe, C., Wagner, M., Tarasov, P.E., Hirasawa, Y., Jordan, P.D. & Kato, H.** (*manuscript submitted March 20, 2020*). Building a high-resolution chronology for a multi-phase maritime forager settlement – a case study of the Hamanaka 2 site in Rebun Island, Hokkaido (Japan). *Journal of Archaeological Science: Reports*.
3. **Junno, A., Isaksson, S., Amano, T., Ono, H., Kato, H. & Jordan, P.D.** (*manuscript submitted August 10, 2020*). Island Ecology, Colonisations and Culture History: Insights into changing patterns of household food consumption in the Susuya, Okhotsk and Satsumon phases of the Kafukai sites, Rebun Island, Japan. *Japanese Journal of Archaeology*.
4. **Junno, A., Llewellyn, M.H., Dury, J.P.R., Amano, T., Ono, H., Jordan, P.D., Kato, H. & Isaksson, S.** (*manuscript*). Radiocarbon dating of purified lipid residues in ancient maritime forager pottery in northern Hokkaido (Japan).
5. **Junno, A., Isaksson, S., Kato, H. & Jordan, P.D.** (*manuscript*). Bringing Home Animals: Exploring Cosmology and Cuisine among the Okhotsk Cultures in northeast Asia.

Contents

Acknowledgements	i
List of Papers	v
1. Introduction	9
2. The General Culture-Historical Context: Prehistoric Hokkaido	13
2.1. The Geography and Climate of Northern Hokkaido	13
2.2. Late Pleistocene & Early Holocene Cultures	14
2.2.1. The Incipient and Initial Jomon Periods	15
2.2.2. The Early Jomon Period	16
2.2.3. The Middle Jomon Period	16
2.3. The Late Holocene Cultures	16
2.3.1. The Late and Final Jomon Periods	16
2.3.2. The Epi-Jomon Period	18
2.3.3. The Susuya Culture in Northern Hokkaido	20
2.3.4. The Okhotsk Cultures	20
2.3.5. The Satsumon Cultures	22
2.3.6. The Emergence of the Ainu Cultures	23
3. Pottery Among Late Pleistocene and Holocene Cultures in Northeast Asia and the Japanese Archipelago	25
3.1. The Emergence of Pottery in the Late Pleistocene	25
3.2. Pottery in the Early Holocene	26
3.3. Pottery in the Late Holocene Hokkaido: What Was its Function?	27
3.3.1. Overview of Main Pottery Traditions and Chronology	28
3.3.2. Preliminary Insights into Container Function	31
4. Micro-Scale Insights into Okhotsk Culture Foodways and Cosmology	33
5. Organic Residue Analysis in Archaeology	38
5.1. Molecular Analysis	38
5.1.1. Lipids	38
5.1.2. Sampling	39
5.1.3. Extraction	42
5.1.4. Identification of Compounds and Biomarkers Using GC–MS	43

5.1.4.1.	Diagnostic Biomarkers	44
5.1.4.2.	Aquatic Biomarkers.....	45
5.1.4.3.	Other Animal Lipid Biomarkers.....	48
5.1.4.4.	Plant Biomarkers	49
5.2.	Stable Isotope Analysis.....	50
5.2.1.	Carbon.....	51
5.2.2.	Nitrogen	51
5.2.3.	Bulk Isotope Analysis	52
5.2.4.	Single-Compound Analysis	53
5.2.5.	Food Sources and the Local Food Web Structure.....	54
5.3.	Preservation and Degradation of Ancient Organic Remains.....	55
5.4.	Contamination.....	57
5.5.	Approaches to Reconstructing Cuisine and Resources Sharing Through Pottery Lipid Analysis.....	58
6.	Food Source Reconstruction Using Bayesian Mixing Models.....	61
6.1.	Bayesian Modelling	61
6.2.	Reconstruction of Prehistoric Pottery Use From Organic Residue Isotope Signatures Using Bayesian Inference	62
7.	Radiocarbon Dating in Archaeology	67
7.1.	The Principles of Radiocarbon Dating.....	67
7.2.	Calibration.....	68
7.3.	Radiocarbon Contaminants and the Suess Effect.....	71
7.4.	Reservoir Effects.....	73
7.5.	Bayesian Chronological Inference	74
7.6.	Direct Dating of Pottery	76
8.	Selection of Study Sites, Samples and Summary of Main Results	80
8.1.	Hamanaka 2.....	80
8.2.	Kafukai 1 & 2.....	81
8.3.	Menashidomari.....	83
9.	The Okhotsk Culture Cuisine in Northwest Hokkaido.....	85
10.	Constructing High-Resolution Chronologies in Late Holocene Hokkaido	91
11.	Conclusions	94
12.	References	95

Appendix	117
----------------	-----

1 Introduction

The overarching theme of this thesis is to understand the foodways of the Late Holocene coastal hunter-gatherer communities of northern Hokkaido, with the main point of focus on the Okhotsk Cultures (400-1100 CE). The coastlines of northern Hokkaido in this period are occupied by diverse hunter-gatherer cultures, each distinguished by unique origins, yet united by a common mode of adaptation to the rich maritime ecosystems (Okada, 1998; Yamaura, 1998; Takase, 2020). Pottery is a critical resource for local archaeologists seeking to track past social dynamics and to reconstruct interactions between the different cultures. Vessel typology, in particular, is also of central importance for building relative chronologies of culture change (Deryugin, 2008). The Okhotsk Cultures particularly stand out among these communities, due to their robust marine hunting subsistence and complex human-animal interactions (Amano, 2003).

Indeed, the Okhotsk were marine hunters and traders with cultural and genetic affinities that originate from the final stages of the local Jomon tradition, but also include external influences from the Sakhalin Island and the Lower Amur cultural interaction spheres, located further to the north, and situated today in present-day Russian territories (Sato et al., 2009). The Okhotsk also developed a complex animal mythology that permeated each facet of the society and influenced their subsistence, household dynamics and burial practices (Oba & Ohyi 1981; Amano, 2003; Hirasawa & Kato, 2019). However, little is known about the Okhotsk Culture foodways, and how the Okhotsk cuisine aligned with their human-animal interactions. In the present thesis, cuisine is understood as a set of conscious choices to select, prepare and consume foodstuffs in particular ways, which are, in turn, also influenced by subsistence, ecological, cosmological and other social factors (Farb & Armelagos, 1980; Mintz, 1996).

As an abundant and ubiquitous resource among Late Holocene cultures in Hokkaido, the ancient food remains preserved in pottery allow for diversity and change in such culinary practices to be reconstructed through organic residue analysis (Isaksson, 2009). This is because the clay matrix's tendency to absorb and preserve lipids for extremely long periods of time ensures the organic remains detectable in pottery characterize the ancient use of the artefact (Evershed, 2008).

This approach has already been widely applied to earlier pottery traditions in the region, covering the Incipient Jomon traditions in the Late Pleistocene, as well as the Initial and subsequent traditions of the Early Holocene periods. This research has shown that the Jomon hunter-gatherer pottery was consistently used to process aquatic resources – a pattern emerging in the Late Glacial period and persisting well into the Holocene, despite the massive environmental, cultural and economic changes that also take place at this time (Craig et al., 2013; Lucquin et al., 2016a, 2018). It is not clear, however, whether this enduring pottery-based cooking tradition persists into the Late Holocene. This is an important question given the series of major technological and cultural transformations that take place, including the introduction of rice farming and iron tool working, and the emergence of new cultures such as the Okhotsk and Satsumon.

Therefore, firstly, in the present study I aim to test two competing hypotheses concerning the Okhotsk container function to see whether the culture's pottery use i) maintains the ancient, highly specialized use of aquatic resources, or ii) whether the Okhotsk were starting to use pottery in more diverse ways. Secondly, another research theme was to understand whether either of the strategies adopted would undergo any long-term “macro-scale” changes over the course of the site occupation sequences studied, and whether these patterns would be shared by other local Late Holocene cultures. Third, to properly address these questions, more accurate chronologies are required for the stratified sites where these long-term patterns of pottery use were investigated, including addressing marine reservoir effects. Fourth, to better understand how social and cosmological factors may have structured Okhotsk foodways, patterns of pottery use within the “micro-scale” social spaces of the Okhotsk household are also investigated.

Consequently, the following three main questions were assumed for this thesis:

- 1) To what extent did the early Holocene aquatic pattern of pottery use persist into the Late Holocene?
- 2) How can the resulting evidence and materials at the study sites be used to construct a more accurate chronological picture of the Late Holocene culture sequence?
- 3) What insights emerge from a “micro-scale” analysis of pottery use within a single household context?

Figure 1. Map of northeast Asia with the location of the three study sites indicated in Rebun Island and mainland Hokkaido.

These overarching questions are addressed through organic residue analysis of pottery collected from three archaeological sites in northern Hokkaido (Fig. 1), combined with radiocarbon dating and Bayesian modelling. The findings are presented as five journal papers. In the first case-study, long-term trends in pottery use are investigated through molecular and isotopic analyses of ceramic containers from the multi-phase Hamanaka 2 site in Rebun Island, running from the Final Jomon to the Late Okhotsk Culture period. A second case-study combines archaeobotanical ^{14}C -dates and existing stratigraphic information from Hamanaka 2 to generate a more accurate chronology of the site's occupation sequence.

The third case-study investigates household pottery to understand whether Susuya, Okhotsk and Satsumon Culture groups at the Kafukai 1 and 2 sites used ceramic cooking containers to process similar or different sets of resources. These results are built into the fourth case-study, which investigates the chronology of these occupations at the same site by

directly dating the different pottery traditions. A new extraction and purification method was employed, which involved extracting lipids absorbed in the pottery matrix for direct AMS (Accelerator Mass Spectrometry) dating. In addition, the results of organic residue analysis from the Kafukai sites enabled the contribution of marine carbon to be estimated using a mixing model, which in turn helps better factor in the marine reservoir effects.

Finally, the fifth case study uses a micro-scale approach to examine patterns in pottery use, and zooms in on container function within the activity zones of a single Okhotsk pit-house. Hence, at the Menashidomari site Okhotsk cuisine and sharing of resources were investigated in a well-excavated long-house where spatial evidence was considered together with the results of organic residue analysis to better understand the socio-cultural factors structuring domestic pottery use.

The following chapters of this introduction support and contextualise the five journal papers. They provide a general background to the Late Holocene prehistory of northern Hokkaido, and introduce the core methods of organic residue analysis and radiocarbon dating, while explaining how they can be deployed to investigate and date the changing use of pottery within the study region. Specifically, Chapter 2 provides the geographic and culture-historic context for the study, while Chapter 3 is primarily focused on discussing the present state of research into pottery use in the prehistoric Japanese archipelago. Chapter 4 provides some context into the Okhotsk cosmology and human-animal interactions, using ethnographic insights to draw some direct historical analogies between the Okhotsk Culture and the traditions of the Ainu Cultures, who are the modern indigenous inhabitants of the region. Chapters 5–7 provide a detailed explanation of the method of organic residue analysis, including the sampling strategy and extraction protocols, as well as radiocarbon dating and Bayesian inference. In Chapter 8, the study sites and materials are briefly presented, along with summary of the main research findings, and the range of analyses that were used to generate them. The results of the organic residue analysis are discussed in Chapter 9 dedicated to the reconstruction of the Okhotsk Culture cuisine, followed by a discussion on the construction of radiocarbon-supported high-resolution chronologies in northern Hokkaido in Chapter 10. Finally, in Chapter 11, general conclusions of the present research are provided.

2 The General Culture-Historical Context: Prehistoric Hokkaido

2.1 The Geography and Climate of Northern Hokkaido

The island of Hokkaido is strategically located at the centre of long chains of islands that run from the mouth of the Amur – one of the great rivers systems of east Asia – via Sakhalin to Hokkaido, Honshu and Kyushu (Fig. 2). To the northeast, Hokkaido is also linked by the Kurils to Kamchatka. As a result of this central location, Hokkaido has also served as a cultural crossroads, with people, commodities and innovations passing both north and south (Fukuda & Grishchenko, 2017). For instance, in the Last Glacial Maximum (LGM), Hokkaido formed a single land mass with Sakhalin (Igarashi, 2016), which was in turn joined to the Siberian mainland, allowing easy movement for Late Palaeolithic populations and the sharing of cultural traditions.

Figure 2. Map of East Asia showing key island chain networks leading in and out of the Japanese archipelago

Warmer climates in the Late Glacial brought higher sea levels, eventually leading to the mainland of Hokkaido, and several smaller offshore islands, including Rebun Island and

Rishiri Island, to become separated from Sakhalin Island and the continent of Far Eastern Russia. Throughout the Holocene, Hokkaido has typically comprised several distinct ecological niches whose climate and ecosystems are controlled by the numerous oceanic currents in the Sea of Japan, the Okhotsk Sea and the Pacific (Igarashi, 2013).

The present thesis is focused on the northern Hokkaido, which is located in the transitional zone dominated by cool-temperate boreal and broad-leaved forests. The climate in northern Hokkaido is primarily conditioned by the East Asian Monsoon System and also marked by strong seasonal cycles (Igarashi, 2013). The winters tend to be humid and stormy, with the interplay of the East Asian Winter Monsoon (EAWM) circulation and the Tsushima warm current (TWC) producing heavy snowfall (Kuroyanagi et al., 2006). In addition, similarly to the circumstances in Rebun Island, the summers on the Okhotsk Sea coast tend to be dry and temperate. The climate there is controlled by the Soya Warm Current, which branches out from the Tsushima Warm Current in the Soya Strait, flowing in the southeast direction along the Okhotsk Sea coast (Igarashi, 2013). In winter, the Okhotsk Sea receives drift ice transported with the Amur River water, which creates ice fields in the sea. Sea ice, in turn, allows local marine mammals, such as fur seals (*Callorhinus ursinus*) and sea lions (*Zalophus californianus japonicus*), to be hunted efficiently (Ono, 2008).

2.2 Late Pleistocene & Early Holocene Cultures

The cultural sequence of Hokkaido from the Late Glacial to the Early Holocene is marked by two major economic shifts. First, communities “diversify” away from the traditional Palaeolithic focus on big game hunting, and start to add plant, fish and marine resources – extracted, processed and stored with new innovative technologies such as pottery, net sinkers and grinding stones. This process is followed by “intensification” of different branches of the economy, generating location-specific adaptive strategies, which in some areas go on to support larger and more sedentary populations, along with higher levels of social complexity, especially in southwest Hokkaido (Abe et al., 2016; Robson et al. *article accepted*).

These major economic and demographic developments appear to coincide with a series of shifts in the material culture of the extended Jomon tradition. These changes – especially in pottery styles – are then used to divide the Jomon sequence into a series of discrete periods consisting of the Incipient, Initial, Early, Middle and Late Jomon (cf. Weber

et al., 2013; Abe et al., 2016). This framework has also been applied to the prehistory of Hokkaido, with pottery typologies defining the chronology of the different Jomon periods. This framework has yet to be fully integrated with a high-resolution radiocarbon chronology, although there is general consensus on the timing of most transitions between the different Jomon periods, and how they correlate with different climatic and palaeo-environmental proxies. These diverse proxies have enabled climatic shifts, fluctuations in sea levels, changes in vegetation cover and the scale and intensity of prehistoric occupations to be correlated over extensive timescales, suggesting that warming climates played a major role in boosting Hokkaido populations, whereas cooling episodes led to falling populations and regional depopulation, especially in northern and inland sites (Abe et al., 2016; Fukuda & Grishchenko, 2017). In this thesis, the chronological and palaeoenvironmental framework published by Abe et al (2016), is generally employed, which in turn is derived from Weber et al. (2013) (for recent unpublished updates see also Robson et al. *article accepted*).

2.2.1 The Incipient and Initial Jomon Periods

Incipient Jomon pottery appears in Hokkaido at the Taisho 3 site c. 14,000-10,000 years before present (BP). The Incipient Jomon populations in Hokkaido are few and concentrated in inland loci, practicing a mix of terrestrial mammal hunting and gathering, and fishing as part of a highly mobile lifestyle that had been adopted from groups in Honshu (Weber et al., 2013; Abe et al., 2016; Fukuda & Grishchenko, 2017).

The transition between the Incipient and Initial Jomon Periods is poorly understood, but it is clear that by the start of the Initial Jomon period, which correlates with the warmer conditions of the early Holocene, populations were starting to grow rapidly, with the climate likely supporting higher population levels compared to the Late Pleistocene conditions (Abe et al., 2016). The Initial Jomon period (10,000–6000 BP) is characterized by seasonally mobile hunter-fisher-gatherer groups. However, some communities are starting to construct large hamlets – in some cases with hundreds of house pits – suggesting growing sedentism in this period, at least on a seasonal basis. Populations grow especially quickly in coastal areas, and are probably attracted by easy access to marine resources. Some settlements contain formal cemeteries and there is also evidence of storing, indicating a more permanent

lifestyle, with the subsistence less concentrated on large terrestrial mammal hunting, and further diversified into gathering and fishing (Weber et al., 2013).

2.2.2 The Early Jomon Period

In the Early Jomon Culture period (6000–5000 BP) the climate warming reaches its peak during the Holocene Climate Optimum, leading to an increase in population sizes across the region (Craig et al., 2013; Abe et al., 2016; Fukuda & Grishchenko, 2017). While this resulting in further increase in settlement size, as well as a diversification of resources between terrestrial animal, plant (e.g. walnut and acorns) and aquatic food webs, the Early Jomon lifestyle in Hokkaido – and in southern Sakhalin for that matter – is still characterized as mobile compared to the more permanent hunter-gatherer economies of Honshu (Fukuda & Grishchenko, 2016; Robson et al. *article accepted*).

2.2.3 The Middle Jomon Period

The Middle Jomon period (5000–4000 BP) sees the highest population density in the Jomon sequence, with all regions of Hokkaido becoming settled, including the northern areas (Abe et al., 2016). The Middle Jomon is characteristic of land-based and marine hunter groups that exploit a wide range of terrestrial and aquatic resources in coastal and river loci, as well as plants. The Middle Jomon groups in Southwest Hokkaido start to inhabit large and fully sedentary village settlements, some with shell midden deposits, though in other parts of Hokkaido this period is still marked by mobile hunter-fisher-gatherer economies (Weber et al., 2013; Mizoguchi, 2020). However, toward the end of the Middle Jomon, a cooling trend sets in after 4.2, probably triggering the steady decrease in population as discussed in detail by Abe et al. (2016).

2.3 The Late Holocene Cultures

2.3.1 The Late and Final Jomon Periods

Northern Hokkaido in the Late Holocene period (4000–850 BP) is inhabited by mobile maritime forager communities, which is evidenced by frequent findings of shell midden

deposits, marine hunting gear and other assemblages associated with prehistoric maritime forager subsistence (Kimura, 1976; Okada, 1998; Yamaura, 1998; Takase, 2019). The Late and Final Jomon, and the Epi-Jomon (Zoku Jomon) cultures represent the last phase of the Jomon Culture succession (4000–1300 BP) in Hokkaido (Abe et al., 2016).

Though the final-stage Jomon cultures held frequent contacts with other Jomon populations in Honshu (cf. Weber et al., 2013), their adaptation to the ecologically diverse Hokkaido region, together with the cultural influence and population movements from Sakhalin and the Lower Amur regions in the north, contributed to their divergent cultural trajectory from the rest of the Japanese archipelago (Oba & Ohyi, 1981; Sato et al., 2009). While primarily focused on aquatic resources, the economies of these cultures were however rather diversified in that terrestrial animal hunting, gathering, small-scale plant cultivation and incipient animal domestication were practiced across this period (Chiyo, 1984; Habu et al., 2003; Habu, 2004; Crawford, 2011).

In the Late Jomon (4000–3300 BP) and the Final Jomon periods (3300–2300 BP), hunting, fishing and gathering are therefore widely relied on, with the trading of commodities such as bitumen and jade practiced in the Tsugaru Strait (Okada, 1998; Weber et al., 2013). In addition, during this period, settlements are moved to lowlands, with elaborate burial practices in large circular cemeteries indicating substantial social differentiation (Ikawa-Smith, 1992; Weber et al., 2013; Abe et al., 2016).

In northwest Hokkaido, the local groups appear to be highly mobile, and special logistical camps are established in Rebun Island by marine-focused hunting groups (Fig. 3). The purpose of these encampments appears to have been the exploitation of the area's abundant marine resources, especially sea mammals (Sakaguchi, 2007; Miyata et al, 2009; Hirasawa & Kato, 2019). A similar – and perhaps of larger scale – circumstance is developed around a marine ecosystem rich in resources in southwestern Hokkaido during the Epi-Jomon phase (Okada, 1998; Horiuchi et al., 2015).

Figure 3. Final Jomon phase context with abundant marine fauna deposited around multiple hearths and clusters of large ceramic containers at the Hamanaka 2 site in Rebun Island. A perforated sea lion cranium, for instance, is interpreted as evidence of ritual treatment (Hirasawa & Kato, 2019).

2.3.2 The Epi-Jomon Period

The increasing social activities in coastal northern Hokkaido anticipate further cultural integration between Hokkaido and the Sakhalin/Lower Amur sphere, which materializes during the Epi-Jomon horizon (300 BCE–650 CE). The Epi-Jomon Cultures developed in northern Honshu through the interactions between the rice-farming Yayoi and the local Jomon populations (see discussion in Crawford (2011)). Similar to the Okhotsk Cultures, these groups often exhibit a high reliance and degree of adaptation to maritime ecosystems (Okada, 1998; Yamaura, 1998; Horiuchi et al., 2015). However, fewer and smaller settlements are attributed to the Epi-Jomon phase than in previous periods, which lead to the Epi-Jomon groups being regarded as seasonally mobile foragers (cf. Weber et al., 2013; Abe et al., 2016).

Figure 4. Location of the Hamanaka 2 and Kafukai rivermouth sites in Rebun Island, Hokkaido.

Some important regional variability exists between Epi-Jomon populations in Hokkaido, which is explained through different cultural contacts and influences. In southwest Hokkaido, interactions with Honshu populations lead to the adoption of localized rice farming (Crawford, 2011; Weber et al., 2013), and the introduction of the first iron tools, while in northwest Hokkaido, where contacts with Honshu were less frequent, the Epi-Jomon populations maintain the previously seen focus on the exploitation of aquatic resources (Okada, 1998; Yamaura, 1998). This is consistent with the presence of shell midden deposits in coastal sites such as Hamanaka 2 in Rebun Island, where also dog (*Canis domesticus*) breeding for food is practiced during this period (Nishimoto, 2000). In this region, increasing

cultural influence from the north sees the Epi-Jomon population merge with local cultures in Sakhalin¹.

2.3.3 The Susuya Culture in Northern Hokkaido

Following what appears to be a long period of cultural continuity during the Jomon sequence, which peaks during the Middle Jomon period, and then starts to break down and undergo transformation under the effects of cooler climates, the Late Holocene archaeology of Hokkaido is much more dynamic. One of the first examples of this is the cultural “fusion” process which culminates in the emergence of hunter-fisher-gatherer groups that bear ‘Susuya’ type pottery in northern Hokkaido. The Susuya Culture groups (300 BCE–600 CE) appear to exhibit material cultural traits derived from both the Hokkaido Jomon and also Neolithic traditions of Sakhalin Island and the Russian Far East (Ito, 1942; Oba & Ohyi, 1981; Ono & Amano, 2002; Kumaki et al., 2017). Therefore, the Susuya are currently assigned to the Epi-Jomon cultural complex. However, more work and evidence is required to fully understand how the communities on both sides of the strait between Hokkaido and Sakhalin (the La Pérouse Strait) relate to each other and what the characteristics are of the processes that lead to their fusion in the first half of the 1st millennium CE (Ono, 2003).

2.3.4 The Okhotsk Cultures

This period of cultural dynamism extends into the emergence of the Okhotsk Cultures, which appear to have originated in the Lower Amur and Sakhalin Island c. 400–500 CE (Amano, 2003). During its earliest phase c. 400–550 cal CE, the Okhotsk show various culture-material traits present in the Susuya (Ono & Amano, 2008; Amano & Ono, 2011) and the Tokarev cultures (Yamaura, 1998). In fact, given the similarities in material assemblages between these cultures – a circumstance likely owing to their shared origins in Sakhalin and the Amur Basin – the Susuya Culture had been previously included in earlier phases of the

¹ In Yamaura (1998), it is stated that since Okhotsk, who appear in Sakhalin c.4th-5th century CE, sea mammal hunting technology (harpoon heads) is derived from the Epi-Jomon Culture in southern Hokkaido, it appears that the indigenous southern Sakhalin populations were influenced to a great degree by the Epi-Jomon Culture.

Okhotsk cultural sequence (Deryugin, 2008). However, in Hokkaido, the emergence of the Okhotsk Culture has been argued to coincide with the disappearance of the Susuya Culture.

Either way, once established, the Okhotsk Culture comprised coastal communities of marine hunters and foragers that lived in permanent and large unicellular pit-houses (Amano, 2003). They derive their ethnogenetic ancestry from the local final-stage Jomon populations, as well as the Lower Amur and Sakhalin Island communities (Sato et al., 2009). In Rebun Island (Fig. 4), lake pollen evidence indicates that the Okhotsk had a notable impact on the local ecosystem, where a deforestation phase is documented at the time of their arrival ca. 500 cal CE, and persisting until ca. 700 cal CE (Leipe et al., 2018). This provides a potentially accurate *terminus post quem* for the Okhotsk arrival in Hokkaido. After initially appearing in the northwest Hokkaido the Okhotsk expanded out rapidly along the northern and eastern coasts of Hokkaido and the Kuriles in the 7th and 8th centuries CE, in what appears to have been a strong demographic increase (Amano, 2003).

Despite their persistent focus on the exploitation of marine resources, in practice the Okhotsk groups operated in mixed forager economies, where wild and domestic plants were sometimes used (Crawford, 2011; Leipe et al., 2017), along with the keeping of domestic dogs, and in some cases, also pigs (*Sus scrofa inoi*) (Watanobe et al., 2001; Amano, 2003; Hirasawa & Kato, 2019). However, regional variability is observed among the Okhotsk communities – especially between the north and east coasts of Hokkaido, where Okhotsk populations show divergent burial practices and economic packages (in the east, this means absence of pig breeding and focus on sea mammal hunting instead of marine fishing). This has been explained as a result of different maritime adaptations on the northern and eastern coasts, since winter fishing in the latter is complicated by the presence of ice floe (Ono, 2008).

In addition, the Okhotsk functioned as key intermediaries in a long-distance trading network in northeast Asia that allowed them to trade for important resources such as metal tools (Amano, 2003), and possibly domestic plants such as barley (*Hordeum vulgare*) and millet (*Panicum miliare*) (Crawford, 2011; Leipe et al., 2017). Eventually, the result of these interactions may have contributed to the Okhotsk and Satsumon cultures' fusion into the Tobinitai Culture in the 12th or 13th century CE in Eastern Hokkaido (Amano, 1979). This process was a culmination of a gradual demographic decline among both northern and eastern

Hokkaido Okhotsk communities that may be related to a global and regional climatic amelioration after a prolonged cooling trend c. 535–660 cal CE (Koizumi et al., 2003; Büntgen et al., 2016). The cold period may have benefited the marine-adapted Okhotsk communities, given that marine hunting likely had higher rates of return during colder winters when seal populations increased due to better sea ice coverage (Ono, 2008). A warming climate would likely have had an adverse effect on such dynamics.

2.3.5 The Satsumon Culture

At the same time that the Okhotsk Culture occupies the northern coasts, the Satsumon Culture emerges in south and central Hokkaido (650-1250 CE). The Satsumon Culture is native to Hokkaido, but was formed as a result of interactions between the Haji-ware Culture (c.300–1100 CE) and groups that migrated from the Tohoku Region of northern Honshu, over to central parts of lowland Hokkaido (Sawai, 2007; Crawford, 2011; Tashiro, 2017). In contrast to the Okhotsk cultures, the Satsumon represent the first sedentary farming communities in prehistoric Hokkaido, where they inhabited large permanent villages, used iron tools and engaged in trading activities with Okhotsk groups (Onishi, 2003; Crawford, 2011; Weber et al., 2013). While the Satsumon engaged in some localized rice farming, they relied more heavily on wheat (*Triticum*) and millet farming (Crawford, 2011), although hunting and river fishing continued to make a major contribution to their subsistence.

Towards the late 1st millennium and early 2nd millennium, the Satsumon started to expand out into northern Hokkaido, which brought encroachment – and probably a growing degree of rivalry – with the established Okhotsk communities (Amano, 1979; Hudson, 2004). Indeed, Satsumon pioneers eventually ventured out as far as Rebun Island c. 11-12th century, but this occupation appears to have been rather short-lived (Oba & Ohyi, 1981). Moreover, it is unclear how these groups actually subsisted on this small and remote island, as their economic package had been developed in very different ecosystems of south and central Hokkaido.

In Eastern Hokkaido the disappearance of the Okhotsk in the 11th century is related to the formation of the Tobinitai Culture resulting from their apparent fusion with the Satsumon. A comparative study of household artefact typologies suggests that initially the Okhotsk influence dominated the new culture's social landscape. However, a gradual

increase of Satsumon-type artefacts in Tobinitai households indicates that the Satsumon lifestyle and associated cultural traditions eventually prevailed (Onishi, 2003).

Figure 5. A painting known as “Ainu hunters” from an unknown 19th century author. Source: <https://commons.wikimedia.org/w/index.php?curid=10969263>

2.3.6 The Emergence of the Ainu Cultures

Out of this complex fusion of different cultures, both local and external, the (historical) Ainu Cultures (Fig. 5) eventually start to emerge. The Ainu represent the last stage of Hokkaido’s extended hunter-fisher-gatherer cultural sequence, appearing in the 13th century and showing notable regional variation in subsistence and cultural traits, likely due to adaptations to the island’s different ecological niches (Ölschleger, 1999). From Hokkaido, the Ainu spread out to Sakhalin, the Kuriles and Kamchatka, further adapting to different maritime environments in the northern Pacific (Kikuchi, 1999). Prehistoric and modern DNA evidence indicates the Ainu derive their genetic ancestry from the ancient Okhotsk and Jomon populations, while also showing genetic affinities with native populations of Far Eastern Russia (for instance, the Lower Amur region) (Sato et al., 2009).

In Hokkaido, the Ainu economies were characterized by either coastal or island adaptations as part of a mixed forager lifestyle, with salmon and terrestrial wild animals (especially deer) caught in inland loci such as river valleys (Watanabe, 1973). In addition, the Ainu also practiced localized farming on plants such as barnyard millet, and their plant use is reported to have been similar to that of the previous Satsumon Culture populations in Hokkaido (Crawford, 2011). The Ainu also apparently acquired rice through trading with Honshu.

Indeed, the Ainu were engaged in frequent trading activities with mainland Japan, acquiring, for instance, iron utensils and prestige objects in exchange for exotic commodities such as seaweed (Kohara, 1999). These interactions intensified over time and lead to acculturation and local skirmishes with the Japanese, who in the 19th century officially annexed Hokkaido. This resulted in further social marginalization of the native Ainu, whose ancient lifestyle and economy became increasingly difficult to maintain due to intense social, political and military pressure from Japan (Kikuchi, 1999).

3 Pottery Among Late Pleistocene and Holocene Cultures in Northeast Asia and the Japanese Archipelago

This thesis examines changing patterns of use in a central material culture tradition: pottery. Analysis of pottery has typically been used to generate typologies and culture-historical sequences. The aim of this thesis is to employ organic residue analysis in order to reconstruct diversity and change in local foodways and culinary traditions. This approach has not been extensively deployed on the Late Holocene cultures that form the focus of this thesis.

3.1 The Emergence of Pottery in the Late Pleistocene

Pottery use emerged first among Upper Palaeolithic hunter-gatherers in China c. 19,000–20,000 BP (Wu et al., 2012), and slightly later, in the Japanese archipelago (c. 16,000–14,000 BP), and the Amur Basin in Far Eastern Russia (c. 16,000–10,000 BP). While the timing of pottery adoption has been well-covered, the social drivers behind its innovation are still widely debated. In the Japanese archipelago, the Jomon tradition is perhaps the most extensively studied and best understood cultural sequence of hunter-gatherer pottery. The oldest Jomon pottery in particular has been critical in explaining the social and economic factors that lead mobile hunter-gatherer groups to invest in this technology, with pottery being adopted early on in various ecological settings and climatic periods throughout the prehistoric Japanese archipelago (Lucquin et al., 2018).

Organic residue analysis of food remains preserved in cooking containers has further elucidated the function of early Jomon pottery in this region, attributing its uptake and use to the processing of aquatic resources from freshwater and marine food webs (Craig et al., 2013). Similar findings have been reported from the earliest Jomon groups in Hokkaido, where pottery from the Late Pleistocene site of Taisho 3 was found to have been used to exploit aquatic organisms, possibly from anadromous food webs (Lucquin et al., 2018).

This pattern remains consistent throughout the Incipient Jomon tradition in the Late Pleistocene, when pottery is produced in low numbers and small volumes – indicating that its role may have been complementary and related to social feasting activities – and into the Early Holocene Initial Jomon period when the production of ceramics sees a notable increase

and the resource becomes a staple among hunter-gatherer groups (Craig et al., 2013). Indeed, results from the multi-phase site of Torihama in western Honshu present molecular and isotopic evidence corroborating a persistent 9,000-year link between the processing of aquatic organisms and pottery throughout various climatic and environmental conditions (Lucquin et al., 2016a).

A similar pattern of use can also be observed in the earliest pottery appearing in the Lower Amur region in Far Eastern Russia, with recent findings of the Osipovka culture linking pottery adoption to the processing of salmon and freshwater fish c. 16,200–10,200 BP (Shoda et al., 2020). Therefore, this evidence suggests that most of the oldest pottery in Japan and the Lower Amur was linked to a process of economic diversification, with the addition of aquatic resources to an existing Late Pleistocene strategy of game hunting.

3.2 Pottery in the Early Holocene

The ‘aquatic’ use-pattern associated with the earliest East Asian pottery appears to persist into the Holocene period, despite the transcendent environmental changes that define the Pleistocene-Holocene transition, including the access to new kinds of plant and game resources. Evidence of aquatic focus in Early Holocene pottery has been found, for instance, in bulk isotope analyses of ceramic food crust materials at a number of coastal sites in the Lower Amur and Primorye (Far Eastern Russia), where marine organisms were processed in ceramic containers (Kunikita et al., 2013, 2017b). In Sakhalin Island, the early pottery adopted by forager communities in the Early Holocene c. 9350–9100 cal BP is also used to process high-trophic level sea mammal and marine fish resources (Gibbs et al., 2017). Similarly, in the Korean Peninsula, pottery appears c. 8000 BP – several millennia after its introduction in the nearby regions – where it is adopted by coastal hunter-fisher-gatherer communities whose aquatic-focused use strategy closely aligns with that of the Jomon and Far Eastern Neolithic groups (Shoda et al., 2017).

In conclusion, a growing body of evidence has confirmed that the oldest pottery in Northeast Asia was used to process aquatic resources, and that this relationship, at the vast majority of archaeological sites examined, persists well into the Holocene, especially in the Japanese archipelago, the Sakhalin Island and the Lower Amur. However, what remains

unclear, is whether this deep-time cultural pattern persists into the Late Holocene in other regions, such as Hokkaido.

Figure 6. Final Jomon pottery recovered at the study site of Hamanaka 2 (Hirasawa & Kato, 2019).

3.3 Pottery in the Late Holocene Hokkaido: What Was its Function?

Though multiple studies employing organic residue analysis have been conducted to tackle questions concerning the uptake, diffusion and function of the earliest pottery in Late Pleistocene and early Holocene northeast Asia, much less attention has been paid to Late Holocene assemblages, and especially to questions regarding their function and use. Certainly, the use of pottery continued well into the Late Holocene, along with the introduction of new and diversified decorative styles throughout northeast Asia. However, hardly anything is known about the relationship between these later pottery styles, resource processing strategies and local foodways, especially after 2000 BCE.

Below are described the most common pottery styles in the Late Holocene period in northern Hokkaido. To examine how the use of this pottery may have changed, they were all

investigated with organic residue analysis (except for Late Jomon pottery, which could not be recovered at the Hamanaka 2 site). This description is followed by a short summary of the few organic residue and bulk crust isotope studies that have addressed Late Holocene container function in the Japanese archipelago.

3.3.1 Overview of Main Pottery Traditions and Chronology

The Late and Final Jomon-style pottery in northwest Hokkaido (Fig. 6) is often produced locally and marked by typical corded decoration characteristic of the Jomon tradition (cf. Hall et al., 2002). In northern Hokkaido, the Epi-Jomon style pottery distinguishes itself from the Final Jomon pottery with its scarce use of cord-marks, often found imprinted on the body of the vessel (Hirasawa & Kato, 2019). In turn, the Susuya Culture is currently defined by a complex of comb-stamped ceramics in northern Sakhalin (400 cal BCE–600 cal CE) and Epi-Jomon potteries in Hokkaido (1–500 cal CE) (Ono & Amano, 2002; Kumaki et al., 2017).

Pottery produced by the Okhotsk is flat based and has a plain body (Ono, 2008). Decoration is concentrated around the exterior of the rim showing several types of easily distinguishable decorative motifs. The Okhotsk cultural sequence can be divided into four stages in northern Hokkaido, according to the four main styles of pottery (Fig. 7). Given the challenges associated with the dating of Okhotsk Culture assemblages – as most datable materials are heavily exposed to marine reservoir effects (see section 7.4) – most chronological work on the Okhotsk is based on comparative analyses of pottery and seriation (Deryugin, 2008; Ono, 2008).

Figure 7. Examples of the four main types of Okhotsk pottery in northern Hokkaido – recovered at the Hamanaka 2 site in Rebun Island (Hirasawa & Kato, 2019).

The earliest Okhotsk pottery in Sakhalin, the so-called ‘Towada’, or Shitotsumon-style (i.e. Early Okhotsk, c. 5th-6th century in Hokkaido), predates the Okhotsk-style pottery in Hokkaido by c. 100 years (Kumaki et al., 2017). Kokumon type² pottery is considered to coincide with the consolidated stage of the expanding Okhotsk colonization of northern Hokkaido around 6th-7th century. This style is followed, and largely substituted, by the Chinsenmon (line-decoration) type in the 7th and 8th century, coincident with the Late Okhotsk period when the culture began its decline. The Motochi style, c. 9th-10th century, is considered the final stage of the Okhotsk Culture and is strictly related to the northernmost parts of Hokkaido, especially the Rebun and Rishiri islands. In northwest Hokkaido, where the Okhotsk were not assimilated by the Satsumon, the abrupt end to this cultural phase may have been related to a migration of these people up north to Sakhalin (see discussion in Hudson (2004)).

² Kokumon-style pottery corresponds to ‘Enoura B’ type pottery in Russian archaeology, where the Okhotsk are viewed as part of the Far Eastern Russian and Sakhalin cultural sequence of the Palaeometal Age – see discussion in Deryugin (2008).

Figure 8. A refitted ceramic container with Haritsukemon-style decoration recovered from an Okhotsk cultural layer at the Hamanaka 2 site, Rebun Island (Hirasawa & Kato, 2019).

In eastern Hokkaido, the variants of Okhotsk pottery associated with the northern Hokkaido region are not retained beyond the first half of the 7th century, with Haritsukemon-style expanding westward all the way to the present-day area of Esashi and Menashidomari. Haritsukemon style (Fig. 8) combines characteristics of Okhotsk and Satsumon style (Fig. 9) pottery, which serve as the stylistic basis for the Tobinitai ware in the 10th-11th century (Onishi, 2003; Ono, 2008). However, pottery use becomes much less frequent in the 12th century, when contacts between Hokkaido and Honshu become more intense and bring about further technological advancements (cf. Crawford, 2011), such as the wide-spread introduction of metal ware, which would replace ceramic cooking pots during the early Ainu period.

Finally, it is important to note that pottery styles, especially those linked with the Okhotsk Culture, do not shift simultaneously in each settlement and across different regions (Ono, 2008). Rather, pottery styles tend to be replaced gradually, and with some vessels combining traits between the earlier and newer styles. Therefore, direct dating of Okhotsk pottery should consider the context dated, and not rely on typological features alone for establishing the nature and timing of cultural transitions and inter-regional affiliations.

Figure 9. Drawings of Satsumon-style pottery recovered from a pit-house context associated with Late Satsumon occupation at the Kafukai 1 site, Rebun Island (Oba & Ohyi, 1981).

3.3.2 Preliminary Insights into Container Function

In the Japanese archipelago, some studies have examined ceramic food crusts with elemental analyzer (EA-IRMS) to investigate the marine reservoir offset (Miyata et al., 2009, 2016), or to reconstruct container function from nitrogen and carbon isotope evidence (Kunikita, 2016; Kunikita et al., 2017a). Indeed, ahead of the present study, AMS-supported radiocarbon dating of ceramic food crusts, coupled with bulk isotope determinations, offered the best line of evidence to evaluate whether the deep-time pattern with early pottery and the processing of aquatic resources extends to the Late Holocene period in the Japanese archipelago. For instance, in Kunikita (2016), nitrogen and carbon isotopes are measured in charred crusts in Late Holocene pottery in Eastern Hokkaido. In that particular study, the Okhotsk container function was reported to be concentrated on the high-trophic level marine food web, while the Satsumon pottery use was found to have been focused on the exploitation of plant resources.

Moreover, in Horiuchi et al. (2015), molecular and isotopic evidence is investigated using GC-MS and GC-C-IRMS in Final Jomon phase pottery c. 2950–2350 BP in the Aomori Prefecture in northern Honshu, where evidence consistent with the processing of freshwater and marine organisms is found at two coastal Kamegaoka Culture sites. However, at the site of Sugisawa, which is located in a mountainous site c. 45 km inland, a more diverse

use pattern was observed, consistent with the exploitation of terrestrial animal and C₃ plant resources.

In sum, while the majority of the Late Holocene sites and materials investigated pointed to a similar reliance to aquatic resources as with the earliest East Asian pottery, some contexts do suggest a divergent pattern that may be indicative of a shift in pottery use strategies, combined with a potential broadening of container function. These results, however, are derived from studies conducted in only a handful of contexts, and mostly based on bulk isotope analyses that do not factor in molecular evidence, such as lipid biomarkers, when determining the function of pottery. Therefore, the results from this thesis present an opportunity to test and refine these initial indications of possible shifts in Late Holocene container function. In particular, they offer a chance to properly test whether the enduring relationship between aquatic resources and pottery use that extends from the Late Pleistocene into and Early Holocene does – *or does not* – extend beyond the final stages of the Jomon tradition and into the diverse Late Holocene cultures of northern Hokkaido.

4 Micro-Scale Insights into Okhotsk Culture Foodways and Cosmology

Most of the discussion so far has focused on understanding the longer-term and macro-scale patterns of pottery use, both within the wider Northeast Asian setting, and in particular, within the cultural trajectories of northern Hokkaido and Rebun Island. In addition, the rich household-scale archaeological record of Late Holocene Hokkaido also offers rich opportunities to examine the same questions about diversity and change in culinary traditions and pottery use, but at a complementary “micro-scale”. Given their mixed forager economy and coastal settlements marked by large pit-houses, where pottery use was widespread, the Okhotsk Cultures represent an ideal focus for this more localised and contextual kind of research. In particular, the exploitation of a broad range of aquatic and terrestrial resources is directly evidenced in faunal remains and elaborate hunting and fishing equipment. But more importantly, it is clear from other lines of archaeological evidence that these straightforward “economic” activities were also informed by cosmology and belief systems. In these contexts, analysis of culinary traditions also requires a more holistic engagement with concepts of social organisation, animal rituals, spirituality and belief. For this reason, further background information about the religion and society of the Okhotsk Culture is required.

Animals were central to the Okhotsk Culture and many traditions appear to have persisted into the culture of the Ainu, who are the modern indigenous people of Hokkaido. This enables both archaeological, ethnographic and folklore to be used as a means of exploring the significance and meaning of Okhotsk Culture cuisine, as well as the likely cosmological and ideological frameworks that may have structured human-animal interactions. For example, the Ainu exhibit a complex cosmological system centred around animal ritualism that was documented extensively by 19th and early 20th century ethnographers (Akino, 1999; Utagawa, 1999). These descriptions, along with further archaeological evidence from numerous Ainu sites throughout Hokkaido, have demonstrated that some of these animal-related ritual traditions directly originate from 1st millennium CE hunter-gatherer cultures such as the Okhotsk (Yamaura, 1998; Sato, 2019). Although a more

widespread animal mythology permeates both these cultures, the most direct line of continuity appears to be linked to the worship of the bear (Masuda et al., 2001; Sato, 2019).

Figure 10. Ainu bear sacrifice. Japanese painting circa 1870. Source:

<https://commons.wikimedia.org/w/index.php?curid=2270079>

The Ainu *iyomante* ritual (Fig. 10) culminates this process of rearing, sacrifice, consumption and then the existential “sending” of the bear (*Ursus arctos*) spirit back to the other world. This event is commonly viewed as a “cosmic-scale” gift-exchange between humans and deities (Utagawa, 1999; Ohnuki-Tierney, 1999). The ritual is somewhat different across the distinct Ainu Cultures, but it is still celebrated at some form in each of them (Utagawa, 1999).

Like the Ainu, the Okhotsk also appear to have engaged in the rearing of live bear cubs, and these earlier traditions appear to be the origins of later Ainu practices (Sato, 2019). Indeed, many interpretations of the significance of Okhotsk human-animal interactions draw on direct historical analogies with the Ainu (Oba & Ohyi, 1981; Masuda et al., 2001; Watanobe et al., 2001; Hirasawa & Kato, 2019; Sato, 2019). The parallels are often striking – for example, in almost all households of the Okhotsk Culture, bear crania are gathered in the sacred rear part of the house, and placed on a special raised platform shrine (Oba & Ohyi,

1981; Masuda et al., 2001; Sato, 2019) – this may have formed a sacred area where likely only certain members of the group are given access.

More generally, these traditions form part of the larger circumpolar complex of bear ceremonialism, and involve hosting the bear as a divine guest and treating it with great reverence and respect. Indeed, the Okhotsk bear worship – as well as the apparent centrality of human-animal interactions in the culture’s cosmology – is a trait shared by numerous native cultures across the Circumpolar Region from northern Eurasia to Far Eastern Russia (Hallowell, 1926). This behaviour is typical for both terrestrial and marine hunter cultures, and it involves an elaborate process of “inviting” specific animal from their domain (i.e. natural habitat) and bringing them into the household spaces of the human world, to be hosted there as divine guests. The animal may be brought home either killed or alive, and there it is sacrificed and consumed by certain members of the group as part of a carefully planned and greatly anticipated ritual event or series of events (Akino, 1999; Ohnuki-Tierney, 1999).

Most of these ethnographically-documented events are held within the domestic space of household, and involve preparation, cooking and serving of particular ritual meals. They are concluded by ritually “sending” the bones of divine visitor back to the world of the spirits, who then conveys the message that humans are kind and generous hosts, ensuring the release of further animals who then give themselves up to the human hunter, ensuring continued hunting success in the following season (Akino, 1999; Ohnuki-Tierney, 1999), though skulls are often retained in the house to provide further spiritual protection and connection. In some Okhotsk pit-houses, pottery has been found deposited in or next to the ‘bear altars’ at the back of the domestic space, and may have been used for special rituals. However, to date, none of these vessels, or the pots recovered from other more “quotidian” part of the house have, to the best of my knowledge, been subjected to comparative analysis to examine whether they were used in different ways.

Investment in the Okhotsk bear rituals appears to have been significant. At the Okhotsk site of Kafukai 1 in Rebun Island, genetic evidence from bear bone remains indicates that cubs must have been acquired through trading with Epi-Jomon communities in southern Hokkaido. In addition, hunting expeditions were apparently sent to catch adult bear individuals in north-central Hokkaido. These both areas contain genetically different sub-populations of bear, which does not naturally exist on Rebun Island (Masuda et al., 2001).

Clearly, these events involved major organisation, investment and planning, and must have led to community-wide banquets, generating opportunities for both individual status signalling and also group-affirming rituals of sharing and consumption (Hayden, 1995; Ohnuki-Tierney, 1999).

While the bear ceremony has perhaps attracted most attention from ethnographers and archaeologists, it is clear that it is just one element in a wider complex of human-animal cosmological beliefs. For example, many Okhotsk Culture sites also contain abundant evidence for a much wider repertoire of elaborate and deeply respectful animal-related mythology, including animal burials, clusters of animal bones subjected to ritualised treatments, with some clusters found in association with elaborate carved objects, that together may have been utilised as part of specific rituals (Sato, 1994; Yamaura, 1998; Takabatake, 2004; Hirasawa & Kato, 2019).

Another dimension to human-animal cosmological relations is the sanctity of shell middens. Again, there appears to be deep continuity between traditions of the Okhotsk and Ainu Cultures. In the Ainu Culture, shell middens comprise a wide range of marine fauna, such as abalone shells, which are not viewed as discarded food or refuse, but rather sacred areas belonging to the spirits and ancestors (cf. Hirasawa & Kato, 2019). In and around these shell middens, animals, plants, tools and other objects important to the Ainu are deposited – and sent back to the deities – through the celebration of sending rites (Akino, 1999; Utagawa, 1999). This tradition aligns well with the material culture and settlement patterning witnessed at numerous Okhotsk sites, including Hamanaka 2 and Kafukai 1, where shell middens accumulate around the habitats and other social spaces. Plenty of material evidence suggests that rituals were performed around these areas, and for instance at Hamanaka 2 several human and dog burials were documented in shell midden contexts (Hirasawa & Kato, 2019). The Okhotsk may therefore have regarded shell middens similarly, or even passed on this tradition to the Ainu in the early 2nd millennium.

Overall then, the Okhotsk Culture inhabited a rich cosmological world, though the extent to which these beliefs were reflected in household culinary traditions has yet to be properly investigated. What is clear is that their large pit-houses were clearly organised according to a set of cosmological principles, with special sacred areas marked by structured deposits of animal bones. Importantly, such questions can now be explored via application

of new methods such as organic residue analysis of ceramic cooking pots, which can complement other lines of archaeological and zooarchaeological data, and build up a richer understanding of Okhotsk Culture communities and worldviews (see section 5.5).

5 Organic Residue Analysis in Archaeology

By using the term “organic residue analysis” I am referring to a range of analytical organic chemical techniques utilized to identify and characterize the source and nature of amorphous organic remains whose investigation is not possible using more traditional techniques in the field of archaeology (Evershed, 2008). Organic residue analysis is a field within biomolecular archaeology – together with ancient DNA, palaeoproteomics and isotopic studies – which in its turn is part of archaeological sciences, all pertaining to archaeological research. In the present study, the primary source of information used to characterize ancient cuisine and food consumption is derived from lipids in ceramic cooking containers, analyzed using devices such as gas-chromatography mass spectrometry (GC–MS). In the following chapter dedicated to organic residue analysis in archaeology, I will give a brief introduction to the field and its key aspects, as well as discuss it from the perspective of my thesis.

5.1 Molecular Analysis

5.1.1 Lipids

Along with proteins and carbohydrates, lipids are constituents in all living organisms. Lipids have different chemical and physical properties depending on their structure and composition (Fig. 11). Their primary function is the storing of energy, signalling and serving as structural components in cell membranes. Lipids comprise a diverse group of biomolecules composed of carbon, hydrogen, nitrogen, oxygen and phosphorus, and they are defined by low water solubility and high solubility in nonpolar organic solvents (Sargaent et al., 2003; Dunne, 2017):

- Fatty acids
- Acylglycerols
- Hydrocarbons
- Terpenes
- Sterols

- Wax esters
- Phospholipids

Figure 11. Structures of certain common lipids. Figure from E. Fahy. Source: https://commons.wikimedia.org/wiki/File:Common_lipids_lmaps.png

Though lipids are known to survive in a wide range of archaeological materials and artefacts – such as lithic tools, fauna and ecofacts, and soil – ancient pottery has been demonstrated to have a high tendency to preserve lipids extremely long periods of time (Evershed, 2008). Thus, over the course of its use history, a ceramic cooking pot is likely to absorb lipids from multiple sources, deposited in its crystalline matrix – and, depending on its usage, in adherent crust materials – that can be examined to study its past function (Evershed, 1993). By accounting for the structural, chemical and quantitative changes occurring when resources are processed in a cooking pot – as well as their degradation and contamination in the burial environment and post-excavation storing conditions – lipids can provide information about their source origin and the activities they resulted from.

5.1.2 Sampling

Organic residue analysis is an intrusive method where pottery samples are commonly recovered by drilling into the sherd wall and collected in ceramic powder. Therefore, sampling strategy is a critical step in pottery lipid analysis – and when dealing with a finite number of samples such as ancient cooking containers, sample size should be properly adjusted according to the objectives of each study. Sample material should therefore be extracted from the pottery matrix in a manner that preserves characteristic features of the potsherd, such as original shape, form and ornamentation, as well as avoiding sherds where sample extraction eliminates the possibility of performing further research, such as thin section analysis.

At the Okhotsk site of Menashidomari, a total of 27 samples were collected across the floor area of a fully excavated pit-house, where the objective of the sampling strategy was to compile a high-resolution dataset that would allow potential spatial patterns in container function to be tentatively observed. At the Hamanaka 2 and the Kafukai sites – where the sampling strategy in case studies I and III targeted multiple cultural layers – the aim was to recover approximately ten samples from each context. These sample sizes were considered high enough to potentially allow for variation in pottery use to be detected, which is largely based on the variability observed in the quantitative evidence, and the magnitude of the difference one is able to detect. In cases where variability was observed, and, importantly, interpreted to have resulted from cultural processes, tests of statistical significance were used, whenever possible, to confirm this.

Figure 12. A refitted ceramic container with Chinsenmon-style decoration. Samples recovered at the Hamanaka 2 site, Okhotsk Culture layer (Hirasawa & Kato, 2019)

To ensure enough lipids were recovered for all necessary chemical analyses, each sample was drilled at an area of 1–2 cm² to collect approximately 0.5–1 g of ceramic powder, with the top 1–2 mm layer of the sherd discarded to eliminate contaminants derived from the burial environment or handling of the sherd (Heron et al., 1991). In addition, when available, approximately 10–50 mg of adherent interior crust material was collected from each sample.

Several factors were considered when selecting the samples. Firstly, whenever possible, sherds with >5 g weight were selected so as to ensure that the sample would not be completely consumed in the recovery of the sample material. Secondly, rim sherds were prioritized, since they have been demonstrated to have higher lipid preservation rate than sherds from the body or bottom of the vessel (Charters et al., 1993). Also, rim fragments allow for the vessel's rim diameter to be approximated, while diagnostic decorative traits in the final-stage Jomon and Okhotsk Cultures are often concentrated around this part (Fig. 12). This is important since both shape as well as decorative motifs may potentially be related to how the vessel was used. Thirdly, duplicate samples were avoided and thus if multiple sherds appeared to have been derived from the same container, only one was retained.

Finally, whenever possible, samples with visible signs of post-excavation treatment, such as refitting, markings, or washing, were avoided and samples with minimum exposure to modern sources of contaminants were prioritized. Aside from these criteria, the sampling was carried out randomly so as to avoid creating any biases.

5.1.3 Extraction

Before organic residues in ceramic powder or charred surface deposits can be properly analyzed using GC–MS, a chemical extraction technique is first employed to recover the lipids from the accompanying inorganic material. Currently, a ‘one-step’ acid extraction and methylation protocol following solvent treatment (from now on referred to as ‘solvent-acid extraction’) is favoured, where ‘free’ lipids (i.e. lipids soluble in the applied organic solvent mixture) are extracted using an organic solvent system, followed by ‘acid extraction’ where acidified methanol is employed (Papakosta et al., 2015). In the solvent phase, chloroform or dichloromethane are mixed with methanol to produce a solvent that is able to remove, when aided by ultrasonication, most free lipids from the crystalline matrix without further breaking down diagnostic compounds such as triacylglycerides and fatty acyl wax esters.

In the acid step, methanol is acidified using sulphuric acid as a catalyst to produce a more potent treatment that is able to release recalcitrant, or ‘bound’ lipids from the clay matrix – and afterwards recover them using a solvent such as hexane. The acid step also produces fatty acid methyl esters as the sulphuric acid catalyses the esterification of carboxylic acid functional groups required for the isotope measurement of the *n*-alkanoic acids C_{16:0} and C_{18:0} (see section 5.2.4). While the proportion of free and bound lipids changes as a result of the solvent–acid treatment, no significant isotopic fractionation has been detected between free and bound lipids in previous studies (Craig et al., 2004).

To confirm that no notable isotopic fractionation was present in the sample materials, duplicates of three pottery samples with absorbed lipid residues were used, one cohort (group A) was extracted using the sulfuric acid/methanol procedure directly without any prior solvent wash, and the other cohort (group B) was first solvent-washed and then extracted using the same sulfuric acid/methanol treatment. The mean difference between the samples was found to be insignificant; according to this test, the mean difference in C_{16:0} and C_{18:0} between sample groups A and B was 0.67‰, which, given that the measurement error with the GC–C–IRMS device employed was observed at a range of 0.1–0.4‰, does not indicate any meaningful isotopic fractionation.

Therefore, in the present study, the solvent–acid extraction protocol was used to process all of the absorbed and surface lipid samples. In addition, both solvent and acid-extracted lipid samples were trimethylsilylated using bis(trimethylsilyl)trifluoroacetamide (BSTFA) and chlorotrimethylsilane (TMCS, 10% (v/v)) prior to the GC–MS analysis. However, the technique was fully employed only in the analysis of the Hamanaka 2 materials. For the Kafukai and Menashidomari assemblages, a slightly different approach was opted for, given their distinct (post-excavation) taphonomic histories and persistence of contaminants. Indeed, both the Kafukai as well as the Menashidomari samples had been excavated several decades ago and kept in storage ever since. While the overall lipid preservation in these samples was on par with that of the Hamanaka 2 assemblage, my preliminary analysis of the Kafukai and Menashidomari samples confirmed a notable presence of different modern contaminants, such as phthalates and paraffin, in approximately 70% of the samples. Given this circumstance, a solvent-based extraction was required to ensure that ^{13}C from modern components is not introduced to the compound-specific measurements.

However, instead of examining the lipid profiles of both the solvent- and acid-treated lipid extracts, the acid-treated samples were prioritized in GC–MS analysis. To make sure that this approach would not create any notable bias in the sample set, a total of 11 and 12 solvent extracts from Menashidomari and the Kafukai sites, respectively, were analyzed using GC–MS. The comparison of these samples with the solvent- and acid-treated samples confirmed that the solvent extraction protocol minimized contamination in the acid-extracted samples, where the identification of compounds was more efficient due to reduced phthalate peaks that would coelute with ancient molecules at retention times of c. 10–25 min. Otherwise, with the exception of 4,8,12-trimethyltridecanoic acid (TMTD), which was detected in less abundance and less frequently in the acid-treated Menashidomari samples, no diagnostically relevant differences in lipid profiles were found between the two extraction techniques, as no triacylglycerols, alkanols or fatty acyl wax esters were detectable in the solvent-treated extracts analyzed. Therefore, this approach likely resulted in minimal loss of compositional information in this study.

5.1.4 Identification of Compounds and Biomarkers Using GC–MS

The GC–MS combines two different analytical devices, the gas chromatograph and the mass spectrometer, to separate and identify molecules in a sample. The separation of molecules is achieved with gas chromatography that uses a capillary column whose diameter, length, polarity and film thickness can be changed. The column is coated with a microscopic layer of liquid or polymer, known as the ‘stationary phase’, which interacts with the analyzed gaseous compounds, causing them to elute at different times (referred to as the retention time).

The first separating parameter in the gas chromatograph is the temperature of the column – i.e. the adjustable oven temperature that heats up the column through which molecules travel – with the time a molecule takes to pass through the column decreasing as a function of temperature. A carrier gas such as helium is used as the ‘mobile phase’ that ensures the conveyance of molecules through the column, promoting separation between different analytes. Based on their chemical properties, different molecules in a mixture have varying elution times. Once it has passed through the full length of the column, the compound enters the mass spectrometer, where molecules are ionized, fragmented, accelerated and detected separately. In the mass spectrometer, each molecule is broken into ionized fragments, which are detected based on their mass-to-charge (m/z) ratio. In this way, molecules with known fragmentation pattern can be identified in mass spectral data.

5.1.4.1 Diagnostic Biomarkers

Diagnostic biomarkers are compounds associated with specific commodities or food groups. Usually, diagnostic biomarkers are discovered through experimental work where the molecular composition of a given commodity is examined to find unique structural patterns or distributions in its lipid profile. This is a critical aspect of organic residue analysis, as it allows for more resources to be detected in archaeological pottery, improving our understanding of its past function. However, whenever the presence of a certain commodity is established in an archaeological cooking pot, further ecological and culture material evidence needs to be considered before assigning the resource, or activity that produced it, to the context studied (Evershed, 2008).

Indeed, in the case of Late Holocene maritime forager communities in northwest Hokkaido the function of pottery is assumed to have been limited to pre-agricultural

commodities, such as aquatic foods, terrestrial animals and plants (Nishimoto, 1978; Amano, 2003; Naito et al., 2010; Tsutaya et al., 2014; Kunikita, 2016; Kunikita et al., 2017a). These cultures did not have access to technologies and resources that would have allowed them to produce dairy products such as milk or cheese, and therefore these types of commodities were not looked for in the sample set. Instead, indicators of terrestrial-based animals such as ruminant adipose (*Cervus nippon*; Sika deer) and porcine fats, along with plant oils and waxes, and marine oils and other aquatic commodities, were searched for in the sample set.

5.1.4.2 Aquatic Biomarkers

Lipid evidence consistent with the processing of aquatic organisms was frequently recorded in the study materials, a circumstance that aligns well with previously published reports linking Late Pleistocene and Early Holocene pottery with aquatic resources in northeast Asia (Craig et al., 2013; Lucquin et al., 2018). Several aquatic biomarkers have been established recently, allowing the presence of resources from the marine, salmonid and freshwater food webs to be demonstrated in archaeological pottery.

C₁₆-C₂₂ ω-(o-alkylphenyl)alkanoic acids (APAAs; Fig. 13)³ are compounds produced by the heating of C₁₆-C₂₂ unsaturated fatty acids, which are present in abundance in aquatic oils (Hansel et al., 2004; Evershed et al., 2008). Though APAAs may result from thermally produced plant and terrestrial animal commodities, the full suite of APAAs with carbon atoms 16, 18, 20 and 22 in an archaeological cooking container are strictly associated with aquatic, and especially marine, resources. By contrast, a clear domination of C₁₈ APAAs may indicate the presence of plant oils since these are rich in C₁₈ unsaturated fatty acids.

³ C_{xx} signifies the number of carbon atoms in the molecular chain of a given compound.

Figure 13. Partial ion chromatograms of C₁₆-C₂₂ ω-(o-alkylphenyl)alkanoic acids from a test sample – identifiable by characteristic ion fragments (m/z) 105, 262, 290, 318 and 346 are visualized in the figure above and were used to identify the compounds.

Since ω-(o-alkylphenyl)alkanoic acids are only formed through a protracted thermal exposure at >270 °C, and therefore unlikely to have been formed without human action, they are potentially a powerful diagnostic biomarker linking ancient pottery with the processing of aquatic commodities (Craig et al., 2013). In the present study, ω-(o-alkylphenyl)alkanoic acids were often detected together with isoprenoid fatty acids in the same sample. Isoprenoid acids are branched-chain fatty acids, of which phytanic acid (3,7,11,15-tetramethyl hexadecanoic acid), pristanic acid (2,6,10,14-tetramethylpentadecanoic acid) and TMTD (4,8,12-trimethyltridecanoic acid) are commonly detected in archaeological pottery. These compounds are present in high concentrations in marine organisms (Ackman & Hooper, 1968), and therefore, when observed together with APAAs, are associated with aquatic commodities (Hansel et al., 2004; Evershed, 2008; Evershed et al., 2008; Lucquin et al., 2018).

Moreover, phytanic acid has two naturally produced diastereomers that permit the compound to be used to distinguish between marine aquatic and terrestrial animal sources in a lipid sample (Schröder & Vetter, 2011). Phytanic acid is produced by bacteria through the oxidation and biohydrogenation of chlorophyll, that naturally appears in the structural forms 3S,7R,11R,15-phytanic acid (SRR) and 3R,7R,11R,15-phytanic acid (RRR) – often in different concentrations depending on the source. The separation of these two diastereomers

of phytanic acid can be achieved with specific GC–MS conditions – i.e. the use of single ion monitoring (SIM) mode and a polar 60 m long column – allowing for their ratio to be calculated in a sample (Lucquin et al., 2016b). Based on a large data set of prehistoric ceramic samples in the Japanese archipelago, an SRR/RRR ratio of 75,5% is reported to be indicative of marine rather than (ruminant) terrestrial animal derived phytanic acid. Conversely, a diastereomer ratio below 75,5% is considered evidence of the presence of phytanic acid of terrestrial animal origin (Lucquin et al., 2018).

Among other branched-chain fatty acids frequently observed in archaeological pottery are the odd-numbered C_{15:0} br and C_{17:0} br. Experimental work has been carried out with a range of animal-derived products to establish a link between the ratio of C_{17:0} br and C_{18:0}, tentatively allowing terrestrial ruminant and dairy products to be distinguished in ancient pottery (Dudd et al., 1999; Hjulström et al., 2008). However, the ratios of different compounds, such as fatty acids, may be increasingly susceptible to alterations during decomposition and therefore they should commonly be regarded as complementary diagnostic tools in organic residue analysis.

Mono- and polyunsaturated fatty acids are found in high concentrations particularly in marine oils and fats. However, unsaturated fatty acids are known to have a poor preservation in archaeological pottery, given their tendency to break down into smaller components during the use of the pot, as well as in the burial environment (Evershed, 2008). Vicinal dihydroxy fatty acids (DHFAs) form during the oxidative degradation of unsaturated fatty acids, which allow the capturing of the original presence of oil and fat resources in ceramic vessels (Copley et al., 2005). Vicinal dihydroxy fatty acids are frequently found in archaeological pottery together with APAAs and isoprenoids, resulting in the compound to be considered a diagnostic biomarker for degraded unsaturated fatty acids of aquatic origin in archaeological pottery (Evershed et al., 2008). Moreover, another compound resulting from the oxidation of unsaturated fatty acids are short-chain (C₇–C₁₄) α,ω -dicarboxylic acids (diacids, or DAs) (Regert et al., 1998; Evershed et al., 2008). Diacids are often reported in archaeological pottery associated with either aquatic or plant resources, given that they result from the thermal degradation of unsaturated fatty acids (cf. discussion in Papakosta et al., 2019).

5.1.4.3 Other Animal Lipid Biomarkers

Cholesterol is a compound present in animal-derived products, and it is used in organic residue analysis to substantiate the presence of animal fats (Evershed et al., 1990). Cholesterol is present in human skin lipids and could be introduced into the ceramic sample if handled with bare hands. Therefore, the compound should be accompanied by its oxidation products, for instance 3,5-Cholestadien-7-one, that are less likely to have resulted from modern contamination. Compound ratios in such cases, as was pointed out earlier, should not be regarded as strong indicators as, for instance, APAAs or isoprenoids, given that their proportions may vary due to diagenetic alteration in the burial environment (Evershed et al., 1992; Hammann et al., 2018).

Saturated fatty acids have a superior preservation rate in archaeological pottery compared to unsaturated fatty acids. While saturated fatty acids are too ubiquitous to be linked with a specific commodity, their homologue distribution and isotopic composition (to be discussed in 5.2) can be utilised to link them with certain food groups. Indeed, palmitic acid ($C_{16:0}$) tends to dominate in aquatic and plant organisms, whereas the concentration of stearic acid ($C_{18:0}$) is more abundant in terrestrial animal – and especially ruminant – food webs (Copley et al., 2005; Dunne et al., 2016). Likewise, increased concentrations of tetradecanoid acid ($C_{14:0}$) in a sample have been linked with the presence of plant resources (Copley et al., 2001).

Figure 14. Partial ion chromatogram of C_{44} – C_{52} triacylglycerides in a Kokumon-type vessel (Okhotsk Culture) at the Hamanaka 2 site (sample 2016HA-0875). Characteristic ion

fragments (m/z) 439, 467, 495, 523, 551 and 579 are visualized in the figure above and were used to identify the compounds.

That being said, triacylglycerides (TAGs; Fig. 14), i.e. esters of glycerol and three fatty acids, are known to survive in archaeological contexts, where their presence can be indicative of diverse animal-derived terrestrial and aquatic resources, such as milk, adipose fats and oils (Charters et al., 1997; Dudd & Evershed, 1998; Evershed et al., 2002; Šoberl et al., 2008). TAGs are also known to break down into simpler and smaller components through hydrolysis – such as palmitic and stearic acid, depending on their initial configuration – in the ceramic vessel, either during its use or in the burial environment (Regert, 2011). Though other diagnostic compounds are required in the identification of the source of TAGs, their presence is often indicative of abundant animal fats, as well as favourable preservation conditions.

5.1.4.4 Plant Biomarkers

A wide range of biomarkers have been developed to infer plant use in archaeological pottery, though few components can be related with specific plant species. Plant biomarkers include, among others, terpenoids, alkanes, long-chain ($C > 20$) alkanols, long-chain fatty acids, phytosterols, alkylresorcinols and miliacin (Medeiros & Simoneit, 2007; Isaksson et al., 2010; Saul et al., 2012; Brettell et al., 2015; Heron et al., 2016; Hammann & Cramp, 2018; Reber et al., 2018). Though some questions have been raised whether plant lipids can be introduced into ancient pottery in the burial environment, for instance, through fungal growth in the ceramic surface, it would appear that most observations of plant lipids are of archaeological origin – especially if abrasive cleaning is carried out before sample extraction. In the study materials, plant presence was inferred on the basis of miliacin, long-chain alkanols, terpenoids, and phytosterols.

Miliacin (olean-18-en-3 β -ol methyl ether) is a component linked with broomcorn millet (*Panicum miliaceum*), with its presence in prehistoric pottery, including northeast Asia, previously demonstrated in Heron et al. (2016) and Kučera et al. (2019). In the study materials, miliacin was found in one of the Okhotsk containers examined, which is consistent

with previous reports of millet being recorded at a number of Okhotsk Culture sites (cf. Hudson, 2004; Crawford, 2011).

In turn, long-chain alkanols (C_{22} – C_{32}) were the most frequently observed plant-related component in the study materials. While they are linked with diverse plant products, including epicuticular waxes (Charters et al., 1997), it remains unclear what plant product they were sourced from. In turn, dehydroabietic acid (DHA), a diterpenoid derived from coniferous tree resin, was similarly prevalent in the data set. Previously, it has been proposed that DHA is introduced to archaeological pottery from fumes when firewood is used to heat the container during its manufacture or cooking events (Reber et al., 2018), though tree resin may also have been used as sealant.

Phytosterols comprise various sterols produced by plants, such as stigmasterol, β -sitosterol, and campesterol. Analysis of trace sterol components has allowed the presence of plant resources to be established in archaeological pottery (Evershed et al., 1992:203). Phytosterols, however, do not tend to appear in archaeological pottery in abundance, likely due to their poor preservation rate – and in the present study they were only sporadically observed in trace quantities in the Hamanaka 2 assemblage. These findings are not species-specific, and they are therefore rather indicative of general plant use in the cooking pots examined.

5.2 Stable Isotope Analysis

Stable isotope analysis has become a critical part of organic residue analysis of pottery in the past 15-20 years. Analysis of isotopes allows for the biological source of residues to be assessed in ceramic containers by comparing their isotopic composition with that of different known local food groups (Mottram et al., 1999; Craig et al., 2012). This information complements molecular evidence very well, since the methods are largely independent of each other, and the molecular composition of a sample need not be properly identified in order to assess its position in the trophic web. Isotopic evidence can be further explored using Bayesian inference and mixing models, allowing for fractional contributions of multiple food sources to be estimated in a single sample or sample set (Fernandes et al., 2018). This is particularly useful when determining the source of carbon as part of direct ^{14}C -dating of

pottery, to be discussed in section 7.6. In the present study, both compound-specific as well as bulk isotope analyses, whenever the size of the sample materials so permitted, were conducted on absorbed and adherent crust residues. Below, the method is discussed within the context of this study. The section provides a short overview of the technique's principles, as well as discussing the use of reference data, while also considering some of the common issues associated with the northern Hokkaido ecology, and archaeological stable isotope analysis in general.

5.2.1 Carbon

Carbon-13 is a stable isotope of carbon, meaning that its concentration relative to the most abundant isotope of carbon (^{12}C) does not change, with all things equal, over time. ^{13}C is commonly used in paleodietary studies to examine the energy flow between the consumer and a set of food groups (Vogel & van der Merwe, 1977; Tauber, 1981; Yoneda et al., 2004). This is possible since the proportion of carbon-13 in an organism – or some part of it – varies as a function of its diet and metabolic properties (DeNiro & Epstein, 1976; also see section 6.2). Carbon-13 enters the food chain through plants by photosynthesis, of which there are three pathways (C_3 , C_4 and CAM; Crassulacean acid metabolism) that result in different carbon isotope concentrations. In northern Hokkaido, there are plants that commonly use C_3 (barley), as well as C_4 (millet) pathways, and their isotopic signatures have been tested in modern and archaeological samples through experimental work (Yoshida et al., 2013). This work also factors in the enrichment of carbon-13 in oceanic ecosystems compared to terrestrial food webs (excluding C_4 plants, which have very high ^{13}C enrichment). This is because marine plants mainly absorb their carbon from dissolved carbonates, which are enriched in $\delta^{13}\text{C}$ in comparison to atmospheric CO_2 (Smith & Epstein, 1971). All carbon-13 measurements are determined by calculating the $^{13}\text{C}/^{12}\text{C}$ ratio and comparing it to the Vienna PeeDee Belemnite (V-PDB) standard, expressed as $\delta^{13}\text{C}$, i.e. the offset between the $^{13}\text{C}/^{12}\text{C}$ ratio of the sample and the V-PDB standard value.

5.2.2 Nitrogen

Nitrogen has two stable isotopes, ^{14}N and ^{15}N , which, similarly to ^{13}C , can be used in trophic web reconstructions (DeNiro & Epstein, 1981). Nitrogen-15 measurements are defined by calculating the ratio of ^{14}N and ^{15}N and comparing it to N_2 in air, expressed as $\delta^{15}\text{N}$, i.e. the offset between the $^{14}\text{N}/^{15}\text{N}$ ratio of the sample and the standard (air) (Ehleringer & Rundel, 1989). Nitrogen enters food web systems mainly through plants and is particularly abundant in proteinaceous materials, such as animal bone collagen and muscle tissues (Schoeller, 1999). The enrichment of ^{15}N in animal tissues gradually increases with each step up in the food chain (DeNiro & Epstein, 1981).

5.2.3 Bulk Isotope Analysis

In the present study, bulk isotope analysis refers to measured carbon-13 and nitrogen-15 concentrations in surface crust deposits of ceramic cooking vessels (Craig et al., 2013). The preparation or processing of various commodities at times leads to some foodstuffs being exposed to high temperatures, either through direct contact with fire or when exposed to too much heat inside the cooking container, promoting the formation of visible charred residues (Heron & Craig, 2015).

The resulting adherent charred crust materials tend to comprise a range of macronutrients, such as proteins, carbohydrates, and fats and oils, from diverse animal and plant food webs. Therefore, the isotopic composition of a charred crust sample is assumed to reflect the biological source of the organisms that its organic residues are derived from. In organic residue analysis, the isotopic composition of charred crusts are often studied ‘in bulk’ – i.e. without separating the different components that the surface deposits consist of. Prior experimental work on various food sources has established specific ranges for different commodities associated with prehistoric subsistence in the Japanese archipelago (Yoshida et al., 2013). The bulk $\delta^{13}\text{C}$ -value of food crusts is known to vary between plants using the C_3 , C_4 and CAM pathways, as well as between terrestrial and oceanic food chains. By contrast, the $\delta^{15}\text{N}$ -value reflects the trophic level of nitrogen-rich organisms (mainly proteins) which tend to form more complex, i.e. longer, food chains within oceanic systems than terrestrial ones – resulting in comparatively higher trophic levels in marine organisms.

The C/N ratio is another useful dietary indicator, and commonly utilised to distinguish between different food groups in adherent charred materials of archaeological

pottery. The C/N ratio is based on the total amount of carbon atoms divided by the total amount of nitrogen atoms in an organic sample and it is known to vary greatly among different food groups depending on how abundant said organisms are, for instance, in carbon-rich fats, or nitrogen-rich proteins.

In the present thesis, bulk isotope analysis was carried out with elemental analyzer – isotope ratio mass spectrometry (EA–IRMS), which requires c. 2 mg of charred crust material to produce a reliable measurement (provided that carbon is present in meaningful amounts, and that nitrogen is present at a quantity of >1%). In this thesis, the charred crusts adhering in either the interior or exterior walls of the ceramic containers examined were analyzed for bulk isotope composition after they were removed with a sterilized scalpel, weighed and homogenised using a pestle and mortar. Instrument precision associated with the EA–IRMS unit employed was determined to be $\pm 0.23\%$ on repeated measurements. In addition, two standard (modern reindeer and seal) collagen samples were analyzed with each series of archaeological samples to determine the accuracy of the equipment, estimated at $\pm 0.24\%$.

5.2.4 Single-Compound Analysis

Since carbon is abundant in lipids, carbon isotopes can be used to examine the source and composition of lipid residues in archaeological pottery to address questions concerning its past function and age. In the present thesis, single-compound ^{13}C analysis of *n*-alkanoic acids $\text{C}_{16:0}$ and $\text{C}_{18:0}$ was employed to investigate the source of lipids in both absorbed and charred surface residues of pottery. Similarly to other isotope-based paleodietary studies, the variations in ^{13}C concentrations in the lipid-containing tissues of end-members are assumed to be reflective of their diet, their metabolism and associated food web (Dudd et al., 1999). In addition, the offset between $\delta^{13}\text{C}_{16:0}$ and $\delta^{13}\text{C}_{18:0}$ values – expressed as $\Delta^{13}\text{C}$, and calculated from $\delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$ – is known to be specific to certain food groups (Copley et al., 2003).

Single-compound, or compound-specific, analyses of palmitic and stearic acids using gas chromatography combustion isotope ratio mass spectrometry (GC–C–IRMS) have become an established method to further characterize the function of ceramic containers in archaeological organic residue analysis. The GC–C–IRMS device allows for the separation of specific compounds in a (lipid) sample for the purposes of measuring their isotopic composition (Mottram et al., 1999). Unlike in bulk isotope analysis, the determination of

fatty acid isotopic composition in ancient pottery requires the extraction, methylation and separation of lipids, which, in the present study, were conducted in conjunction with the molecular analyses by GC–MS. The prior analysis by GC–MS serves several purposes: to identify the components examined, the screening for potential contamination in the sample material, and the quantification of the FAMES in order to properly estimate the concentration of the targeted compounds in the GC-C-IRMS analysis. In this thesis, each sample was analyzed twice and the mean of both measurements was taken as the value that represents the sample's isotopic composition. The instrument precision throughout the analyses ranged between 0.1–0.4‰, as reflected by the mean difference of duplicate measurements.

5.2.5 Food Sources and the Local Food Web Structure

Trophic web reconstructions relying on isotopic evidence require information about the regional isotopic ecology and food chain structure (Richards & Hedges, 1999). This information is often derived from regional baseline data consisting of a number of isotopic measurements across several food groups, using either ancient or modern samples. In the present study, the isotopic measurements were compared with isotope data sets reported in Yoneda et al. (2004), Yoshida et al. (2013), Craig et al. (2013), Lucquin et al. (2016a) and Lucquin et al. (2018). In addition, isotopic evidence from ancient bone collagen measurements at Kafukai 1 – one of the study sites – was employed to approximate an isotopic signature for a number of terrestrial animal species. These measurements had to be transformed into equivalent lipid isotope ranges, which, according to experimental work conducted in Fernandes et al. (2015:329), requires an adjustment of -8‰ when converting (terrestrial animal) collagen isotope values to lipid isotope values (between aquatic collagen and lipid isotope values the offset recommended was -7‰).

The local subsistence in northern Hokkaido is heavily skewed towards the consumption of marine resources (Naito et al., 2010; Tsutaya et al. 2014; Kunikita et al., 2017a). According to analysis of marine fauna at several Okhotsk and final-stage Jomon settlements in the region, a diverse range of marine species were consumed in the Late Holocene period (Nishimoto, 1978; Oba & Ohyi, 1981; Sato, 1994; Hirasawa & Kato, 2019). This includes local species such as sea urchin (*genus Echinoidea*), shellfish (*ex. Sakhalin surf clam, Pseudocardian sachalinensis*) and marine fish, including the Pacific cod (*Gadus*

macrocephalus) and herring (*Clupea pallasii*), as well as sea mammals such as the Japanese sea lion and the fur seal, and also whales (*Globicephala sp*) and sharks (*Selachimorpha*). Since molecular evidence cannot distinguish between these different marine species with distinct isotopic signatures, a range between -25.5 and -20‰ was established to reflect the entire marine food web in northern Hokkaido (using $1-\sigma$, i.e. 68.2% confidence interval).

This range partly overlaps with salmonid species (*genus Oncorhynchus*), which were an important food resource for all Late Holocene cultures in northwest Hokkaido and was likely also consumed by the Okhotsk and final-stage Jomon communities at the study sites. Based on modern reference data, anadromous organisms can be expected to have $\delta^{13}\text{C}$ values between -27.5 and -23.5‰ (using $1-\sigma$ confidence interval) in the study region. In turn, there is little faunal evidence to suggest that freshwater resources were exploited by Late Holocene cultures in the study region, though they likely had a complementary role in the subsistence. Therefore, freshwater ranges had to be established based on data available from southern Hokkaido and Honshu (Yoneda et al., 2004; Lucquin et al., 2016a, 2018).

According to the material evidence at sites such as Hamanaka 2, Kafukai and Menashidomari, the Late Holocene cultures also exploited a range of terrestrial animal resources, including dog, pig/wild boar, bear and the Sika deer (Nishimoto, 1978; Oba & Ohyi, 1981; Naito et al., 2010; Hirasawa & Kato, 2019). While dog, at least in the Okhotsk period, appears to have an isotopic signature similar to that of a marine mammalian piscivore – most likely due to human feeding practices (Tsutaya et al., 2014) – and therefore indistinguishable (isotopically) from the marine food web, the contribution from deer and porcine resources were also examined in this thesis.

Finally, contribution from the plant food web was considered, since plant use is well documented throughout the Late Holocene (Crawford, 2011; Leipe et al., 2017), including the use of barley and millet, as well as several wild species. In addition, chestnuts (*genus Castanea*) have been widely exploited across the prehistoric Japanese archipelago, and, in fact, their role in the adoption of pottery had been previously suggested (cf. discussion and references in Lucquin et al., 2016a).

5.3 Preservation and Degradation of Ancient Organic Remains

Organic remains in archaeological pottery become altered during the use of the container and after it is discarded (Evershed, 1993). Therefore, ancient lipid profiles consist of various degraded residues of compounds from foodstuffs that were previously processed in archaeological pottery. It is assumed that the lipids remaining in the pottery matrices result from the last few processing events prior to the container being discarded, but this assumption should rather be regarded as a starting point when interpreting the lipid profile of a new sample.

Importantly, both anthropogenic and taphonomic processes need to be accounted for when interpreting molecular (and isotopic) data (Evershed, 2008). Indeed, a wide range of factors affect the preservation of archaeological lipids, such as the time of burial, soil type, and the potential diagenetic processes such as bioturbation, leeching, weathering and microbial activity, that should all be considered when organic residue analysis is conducted (Lyman, 2002; Grupe & Harbeck, 2015). In addition, these factors may affect different compounds and classes of lipids differently, potentially promoting the survival of one class of lipids over another (Dudd et al., 1999).

In the Japanese archipelago, organic materials are known to preserve poorly in the burial environment due to the region's highly acidic soil. This may particularly affect osseous assemblages, as well as faunal and archaeobotanical materials. It would seem, however, that organic residues in pottery are better protected from the effects of acidic soil, since archaeological pottery in the region appears to have a rather favorable preservation of lipids, even in very old contexts (Craig et al., 2013; Yoshida et al., 2013; Lucquin et al., 2018). It is also possible that soil acidity reduces microbial activity in the burial environment, thus ensuring a better preservation for lipids in pottery matrices.

In the present thesis, no notable issues with preservation were detected, and the pottery residues showed a high lipid preservation rate, given that >95% of the samples analyzed had lipid concentrations above the conventional 5 $\mu\text{g/g}^{-1}$ threshold. This may be a combination of several factors, including the rather young age of the cultures studied (between 2750 and 1000 years BP), a temperate climate zone that may reduce microbial activity through cooler soil temperatures, as well as favorable burial conditions in clayish, oxygen-free soil types at shell midden-type sites.

However, some disparities were observed between the Hamanaka 2, and the Kafukai and Menashidomari site assemblages. Absorbed lipids proved to have been better preserved than lipids in the charred crusts, which is likely due to the fact that the clay matrix protects absorbed lipids better in the burial environment. It is also noteworthy to point out that while the ceramic samples collected at the Menashidomari and Kafukai sites had been excavated, and subsequently stored, approximately 40–50 years ago, the Hamanaka 2 materials were recovered only a few years ago – with most of them collected directly from their archaeological context. Though no drastic differences were detected in the lipid concentrations between these three assemblages, the preservation rate of compounds and biomarkers did highlight divergent taphonomic life histories. Indeed, the ceramic containers derived from the Hamanaka 2 site had notably more plant biomarkers compared to the Kafukai and Menashidomari samples, which is likely related to a survival bias previously reported with plant lipids that appear to be underrepresented in archaeological pottery (Hammann & Cramp, 2018). Plants, however, were not considered a primary component in the Hamanaka 2 samples, as indicated by the isotopic measurements consistent with the processing of aquatic and terrestrial animal products. Therefore, the potential underrepresentation of plant lipids in the Kafukai and Menashidomari samples is unlikely to have seriously obscured the inference of the primary container function at these sites.

5.4 Contamination

Similar to processes relating to the degradation and preservation of ancient lipids in pottery, contamination should be considered in archaeological lipid residue analysis. Contamination is understood as the introduction of modern compounds and residues into an ancient sample, where they may either be confused with or mask ancient molecules. This is a particularly serious issue in radiocarbon dating, where carbon not pertinent to the material studied may cause the ^{14}C -age of a sample to deviate considerably from its true age (see section 7.3). A similar issue may occur with stable isotope analysis, where carbon or nitrogen introduced from modern sources is likely to alter the isotopic signature of an ancient sample.

Laboratory contaminants are another potential source of contamination in archaeological pottery lipid samples, for instance through the introduction of phthalates from plastic gloves, or detergent used to clean the glassware before use. However, the composition

of laboratory contaminants most often deviates distinctively from those of typical authentic food lipid residues, and therefore their impact on organic residue analysis is often fairly limited.

In order to minimize contamination in the current sample set, abrasive cleaning was carried out before the extraction of sample material. This way some degree of contamination could be avoided by discarding the part of the sherd most likely to have been in direct contact with modern sources of contamination, such as human skin (squalene, skin creams etc.), plastics and adhesives. In addition, plastic gloves were used at all times when handling the samples to avoid further contamination. Also, all glassware, scalpel- and drill heads were washed with dichloromethane to remove any potential exogenous compounds.

Moreover, the sources of contamination were further managed in this thesis by analyzing each sample with GC–MS before isotopic composition was measured using EA–IRMS or GC–C–IRMS, allowing samples with high level of contamination to be omitted from these analyses. At Kafukai, four samples in total were omitted due to high levels of contamination, combined with the lack of appreciable amounts of ancient components. Indeed, some contamination from plasticizers and paraffins was detectable in the Kafukai and Menashidomari samples – a circumstance that was managed with the lipid extraction method.

5.5 Approaches to Reconstructing Cuisine and Resource Sharing Through Pottery Lipid Analysis

Given that pottery is a cultural device and an implement often used in the preparation and storing of foods, it holds a special value for researchers concerned with the study of prehistoric cuisine. As was mentioned previously, cuisine comprises a specific set of choices steered by subsistence, ecological, cosmological and social factors. Indeed, what to eat and how to prepare one's food is a conscious choice that appears in different styles of cooking practices, choices of foods, preparation methods, food procurement strategies, rules for consumption, and even flavor principles (Farb and Armelagos 1980; Mintz 1996). Therefore, cuisine is an inseparable part of cultural and social identity, and one of the key concepts

considered in explaining pottery uptake among Late Glacial forager groups in East Asia (Lucquin et al., 2016a).

From the perspective of traditional archaeology, most material assemblages at an archaeological site are somehow related to cuisine and foodways, including structures such as the household where food is consumed and prepared, as well as middens and refuse pits where food remains are discarded, and, also storage pits where food is kept. Certain features in an archaeological site such as hearths, cooking pits and animal bone clusters also allow for particular cuisine-related activity areas to be established by associating them with food processing or cooking. Moreover, most artefacts other than pottery are also linked with cuisine, including lithic materials, animal bone artefacts, and fauna (Isaksson, 2009).

While this traditional information is essential for archaeologists looking to understand ancient foodways, organic residue analysis of pottery – and other food-related artefacts such as lithics – has become a very powerful method in the reconstruction of prehistoric cuisine. Indeed, pottery residue analysis allows for the recovery and characterization of amorphous non-cultural materials such as lipids that are otherwise impossible to get to. These evidence amount to a molecular signal – which could be viewed as a culture-technological diagnostic marker or package, similarly to a tool kit or pottery-making tradition – that can potentially be used to distinguish cultural groups (Isaksson et al., 2019). Therefore, the reconstruction of pottery use helps archaeologists to further understand prehistoric foodways and other processes, such as cosmology, cooperation and subsistence, that relate to it.

Molecular evidence recovered from pottery is often derived from multiple ingredients that add considerable chemical complexity and challenge to the characterization of pottery use. In addition, pottery is a critical prehistoric technology whose applications extend well beyond food-making and consumption – including the processing of blubber (Miyata et al., 2009) and the burning of animal and plant oils used as illuminants (Copley et al., 2005). Therefore, pottery residue analysis needs to be coupled with contextual data for it to properly serve as a tool in the characterization of ancient foodways. Indeed, interpreting pottery residues through a context-specific approach where both cultural and subsistence, as well as ecological – such as resource conditions and food availability – are considered, is likely to yield the most comprehensive picture of ancient foodways.

For these questions to be assessed properly, pottery use should be investigated through a sampling strategy that targets specific archaeological contexts where availability of material information concerning foodways and the social processes it relates to are maximized. In this way, the related material assemblage is likely to further contextualize the molecular findings in pottery and allow for an artefact biography to be established for the container – or even for the molecules in its structure. With this approach, the concept of cuisine can be further developed and used to investigate specific activities, such as human-animal interactions, division of labor and cooperation, as well as food sharing between individuals within a social space, such as household (Pecci et al., 2018).

Figure 15. Reconstruction of household activity zones based on artefact type and distribution data. Picture adapted from Takeda (1996).

In the present thesis, the Okhotsk Culture was identified as a viable case study in the investigation of ancient cuisine and the social contexts that it was practiced in. The potential for Okhotsk pottery and other related assemblages in the reconstruction of cuisine is especially apparent at sites such as Hamanaka 2 (Fig. 3), Menashidomari and Tokoro 15 (Fig. 15), where an abundance of a wide range of materials across different social spaces and activity zones can help contextualize molecular findings in pottery. In addition, the Okhotsk Cultures are particularly known for their complex animal cosmology that gives a rich context

in which to explore patterns of pottery use and food consumption, especially inside the household, where some of the animal-related activities appear to have taken place.

6 Food Source Reconstruction Using Bayesian Mixing Models

6.1 Bayesian Modelling

Statistical modelling has become an increasingly important tool for archaeological scientists, whose work is often conducted as part of a larger group of interdisciplinary researchers and broader study objectives. Indeed, archaeological assemblages comprise a wide range of artefact and ecofact categories that yield paleoecological and dietary information specific to human diet, cultural activities and food webs. While this evidence is useful to both archaeologists as well as other researchers in the fields of life and earth sciences, its full application as part of scientific research often requires interdisciplinary collaboration and use of statistical techniques.

Bayesian inference is a method in the field of statistics where Bayes' theorem is used to update the probability for a theory or hypothesis when more evidence becomes available (Bayes, 1763; Lee, 2012). In probability theory, Bayes' theorem describes the likelihood of an event, given prior knowledge of conditions that may be related to the event. The approach allows for the incorporation of user-defined prior distributions of model parameters. The posterior probability stems from a consequence of two precedents: a prior probability and the “likelihood”, which are variables based on observed data and the statistical model. Unknown parameters can either be approximated or derived randomly⁴.

The posterior probability is computed according to Bayes' theorem, where A and B are events, with $P(A | B)$ representing the probability of A given B, $P(B | A)$ representing the probability of B given A, and $P(A)$ and $P(B)$ being independent probabilities of A and B:

⁴ Instead of using potentially uninformed or random values, some software in Bayesian statistics provide an option to allow unknown parameters to be defined by the algorithm over the course of the simulation (for instance, see Drummond et al., 2012).

$$P(A | B) = \frac{P(B | A) \cdot P(A)}{P(B)}$$

This approach has a wide range of applications in statistical modelling, where a set of assumptions about variables of varying degrees of complexity is investigated with sample data. Statistical models can be tested with automated randomized algorithms, such as the Markov chain Monte Carlo that sample from a probability distribution (Gilks, 2005). This allows models to be tested various times with different sets of values and properties assigned to variables during each step of the chain, improving our understanding of the model as more steps are added.

6.2 Reconstruction of Prehistoric Pottery Use From Organic Residue Isotope Signatures Using Bayesian Inference

Since organic residues in pottery matrices are often mixtures of different food groups, a reconstructed isotopic and molecular signal for a cooking container tends to represent the sum of multiple source fractions (Fernandes et al., 2018). This tends to obscure the reconstruction of the vessel's function, which is critical, for instance, in direct ^{14}C dating of pottery (see section 7.6). Mixing models provide a solution to this by allowing for the quantification of source contributions to a mixture (Phillips et al., 2005). Indeed, statistical models can be used to process dietary proxy signals from macronutrients to reconstruct unknown mixing contributions of certain food groups in consumers (Böhning et al., 2007).

As was discussed in chapter 5, the isotopic composition of organic residues in pottery can be measured for estimating their source origin among different food groups. This approach requires knowledge of the region's isotopic ecology and food web structure. Such information tends to be available in baseline data sets that consist of a series of isotopic determinations of tissue and bone samples across various food groups in a specific region (Richards & Hedges, 1999). These baseline data sets are often compiled from one or several modern and ancient trophic web studies (Etu-Sihvola et al., 2019). For instance, ^{13}C in palmitic ($\delta^{13}\text{C}_{16:0}$) and stearic acids ($\delta^{13}\text{C}_{18:0}$) from tissue or adipose fat lipids are specific to an organism or food group, with numerous available regional data sets characterizing their

concentration across terrestrial and aquatic food webs (Dudd & Evershed, 1998; Craig et al., 2011; Lucquin et al., 2018).

However, the quantification of food group fractions on the basis of isotopic data in archaeological pottery involves a number of sources of uncertainty that should be managed accordingly (Fernandes et al., 2014, 2018). Paleodietary studies are based on the notion that ‘you are what you eat’, meaning that the consumption from different food groups is assumed to produce a dietary signal proportional to the fraction of different foods consumed (DeNiro & Epstein, 1976). However, both terrestrial and aquatic food webs are complex systems, where the diet and isotopic signature of a consumer may deviate significantly from the food group it is primarily associated with (Schoeninger et al., 1983).

Indeed, distinct food fractions tend to produce isotopic signatures disproportionately to their occurrence in the diet. In addition, an offset in the diet-to-tissue signal, where isotopic fractionation takes place at different stages of metabolic processes, may also contribute to further uncertainty in food web studies (Katzenberg & Harrison, 1997; Passey et al., 2005; Warinner & Tuross, 2010; Fernandes et al., 2014). Knowledge of food group-specific concentrations and dietary routing should therefore be included in a mixing model, where the associated uncertainties are properly estimated.

Bayesian inference provides a convenient approach to addressing these issues within a probabilistic framework. FRUITS (Food Reconstruction Using Isotopic Transferred Signals) software employs a Bayesian mixing model that approximates the contribution of different food groups in a consumer on the basis of isotopic signatures in tissue and other materials (Fernandes et al., 2014). It allows multiple sources of uncertainty, along with prior expert information, to be factored in a model that employs an iterative MCMC-based algorithm. Using FRUITS, isotopic (or elemental) data measured from the consumer are compared against a set of baseline data that consist of sources expected to represent a simplification of the food web system modeled. A sufficiently efficient model is often achieved with a limited number of sources (Passey et al., 2005). Therefore, to avoid creating an overly complex food web model, where too many interpretable results may obscure dietary inference, multiple species within a trophic segment should be merged into one source.

To properly manage uncertainty, FRUITS accounts for a potential diet-to-tissue offset, while also adjusting for the contribution of concentration. While these parameters are recognized in most mixing models, FRUITS also allows for the weight of different food fractions to be factored in. In the present study, the concentrations of palmitic and stearic acid specific to each food group were modeled using data from USDA Food Composition Databases (<https://ndb.nal.usda.gov/ndb/>), as previously reported in Lucquin et al. (2018). However, further experimental work should be conducted to investigate and quantify the potential offset stemming from the weight of different food fractions.

Figure 16. Results of simulated contributions of five primary food sources in a lipid sample extracted from an Okhotsk container at the Hamanaka 2 site (2016HA-0881), according to a concentration-dependent mixing model (using FRUITS 3.0 beta; Fernandes et al., 2014). Estimated probability of contribution visualized using a box-plot chart (A), and plotted summed probability density functions of the five food groups (B). Reference values derived from Lucquin et al. (2018).

In addition, archaeological and molecular prior information can be incorporated into the mixing model with FRUITS (Fig. 16). This approach has been adopted previously in

Lucquin et al. (2018), where priors were used to reflect the molecular data in the sample set. In this model, if certain molecular criteria were met a prior was introduced assigning a sample a higher contribution within a specific food group by discriminating the contribution from others. For instance, if phytanic acid was detected in the samples, then the highest contribution was simulated from either ruminant or aquatic sources. Also, in samples with an SRR diastereomer ratio >75.5% or C₂₀ APAAs detected, then aquatic components were set to have the highest contribution.

Though this approach can potentially result in a more realistic estimation of a sample's lipid contribution, it may also enhance the effects of survivorship bias in some samples or sample sets. For instance, in the present study, aquatic biomarkers in lipids were found more frequently among the Hamanaka 2 ceramic samples compared to the sample sets of the Kafukai and the Menashidomari sites. This is likely related to post-depositional and post-excavation taphonomic loss (i.e. the elimination of compounds resulting from modern contamination, and exposure to plasticizers and adhesives in storing conditions for several decades) rather than ancient cooking practices. If the source of lipids were modelled in these samples using molecular priors, the contribution of aquatic lipids in the Kafukai and Menashidomari samples would be underestimated relative to the Hamanaka 2 materials. Moreover, a notable survivorship bias has been recognized in organic residue analysis such as plant residues that tend to have a lower preservation rate and proportionately lower visibility relative to their contribution to lipid profiles in archaeological pottery (cf. Colonese et al., 2017). Therefore, more experimental work should be conducted to better approximate what are the rates of survivorship among different lipid biomarkers before applying them as priors in mixing models.

That being said, GC–MS-based molecular evidence from pottery does not easily translate to quantifiable proxy-data, and it is not well-suited for observing fractional lipid source contributions. In addition, molecular data is not optimal for visualizing results from multiple samples. In turn, Bayesian mixing modelling provides a way to further assess the source of the commodities observed in archaeological cooking pots, and therefore the approach should be regarded as an important complementary technique in organic residue analysis. With proper model construction to account for various sources of uncertainty and the incorporation of accurate baseline data, and perhaps the inclusion of molecular priors if

the data set is consistent and their usefulness as quantifiable food source proxies can be demonstrated, mixing models such as FRUITS can further elucidate the function of archaeological cooking containers.

7 Radiocarbon Dating in Archaeology

7.1 The Principles of Radiocarbon Dating

Estimating the age and order of past events and processes is a critical part of archaeological research. Before the adoption of radiocarbon dating temporal inference relied on relative dating methods such as seriation, where ancient assemblages were placed in chronological order using contextual and typological evidence. Radiocarbon dating, similarly to other absolute dating techniques such as thermoluminescence (Mejdahl, 1979) and potassium-argon dating (Aitken, 2014), allows for the age of archaeological materials to be measured directly and expressed using a numerical value and an estimate of statistical uncertainty. The resulting age determination is independent of the sample's contextual and typological affiliations. Since its adoption, ^{14}C -dating has become increasingly accurate and cost-effective due to continuous efforts to improve instrumentation and extraction protocols, and the technique has become largely accessible to most researchers in the field of archaeology. This has allowed the construction of high-resolution chronologies with regional sample sets consisting of hundreds or even thousands of archaeological dates (Gajewski et al., 2011; Williams, 2012), leading to more accurate reconstruction of past social and cultural processes (Tallavaara et al., 2010; Kelly et al., 2013).

Figure 17. Visual representation describing the interaction of ^{14}N and neutrons in the Earth's atmosphere. The neutrons in this reaction are produced by cosmic radiation. Adapted from <https://commons.wikimedia.org/w/index.php?curid=14849529>.

In radiocarbon dating the proportion of radiogenic ^{14}C relative to the more abundant and stable ^{12}C isotope of carbon is measured in a sample (Libby, 1946, 1955). This is an inverse relationship, meaning that the higher the proportion of ^{14}C the younger the sample. All naturally occurring ^{14}C forms in the upper atmosphere through the interaction of cosmic radiation and ^{14}N (Fig. 17). With time, however, the process is reversed and the unstable properties of the ^{14}C isotope will see it eventually turn back into ^{14}N . This decay rate is gradual and, in principle, predictable with a half-life of 5730 ± 40 (Godwin, 1962). The ^{14}C isotope can therefore be used to approximate the moment in which the dated organism or material ceased its exchange of carbon with its respective carbon source. For instance, when dating an ancient fish bone, the resulting age estimate would correspond to the moment when the fish died and ceased to metabolize oceanic carbon. However, the low concentration of ^{14}C in the atmosphere requires (i.e. 1–1.5 atoms per 10^{12} atoms of carbon) highly sensitive instrumentation – such as AMS – to be used for its precise measurement in organic materials. This imposes a constraint with respect to how far back materials can be dated, with the instrumental measurement error increasing as a function of the specimen's antiquity. Currently, 50,000 years is considered as the upper limit for radiocarbon dating, after which the amount of ^{14}C can no longer be reliably measured (Reimer et al., 2013).

The age determination is initially provided in 'radiocarbon years'. This is a numerical value that simply reflects the measured sample's remaining ^{14}C concentration relative to what it was when it was still actively exchanging carbon. The value is accompanied by an instrumental error that represents the accuracy estimated on repeated measurements, and expressed as ' $\pm$ ' years of a standard deviation ($1-\sigma$). Therefore, a radiocarbon date is expressed as 'years before present' (BP), with the year 1950 CE elected as the date from which radiocarbon dates are counted back from (Hedges et al. 1989)⁵.

7.2 Calibration

Since the ratio of ^{14}C and ^{12}C in the atmosphere varies over time, the measurement of ^{14}C remaining in a dated sample does not reflect its 'true age' in calendar years (de Vries, 1958a). These fluctuations result from natural processes such as solar activity and changes

⁵ A BP age can also post-date 1950 CE, depending on the outcome of the dating.

in earth's magnetic field, as well as human activities such as the release of fossil fuels and atmospheric nuclear testing (de Vries, 1958b). Therefore, when computing the true age of a radiocarbon date a calibration operator needs to be introduced that accounts for these changes and uses information of past $^{14}\text{C}/^{12}\text{C}$ fluctuations to translate radiocarbon years into calendric years (van der Plicht, 1993). Perhaps the most widely accepted approach for calibrating radiocarbon years is the absolutely dated IntCal13 calibration curve (Fig. 18) that uses tree rings, speleothems, plant macrofossils, corals and foraminifera of the past 50,000 years to track the annual variability in atmospheric ^{14}C concentration (Reimer et al., 2013).

Figure 18. The complete IntCal13 calibration curve. Source:

<https://commons.wikimedia.org/w/index.php?curid=33571887> (M. Christie)

Such data sets can be used as part of a probabilistic model to establish a series of outcomes for a sample's age when its remaining ^{14}C contents are compared with historical

levels of ^{14}C in the atmosphere. Since some degree of uncertainty is involved in both the measurement of the sample's isotopic composition, as well as in the recording of past variability in atmospheric radiocarbon, virtually any calibration operation will have a non-linear outcome (Weninger et al, 2011) that needs to be expressed – instead of a single value – using a probability density function. Statistical tools such as OxCal (Bronk Ramsey, 2017) and Calib (Stuiver et al., 2020) provide a Bayesian framework for calibrating radiocarbon dates and managing dating uncertainty with user-defined parameters and priors (see sections 6.1 and 6.2), as well as the option to select from different calibration curves and visualize results using different confidence intervals.

A further source of dating uncertainty stems from periodically occurring violent fluctuations in atmospheric ^{14}C concentrations that lead to organisms absorbing ^{14}C at rates that deviate from the long-term average (Bartlein et al., 1995). Sudden spikes and drops in atmospheric radiocarbon levels are likely to produce either peaks or plateaus in the calibration curve, which complicate chronological inference by increasing the number of corresponding calendric dates for a radiocarbon age (Bamforth & Grund, 2012). These potential outcomes are often spread out over a prolonged period of time. Two occurrences of this process coincide at critical times in the northern Hokkaido cultural sequence, with the calibration curve experiencing a trough-shape anomaly, followed by a peak, in the final-stage Jomon period in 335–215 cal BCE, and later in synchrony with the emergence of the Okhotsk Cultures in 440–525 cal CE (Fig. 19).

Figure 19. Posterior probability distribution of a calibrated radiocarbon date (Poz-102853) from the Hamanaka 2 site (Layer V – Towada phase). The multimodal distribution is caused by a plateauing calibration curve that illustrates the complications in chronological inference of terrestrial samples between c. 420 and 570 cal CE. Calibration with OxCal v.4.3.2 (Bronk Ramsey, 2017).

7.3 Radiocarbon Contaminants and the Suess Effect

Besides measurement error and variance in atmospheric ^{14}C concentrations there are other factors that add uncertainty to radiocarbon dating. Contamination is a persistent issue in radiocarbon dating that needs to be managed in a sample before its age is measured (Alon et al., 2002; Berstan et al., 2008). Given that the age measurement is a function of the specimen's remaining ^{14}C contents, the introduction of exogenous carbon with distinct levels of radiocarbon is likely to cause the measured age to notably deviate from the sample's 'true age'. Therefore, samples are often pretreated prior to dating, allowing the most common sources of contamination to be removed (Yizhaq et al., 2005; Brock et al., 2010). Natural sources of contamination are agents that alter the chemical composition of an ancient organic

sample in the burial environment, for instance root intrusions, which expose the specimen to foreign carbon with a distinct ^{14}C profile. Indeed, the introduction of organic compounds – such as humic and fulvic acids with a modern carbon signature – into the sample material may have a notable effect on its age determination and cause it to appear younger when dated (Olson & Broecker, 1958). Therefore, washing samples with hydrochloric acid and sodium hydroxide, as well as the picking of visible roots and other modern organic remains have been found to effectively remove a number of natural contaminants prior to dating (Brock et al., 2010).

In turn, artificial contamination occurs when exogenous agents are introduced in a datable sample after its recovery from the burial environment. If safety precautions are neglected when the sample is excavated, stored and subsequently prepared for analysis, a wide range of contaminants may be introduced into the sample material, such as hairs, fats and oils, as well as plasticizers and adhesives. Any of these contain carbon in concentrations of ^{14}C that likely deviate significantly from that of the ancient sample. Therefore, when absorbed by the sample targeted for dating, this will result in erroneous age estimations.

During the Industrial Age anthropogenic activities have had a notable effect on Earth's natural carbon cycle, resulting in the isotopic ratio of both ^{13}C and ^{14}C shifting in the atmospheric and oceanic carbon reservoirs (Keeling, 1979). The Suess Effect describes the decrease of ^{14}C in atmospheric CO_2 due to the admixture of CO_2 produced by the combustion of fossil fuels (Suess, 1965). With an age of hundreds of thousands or millions of years, fossil fuels such as coal and crude oil are depleted in ^{14}C and therefore their burning and subsequent release into the atmosphere, for instance, in the form of CO_2 , has a dilutive effect on the proportion of radiocarbon in active carbon reservoirs. Besides the obvious risk of contamination between ancient and modern radiocarbon (Aitken, 2014), in archaeology, the Suess Effect must also be corrected when experimental work is carried out to build baseline data sets with modern ^{13}C samples (Correa-Ascencio & Evershed, 2014; Lucquin et al., 2016a).

Figure 20. A simplified schematic of the cycle of carbon between distinct reservoirs on Earth. Diagram adapted from: <https://commons.wikimedia.org/w/index.php?curid=4956173> (H. Grobe)

7.4 Reservoir Effects

In radiocarbon dating a reservoir effect refers to the build-up of ^{14}C -depleted carbon in a reservoir or a segment of it. The marine reservoir effect (MRE) occurs in radiocarbon dating due to the slower mixing and much longer time of residence of dissolved carbonates in the oceanic hydrosphere compared to the carbon dioxide gas of the atmosphere (Stuiver & Braziunas, 1993; Ascough et al. 2005). The result of this is a difference of ^{14}C concentrations in carbon between organisms of same age within the atmospheric and oceanic systems, with marine-derived samples appearing older than their contemporaneous terrestrial samples (Reimer et al., 2013).

Moreover, while the surface ocean water exchanges carbon in a shorter cycle with the atmosphere, radiocarbon tends to have a longer cycle in deep ocean waters (Fig. 20). Therefore, within oceanic systems, the marine reservoir effect produces different concentrations of ^{14}C between surface and deep ocean waters. Depending on the intensity in the dilution of ^{14}C in a given reservoir, and the degree to which distinct organisms are exposed to it through their diet, the offset (i.e. the difference between the measured age and

the sample's true, calendar age) tends to range from tens of years to several hundred years (Yoneda et al., 2001). For oceanic systems and regions where the marine carbon cycle approximates global values of an approximately 400-year offset, the Marine13 calibration curve is made available (Reimer et al., 2013). However, in some cases – for instance, in enclosed freshwater systems rich in dissolved ancient calcium carbonates (i.e. the ‘hardwater effect’) – an offset can be considerable (Shishlina et al., 2007; Philippsen 2015).

Along the coast of Hokkaido, however, the offset caused by the MREs appears to be increasingly variable, with ΔR values (i.e. offset expressed in radiocarbon years) having been demonstrated to fluctuate depending on the oceanic current and the area from which a dated organism or sample originated from (Kuzmin et al., 2007; Miyata et al., 2009). Indeed, at the Hamanaka 2 site in Rebun Island, offsets of local ancient sea mammal, bird and mollusc samples were reported to range between 133 and 431 years (Miyata et al. 2016). According to this study, a ΔR offset of 172 ± 39 was calculated for a marine shell sample, likely reflecting the MRE associated with the local Soya Current. In turn, migratory species such as the Japanese Sea lion measured ΔR values of 389 ± 45 years, reflecting its diet on deep ocean fish and long migratory routes. Furthermore, in what appears an even more complex carbon cycle and food web structure, ΔR values of 447 ± 55 were assigned to charred crusts in ceramic cooking pots.

Therefore, in a region with such a dynamic isotope ecology an accurate reconstruction of the species, diet and natural habitat of the targeted marine organism is critical to successful radiocarbon dating. However, with peaking maritime activities and a subsistence highly focused on aquatic resources, even land-based organisms in northern Hokkaido are heavily exposed to oceanic carbon (Naito et al., 2010). This includes both humans and wild animals, as well as domestic dogs that were apparently fed on marine fish during the Okhotsk Culture period (Tsutaya et al., 2014). Therefore, accurate radiocarbon dating of these materials will have to account for the marine age-offset through analysis of isotopic evidence to reconstruct the contribution of oceanic carbon in a sample, as well as estimating its specific source (i.e. species) and related ΔR (Naito et al., 2010).

7.5 Bayesian Chronological Inference

In radiocarbon dating, Bayesian statistics provide a convenient framework for embedding contextual evidence as part of chronological inference (Buck et al., 1996; Bronk Ramsey, 2009a). Indeed, archaeological assemblages are often deposited in environments where relative chronological information, such as stratigraphic and typological evidence, can be used to infer the order of artefacts or contexts. Such information is useful in the calibration of radiocarbon dates, as contextual information can be introduced as priors in the statistical model that, together with the calibration operator, computes a probable age for the sample. When certain parts of the calendric timeline can be ruled out in an age estimation, for instance due to laws of archaeological stratigraphy that establish a temporal order for ancient artefacts or anthropogenic layers (Harris, 1979), the age ranges of calibrated dates are narrowed down (Buck et al., 1996; Benz et al., 2011).

The OxCal calibration software employs an automated random sampling algorithm coupled with a wide ranging set of dating parameters and scenarios that allow the construction and testing of complex chronological models using prior expert information (Bronk Ramsey, 2009a, 2017). Such tools are optimal in creating and improving chronologies for extensively dated multi-phase archaeological sites, where stratigraphic priors in a carefully designed statistical model can have a considerable effect in reducing dating uncertainty. In addition, the use of chronological models leads to increased chances for identifying and eliminating outliers in a set of ^{14}C dates (Bronk Ramsey, 2009b).

Outlier is a dated sample whose measured age does not correspond with its expected age, or the age of its archaeological context. This may be the result of contamination with modern carbon, or, for instance, the sample being out of its original stratigraphic and archaeological context. While various opinions exist on whether samples or data should be eliminated when they contradict a statistical model, the removal of outliers allows a statistical model to be tested more effectively. Therefore, the cost-benefit ratio between the loss of data and increased modelling efficiency should be carefully weighed when eliminating outliers

However, without a systematic approach to assessing a single date's agreement within the broader chronological context of a settlement, identifying an outlier and demonstrating this can be challenging. Since the usefulness of Bayesian inference is largely dependent on the quality of data employed, in the present thesis measures were taken to ensure that the samples dated were most likely – based on both contextual as well as typological evidence

available – associated to the context they were deposited in. The elimination of a sample as outlier was done if it was clear that the sample's age was an archaeological impossibility, i.e. the sample's date contradicted the prior age estimate of the context and culture so drastically that its acceptance would have discounted most previously conducted chronological and culture-historical research in the region (e.g. a pottery lipid date from the earliest Okhotsk Culture context at Kafukai in thesis paper IV, which gave an age estimate that predated the culture's consensus earliest date, and its paired charred crust date, by c. 800 calendar years).

Alternatively, outlier may be eliminated based on the assessment of each date's goodness of fit with the rest of the sample set (Bronk Ramsey, 2009b). This approach may be useful when prior typological information is not available and cannot be used to assess the sample's pertinence to the context it was deposited in. In thesis paper II, where a chronological model was developed for a series of carbonized seed and charcoal samples, this approach was deemed necessary, given that none of the materials dated contained any cultural diagnostic features. In my opinion, the removal of outliers should therefore be carried out consistently across the data set, where the parameters for the elimination of one sample should stay constant and unchanged for each sample. This way, the effects of the researcher's personal bias can be tempered, as they already tend to be notable in Bayesian inference.

7.6 Direct Dating of Pottery

In chronological inference, archaeological pottery holds a number of key advantages over other materials that make its consideration for direct ^{14}C dating logical. Firstly, pottery can be easily identified in archaeological assemblages, and it establishes an unequivocal link with a human activity. Secondly, pottery is a nearly universal resource from the Neolithic period and onwards (as is mentioned in Chapter 3, pottery appears, though in comparably smaller numbers, in the Late Pleistocene in East Asia), appearing in virtually all types of archaeological contexts, including burial sites, refuse pits and household contexts. In addition, pottery often contains diagnostic decorative traits that allow it to be associated with a specific culture and period.

Pottery used for cooking and heating of foods and other organic products tends to contain charred surface crusts that can be used in radiocarbon dating. In the dating of pottery residues, the dated event is the moment when the organism where the residues were derived

from ceased to exchange carbon in its respective biosphere (i.e. moment of death). This date, in general, can be expected to correspond fairly closely to the time/moment the ceramic container was used – assuming that its function was to process or store fresh food or other organic commodities – and therefore yield an accurate estimate of its age. Any deviation of this as a result of different selection of materials – for instance the burning of several years old vegetable oils as illuminants – is likely not meaningful on prehistoric time scales.

A major drawback in most attempts to directly date pottery, however, is owed to the uncertainty and complications in sourcing the datable remains in ceramics (Berstan et al., 2008)⁶. Indeed, if the food web contribution in the organic residues dated cannot be properly provenanced, the resulting date may be exposed to significant unaccounted offsets. For instance, some freshwater fish do not produce molecular biomarkers that are usually associated with aquatic products, such as APAAs or isoprenoids (Olsson & Isaksson, 2008). Therefore, a cooking pot showing no molecular or isotopic evidence for the presence of aquatic organisms may still be exposed to a significant radiocarbon offsets depending on freshwater reservoir effect and/or hardwater effects, if lean lake fish were processed in it. At certain river and lakeside settlements, this has been found to be the case, which has caused these dates to be inaccurate and hold little value in chronological inference unless their offsets can be properly accounted for (Boudin et al., 2009). On the other hand, a complicated picture with marine reservoir effects, as the one present in northern Hokkaido, can be an equally challenging circumstance for reliable direct dating of pottery (Miyata et al., 2009).

In addition, contamination may also complicate accurate direct dating of pottery. Indeed, contaminants from packaging materials and handling can potentially present a problem unless they are detected and removed from the sample dated. Therefore, this question should be addressed with proper sample selection, where datable materials are recovered, whenever possible, directly from their burial environment, and handled as well as stored in a manner that minimizes their exposure to exogenous sources of carbon. Also, whenever available, samples with highest lipid concentration and least mixing from different food webs, should be prioritized to minimize further dating uncertainty.

⁶ There are other approaches to directly dating pottery, such as luminescence dating of minerals in ceramic clay (see Wintle 1997).

That being said, one solution to managing the uncertainty related with the sourcing of pottery residues is compound-specific dating (Smittenberg et al., 2002). In compound-specific dating, the ^{14}C measurement targets either a single compound or a set of compounds in an organic extract. While the radiocarbon dating of bulk materials such as charred surface crusts provide the average ^{14}C contents in said sample, a compound-specific measurement expresses the radiocarbon age of the dated compounds. The datable extract may be derived from organic temper, charred surface crust or lipids absorbed in the vessel matrix. The most suitable of these sources of residues tend to be absorbed lipids, as, unlike organic temper and surface crust residues, they are protected against diagenetic processes and exposure to exogenous carbon by the ceramic clay (Casanova et al., 2020). Single-compound techniques have the potential for insulating the age determination from compounds and food sources that are known to contain considerable dating uncertainty, and therefore yield a more reliable age estimate for the cooking vessel (Stott et al., 2001; Lampert et al., 2003).

Single-compound dating techniques, however, entail a number of disadvantages that have hindered its wide-scale adoption in archaeology. Firstly, in order to carry out a reliable single-compound age determination of an absorbed pottery extract, the concentration of datable materials (e.g. lipids such as *n*-alkanoic acids) needs to be sufficiently high. In Casanova et al. (2020), single-compound ^{14}C determinations were reported on samples with a lipid concentration of $>323 \mu\text{g/g}^{-1}$ in *n*-alkanoic acids ($\text{C}_{16:0}$ and $\text{C}_{18:0}$). Such fatty acid concentration is not present in all archaeological ceramic ware, ruling out the approach for samples with poor yields. Moreover, this approach is commonly carried over using preparative capillary gas chromatography (pcGC), where chemically pure fatty acids are isolated from other absorbed compounds. This is a costly task that requires considerable time and resources compared to bulk AMS dating approaches.

The dating of total lipid extracts (TLE) in pottery offers an alternative that under certain conditions may be more suitable than bulk and single-compound dating techniques. In total lipid extract dating, pottery lipids are recovered from the ceramic matrix using a solvent treatment (Llewellyn et al., *article in preparation*). The advantages of this approach are several. First of all, the recovery and dating of solvent-treated total lipid extracts permits the dating of samples with lower yields, while also avoiding the costly isolation of pure FAs using pcGC. Secondly, TLE dating permits a high level of quality control, as the sample's

molecular and isotopic signatures can be analyzed using GC–MS and GC–C–IRMS, allowing the sample’s food source to be characterized. In TLE dating, an ultrasonication-supported homogenization and chemical extraction of lipids using a chloroform and methanol solution is utilised to recover lipids from ceramic materials. The potential problems arising from the incomplete elimination of carbon present in organic solvents ahead of radiocarbon analysis has been recognized for applications of compound specific radiocarbon dating (Casanova et al., 2018) and this concern is similarly relevant in TLE dating. Should any ^{14}C -depleted solvent be retained in the organic sample, the dated sample will appear older than expected. Therefore, rigorous quality screening and analysis of paired materials to detect inaccuracies is recommended. However, while the reliability and accuracy of TLE dating is not on par with the single-compound technique, the dating of total lipid extracts nevertheless provides a viable option to directly date pottery with lower lipid yields and lower analytical costs, in cases where contamination is not an issue.

Despite multiple technical and practical challenges, direct dating of pottery continues to be developed, and recent efforts to further advance this technique have demonstrated that it should be viewed as a viable option in archaeological chronology studies. However, in particular, some questions persist with source-related uncertainty in dated materials. Bayesian mixing models provide a platform for assessing the impact of radiocarbon reservoir effects in individual samples, allowing these sources of uncertainty to be quantified and managed probabilistically (Fernandes et al., 2016, 2018). There will likely be multiple solutions to some of the issues raised above, with each approach providing a trade-off that should be considered given the specifics of each individual research context. Preliminary results indicate that the dating of total lipid extracts in pottery shows promise, but more work is required to further develop the technique to minimize some of the potential sources of uncertainty that its application seems to generate.

8 Selection of Study Sites, Samples and Summary of Main Results

Three sites were selected to address the three main research objectives of the thesis. Hamanaka 2 site is a stratified beach front site with over 3000-year occupation sequence. It is currently the focus of long-term research and annual excavations campaigns, which generated opportunities to sample fresh materials. The stratified Kafukai 1 and 2 sites were excavated in the 1960's and 1970's, and offered the opportunity to study the foodways of a series of different cultures that occupied the river mouth area. Excavations of the Menashidomari site in the 1970's discovered a well-preserved Okhotsk long-house structure, enabling pottery samples to be selected in situ and from a single occupation phase. From these combined sites, a total of 127 ceramic samples were collected and analysed.

The permissions for sampling at Hamanaka 2 were provided by the third supervisor of this thesis, Prof. Hirofumi Kato, from the Centre for Ainu and Indigenous Studies of Hokkaido University; for Kafukai 1 and 2 by Prof. Masaki Eda of the Hokkaido University Museum of Hokkaido, Hokkaido University; and for Menashidomori by Takamune Takabatake of Esashi Archaeological Museum. In addition, three carbonized archaeobotanical samples from the Hamanaka 2 were ¹⁴C-dated to obtain an age estimate of the Towada-phase of the Okhotsk Culture period, and a further twelve radiocarbon dates were obtained from a total of six ceramic sherds from the Kafukai sites. Below, a short description of the sites is provided, along with a summary of the key findings, discussed in more detail in chapters 9 and 10, and thesis papers I–V.

8.1 Hamanaka 2

Rebun Island is a hilly island in the Sea of Japan, located 50 km west of mainland Hokkaido and 90 km south of the Sakhalin Island. Rebun has a maximum length and width of 20 km and 6 km, respectively, and a land surface area of c. 80 km². Rebun Island is located in a region with abundant marine offshore and riverine fish resources that formed the basis of the local subsistence throughout the Middle and Late Holocene periods (Okada, 1998; Yamaura, 1998). Located on the northern coast of Rebun Island, Hamanaka 2 comprises shell-midden deposits on top of a sand dune (Hirasawa & Kato 2019). The studied stratigraphic succession at Hamanaka dates back to the Final Jomon and the Epi-Jomon

periods, and also covering the Okhotsk and Ainu Culture periods (c. 1750 BCE–1850 CE). This type of well-excavated and lengthy cultural succession with a rich material record provided an ideal setting for investigating long-term trends in Late Holocene pottery use, as well as for employing statistical methods to refine the region's radiocarbon chronology.

A total of 66 ceramic sherds were collected at the site from eight stratigraphic layers pertaining to the Final Jomon, Epi-Jomon and Okhotsk Culture phases. The molecular and isotopic analysis of these materials (thesis paper I) revealed evidence of the processing of a diverse range of resources, including marine and terrestrial animal, and plants. In addition, a notable pattern was observed in how pottery use changed over time, with the earliest Final Jomon layer showing a container function orientated towards the processing of marine commodities, with the late Final Jomon and Epi-Jomon, as well as most of the Okhotsk Culture periods marked by a diverse exploitation of resources from both the aquatic and terrestrial food webs. Evidence of plant use was surprisingly frequent in Hamanaka pottery, as indicated by molecular findings of phytosterol, long-chain alkanols, terpenoids and even miliacin (millet). Finally, container function in the Final Okhotsk period appears to have been re-focused into the exploitation of marine resources, with little evidence of commodities from other food groups in this phase.

The organic residue analysis at Hamanaka 2 was followed by a chronological study (thesis paper II) that examined the timing of the final-stage Jomon and Okhotsk (as well as Satsumon and Ainu) culture layers. The study was primarily conducted on previously published archaeobotanical samples (Leipe et al., 2017) that were calibrated using a Bayesian chronological model. This approach allowed us to estimate the timing of the earliest Okhotsk occupation (Towada-style pottery) at the site c. 450–550 cal CE, which is followed by well-defined age-ranges for Middle (Kokumon) and Late Okhotsk (Chinsenmon) periods c. 550–700 cal CE and 700–800 cal CE, respectively. Moreover, increasingly accurate temporal boundaries were provided for the previously identified occupation hiatus at the site. The timing of the hiatus was estimated between c. 250 cal BCE and 450 cal CE, which is consistent with the timing of the Susuya occupation of coastal northern Hokkaido and Rebun Island c. 1 – 500 cal CE (Kumaki et al., 2019).

8.2 Kafukai 1 & 2

Both Kafukai sites (No. 1 and 2) are Late Holocene period settlements comprising of clusters of pit-houses located at the Kafukai river mouth, on the eastern coast of Rebun Island. Given that Hamanaka 2 is a site comprising of various types of activity zones without living structures, the well-excavated and stratified household occupations at the Kafukai sites provided an opportunity to investigate a different aspect of pottery use among Late Holocene hunter-gatherer cultures, while still retaining the previous long-term perspective.

The Kafukai river mouth is an alluvial plain, and it is surrounded by 10–20 m high hilltops in a valley that extends to the sea with a long sand dune shoreline. The earliest of the two settlements, Kafukai 2, is considered to have been occupied by the Susuya Culture at some point before the Okhotsk settlement was established c. 5th century CE (Kumaki et al., 2017). However, the chronology of the site is not well known due to lack of accurate radiocarbon dates. In turn, Kafukai 1 was settled by the Okhotsk Culture from c. 450–1000 cal CE, followed by a short occupation by Satsumon groups, approximately 1000–1150 CE (Oba & Ohyi, 1981). In the Okhotsk Culture period, the households generated refuse such as marine fauna that formed a clear succession of shell-midden type deposits, or ‘fishbone layers’, around the pit-houses that were occupied without interruptions (Oba & Ohyi 1981).

A total of 34 ceramic sherds were collected for organic residue analysis from one Susuya Culture pit-house at Kafukai 2, and two Okhotsk Culture pit-houses and one Satsumon Culture pit-house at Kafukai 1. A clear pattern in the use of resources was observed between the first three occupation phases, with evidence of the Susuya pottery characterized by the processing of intermediate trophic-level aquatic resources, most likely anadromous fish, and the earliest Okhotsk pottery (c. 400–550 CE) marked by the exploitation of high-trophic level marine resources. In turn, the pottery examined in the later Okhotsk period household (c. 550–650 CE) showed a more diverse use pattern, with both aquatic and terrestrial animal resources exploited. The characterization of the Satsumon Culture pottery use had to be inferred on the basis of two samples, which indicate a mixed use of aquatic and terrestrial resources. Evidence of plant use was subdued in this sample set, which is a circumstance likely related to the taphonomic history of the samples, as the storage of the material for over five decades may have resulted in the disappearance of some of the lighter compounds, such as phytosterols, long-chain alkanols and other plant biomarkers.

Further, the timing of the Kafukai sites was studied by directly dating pottery residues from three pit-houses (thesis paper IV). A total of six sherds exhibiting molecular and isotopic evidence of the processing of marine organisms were chosen for bulk crust and absorbed lipid residue dating. To properly manage the complex marine reservoir effect in these materials, the contribution of oceanic carbon was estimated on the basis of stable isotope measurements using a mixing model (Fernandes et al., 2014). The resulting dates were calibrated with a Bayesian chronological model similar to the one employed at Hamanaka 2, allowing for prior archaeological and stratigraphic information to be used to order the samples temporally. This resulted in consistent age-estimates for all three phases dated, and allowed us to propose a tentative chronology for the Susuya and Okhotsk occupations at Kafukai c. 1–450 cal CE and 450–1000 cal CE, respectively.

8.3 Menashidomari

The Menashidomari site complex is located on the Okhotsk Sea coast in the northwest part of the Hokkaido mainland, some 10 km north of Esashi city and 60 km south of Wakkanai city. The site is a large village consisting of Okhotsk Culture pit-houses dating between c. 750 and 850 CE. A number of fully excavated Okhotsk pit-houses provided an ideal opportunity for pottery use to be reconstructed and observed within a well-defined social context, as per the initial aim of this thesis. Furthermore, the preservation at the site is excellent and abundant pottery, lithics, ecofacts and zooarchaeological assemblages are recorded in its material assemblage, providing plenty of contextual evidence to support the interpretation of the pottery lipid analyses conducted.

While c. 90% of the documented animal bones comprise of marine species, about 10% of the zooarchaeological remains are derived from several different terrestrial animal species, including dog, pig, deer and bear. Some of the animal remains may not relate directly to the local subsistence, however, since the site also contains plenty of evidence indicating the celebration of animal rituals. Indeed, especially bear and sea mammal bones, often recorded in clusters around the houses, appear to have been treated ritually (Sato, 1994; Takabatake, 2004).

To investigate spatial patterning in household container function at the site, a total of 27 ceramic samples were collected from a large (c. 90 m²) and well-excavated Okhotsk pit-

house. The location of 23 of the 27 samples collected had been recorded within a grid system, allowing me to test whether pottery use would change within the household space (thesis paper V). Similar to the Kafukai and Hamanaka 2 sites, molecular and isotopic evidence consistent with the processing of aquatic and terrestrial animal resources were discovered in these samples. In general, the pottery use at the site appears to have been heavily focused on the processing of marine and anadromous resources. However, while no spatial patterning was observed in pottery use at the pit-house, the largest containers in the habitat appear to have been used to process terrestrial animal commodities. Finally, limited evidence of plant use was documented in these assemblages, that, similarly to the Kafukai materials, may have been a result of c. 50-year post-excavation storing having eliminated some of the lighter compounds in the potsherds.

9 The Okhotsk Cuisine in Northwest Hokkaido

The present thesis aimed at identifying what was processed in Late Holocene pottery in northern Hokkaido, whether its function changed during this period, and whether pottery use could be further contextualized in a single household space, providing further insight into Okhotsk Culture perspectives into cuisine and resource use. A major point of interest ahead of this study was also whether the Late Holocene vessel use strategy would align with the deep-time pattern of aquatic focus established for early pottery in northeast Asia. Moreover, the Okhotsk pottery use was expected to either confirm the culture's highly adapted maritime subsistence by showing a container function consistent with the processing of aquatic resources, or, alternatively, reveal a diversified resource management strategy where a wide range of commodities were processed in pottery – possibly linked with the culture's complex human-animal interactions. For this purpose, pottery use was examined from a slightly different contextual and temporal perspective at three distinct Late Holocene sites. This approach resulted in a multi-faceted picture of Okhotsk foodways and human-animal interactions that provided insight to the initial questions raised.

Firstly, at the Hamanaka 2 site Okhotsk container function was characterized as part of a multi-millennial cultural sequence, allowing the culture's pottery use to be observed within the broader Late Holocene culture-historical context. There, a dual function for Okhotsk pottery could be observed, with both molecular and isotopic evidence indicating that separate cooking pots were used for the processing of aquatic and terrestrial resources.

The majority of the Okhotsk vessels (c. 70%) at Hamanaka retained the aquatic focus in pottery that had been previously established for most Late Pleistocene and Early Holocene cultures in northeast Asia (Craig et al., 2013; Lucquin et al., 2016a, 2018; Shoda et al., 2018, 2020). Indeed, the majority of the samples showed lipid profiles and isotopic values consistent with the presence of abundant degraded and thermally processed aquatic oils and fats primarily derived from marine fish and sea mammal organisms. When considered with the fact that these samples contained abundant charred surface crusts, the likely function for these vessels was intensive and repetitive heating of marine fish and sea mammal commodities. This may have been a result of industrial scale extraction of blubber through boiling (Miyata et al., 2009), or preparation of marine and salmonid commodities as part of

daily cooking activities in nearby households. Considering that the Hamanaka 2 site comprises shell midden deposits that primarily consist of marine fauna and ceramic fragments, the latter of the two scenarios seems the most likely, although both strategies may have been employed.

In turn, the remaining c. 30% of the ceramic sherds examined showed molecular and isotopic evidence consistent with either mixing of both marine and terrestrial commodities, or exclusive processing of terrestrial animal products, possibly derived from pig/wild boar, bear, dog and, perhaps, Sika deer, carcass and adipose fats. These samples had lower lipid concentrations and did not have any visible food crust, indicating that they were likely used very differently than the containers reserved for aquatic products. Given that Hamanaka 2 is a site associated with both ritual behaviour and burial practices (Hirasawa & Kato, 2019), the pots used for the processing of terrestrial animal resources may have been used as part of the celebration of animal rituals, spirit sending rites or community-level feasts.

That said, among the most surprising discoveries in the Hamanaka 2 pottery was the persistence of plant lipids in all final-stage Jomon and Okhotsk Culture phases – and an indication of continuity of a certain culinary practice. While the plant-derived lipids were not abundant in any of the samples examined – and also there were no isotopic values measured in the ranges established for plant resources (Yoshida et al., 2013) – their prevalence (>90%) in the data set confirms the complexity of both Late Holocene and Okhotsk Culture cuisine in northern Hokkaido. Plant use was even associated in the earliest phase studied at Hamanaka 2, the early Final Jomon phase, where pottery otherwise reflected a strong focus to marine aquatic resources. The presence of millet (cf. Heron et al., 2016) was confirmed in one Kokumon-style container that had a strong aquatic component in its lipid profile, further suggesting that aquatic foods may have been consumed mixed with plants or other commodities. Some of the plant lipids may have been derived from seaweed, considering how important a resource kelp was in the region during the Ainu Culture period (Kohara, 1999) – and continues to be to this day – and how easy its collection in the coastal areas of Hokkaido and Rebun Island is.

At Kafukai 1, a slightly more specialized pottery use strategy was observed, especially in the earliest occupation phase. Indeed, the earliest Okhotsk pit-house – which may be the earliest Okhotsk occupation in Rebun Island, and even Hokkaido – was marked

by a pottery use highly focused on the marine food web, and with little signs of the diverse use strategies observed at the Hamanaka 2 site. This phase is followed by another occupation phase, approximately 100–200 years later, where similarly to Hamanaka 2 the household pottery function appears to become diversified across marine, salmonid and terrestrial animal resources. Very few signs of plant use was found, which, as was mentioned previously, might be a result of taphonomic loss rather than an altogether absence of these resources in pottery.

While the marine aquatic lipid profiles observed in the Kafukai 1 materials are very similar to those found in the Hamanaka 2 assemblages, the pottery use at Hamanaka 2 does stand out for its higher diversity across multiple food webs, including terrestrial animals and plants. This may well boil down to site function – i.e. spatial organisation of food procurement strategies – since Hamanaka 2 is a shell midden site with a collection of site activity areas with evidence of ritual behaviour and feasting, and Kafukai 1 is a household context where pottery is likely primarily used as part of daily cooking activities.

It is interesting to note, though, that the Okhotsk pottery use during its earliest occupation at Kafukai 1 was so focused on the marine food web, and that this was not even relatable to the earlier Susuya pottery use, orientated towards the processing of salmonid resources. As I point out in the discussion part of paper III, the concentration towards marine resources in the earliest Okhotsk occupation is consistent with the site material record – where the use of marine resources is proportionally higher than in any other phase – and perhaps a result of deteriorated resource conditions during a cold climate period (cf. Koizumi et al. 2003; Abe et al., 2016).

Figure 21. Drawing of the house floor of Pit-House No. E-4 with the excavation grid system and sampled grids (colored) indicated. Each grid was assigned into one of four sectors whose isotopic signals were combined and compared through the use of a mixing model (Fernandes et al., 2015). Blue-colored grids express sample(s) with lipids determined to have been derived from aquatic food groups; green-marked grids indicate a potential mixture of aquatic and terrestrial lipids; yellow color expresses the presence of terrestrial animal lipids.

At Pit-House No. E-4, the distribution of potsherds appears intentional and related to the social division of space within the habitat (Fig. 21). Indeed, the samples were clustered around both of the longitudinal sides of the pit-house, which are areas associated with personal space, including sleeping and food consumption (Sato, 1994; Takabatake, 2004). Therefore, it is likely that most of these samples relate to daily food consumption and cooking activities, though activities such as feasting and the celebration of sending rites, as suggested by the presence of a cluster of bear crania in the back of the house, cannot be ruled out.

The results of the molecular and isotopic analyses of the Menashidomari long-house samples exhibit, in general, a pottery use strategy similar to the one observed at both Okhotsk sites in Rebun Island, with container function primarily orientated towards the processing of marine aquatic organisms and anadromous fish. In addition, approximately 15–20% of the samples showed a distinct use pattern consistent with the processing of terrestrial animal resources, perhaps carcass meat and adipose fats derived from dog, pig/wild boar, bear and, to lesser extent, Sika deer. Similar to Kafukai, the evidence concerning plant use was very limited, which may be a result of taphonomic elimination of these compounds due to a lengthy post-excavation storing time (c. 50 years).

The fact that no spatial pattern was detected between the four sectors of the household suggests that resource-sharing among the Okhotsk was common, and that all members of the group had access to the same range of resources. This reasoning, however, is likely applicable to daily food consumption only, and the distribution of resources during the celebration of community-scale feasts and seasonal animal rituals was likely asymmetrical, as suggested by prior ethnographic evidence of the descendant Ainu Culture (cf. Ohnuki-Tierney, 1999).

Curiously, two of the three largest containers sampled showed lipid profiles and isotopic values consistent with the presence of terrestrial animal resources, which strongly indicates that these vessels had a different function from the smaller ones. This may relate to either quotidian activities such as the storing of terrestrial resources, be it food or other types of commodities, or an altogether different social context, for example linked with ritual behaviour or feasting, etc.

In sum, the results of pottery lipid analysis at these three Okhotsk sites provide compelling evidence that pottery use and cuisine were much more diverse among the Late Holocene Okhotsk communities compared to the Late Pleistocene and Early Holocene hunter-gatherer groups in the northeast Asia. Indeed, in the Late Holocene period in northern Hokkaido, pottery appears to be a complex cultural resource that permeates all aspects of social life, including common cooking, feasting, and burial and ritual practices. These results do not fully align with the subsistence and ecology of the region, marked heavily by maritime resources, and, instead, show that some strategic distinctions were made between aquatic and terrestrial resources. This notion is further reinforced by different use strategies for larger vessels in the Menashidomari long-house, where resource-sharing appears otherwise equal.

Further experimental work is required, however, to identify the specific source of terrestrial animal lipids and better characterize the use of plants in the containers examined. In addition, the analysis of further contextual data – currently under investigation at the Hamanaka 2 site – should elucidate the type of social situations where Okhotsk pottery was used, providing vital information about Okhotsk human-animal interactions that could be employed in the reconstruction of the Ainu ethnogenesis.

10 Constructing High-Resolution Chronologies in Late Holocene Hokkaido

Over the course of this thesis, a research gap was identified in northern Hokkaido archaeology that could be addressed using two separate approaches. More specifically, the research into the relationship and interactions between Late Holocene cultures in northern Hokkaido is ongoing, but has been somewhat hindered due to complications in establishing an accurate timeline for this cultural sequence. This is primarily a result of various marine reservoir effects that challenge the archaeological radiocarbon dating in the north Pacific (Yoneda et al., 2004; Kuzmin et al., 2007; Miyata et al., 2016). Moreover, due to peaking maritime activities in the region, few datable materials with terrestrial carbon are available, limiting options to avoid MRE with alternative sample selection strategies.

While a comprehensive radiocarbon study into past human-ecodynamics was recently conducted in the Kuriles (Fitzhugh et al., 2016), similar approaches have not been attempted at large enough scale in northern Hokkaido. Though such large-scale studies are well outside the scope of the present thesis, some of the site materials, and especially the ceramic cooking containers examined, permitted a set of alternative approaches to be pursued in two pilot studies. Indeed, as was outlined previously, the research aimed to answer whether it is possible to either avoid or manage marine reservoir offsets in radiocarbon dating by targeting well-researched contexts where prior expert information can be used to minimize dating uncertainty. The two methodological case studies explored this question, as discussed below.

At the multi-phase site of Hamanaka 2, the stratigraphy, along with the availability of terrestrial organic samples allowed for a pilot study to be conducted, a Bayesian stratigraphic model was employed to produce an absolute chronology for the site timing while avoiding the issues related with the marine reservoir effects. This resulted in a high-resolution, radiocarbon-supported timeline for the site's lengthy cultural sequence, providing researchers at similar ecological settings a blueprint for managing MRE in ^{14}C -dating. The timing of some layers, such as the Final Okhotsk phase (Motochi), however, could not be modelled properly due to a low number of reliable samples. While this issue cannot be solved without adding more samples, the Early, Middle and Late Okhotsk phases were age-estimated with high resolution. Therefore, the results of this exercise were promising, and

they should encourage researchers to employ the approach at different northern Hokkaido sites.

Moreover, the narrowed-down timeline for the Okhotsk Culture – and its four different phases, observed through the occurrence of four distinct decorative styles – was useful in understanding the ecological and culture-historical context of the observed pottery use at the Hamanaka 2 and Kafukai sites. According to this model, the earliest Okhotsk occupation in Hokkaido takes place late in the 5th century, around the Kofun cold period that may have favoured the Okhotsk maritime-focused subsistence (Koizumi et al., 2003) in the Early Okhotsk period characterized by the Towada and Kokumon pottery styles (Ono, 2008). This age estimate was coincident with palynological evidence from the nearby Lake Kushu, where a deforestation episode taking place around 500 cal CE was previously inferred (Fig. 22) (Leipe et al., 2018).

Figure 22. Archaeological radiocarbon data compared with lake pollen evidence from Lake Kushu in Rebun Island. Mean age-ranges for all modeled phases from archaeobotanical ¹⁴C-dates (Leipe et al., 2017, 2018).

At the Kafukai sites pottery was dated directly from charred crust and absorbed lipid samples at one Susuya and two Okhotsk Culture household contexts. While some issues were

observed in the extraction and dating of absorbed lipid residues – possibly due to the introduction of ‘dead carbon’ in the samples from the solvent used in the lipid extraction – the overall outcome of this exercise was a considerably improved chronology for the study sites. Indeed, the resulting dates allowed us to establish a time-frame for the Susuya Culture in Rebun to the first half of the 1st millennium CE – coincident with the previously reported age-range for the culture in Hokkaido in Kumaki et al. (2017). In addition, according to these datings, the earliest date for the Okhotsk emergence in Rebun and northern Hokkaido likely takes place in the 5th century cal CE – also in general agreement with previously proposed dates for Okhotsk appearance in Hokkaido (cf. Amano, 2003, Ono, 2008).

Therefore, the direct dating of Kafukai pottery was largely consistent with the age-ranges obtained at Hamanaka 2. This is encouraging since the approaches, in general, were rather independent of each other, given that they dated materials from different carbon reservoirs. Further research, however, is required to confirm that the timing of the Late Holocene cultural sequences at Hamanaka 2 and Kafukai 1 and 2 are applicable to other sites and regions in the northern Japanese archipelago and the Sakhalin Island, and to confirm that these approaches can be employed as part of chronological inference in other coastal environments.

11 Conclusions

This thesis aimed to understand diversification and change in cooking traditions in the Late Holocene cultures in Hokkaido. Both methodological as well as culture-historical questions were tackled in the five case studies presented, employing organic residue analysis as the primary research technique. We already knew that during the Late Pleistocene and Early Holocene periods pottery function in northern Japan appears to have been highly specialized and was primarily focused on the processing of aquatic resources. In the present thesis I have been able to demonstrate that this enduring relationship between pottery and aquatic resources was breaking down into more complex patterns of use, including the addition of other food stuffs, and use of different pots for different sets of resources. Especially among the Okhotsk communities, new insights generated by this thesis suggest that pottery use was, in fact, a multi-faceted cultural tradition, with complex social significance that extended well beyond daily cooking activities and routine subsistence. This phenomenon may be limited to marine hunter economies in the Hokkaido and Sakhalin cultural spheres – or it may be a characteristic of many other Circumpolar cultures with complex human-animal interactions. The thesis has also made additional advances in chronological inference, where two different approaches were tested in the ^{14}C -dating of archaeological materials, resulting in an improved timeline for the two study sites at Rebun Island, and a solution to managing the region's complex marine reservoir effects. However, further work on the interpretation of the lipid results still needs to be done, as species-specific characterizations of the resources processed in the analyzed pottery could not be completed within the limited scope of a PhD thesis. This was also due to methodological limitations that may be resolved in the future by conducting further experimental work in order to gain a better understanding of the region's food web, as well as, importantly, the role of plants in maritime forager cuisine. In conclusion, these combined results have resolved a number of important questions, and will open up new lines of research in East Asia, especially in relation to the processes driving the diversification of pottery use in the Late Holocene, as well as the chronology of these developments, and how they relate to other cultural, environmental and climatic variables.

13 References

Ackman, R. G., & Hooper, S. N. (1968). Examination of isoprenoid fatty acids as distinguishing characteristics of specific marine oils with particular reference to whale oils. *Comparative Biochemistry and Physiology*, 24(2), 549-565.

Aitken, M. J. (2014). Science-based dating in archaeology. Routledge.

Akino, S. (1999). Spirit-Sending Ceremonies. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 248-255.

Alon, D., Mintz, G., Cohen, I., Weiner, S., & Boaretto, E. (2002). The use of Raman spectroscopy to monitor the removal of humic substances from charcoal: Quality control for ¹⁴C dating of charcoal. *Radiocarbon*, 44(1), 1-11.

Amano, T. (1979). Ohotsuku bunka no tenkai to chi'ikisa. *Hoppo Bunka Kenkyu* 12, 75-92.

Amano, T. (2003). What is the Okhotsk Culture? In: Nomura T. and Utagawa Y (eds.), Epi-Jōmon, Okhotsk Culture. *Hokkaido Shinbunsha*, Sapporo, p. 110-133 (In Japanese).

Amano, T., & Ono, H. (2002). Formative process of the Okhotsk Culture—What precede the “Towada Stage”? Amano T. and Vasilevski A.A. (eds.), *Okhotsk Culture—Formation, Meta-morphosis and Ending: Japan and Russia Cooperative Symposium*. Hokkaido University Museum, Sapporo. pp. 115-118. (In Japanese)

Ascough, P., Cook, G., & Dugmore, A. (2005). Methodological approaches to determining the marine radiocarbon reservoir effect. *Progress in Physical Geography*, 29(4), 532-547.

Bamforth, D. B., & Grund, B. (2012). Radiocarbon calibration curves, summed probability distributions, and early Paleoindian population trends in North America. *Journal of Archaeological Science*, 39(6), 1768-1774. <https://doi.org/10.1016/j.jas.2012.01.017>

Bartlein, P. J., Edwards, M. E., Shafer, S. L., & Barker, E. D. (1995). Calibration of radiocarbon ages and the interpretation of paleoenvironmental records. *Quaternary research*, 44(3), 417-424.

Bayes, T. (1763). LII. An essay towards solving a problem in the doctrine of chances. By the late Rev. Mr. Bayes, FRS communicated by Mr. Price, in a letter to John Canton, AMFR S. *Philosophical transactions of the Royal Society of London*, (53), 370-418.

Benz, M., Coskun, A., Hajdas, I., Deckers, K., Riehl, S., Alt, K.W., Weninger, B., & Ozkaya, V. (2012). Methodological implications of new radiocarbon dates from the early Holocene site of Kortik Tepe, Southeast Anatolia. *Radiocarbon*, Vol 54(3-4), p. 291-304. <https://doi.org/10.1017/S0033822200047081>

Berstan, R., Stott, A. W., Minnitt, S., Bronk Ramsey, C., Hedges, R. E., & Evershed, R. P. (2008). Direct dating of pottery from its organic residues: new precision using compound-specific carbon isotopes. *Antiquity*, 82(317), 702-13. <https://doi.org/10.1017/S0003598X00097325>

Böhning, D., Seidel, W., Alfó, M., Garel, B., Patilea, V., & Walther, G. (2007). Advances in mixture models. *Computational Statistics & Data Analysis*, 51(11), 5205-5210.

Boudin, M., Van Strydonck, M., & Crombé, P. (2009). Radiocarbon Dating of Pottery Food Crusts: Reservoir Effect or not? The case of the Swifterbant pottery from Doel “Deurganckdok. In: *Chronology and Evolution within the Mesolithic of North-West Europe* (pp. 727-745). Cambridge Scholars Publishing.

Brettell, R. C., Schotsmans, E. M., Rogers, P. W., Reifarth, N., Redfern, R. C., Stern, B., & Heron, C. P. (2015). ‘Choicest unguents’: molecular evidence for the use of resinous plant exudates in late Roman mortuary rites in Britain. *Journal of Archaeological Science*, 53, 639-648.

Brock, F., Higham, T., Ditchfield, P., & Ramsey, C. B. (2010). Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon*, 52(1), 103-112.

Bronk Ramsey, C. (2009a). Bayesian analysis of radiocarbon dates. *Radiocarbon*, 51(1), 337-360.

Bronk Ramsey, C. (2009b). Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon*, 51(3), 1023-1045.

Bronk Ramsey, C. (2017). Methods for Summarizing Radiocarbon Datasets. *Radiocarbon*, 59(2), 1809-1833.

Büntgen, U., Myglan, V.S., Charpentier Lundqvist, F., McCormick, M., Di Cosmo, N., Sigl, M., Jungclaus, J., Wagner, S., Krusic, P.J., Esper, J., Kaplan, J.O., de Vaan, M.A.C., Luterbacher, J., Wacker, L., Tegel, W., & Kirdyanov, A.V. (2016). Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience* 9, 231-236 (2016). <https://doi.org/10.1038/ngeo2652>

Buck, C.E., Cavanagh, W.G., Litton, C.D. (1996). Bayesian Approach to Interpreting Archaeological Data. Chichester: Wiley.

Casanova, E., Knowles, T.D.J., Williams, C., Crump, M.P., & Evershed, R.P. (2018). Practical Considerations in High-Precision Compound-Specific Radiocarbon Analyses: Eliminating the Effects of Solvent and Sample Cross-Contamination on Accuracy and Precision. *Anal Chem.* 90:11025–32.

Casanova, E., Knowles, T.D.J., Bayliss, A., Dunne, J., Baranski, M.Z., Denaire, A., Lefranc, P., di Lernia, S., Roffet-Salque, M., Smyth, J., Barclay, A., Gillard, T., Classen, E., Coles, B., Ilett, M., Jeunesse, C., Krueger, M., Marciniak, A., Minnitt, S., Rotunno, R., van de Velde, P., van Wijk, I., Cotton, J., Daykin, A., & Evershed, R.P. (2020). Accurate compound-specific ^{14}C dating of archaeological pottery vessels. *Nature* 580:506–510.

Charters, S., Evershed, R. P., Goad, L. J., Leyden, A., Blinkhorn, P. W., & Denham, V. (1993). Quantification and distribution of lipid in archaeological ceramics: implications for sampling potsherds for organic residue analysis and the classification of vessel use. *Archaeometry*, 35(2), 211-223.

Charters, S., Evershed, R.P., Quye, A., Blinkhorn, P.W., & Reeves, V. (1997). Simulation experiments for determining the use of ancient pottery vessels: the behaviour of epicuticular leaf wax during boiling of a leafy vegetable. *Journal of Archaeological Science*, 24, 1 - 7.

Chiyo, H. (1984). The Life of the Epi-Jomon Culture. *New Science Sha Press*, Tokyo. (In Japanese).

Colonese, A. C., Hendy, J., Lucquin, A., Speller, C. F., Collins, M. J., Carrer, F., Regula Gubler, R., Kühn, M., Fischer, R., & Craig, O. E. (2017). New criteria for the molecular identification of cereal grains associated with archaeological artefacts. *Scientific reports*, 7(1), 1-7. <https://doi.org/10.1038/s41598-017-06390-x>

Copley, M. S., Rose, P. J., Clapham, A., Edwards, D. N., Horton, M. C., & Evershed, R. P. (2001). Detection of palm fruit lipids in archaeological pottery from Qasr Ibrim, Egyptian Nubia. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1467), 593-597.

Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, A. J., Straker, V., Payne, S., & Evershed, R. P. (2003). Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences*, 100(4), 1524-1529. <https://doi.org/10.1073/pnas.0335955100>

Copley, M. S., Bland, H. A., Rose, P., Horton, M., & Evershed, R. P. (2005). Gas chromatographic, mass spectrometric and stable carbon isotopic investigations of organic residues of plant oils and animal fats employed as illuminants in archaeological lamps from Egypt. *Analyst*, 130(6), 860-871.

Crawford, G.W. (2011). Advances in Understanding Early Agriculture in Japan. *Current Anthropology*, Vol. 52, S4 (October 2011): S331-S345

Craig, O. E., Love, G. D., Isaksson, S., Taylor, G., & Snape, C. E. (2004). Stable carbon isotopic characterisation of free and bound lipid constituents of archaeological ceramic vessels released by solvent extraction, alkaline hydrolysis and catalytic hydrolysis. *Journal of Analytical and Applied Pyrolysis*, 71(2), 613-634.

Craig, O. E., Steele, V. J., Fischer, A., Hartz, S., Andersen, S. H., Donohoe, P., Glykou, A., Saul, H., Jones, D.M., Koch, E., & Heron, C. P. (2011). Ancient lipids reveal continuity in culinary practices across the transition to agriculture in Northern Europe. *Proceedings of the National Academy of Sciences*, 108(44), 17910-17915. <https://doi.org/10.1073/pnas.1107202108>

Craig, O. E., Allen, R. B., Thompson, A., Stevens, R. E., Steele, V. J., & Heron, C. (2012). Distinguishing wild ruminant lipids by gas chromatography/combustion/isotope ratio mass spectrometry. *Rapid communications in mass spectrometry*, 26(19), 2359-2364.

Craig, O.E., Saul, H., Lucquin, A., Nishida, Y., Tache, K., Clarke, L., Thompson, A., Altoft, D.T., Uchiyama, J., Ajimoto, M., Gibbs, K., Isaksson, S., Heron, C.P., & Jordan, P. (2013). Earliest evidence for the use of pottery. *Nature*, Vol. 496, p. 351-354.

DeNiro, M. J., & Epstein, S. (1976). You are what you eat (plus a few permil): The carbon isotope cycle in food chain. *Geological Society of America Abstracts with Programs* 8: 834-835.

DeNiro, M. J., & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et cosmochimica acta*, 45(3), 341-351.

Deryugin, V.A. (2008). On the definition of the term ‘Okhotsk Culture’. *Archaeology Ethnology and Anthropology of Eurasia* 33/1 (2008) 58-66.

de Vries, H. (1958a). Variation in concentration of radiocarbon with time and location on earth. *Proceedings Koninklijke Nederlandse Akademie van Wetenschappen* 61(B): 1–9.

de Vries, H. (1958b). Atomic bomb effect: variation of radiocarbon in plants, shells, and snails in the past 4 years. *Science*, 128(3318), pp.250–251.

Drummond, A. J., Suchard, M. A., Xie, D., & Rambaut, A. (2012). Bayesian phylogenetics with BEAUti and the BEAST 1.7. *Molecular biology and evolution*, 29(8), 1969-1973.

Dudd, S. N., & Evershed, R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science*, 282(5393), 1478-1481.

Dudd, S.N., Evershed, R.P., & Gibson, A.M. (1999). Evidence for varying patterns of exploitation of animal products in different prehistoric pottery traditions based on lipids preserved in surface and absorbed residues. *J Arch Sci* 26, p. 1473-1482. <https://doi.org/10.1006/jasc.1998.0434>

Dunne, J. (2017). *Organic Residue Analysis and Archaeology*. Historic England.

Dunne, J., Mercuri, A. M., Evershed, R. P., Bruni, S., & di Lernia, S. (2016). Earliest direct evidence of plant processing in prehistoric Saharan pottery. *Nature plants*, 3(1), 1-6.

Ehleringer, J. R., & Rundel, P. W. (1989). Stable isotopes: history, units, and instrumentation. In: *Stable isotopes in ecological research* (pp. 1-15). Springer, New York, NY.

Etu-Sihvola, H., Bocherens, H., Drucker, D. G., Junno, A., Mannermaa, K., Oinonen, M., Uusitalo, J. & Arppe, L. (2019). The dIANA database–Resource for isotopic paleodietary research in the Baltic Sea area. *Journal of archaeological science: Reports*, 24, 1003-1013. <https://doi.org/10.1016/j.jasrep.2019.03.005>

Evershed, R.P., Heron, C., & Goad, L.J. (1990). Analysis of organic residues of archaeological origin by high-temperature gas chromatography and gas chromatography – mass spectrometry. *Analyst*. Vol. 115, p. 1339-1342. <https://doi.org/10.1039/AN9901501339>

Evershed, R. P., Heron, C., Charters, S., & Goad, L. J. (1992). The survival of food residues: new methods of analysis, interpretation and application. In: Pollard, A.M (Ed.), *New Developments in Archaeological Science*. Oxford University Press, Oxford, pp. 187-208.

Evershed, R. P. (1993). Biomolecular archaeology and lipids. *World archaeology*, 25(1), 74-93.

Evershed, R. P., Dudd, S. N., Copley, M. S., Berstan, R., Stott, A. W., Mottram, H., Buckley, S.A., & Crossman, Z. (2002). Chemistry of archaeological animal fats. *Accounts of chemical research*, 35(8), 660-668.

Evershed, R. P. (2008). Organic residue analysis in archaeology: the archaeological biomarker revolution. *Archaeometry*, 50(6), 895-924.

Evershed, R. P., Copley, M. S., Dickson, L., & Hansel, F. A. (2008). Experimental evidence for the processing of marine animal products and other commodities containing polyunsaturated fatty acids in pottery vessels. *Archaeometry*, 50(1), 101-113.

Farb, P., & Armelagos, G. (1980). Consuming passions, the anthropology of eating. Houghton Mifflin.

Fernandes, R., Millard, A. R., Brabec, M., Nadeau, M. J., Grootes, P. (2014). Food reconstruction using isotopic transferred signals (FRUITS): a Bayesian model for diet reconstruction. *PloS One*, 9(2). <https://doi.org/10.1371/journal.pone.0087436>

Fernandes, R., Grootes, P., Nadeau, M.J., & Nehlich, O. (2015). Quantitative Diet Reconstruction of a Neolithic Population Using a Bayesian Mixing Model (FRUITS): The Case Study of Osterf (Germany). *Am J Phys Anth* 158, p. 325-340. <https://doi.org/10.1002/ajpa.22788>

Fernandes, R., Rinne, C., Nadeau, M. J., & Grootes, P. (2016). Towards the use of radiocarbon as a dietary proxy: establishing a first wide-ranging radiocarbon reservoir effects baseline for Germany. *Environmental Archaeology*, 21(3), 285-294.

Fernandes, R., Eley, Y., Brabec, M., Lucquin, A., Millard, A., & Craig, O. E. (2018). Reconstruction of prehistoric pottery use from fatty acid carbon isotope signatures using Bayesian inference. *Organic geochemistry*, 117, 31-42.

Fitzhugh, B., Gjesfjeld, E.W., Brown, W.A., Hudson, M.J., & Shaw, J.D. (2016). Resilience and the population history of the Kuril Islands, Northwest Pacific: A study in complex human ecodynamics. *Quaternary International*, Vol 419(17), 2016, p. 165-193. <https://doi.org/10.1016/j.quaint.2016.02.003>

- Fukuda, M., & Grishchenko, V.A.** (2017). The Adaptation of Neolithic Culture in the Sakhalin/Japanese Archipelago. *The Proceedings of the 31st International Abashiri Symposium* (2017), p. 6-12.
- Gajewski, K., Muñoz, S., Peros, M., Viau, A., Morlan, R., & Betts, M.** (2011). The Canadian archaeological radiocarbon database (CARD): archaeological 14 C dates in North America and their paleoenvironmental context. *Radiocarbon*, 53(2), 371-394.
- Gilks, W. R.** (2005). Markov Chain Monte Carlo. *Encyclopedia of biostatistics*, 4.
- Godwin, H.** (1962). Half-life of radiocarbon. *Nature*, 195(4845), 984-984.
- Grupe, G. & Harbeck, M.** (2015). Taphonomic and Diagenetic Processes. In W. Henke & I. Tattersall (eds.), *Handbook of Paleoanthropology*. Berlin, Heidelberg: Springer, Berlin, Heidelberg, pp. 417–439.
- Habu, J.** (2004). Ancient Jomon of Japan (Vol. 4). Cambridge University Press.
- Habu, J., Savelle, J. M., Koyama, S., & Hongo, H.** (2003). Hunter-gatherers of the north Pacific rim. *Senri Ethnological Studies*, vol. 63. National Museum of Ethnology, Osaka.
- Hall, M., Maeda, U., & Hudson, M.** (2002). Pottery production on Rishiri Island, Japan: perspectives from X-ray fluorescence studies. *Archaeometry*, 44(2), 213-228.
- Hallowell, A. I.** (1926). Bear ceremonialism in the northern hemisphere. *American Anthropologist*, 28(1), 1-175.
- Hammann, S., & Cramp, L. J.** (2018). Towards the detection of dietary cereal processing through absorbed lipid biomarkers in archaeological pottery. *Journal of Archaeological Science*, 93, 74-81.
- Hammann, S., Cramp, L. J., Whittle, M., & Evershed, R. P.** (2018). Cholesterol degradation in archaeological pottery mediated by fired clay and fatty acid pro-oxidants. *Tetrahedron Letters*, 59(50), 4401-4404.

Hansel, F.A., Copley, M.S., Madureira, L.A., & Evershed, R.P. (2004). Thermally produced ω -(o-alkylphenyl)alkanoic acids provide evidence for the processing of marine products in archaeological pottery vessels. *Tetrahedron Letters* 45 (2004) p. 2999-3002. <https://doi.org/10.1016/j.tetlet.2004.01.111>

Harris, E. C. (1979). The laws of archaeological stratigraphy. *World Archaeology*, 11(1), 111-117.

Hayden, B. (1995). The emergence of prestige technologies and pottery. The emergence of pottery: technology and innovation in ancient societies, 257-265.

Hedges, R. E. M., Law, I. A., Bronk, C. R., & Housley, R. A. (1989). The Oxford accelerator mass spectrometry facility: technical developments in routine dating. *Archaeometry*, 31(2), 99-113.

Heron, C., Evershed, R. P., & Goad, L. J. (1991). Effects of migration of soil lipids on organic residues associated with buried potsherds. *Journal of Archaeological Science*, 18(6), 641-659.

Heron, C., & Craig, O. E. (2015). Aquatic resources in foodcrusts: identification and implication. *Radiocarbon*, 57(4), 707-719.

Heron, C., Shoda, S., Barcons, A. B., Czebreszuk, J., Eley, Y., Gorton, M., Kirleis, W., Kneisel, J., Lucquin, A., Muller, J., Nishida, Y., Joon-ho, S., & Craig, O.E. (2016). First molecular and isotopic evidence of millet processing in prehistoric pottery vessels. *Scientific Reports*, 6, 38767. <https://doi.org/10.1038/srep38767>

Hirasawa, Y., & Kato, H. (eds.). (2019). Preliminary Excavation Report of the Hamanaka 2 Site, Rebun Island, Hokkaido, Japan. Center for Ainu & Indigenous Studies, Hokkaido University, Sapporo (In Japanese).

Hjulström, B., Isaksson, S., & Karlsson, C. (2008). Prominent migration period building. Lipid and elemental analyses from an excavation at Alby, parish of Botkyrka, Södermanland, Sweden. *ACTA Archaeologica*, 79:62-78. <https://doi.org/10.1111/j.1600-0390.2008.00109.x>

- Horiuchi, A., Miyata, Y., Kamijo, N., Cramp, L., & Evershed, R. P.** (2015). A dietary study of the Kamegaoka culture population during the Final Jomon Period, Japan, using stable isotope and lipid analyses of ceramic residues. *Radiocarbon*, 57(4), 721-736.
- Hudson, M. J.** (2004). The perverse realities of change: world system incorporation and the Okhotsk culture of Hokkaido. *Journal of Anthropological Archaeology*, 23(3), 290-308.
- Igarashi, Y.** (2013). Holocene vegetation and climate on Hokkaido island, northern Japan. *Quaternary International*, 290-291(2013), p. 139-150.
- Igarashi, Y.** (2016). Vegetation and climate during the LGM and the last deglaciation on Hokkaido and Sakhalin Islands in the northwest Pacific. *Quaternary International*, 425, 28-37(2016).
- Ikawa-Smith, F.** (1992). Kanjodori: communal cemeteries of the Late Jomon in Hokkaido. Pacific Northeast Asia in Prehistory, Washington State University Press, Pullman, 83-89.
- Isaksson, S.** (2009). Vessels of change. *Current Swedish Archaeology*, 17, 131-149.
- Isaksson, S., Karlsson, C., & Eriksson, T.** (2010). Ergosterol (5, 7, 22-ergostatrien-3 β -ol) as a potential biomarker for alcohol fermentation in lipid residues from prehistoric pottery. *Journal of Archaeological Science*, 37(12), 3263-3268.
- Isaksson, S., Gibbs, K. & Jordan, P.** (2019). Maritime nomads of the Baltic Sea. In: *Ceramics in Circumpolar Prehistory : Technology, Lifeways and Cuisine*. Cambridge University Press, p. 63-80.
- Ito, N.** (1942). An Essay on Chronology of Prehistoric Potteries in Sakhalin, in: *The Collections of the University of Tohoku, The Society of Japan History, Daitoshokan*, Tokyo. (In Japanese).
- Katzenberg, M. A., & Harrison, R. G.** (1997). What's in a bone? Recent advances in archaeological bone chemistry. *Journal of Archaeological Research*, 5(3), 265-293.

Keeling, C. D. (1979). The Suess effect: ^{13}C - ^{14}C interrelations. *Environment International*, 2(4-6), 229-300.

Kelly, R. L., Surovell, T. A., Shuman, B. N., & Smith, G. M. (2013). A continuous climatic impact on Holocene human population in the Rocky Mountains. *Proceedings of the National Academy of Sciences*, 110(2), 443-447.

Kikuchi, T. (1999). Ainu Ties with Ancient Cultures of Northeast Asia. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 47-51.

Kimura, H. (1976). Subsistence Equipment of the Epi-Jomon Culture. *Dolmen* No. 10. Tokyo. (In Japanese)

Kohara, T. (1999). Foods of Choice. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 202-207.

Koizumi, I., Shiga, K., Irino, T., & Ikehara, M. (2003). Diatom record of the late Holocene in the Okhotsk Sea. *Marine Micropaleontology*, 49(1-2), 139-156.

Kučera, L., Peška, J., Fojtík, P., Barták, P., Kučerová, P., Pavelka, J., Komárková, V., Beneš, J., Polcerová, L., Králík, M. & Bednář, P. (2019). First direct evidence of broomcorn millet (*Panicum miliaceum*) in Central Europe. *Archaeological and Anthropological Sciences*, 11(8), 4221-4227. <https://doi.org/10.1007/s12520-019-00798-4>

Kumaki, T., Fukuda, M., & Kunikita, D. (2017). Chronological Study of Susuya Type Pottery: In Relation to “Karafuto Kiko” by Kunio Yanagita. *Bulletin of the National Museum of Japanese History* 202:101-135. (In Japanese with English summary)

Kunikita, D. (2016). Radiocarbon dating of charcoal and carbon and nitrogen stable isotope analysis of charred material on the pottery surfaces from the Oshima 2 site. In Kumaki, T. ed. *Research on the Interaction and Social Change of Coastal Areas of the Sea of Okhotsk in the Satsumon Culture: Archaeological Research of Oshima 2 Site*. Vol. 1, p.90-99, The University of Tokyo.

Kunikita, D., Shevkomud, I., Yoshida, K., Onuki, S., Yamahara, T., & Matsuzaki, H. (2013). Dating charred remains on pottery and analyzing food habits in the Early Neolithic period in Northeast Asia. *Radiocarbon*, 55(3), 1334-1340.

Kunikita, D., Takase, K., Kumaki, T., & Matsuzaki, H. (2017a). Analyzing food habits using charred remains on pottery after the Epi-Jomon culture in Hokkaido. *The 34th JSSSCP Annual Meeting in Yamagata*. June 9-11 (2017).

Kunikita, D., Popov, A. N., Lazin, B. V., Morisaki, K., & Matsuzaki, H. (2017b). Dating and stable isotope analysis of charred residues from Neolithic sites in the Primorye, Russian Far East. *Radiocarbon*, 59(2), 565-573.

Kuroyanagi, A., Kawahata, H., Narita, H., Ohkushi, K. I., & Aramaki, T. (2006). Reconstruction of paleoenvironmental changes based on the planktonic foraminiferal assemblages off Shimokita (Japan) in the northwestern North Pacific. *Global and Planetary Change*, 53(1-2), 92-107.

Kuzmin, Y. V., Burr, G. S., Gorbunov, S. V., Rakov, V. A., & Razjigaeva, N. G. (2007). A tale of two seas: reservoir age correction values (R , ΔR) for the Sakhalin Island (Sea of Japan and Okhotsk Sea). *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 259(1), 460-462.

Lampert, C. D., Glover, I. C., Hedges, R. E. M., Heron, C. P., Higham, T. F. G., Stern, B., Shoocongdej, R., & Thompson, G. B. (2003). Dating resin coating on pottery: the Spirit Cave early ceramic dates revised. *Antiquity*, 77(295), 126-133. <https://doi.org/10.1017/S0003598X0006141X>

Lee, P.M. (2012). *Bayesian Statistics: An Introduction*, 4th Edition. John Wiley & Sons.

Leipe, C., Sergusheva, E.A., Muller, S., Spengler, R.N., Goslar, T., Kato, H., Wagner, M., Weber, A.W., & Tarasov, P.E. (2017). Barley (*Hordeum vulgare*) in the Okhotsk culture (5th-10th century AD) of northern Japan and the role of cultivated plants in hunter-gatherer economies. *PLOS One* March 29, 2017.

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

Libby, W. F. (1946). Atmospheric helium three and radiocarbon from cosmic radiation. *Physical Review*, 69(11-12), 671.

Libby, W. F. (1955). Radiocarbon dating. University of Chicago Press.

Lucquin, A., Gibbs, K., Uchiyama, J., Saul, H., Ajimoto, M., Eley, Y., Radini, A., Heron, C.P., Shoda, S., & Nishida, Y. (2016a). Ancient lipids document continuity in the use of early hunter-gatherer pottery through 9,000 years of Japanese prehistory. *Proc Natl Acad Sci*, April 12, 2016, Vol. 113, No. 15. p 3991-3.

Lucquin, A., Colonese, A. C., Farrell, T. F., & Craig, O. E. (2016b). Utilising phytanic acid diastereomers for the characterisation of archaeological lipid residues in pottery samples. *Tetrahedron Letters*, 57(6), 703-707.

Lucquin, A., Robson, H., Eley, Y., Shoda, S., Veltcheva, D., Gibbs, K., Heron, C.P., Isaksson, S., Nishida, Y., Taniguchi, Y., Nakajima, S., Kobayashi, K., Jordan, P., Kaner, S., & Craig, O.E. (2018). The impact of environmental change on the use of early pottery by East Asian hunter-gatherers. *Proc Natl Acad Sci*, June 18, 2018.

Lyman, R.L. (2002). Taphonomic Agents and Taphonomic Signatures. *American Antiquity*, 67(2), pp.361–365.

Masuda, R., Amano, T., & Ono, H. (2001). Ancient DNA Analysis of Brown Bear (*Ursus arctos*) Remains from the Archaeological Site of Rebun Island, Hokkaido, Japan. *Zoological Science* 18(5):741-751 (2001).

Medeiros, P. M., & Simoneit, B. R. (2007). Analysis of sugars in environmental samples by gas chromatography–mass spectrometry. *Journal of Chromatography A*, 1141(2), 271-278.

Mejdahl, V. (1979). Thermoluminescence dating: beta-dose attenuation in quartz grains. *Archaeometry*, 21(1), 61-72.

Mintz, S. W. (1996). Tasting food, tasting freedom: Excursions into eating, culture, and the past. Beacon Press.

Miyata, Y., Horiuchi, A., Paleo Labo AMS Dating Group, & Nishimoto, T. (2009). Traces of sea mammals on pottery from the Hamanaka 2 archaeological site, Rebun island, Japan: Implications from sterol analysis, stable isotopes, and radiocarbon dating. *Res Org Geochem* 25, 15-27 (2009).

Miyata, Y., Horiuchi, A., Kondo, M., Onbe, S., Yoshida, K., Nagao, S., Paleo Labo AMS Dating Group, & Nishimoto, T. (2016). Marine reservoir effects deduced from ¹⁴C dates on pottery residues, bones, and molluscan shells from the Hamanaka 2 archaeological site, Rebun island, Hokkaido, Japan. *Radiocarbon*, Vol. 58, Nr 4, 2016, p. 755–770.

Mizoguchi, K. (2020). Making Sense of Material Culture Transformation: A Critical Long-Term Perspective from Jomon-and Yayoi-Period Japan. *Journal of World Prehistory*, 1-23.

Mottram, H. R., Dudd, S. N., Lawrence, G. J., Stott, A. W., & Evershed, R. P. (1999). New chromatographic, mass spectrometric and stable isotope approaches to the classification of degraded animal fats preserved in archaeological pottery. *Journal of Chromatography A*, 833(2), 209-221. [https://doi.org/10.1016/S0021-9673\(98\)01041-3](https://doi.org/10.1016/S0021-9673(98)01041-3)

Naito, Y.I., Chikaraishi, Y., Ohkouchi, N., Mukai, H., Shibata, Y., Honch, N.V., Dodo, Y., Ishida, H., Amano, T., Ono, H., & Yoneda, M. 2010. Dietary Reconstruction of the Okhotsk Culture of Hokkaido, Japan, Based on Nitrogen Composition of Amino Acids: Implications for Correction of ¹⁴C Marine Reservoir Effects on Human Bones. *Radiocarbon*, Vol 52, Nr 2-3, 2010, p. 671-681. <https://doi.org/10.1017/S0033822200045690>

Nishimoto, Y. (1978). On the subsistence of Okhotsk culture. *Material cultures (Bussitsu Bunka)* 31:1-12. (in Japanese)

- Nishimoto, T.** (2000). Inu [Dogs]. In Hamanaka-2 Iseki Hakkutsu Chosa Hokokusho [Report on the Research Excavation at the Site of Hamanaka-2]. Oyohiro Nishimoto, ed. P 240-253. Sakura: *Bulletin of the National Museum of Japanese History*, 85.
- Oba, T., & Ohyi, H.** (1981). The Kabukai sites II. *Studies on Okhotsk Culture*, Vol 3. University of Tokyo Press 1981.
- Ohnuki-Tierney, E.** (1999). Ainu Sociality. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 240-245.
- Okada, A.** (1998). Maritime adaptations in Hokkaido. *Arctic Anthropology*, 340-349.
- Ölschleger, H.D.** (1999). Technology, Settlement, and Hunting Ritual. Spirit-Sending Ceremonies. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 208-221.
- Olson, E. A., & Broecker, W. S.** (1958). Section of geology and mineralogy: sample contamination and reliability of radiocarbon dates. *Transactions of the New York Academy of Sciences*, 20(7 Series II), 593-604.
- Olsson, M., Isaksson, S.** (2008). Molecular and isotopic traces of cooking and consumption of fish at an Early Medieval manor site in eastern middle Sweden. *Journal of Archaeological Science*, 35(3), 773-780.
- Onishi, H.** (2003). Residents of a Cultural Boundary Area: Lineage and Household Composition of the Tobinitai Culture in Northern Japan. *Journal of the Japanese Archaeological Association*, Vol 10(15), p. 157-177 (In Japanese with English summary).
- Ono, H., & Amano, T.** (2002). The formative process of the Susuya Culture. Amano T. and Vasilevski A. A. (eds.), *Okhotsk Culture—Formation, Meta-morphosis and Ending: Japan and Russia Cooperative Symposium*. Hokkaido University Museum, Sapporo. p. 107-114. (In Japanese)

Ono, H. (2008). Differences in Environmental Adaptation between Northern and Eastern Okhotsk Cultures and Their Cultural Backgrounds. *Problems of Biological and Cultural Adaptation of Human Populations. Vol. 1, Archaeology: Adaptation Strategies of the Ancient Population of Northern Eurasia: Raw Materials and Processing Techniques*, RAS, St. Petersburg, p. 186-196.

Ono, H., & Amano, T. (2008). Cultural genealogy related to the formation and development of the Okhotsk Culture. Emori S. et al., (eds.). *Emishi, Ezo, and Ainu—the formation and acculturation, mainly on the trade and interchange*. p. 139-192. (In Japanese)

Papakosta, V., Smittenberg, R.H., Gibbs, K., Jordan, P., & Isaksson, S. (2015). Extraction and derivatization of absorbed lipid residues from very small and very old samples of ceramic potsherds for molecular analysis by gas chromatography-mass spectrometry (GC-MS) and single compound stable carbon isotope analysis by gas chromatography-combustion-isotope ratio mass spectrometry (GC-c-IRMS). *Microchemical Journal*, 123 (2015) 196-200. <https://doi.org/10.1016/j.microc.2015.06.013>

Papakosta, V., Oras, E., & Isaksson, S. (2019). Early pottery use across the Baltic—a comparative lipid residue study on Ertebølle and Narva ceramics from coastal hunter-gatherer sites in southern Scandinavia, northern Germany and Estonia. *Journal of Archaeological Science: Reports*, 24, 142-151.

Passey, B. H., Robinson, T. F., Ayliffe, L. K., Cerling, T. E., Sponheimer, M., Dearing, M. D., Roeder, B.L., & Ehleringer, J. R. (2005). Carbon isotope fractionation between diet, breath CO₂, and bioapatite in different mammals. *Journal of Archaeological Science*, 32(10), 1459-1470. <https://doi.org/10.1016/j.jas.2005.03.015>

Pecci, A., Domínguez-Bella, S., Buonincontri, M. P., Miriello, D., De Luca, R., Di Pasquale, G., Cottica, D., & Bernal-Casasola, D. (2018). Combining residue analysis of floors and ceramics for the study of activity areas at the Garum Shop at Pompeii. *Archaeological and Anthropological Sciences*, 10(2), 485-502. <https://doi.org/10.1007/s12520-017-0573-7>

Phillips, D. L., Newsome, S. D., & Gregg, J. W. (2005). Combining sources in stable isotope mixing models: alternative methods. *Oecologia*, 144(4), 520-527.

Philippsen, B. (2015). Hard water and old food. The freshwater reservoir effect in radiocarbon dating of food residues on pottery. *Documenta Praehistorica*, 42, 159-170.

Reber, E.A., Kerr, M.T., Whelton, H.L., & Evershed, R.P. (2018). Lipid residues from low-fired pottery. *Archaeometry*, 61(1), 131-144. <https://doi.org/10.1111/arcm.12403>

Regert, M., Bland, H. A., Dudd, S. N., Bergen, P. V., & Evershed, R. P. (1998). Free and bound fatty acid oxidation products in archaeological ceramic vessels. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 265(1409), 2027-2032.

Regert, M. (2011). Analytical strategies for discriminating archeological fatty substances from animal origin. *Mass spectrometry reviews*, 30(2), 177-220.

Reimer, P.J., Bard, E., Bayliss, A., Beck, W.J., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Chen, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hafflidason, H., Hajdas, I., Hatte, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J. 2013. INTCAL13 and MARINE13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP. *Radiocarbon*, Vol 55(4), p. 1869-1887.

Richards, M. P., & Hedges, R. E. (1999). Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science*, 26(6), 717-722.

Robson, H.K., Lucquin, A., Gibbs, K., Saul, H., Tomoda, T., Hirasawa, Y., Yamahara, T., Kato, H., Isaksson, S., Craig, O.E., & Jordan, P.D. (*article accepted*). Nuts, Salmon and Sika Deer: Tracking the Evolution and Diversification of Jomon “Culinary” Traditions in Prehistoric Hokkaido. *Journal of Anthropological Archaeology*.

Sakaguchi, T. (2007). Refuse patterning and behavioral analysis in a pinniped hunting camp in the Late Jomon Period: A case study in layer V at the Hamanaka 2 site, Rebun Island, Hokkaido, Japan. *Journal of Anthropological Archaeology*, 26(1), 28-46.

Sargent, J. R., Tocher, D. R., & Bell, J. G. (2003). The lipids. In: *Fish nutrition* (pp. 181-257). Academic Press.

Sato, T. (ed.). (1994). Esashi-Town Board of Education (1994) Research Report of Menashidomari Site. Esashi-Town Board of Education, Hokkaido (in Japanese)

Sato, T. (2019). A Zooarchaeological Study of the Formation Process of the Ainu Bear-sending Ceremony. In: Mattila, R., Ito, S., Fink, S. (Eds.), *Animals and their Relation to Gods, Humans and Things in the Ancient World*, Universal- und kulturhistorische Studien. Studies in Universal and Cultural History, Springer, p. 389-408.

Saul, H., Wilson, J., Heron, C. P., Glykou, A., Hartz, S., & Craig, O. E. (2012). A systematic approach to the recovery and identification of starches from carbonised deposits on ceramic vessels. *Journal of Archaeological Science*, 39(12), 3483-3492.

Sawai, G. (2007). The Dynamics of the Satsumon Culture read its potteries and the distribution of pit-houses. Amano, T. & Ono, H. (eds.). *Ancient Emishi to Ainu. Yoshikawa-Kobunkan*, Tokyo. p. 324-351. (In Japanese)

Schoeller, D. A. (1999). Isotope fractionation: Why aren't we what we eat?. *Journal of Archaeological Science*, 26(6), 667-673.

Schoeninger, M. J., DeNiro, M. J., & Tauber, H. (1983). Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science*, 220(4604), 1381-1383.

Schröder, M., & Vetter, W. (2011). GC/EI-MS determination of the diastereomer distribution of phytanic acid in food samples. *Journal of the American Oil Chemists' Society*, 88(3), 341-349.

Shishlina, N. I., Van der Plicht, J., Hedges, R. E. M., Zazovskaya, E. P., Sevastyanov, V. S., & Chichagova, O. A. (2007). The Catacomb cultures of the North-west Caspian steppe: 14 C chronology, reservoir effect, and paleodiet. *Radiocarbon*, 49(2), 713-726.

Shoda, S., Lucquin, A., Ahn, J. H., Hwang, C. J., & Craig, O. E. (2017). Pottery use by early Holocene hunter-gatherers of the Korean peninsula closely linked with the exploitation of marine resources. *Quaternary Science Reviews*, 170, 164-173.

Shoda, S., Lucquin, A., Yanshina, O., Kuzmin, Y., Shevkomud, I., Medvedev, V., Derevianko, E., Lapshina, Z., Craig, O.E., & Jordan, P. (2020). Late Glacial hunter-gatherer pottery in the Russian Far East: Indications of diversity in origins and use. *Quaternary Science Reviews*, 229, 106–124.

Smith, B. N., & Epstein, S. (1971). Two categories of $^{13}\text{C}/^{12}\text{C}$ ratios for higher plants. *Plant physiology*, 47(3), 380-384.

Smittenberg, R. H., Hopmans, E. C., Schouten, S., & Damsté, J. S. S. (2002). Rapid isolation of biomarkers for compound specific radiocarbon dating using high-performance liquid chromatography and flow injection analysis–atmospheric pressure chemical ionisation mass spectrometry. *Journal of Chromatography A*, 978(1-2), 129-140.

Šoberl, L., Gašparič, A. Ž., Budja, M., & Evershed, R. P. (2008). Early herding practices revealed through organic residue analysis of pottery from the early Neolithic rock shelter of Mala Triglavca, Slovenia. *Documenta praehistorica*, 35, 253-260.

Stott, A. W., Berstan, R., Evershed, P., Hedges, R. E. M., Ramsey, C. B., & Humm, M. J. (2001). Radiocarbon dating of single compounds isolated from pottery cooking vessel residues. *Radiocarbon*, 43(2A), 191-197.

Stuiver, M., Reimer, P.J., & Reimer, R.W. (2020). CALIB 7.1 [WWW program] at <http://calib.org>, accessed 2020-6-8.

Suess, H. E. (1965). Secular variations of the cosmic-ray-produced carbon 14 in the atmosphere and their interpretations. *Journal of Geophysical Research*, 70(23), 5937-5952.

- Takabatake, T.** (ed.). (2004). Esashi-Town Board of Education, Menashidomari Site (Excavation report 2004). Esashi-Town Board of Education, Hokkaido. (in Japanese)
- Takase, K.** (2019). Long-term marine resource use in Hokkaido, Northern Japan: new insights into sea mammal hunting and fishing. *World Archaeology*, 51(3), 408-428.
- Takeda, O.** (1996). Ohotsuku bunka tateana jukyonai no ibutsu shutsudo patan ni tsuite. *Kodai Bunka* 48, 3-13. (in Japanese)
- Tallavaara, M., Pesonen, P., & Oinonen, M.** (2010). Prehistoric population history in eastern Fennoscandia. *Journal of Archaeological Science*, 37(2), 251-260.
- Tashiro, Y.** (2017). ¹⁴C Dating Model of Satsumon Culture Period in Hokkaido. *Hokkaido Kokogaku* 53: 153-162. (In Japanese)
- Tauber, H.** (1981). ¹³C evidence for dietary habits of prehistoric man in Denmark. *Nature*, 292(5821), 332-333.
- Tsutaya, T., Naito, Y., Ishida, H., & Yoneda, M.** (2014). Carbon and nitrogen isotope analyses of human and dog diet in the Okhotsk culture: perspectives from the Moyoro site, Japan. *Anth Sci* 122(2):89-99, August 2014. <https://doi.org/10.1537/ase.140604>
- Utagawa, H.** (1999). The Archaeology of Iyomante. In: Fitzhugh W.W. and Dubreuil C.O. (eds.), *Ainu: Spirit of a Northern People*. National Museum of Natural History, Smithsonian Institution, Washington DC, p. 256-260.
- van der Plicht, J.** (1993). The Groningen radiocarbon calibration program. *Radiocarbon*, 35(1), 231-237.
- Vogel, J. C., & van der Merwe, N. J.** (1977). Isotopic evidence for early maize cultivation in New York State. *American Antiquity*, 238-242.
- Warinner, C., & Tuross, N.** (2010). Brief communication: Tissue isotopic enrichment associated with growth depression in a pig: Implications for archaeology and ecology.

American Journal of Physical Anthropology: *The Official Publication of the American Association of Physical Anthropologists*, 141(3), 486-493.

Watanabe, H. (1973). The Ainu ecosystem. Environment and group structure. *American (The) Ethnological Society*, Monograph Seattle, DC, (54), 1-170.

Watanobe, T., Ishiguro, N., Okumura, N., Nakano, M., Matsui, A., Hongo, H., & Ushiro, H. (2001). Ancient Mitochondrial DNA reveals the origin of sus scrofa from Rebun island, Japan. *J Mol Evol* (2001), 52:281-289.

Weber, A. W., Jordan, P., & Kato, H. (2013). Environmental change and cultural dynamics of Holocene hunter–gatherers in Northeast Asia: Comparative analyses and research potentials in Cis-Baikal (Siberia, Russia) and Hokkaido (Japan). *Quaternary International*, 290, 3-20.

Weninger, B., Edinborough, K., Clare, L., & Jöris, O. (2011). Concepts of probability in radiocarbon analysis. *Documenta Praehistorica*, 38, 1-20.

Williams, A. N. (2012). The use of summed radiocarbon probability distributions in archaeology: a review of methods. *Journal of Archaeological Science*, 39(3), 578-589.

Wintle, A. G. (1997). Luminescence dating: laboratory procedures and protocols. *Radiation measurements*, 27(5-6), 769-817.

Yamaura, K. (1998). The sea mammal hunting cultures of the Okhotsk Sea with special reference to Hokkaido prehistory. *Arctic Anthropology*, 321-334.

Yizhaq, M., Mintz, G., Cohen, I., Khalaily, H., Weiner, S., & Boaretto, E. (2005). Quality controlled radiocarbon dating of bones and charcoal from the early Pre-Pottery Neolithic B (PPNB) of Motza (Israel). *Radiocarbon*, 47(2), 193-206.

Yoneda, M., Hirota, M., Uchida, M., Uzawa, K., Tanaka, A., Shibata, Y., & Morita, M. (2001). Marine radiocarbon reservoir effect in the western North Pacific observed in archaeological fauna. *Radiocarbon*, 43(2A), 465-471.

Yoneda, M., Suzuki, R., Shibata, Y., Morita, M., Sukegawa, T., Shigehara, N., & Akazawa, T. (2004). Isotopic evidence of inland-water fishing by a Jomon population excavated from the Boji site, Nagano, Japan. *Journal of Archaeological Science*, 31(1), 97-107.

Yoshida, K., Kunikita, D., Miyazaki, Y., Nishida, Y., Miyao, T., & Matsuzaki, H. (2013). Dating and stable isotope analysis of charred residues on the Incipient Jomon pottery (Japan). *Radiocarbon*, 55(3), 1322-1333.

Appendix

Sammanfattning på svenska

I den här avhandlingen har jag undersökt organiska rester i forntida keramik för att rekonstruera förändring i matkultur hos kustlevande jägarsamlarsamhällen i norra Hokkaido under perioden 1750 f. Kr–1250 e. Kr. Den sena holocenperioden i denna region är mycket dynamisk och kännetecknas av omfattande migration och kulturell förändring. Forskningen om dessa processer har i allmänhet fokuserat på typologisk variation i keramik, en föremålskategori som var och en av periodens olika kulturer använde flitigt. Denna avhandling använder en ny metod och analys av organiska lämningar i keramiken för att undersöka mönster av kontinuitet och förändring i matlagningssätt, och använder sig av begreppet cuisine för att tolka resultaten. I synnerhet bildar Okhotsk-kulturer (400–1100 e. Kr) ett centralt fokus i avhandlingen; med sin komplexa djurkosmologi, sin mångsidiga försörjning och mångfacetterade hushållsaktivitet erbjuder den ett rikt sammanhang för att undersöka förändrade livsmedel.

Det huvudsakliga målet är att förstå långsiktiga och ”makro”-mönster i kontinuitet och förändring, och detta kräver också förbättring av befintliga kronologiska ramverk, som till stor del förlitar sig på keramiktypologier snarare än kol-14-datering. Förfining och förbättring av befintliga kronologier utgör därför det andra målet med avhandlingen. Det tredje målet är att undersöka matkulturen i en mer kontextuell ”mikroskala”. Det handlar om att studera hur keramikanvändningen organiserades rumsligt i det enskilda huset inom Okhotsk-kulturen, och hur dessa praktiker påverkades av sociala relationer och kosmologin kring interaktionen mellan människor och djur.

Den här avhandlingen består av en utökad introduktion, som sätter in forskningen i en bredare regional och kulturhistorisk miljö och presenterar också de viktigaste metoderna, begreppen och strategierna. Den centrala forskningsfrågan är huruvida den nära kopplingen mellan keramikanvändning och utnyttjandet av akvatiska resurser, som påbörjades redan under tidig holocen, fortfarande kvarstår i dessa kulturer under sen holocen. I avhandlingen adresseras denna fråga i fem tidskriftsartiklar, som fokuserar på de arkeologiska lokalerna Hamanaka 2, Kafukai 1 och 2, och Menashidomari. De övergripande resultaten indikerar att

det äldre mönstret började brytas ner och att en rad nya och mer mångsidiga matlagningssätt växte fram. Avhandlingen visar också att dessa viktiga förändringar i köket också kan knytas till kronologiska ramar med högre upplösning med nya metoder och analystekniker. Slutligen indikerar analysen på "mikroskalnivå" att kärnanvändningen inom ett enda hushåll återspeglar att strategisk skillnad gjordes mellan olika livsmedelskällor.

Samenvatting in het Nederlands

Organische resten die zijn achtergebleven in oud aardewerk worden in dit proefschrift gebruikt om de diversiteit en verandering in de voedselverwerking van laat-Holocene jager-verzamelaars gemeenschappen in het kustgebied van Noord-Hokkaido (1750 v.Chr.-1250 n.Chr.) te reconstrueren. De late Holocene-periode in deze regio was zeer dynamisch en werd gekenmerkt door migraties en culturele overgangen. Het onderzoek naar deze processen is over het algemeen gebaseerd op typologische variatie in aardewerk, dat veelvuldig is teruggevonden uit deze periode. De Okhotsk-culturen (400-1100 n.Chr.) vormen de focus van dit proefschrift. Hun complexe aanbidding van dieren, hun gevarieerde stijl van levensonderhoud en de veelzijdige huishoudelijke activiteiten bieden een rijke context om veranderende voedselgewoonten verder te onderzoeken. Het primaire doel is om patronen van continuïteit en verandering nader te begrijpen, zowel op de lange termijn als op een grote schaal. Dit vereiste een verbetering van de chronologie van de regio, die grotendeels berustte op aardewerk typologieën in plaats van koolstofdateringen. De grote vraag daarbij was of de nauwe samenhang tussen het gebruik van aardewerk en de verwerking van aquatische hulpbronnen in het vroege holocene, ook in deze laat-holocene culturen bleef voortbestaan. De conclusie in dit proefschrift is dat dit oude patroon verdween en dat er een grotere verscheidenheid aan aardewerk opkwam. Deze belangrijke verschuivingen in de keuken kunnen dankzij nieuwe onderzoeksmethoden beter gedateerd worden. Ten slotte suggereert de analyse binnen één huishouden dat er een differentiatie ontstond in gebruik van aardewerk bij het verwerken van verschillende voedselbronnen.

License Agreement

In agreement with the policies of the University of Groningen and Stockholm university, Articles II, III, IV and V and their contents in the present thesis are placed under embargo and are therefore exempt from any type of publication, unless authorized by the author of the thesis, until 30 September 2021.