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Food life history and cold storage in Greater Beringia. Part I: Preliminary interdisciplinary investigation

Kazuyuki Saito [a,c,*], Yoko Kugo [b], Michael Koskey [b], Go Iwahana [c], Yu Hirasawa [d], Shirow Tatsuzawa [e], Yuriy Zhegusov [f], Yamkhin Jambaljav [g], Theresa Arevgaq John [b]

[a] *Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa, Japan*
[b] *Center for Cross-Cultural Studies, University of Alaska Fairbanks, 1736 Tanana Loop, Fairbanks, AK, USA*
[c] *International Arctic Research Center, University of Alaska Fairbanks, 2160 Koyukuk Drive, Fairbanks, AK, USA*
[d] *University of East Asia, 2-1 Ichinomiya Gakuen Chou, Shimonoseki, Yamaguchi, Japan*
[e] *Hokkaido University, Kita 8, Nishi 5, Kita-ku, Sapporo, Hokkaido, Japan*
[f] *Institute for Biological Problems of Cryolithozone, Siberian Branch of the Russian Academy of Sciences, 41, Lenina Ave., Yakutsk, Sakha Republic, Russia*
[g] *Geocryo LLC, Oyutan Street 14/4, Sukhbaatar District, Ulaanbaatar, Mongolia*

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ABSTRACT

Cold storage of food using a natural cold environment (i.e., frozen ground, ice, snow, and freezing air) is globally found to be compatible with the local environment, and within the cultural traditions of communities. Our interdisciplinary project, focusing on four areas from Beringia (Alaska and easternmost Siberia) to the middle latitudes (Mongolia and Japan) of the northern hemisphere, aims to 1) document the variations and commonalities in the history, present situations, and future concerns of cold storage facilities, 2) review the roles and functionalities of the practice through the "Food Life History" concept, a new framework to address local food issues in a global context on the history of interactions between humanity and the environment, and 3) co-produce knowledge and strategies to facilitate cold storage practices for local adaptation to environmental and economic challenges. In this preliminary study conducted from 2021 to 2023, we initiated communication with local leaders and knowledge-bearers, examined current conditions, and installed temperature monitors in cold storage structures where available. The results illustrate the presence of practices of various types, specifications, and conditions, commonly challenged by environmental changes both natural (e.g., permafrost thawing and ground wetting) and social (e.g., modern technologies, education, and economy).

1. Introduction

Food is essential to life. The food system of a community, from procurement to transportation, storage, distribution, consumption, and disposal, is closely related to the local environmental condition of a community in a global context (Burgess, 2017; Foote, 1960; Jaine, 2014; Klein and Watson, 2016; Wong 2017), as well as in the regional context of the circumpolar North (Inuit Circumpolar Council Alaska (ICC-AK), 2020; Kishigami, 2013; Loring and Gerlach, 2009; Sakakibara, 2016; Yamin-Pasternak and Pasternak, 2021). Over the recent decades and centuries, local and global food systems have been strained by natural and social environmental changes. The natural environmental and climatic changes include warming and cooling, strengthened hydrological cycles (e.g., increased floods and severe droughts), permafrost thawing, changes in snow accumulation and ice formation, as well as changes in habitat and seasonality of harvests (IPCC, 2023; AMAP, 2011; 2017). Societal changes include colonization and globalization, such as the introduction of monetary and market economies, dependency on prevailing global supply chains, the spread of electricity and freezers, and changes in dietary habits (Moore 2016; Olstad et al., 2023; Scott, 2017).

Storage is an important element of the food system. Humanity has developed a variety of storage practices in different regions in accordance with the local natural conditions in terms of climate and food resources (Food Safety Network, 2009; Mandiwana, 2017; Nyland et al., 2017; Reynolds, 1993; Sunano, 2020; Testart et al., 1982; Wade, 1999). Cold storage using natural cold energy is a unique component of the specific food-related traditions and cultures in Greater Beringia, nurtured by local communities throughout their history. This creates a

* Corresponding author. Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa, Japan.
E-mail address: ksaito@jamstec.go.jp (K. Saito).

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sustainable interdependency between a community and its local natural environment.

In Arctic and Subarctic regions, despite limited ecological resources, winter provides sufficient cold for storage (Yamin-Pasternak and Pasternak, 2021), such as prevailing cold air temperatures, accumulation of snow, formation of ice on waterbodies, and freezing ground. The types, functions, and roles of traditional cold storage vary in development and usage, reflecting local natural conditions and societal needs (Dehghani-Sanij and Bahadori, 2021). For example, underground storage facilities with built structures (*buluus* in Sakha) are used in Siberia for family-based storage of harvests (game, fish, and local plants), as well as ice for drinking-water in summer (Yoshikawa et al., 2022; Maslakov et al., 2020). In Arctic and Subarctic Alaska, Iñupiaq and Saint Lawrence Islander Yupik people built similar facilities (*siġḷuat* in Iñupiaq and *siqlugaq* in Saint Lawrence Yupik); however, their sizes are relatively smaller than *buluus* in Siberia. They also use surface pits for cold storage to preserve and share locally harvested food and maintain their lifeways (Andrew, 2008; Binford, 1978; Burch, 2006; Campbell, 1998; Fienup-Riordan, 2007; Hughes, 1960; Jolles, 2003; Nyland et al., 2017; Spencer, 1976; Wolforth, 2015; Yamin-Pasternak et al., 2014). In Mongolia, large ice cellars (*moson zoori*) were built in Ulaanbaatar and other cities during the Soviet regime (Lonjid and Enkh-Amgalan, 2001). Japan has a history of cold storage practices of more than a thousand years, namely, *himuro*, which literally indicates "ice houses" but has conventionally included snow houses (Inoue, 1979; Kawamura, 2008; Takei, 2022). In addition are *fuketsu,* a natural landform on a gully slope that preserves winter cold air until the warm season, widely found from Kyushu to Hokkaido (Shimizu and Sawada, 2015; Shimizu et al., 2020).

Historically, local communities have maintained self-sufficient and sustainable lifeways under given local environmental conditions. In many cases, the communal ties and identities nurtured through sharing foods helped maintain such a way of life (Kishigami, 2021). Current food-related issues and conditions, including food security and food sovereignty, are derived through the long-maintained interdependency of humanity and environment in local and regional contexts. The current global way of life, as represented by urban lives depending on the global supply chain, is apparently facing a limit as the recent pandemic, the Russo-Ukrainian War, and global climate change revealed. We need to seriously reconsider locally sustainable alternatives. This alternative of natural cold storage is an important aspect of traditional practices that could enable the re-establishment or revitalization of the local community. Revitalization of cold storage is key to fostering sustainability and resilience to counteract the external, larger-scale environmental and socioeconomic changes. Moreover, natural cold energy is renewable; the sophistication of its use (e.g., more skillful management, introduction of locally appropriate and sustainable newer techniques and technology, and more efficient maintenance) can contribute to the decarbonization of energy production to possibly counter global warming, and to lessen dependency on external energy providers, which thereby provides increased energy security and sovereignty, and overall autonomy of local, often Indigenous, communities.

The research team developed a project in the context of the above-mentioned problem statement and research questions, funded by the Research Institute for Humanity and Nature (FY 2020-2022), and by the National Science Foundation (2022–2025). The project goals are to 1) document the variations and commonalities in the history, present situations, and future issues of these cold storage facilities, 2) review the roles and functionalities of the practice through the "Food Life History" concept, a new framework to address local food issues in a global context on interactive history of human and environment, and 3) co-produce knowledge and strategies to facilitate the practice for local adaptation to environmental and economic challenges. The project consists of an international, interdisciplinary research team from Japan, the United States of America, Russia, and Mongolia, whose expertise includes cultural anthropology, archaeology, sociology, preservation ecology, physical geography, permafrost science, climatology, and Indigenous knowledge systems.

This paper reports on the preliminary investigations on cold storage facilities conducted in Alaska, Siberia, Mongolia, and Japan, mainly from 2021 to 2023. The overall research plan and framework are described in Section 2.1, and background information of the study areas may be found in section 2.2. In section 2.3, we briefly explain the concept of "Food Life History," a guiding conceptual framework of the research project, and we provide the interdisciplinary approaches applied in the social and natural sciences in Section 2.4. Respective results from each study area, followed by overarching comparison and discussions, are provided in Section 4. Section 5 concludes with a comprehensive summary. In our preliminary investigations we found in all locales an interest in maintaining or revitalizing use of cold storage traditions in spite of climate and global economic changes amid increasing dependency on global markets.

2. Methods

2.1. Overall research framework

The research project includes an activity plan that commonly encompasses all four study areas, combining aspects of social and natural sciences. Table 1 schematically shows the overall research plan of the project, and the progress made as of the summer of 2023. The project utilizes standard research steps and approaches for all four areas, but their implementation strategy and procedures are different in each area, owing to differences in the nature of the cold storage practices, the background of local culture, history, and politics, and the socioeconomic and administrative systems. The study areas are described in detail in Section 2.2.

The left three columns in Table 1 denote the procedural steps for engaging local communities to develop a cooperative relationship and conduct research activities. Personal or individual consent suffices to conduct research activities of both social and natural science research in some areas (i.e., Siberia, Mongolia), while formal procedures and institutional approval, initiated in preliminary visits, are obligatory in other areas (i.e., Alaska, Japan). Research results and outcomes will be shared and discussed in all communities to ensure accuracy and transparency. As of the summer of 2023, this research stage was not completed in any of the four areas. We intend to complete this stage in 2024 in the Alaska region, and by 2026 in the other three regions.

Although we are conducting the project according to the respective disciplinary approaches of the social and natural sciences, we also intend to conduct our inquiries and analyses through a unified perspective and research framework. We do not intend to evaluate issues of natural cold storage as a mere collection of the separate examples of traditions that use a natural cold environment. Rather, we are working to find the commonalities and differences regarding the utilization of the surrounding natural resources by human beings. We begin with general comparisons to understand the capacity of these lifeways to endure challenges and maintain resiliency, in terms of food security and sovereignty, under conditions of global environmental change (Ford, 2009). For this objective, we needed to build a new framework that enables us to integrate and compare the differences in the food systems of different communities developed within different historical, socioeconomic, and political contexts, and under different environmental conditions at a global scale. This perspective, the "food life history" concept described in Section 2.3 below, constitutes a paradigm within which to combine and compare sometimes disparate results from different communities (culturally and geographically) in a context of global environment and human history. The results of the respective disciplinary approaches are listed in the middle and right column in Table 1 and are explained in Section 2.4.

Table 1
Overall plan of the research activities, and the current progresses and plans for each study area as of summer in 2023.

	Overall Procedures			Social Science			Natural Science		
Stages	Preliminary or informal visit, Personal survey	Formal or institutional visit, community meeting	Feedback to the surveyed	Oral history, Individual interview	Questionnaires, Census of households, group interview	Analysis	Installment	Data retrieval	Analysis
Area									
Alaska									
Anaktuvuk Pass (AP) Gambell (GB) Savoonga (SV) Point Hope (PH)	AP, GB, SV, PH	AP, GB, SV, PH	Not started yet	AP, GB, SV (2022, 2023) PH (planned in 2024)	Not planned	Ongoing	AP (1, 2023)GB (2, 2022)SV (ongoing)PH (3, 2023)	Planned in 2024	Not started yet
Siberia									
Tattinsky (TT) Verkhnevilyuisky (VN) Megino (MG) Churapchinsky (CH) Yakutsk (YK)	TT, VN	N/A	Not started yet	Not planned	TT (2021) VN (2022)	Ongoing	TT (6, 2021-22) VN (4, 2022), MG (2, 2021) CH (2, 2023) YK (2, 2023)	Planned in 2024	Not started yet
Mongolia									
Tsagaannuur (TS) Ulaanbaatar (UL)	UL, TS	N/A	Not started yet	Not started yet	Not started yet	Not started yet	UL (2019)TS (2024)	UL (2026), TS(2026)	Not started yet
Japan									
Hasedani (HS) Yuwaku (YW)	YW, HS	Not started yet	Not started yet	Not started yet	Not started yet	Not started yet	YW (planned in 2024)	Planned in 2026	Not started yet

2.2. Study areas

This project focuses on areas extending from Siberia to Alaska, the "divided twins" of Beringia, to the middle latitudes, where the practices and facilities of cold storage are found. We treat the area as "Greater Beringia." We conducted preliminary investigations in these areas, namely Alaska, eastern Siberia, Mongolia, and Japan. This section provides a basic background description for each area.

2.2.1. Alaska

Alaska study communities include Gambell (*Sivuqaq*) and Savoonga (*Sivungaq*) on Saint Lawrence Island in the Bering Sea, Point Hope (*Tikiġaq*) on Alaska's northwest coast, and Anaktuvuk Pass (*Anaqtuuvak*) in Alaska's central Brooks Range (Fig. 1a). The population (estimated in 2022 by the United States Census Bureau) is 626 in Gambell, 814 in Savoonga, 805 in Point Hope, and 415 in Anaktuvuk Pass. The minimum recorded temperature on Saint Lawrence Island in the period from 1991 to 1999 was −24 °C, but no annual total precipitation data was reported (Gambell Airport, National Oceanic and Atmospheric Administration, 2024). The historical seasonal temperatures (1950–2009) range between −26.5 °C and 10.0 °C in Point Hope, and −31.4 °C and 12.5 °C in Anaktuvuk Pass, while the respective annual total precipitation is 228 and 334 in millimeters, according to the reanalysis data (Northern Climate Reports, 2024; Walsh et al., 2018).

On Saint Lawrence Island, the main use of underground food storage facilities is to store and ferment walrus meat. Saint Lawrence Island Yupik people hunt whales, walrus, other marine mammals, migratory birds, plants, and reindeer, the latter of which the US government introduced in the early 1900s (Houlette, 2009; Hughes, 1960). The underground food storage facility is called a *siqlugaq* in the Saint Lawrence Island Yupik language, a variation of what linguists call "Siberian Yupik." It is nearly identical to the nearest Siberian Yupik language spoken on the eastern coasts of the Chukchi Peninsula of the Russian Far East (sometimes called "eastern Siberia").

The people of Point Hope (*Tikiġaq*), who are coastal Iñupiat (*Taġiuġmiut*), have hunted and lived with bowhead whales, bearded seals, other marine mammals, fish, migratory birds, caribou and other sources of wild food in their region for many generations (Foote, 1992; Sakakibara, 2020). The coastal Iñupiat store whale blubber and meat in specific ways, as well as other seafood, in underground caches, which are called *siġḷuat* (pl.) in their Iñupiaq language.

In contrast, Inland Iñupiat (*Nunamiut*) in Anaktuvuk Pass traditionally stored food in small semi-subterranean caches and/or pits along trails. After the *Nunamiut* settled at the current location of Anaktuvuk Pass in the 1940s and 1950s, the community leaders built three community cellars (*hiġḷuat* (pl.)) to store caribou in 1949 (Campbell, 1998; Ingstad, 1954). Residents stopped using the *hiġḷuaq* (sg.) in the late 1970s in part due to the arrival of electricity and the electric freezer. Three cellars have been identified by the community and research team, all of which are currently inundated (Fig. 2a).

2.2.2. Siberia

For this project, we focus on interior eastern Siberia, specifically communities in the Sakha Republic of the Russian Federation. The major type of ice cellar (*lédniki* (pl.) in Russian and *buluustar* (pl.) in Sakha) in this region is built underground with one or more chambers with a height of about 2 m and equipped with a vertical entry with ladders, or a slanted entry with steps (Fig. 2c–d). Sakha residents store their harvests (game, fish, and local plants) and ice for drinking-water in summer in the ice cellars. A *buluus* (sg.) in this region is owned and maintained by families. This family ownership is different from large community ice cellars in eastern Chukotka that were constructed under the socialist regime (Maslakov et al., 2020; Yoshikawa et al., 2016, 2022).

Preliminary investigations were conducted in 2021 and 2022 in two inland districts (*uluses*) near Yakutsk in the Sakha Republic: the Tattinsky and Verkhnevilyuisky *uluses* (Fig. 1a). Tattinsky *ulus* (Google Map, 2023a, Fig. 1a) is located on the right bank of the Lena River. It has a population of 17,242 (2010 Census. Russian Federal State Statistics Service, 2011), and its primary economy is agriculture, including animal husbandry and cultivation. The climate is very continental. The range of average monthly temperatures is from −40.8 °C in January to 20.2 °C in July. The average minimum temperature is −43.7 °C observed in January. Annual precipitation is 139 mm (observations at Yakutsk Airport, 62.1°N, 129.8°E, between 2019 and 2023). The other district

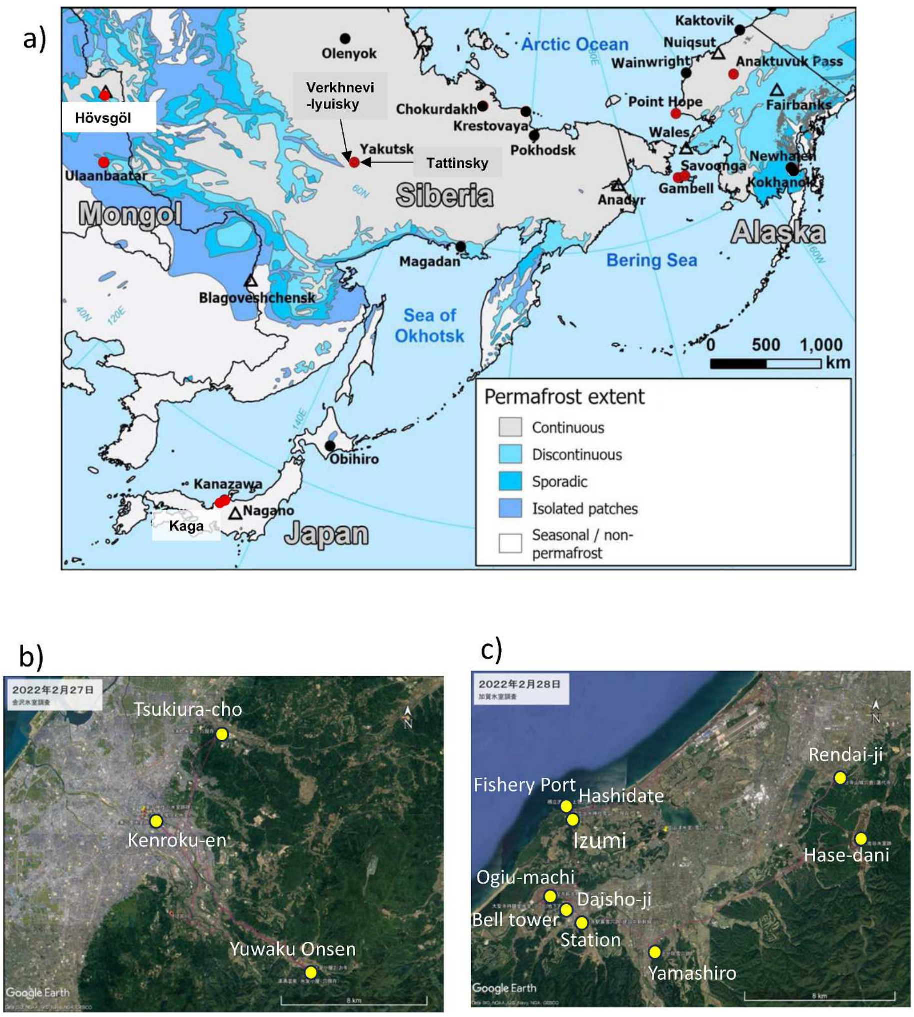

Fig. 1. a) Map of the target sites in Greater Beringia. Red-filled circles show the sites visited in the preliminary study. b) Map of the snow pits and snow houses in Kanazawa City visited for the preliminary investigation. c) Same as b) except for Kaga City. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

surveyed, Verkhnevilyuisky *ulus* (Google Map, 2023b; Fig. 1a) is located on the left bank of the Lena River. It has a population of 21,661 (2010 Census), its primary economy is agriculture, including animal husbandry and forestry. This district also has a very continental climate. The range of average monthly temperatures is −29.9 °C in January and 24.1 °C in July. The average minimum temperature is −35.1 °C observed in January. Annual precipitation is 200 mm (observations at Mirny Airport, 62.5°N, 114.0°E, between 2019 and 2023).

2.2.3. Mongolia

Mongolia has an extreme continental climate because of its high altitude and location far from oceans. Winters in the northern regions are cold and short with temperatures dropping down to −30 °C, while the southern dry region, particularly in the Gobi Desert, experiences warm summers. The frozen ground extends widely from the continuous permafrost zone in the northern highlands through discontinuous and sporadic permafrost zones in the middle plains to the southern regions of seasonally frozen ground. In 1961, the first ice cellar was built in Ulaanbaatar, the capital of Mongolia (Lonjid and Enkh-Amgalan, 2001). Between 1961 and 1988, twelve ice cellars were built in Ulaanbaatar and twelve more ice cellars were built in rural areas in northern Mongolia. A Mongolian ice cellar (*moson zoori*, where *moson* literally translates as ice and *zoori* as cellar) is constructed with river ice, contains multiple rooms, and is usually located partly underground. Mostly meat products are stored there (Fig. 3a). The aboveground parts are covered by thermally insulating materials such as ash (40 cm thick), scrap wood (60 cm thick), and clay (20 cm thick). Storage capacity is between 30 and 2000 tons. Recently, a family-managed cellar (*zoori*) still in active use was found in the regional (*sum*) center of Tsagaannuur, a northern village also referred to Tsagaannuur.

In this study, cold storage practices were investigated for preliminary and preparatory purposes in two areas, one in the city of Ulaanbaatar, and the other in the northern village Tsagaannuur in Tsagaannuur district (*sum*), Hövsgöl Province (*aimag*) (Fig. 1a). The city of Ulaanbaatar has a close to 1.6 million residents while Tsagaannuur has 1978 residents (National Statistics Office, Mongolia, 2024). Ulaanbaatar has a monthly mean temperature in the coldest month (January) of −21.3 °C, and in the warmest month (July) of 16.5 °C, with the coldest air temperature at −25.6 °C, and a total annual precipitation of 260 mm. For Hövsgöl Province, the monthly mean temperature of the coldest month (January) is −23.3 °C, and of the warmest month (July) is 13.2 °C (observed at the Khatgal meteorological station, Hövsgöl). The coldest recorded air temperature is −29.4 °C, and the total annual precipitation is 313.9 mm (Climatology for 1991–2020 by World Meteorological Organization, National Oceanic and Atmospheric Administration, 2023).

2.2.4. Japan

Japan, extending from the subtropical to subarctic climate zones, lies within areas ranging from no ground freezing to seasonally frozen

Fig. 2. Underground cache facilities in a) Anaktuvuk Pass (Alaska), and b) Gambell (Alaska). c) Entrance and d) inside of a *buluus* in Ytyk-Kyuel (Tattisky *ulus*).

ground (except for azonal permafrost at high altitudes). Located in the middle latitudes (ca. 35–45°N), the main island, Honshu, has contrasting snow conditions between the western (facing the Sea of Japan) and eastern (facing the Pacific Ocean) sides of the island. Weather consists of cloudy winters with heavy snow accumulation to the west, and clear-sky winters with a little snowfall to the east. These contrasting snow conditions led to the development of different techniques for preserving cold during the warm seasons. Accumulated snow was used on the western side while ice on the ponds was used on the eastern side. *Himuro* (including both ice houses and snow houses) and *fuketsu* are found in many areas from Kyushu, Japan's southwestern island, to Hokkaido, Japan's northern island (Shimizu et al., 2020; Takei, 2022).

Ice formed in ponds or accumulated snow was stored in *himuro* until the following summer to be used for ritual or diplomatic purposes in the imperial courts (i.e., in the ancient to medieval periods) and shogunate system (i.e., in early modern periods; Inoue, 1979; Kawamura, 2008; Takei, 2022). Together with *fuketsu*, these natural landforms were extensively used for sericulture (silk farming) in the Meiji and Taisho eras (late 19th to early 20th century), which was a major industry at the time, to store silkworm eggs as well as foods (Shimizu and Sawada, 2015; Shimizu et al., 2020). Arafune and Azumaya *fuketsu* in Tochigi were designated as national historical remains in 2010 and constitute the World Heritage Site "Tomioka Silk Mill and Related Sites'' designated in 2016 for its sericultural importance to the preservation of silkworm eggs (International Council on Monuments and Sites, 2014).

Traditional forms of renewable energy systems of *himuro* and *fuketsu* generally declined due to their locations in remote mountainous areas, and due to the spread of electric refrigerators alongside rural depopulation until the 1960s. A movement to utilize natural cold through the application of science and technology has been underway since the 1990s (Takei, 2022). Examples include the use of heavy machinery and snow containers, ice formation by freezing air (ice shelters), and the use of the cold energy of snow and ice in combination with electrical energy (Kimura et al., 2020; Ministry of Economy, Trade and Industry Hokkaido Bureau of Economy, Trade and Industry, 2012).

The research focus of this portion of this study is relict snow pits and restored snow houses in Kanazawa and Kaga cities, Ishikawa prefecture, on the Sea of Japan side of Honshu. The area belongs to the region of snow houses that use snow for preserving coldness (Takei, 2022). The population as of May 1, 2023, is 458,460 in Kanazawa and 60,783 in Kaga (Ishikawa Prefecture, 2023). Kanazawa has an average total annual precipitation of 2402 mm, of which snowfall is 157 cm. The mean temperature in the coldest (January) and warmest (August) months is 4.0 °C and 27.3 °C, respectively, with the mean daily minimum temperature being 1.2 °C in January (Kanazawa for 1991 to 2020. Japan Meteorological Agency, 2023).

In each of the four study areas above—Alaska, Siberia (Sakha), Mongolia, and Japan—cold climate or cold weather conditions enable the use of cold storage, primarily for food preservation (Lobanov et al., 2019). However, cultural differences between these four regions are many, and in each region local cultures have adapted their cold storage techniques to natural local environmental conditions. In order to meaningfully compare conditions and techniques of cold storage among culturally disparate people, the need for a common framework for analysis was apparent, and so we are developing the "food life history" concept to facilitate this analysis.

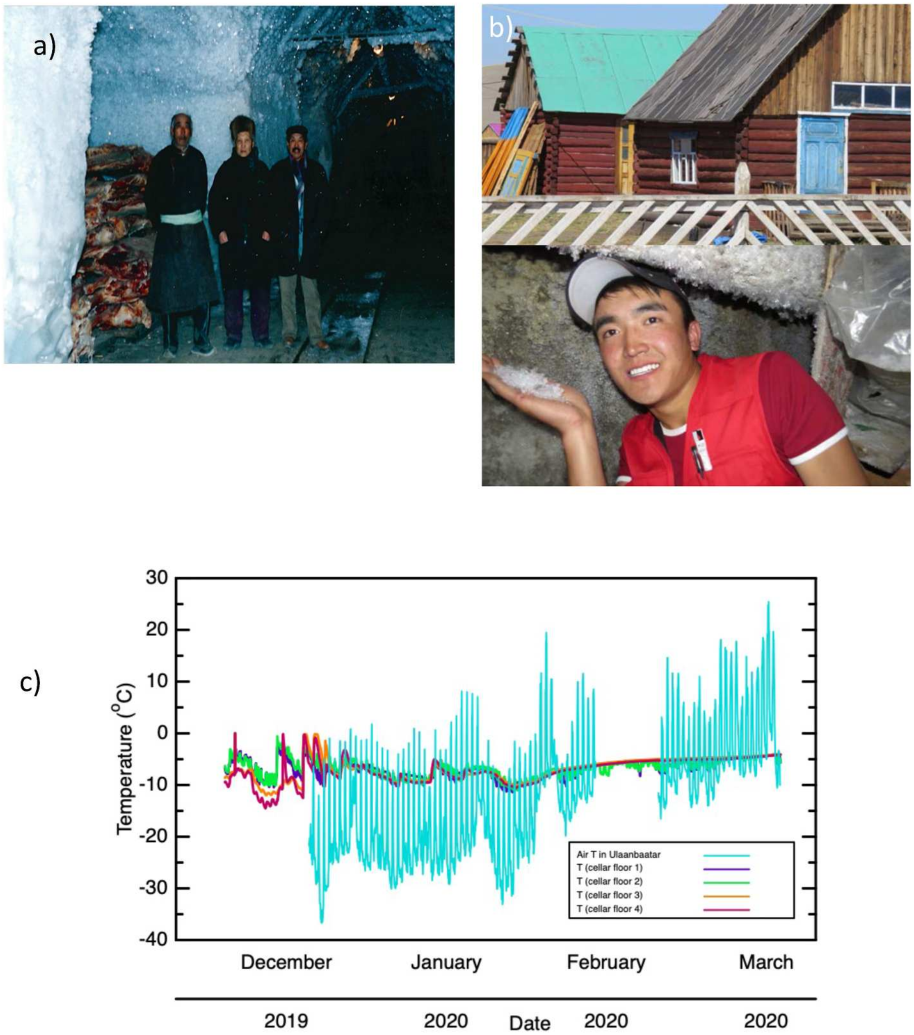

Fig. 3. a) Ice cellars in Mongolia: large city cellar in Ulaanbaatar. b) family-managed cellar in the northern region. c) Air and cellar floor temperatures in Ulaanbaatar for the winter of 2019–2020.

2.3. Food life history

Food Life History (hereafter referred to as FLH) is a developing conceptual framework for the research project. This experimental holistic concept seeks to evaluate humanity, food, food resources (i.e., animals and plants), and the natural environment, in relation to local and global factors. Food is one of the most fundamental needs for living organisms, including human beings. The study of food security and food sovereignty, especially as concerns Indigenous communities' well-being, requires a comprehensive understanding of a research community through multidisciplinary approaches, together with their internal (intrinsic, local) and external (adventive, global) influences (Garine, 2022). This requires deep local ecological and sociological knowledge, and awareness and understanding of these local perspectives, to assess sociocultural and socioecological conditions adequately and accurately (Gerlach and Loring, 2013). The FLH concept works as a hypothetical framework to address how we might most effectively theoretically view and investigate the relationship between the global natural and social environments and local food issues of diverse cultures. It will facilitate otherwise difficult comparisons between very different cases in different communities and lifeways (e.g., northern and tropical Indigenous communities, Indigenous and urban lifeways, lifeways before and after electricity). In the following, we provide a brief description of FLH.

In the past, global environmental and food issues have been discussed in terms of "food resource supply," "food production" (especially agriculture), and "food security" (Djekic et al., 2018; Ericksen, 2008; Godfray et al., 2010; Lynn et al., 2013). In the effort to attain maximum efficiency within the globalized food resource distribution network and the world food system that supports urban consumption (from acquisition/production to transportation, distribution, consumption, and disposal of food), long-existing local food production systems have been marginalized as part of the justification to solve global-scale problems (e.g., Gerlach and Loring, 2013; Inuit Circumpolar Council Alaska (ICC-AK), 2015; Porter et al., 2014). Environmental issues, which have been a common concern for all humankind since the early 19th century, with widespread awareness in the second half of the 20th century, form the basis of the fundamental question of how to devise and integrate a global approach to solving global-scale problems. This question, alongside a focused approach to dealing with specific local problems, remains unanswered (Brosius, 1999; Bonneuil and Fressoz, 2016). It is important to note that we may fall into a similar dilemma when examining topics and relationships of food and the environment. The more we consider ways to solve global problems across political, economic, and geographic borders, the more we are forced to focus on global homogeneity and uniformity from the moral perspective of equality and equity. As a result, within the context above, the diverse local food systems and environmental adaptation systems that were formed in diverse environments tend to be neglected and undervalued (Menezes, 2001; Pottier, 1999). On the other hand, no matter how many individual local cases are accumulated with an emphasis on regional differences and characteristics, it is difficult to generalize or synthesize the global-scale environmental and food problems. Ideally, a framework is required that allows for the generalization of the problem and the logical connection of cases from different regions with different conditions. As it is global processes (global climate change and economic globalism) that are causing changes that are experienced locally, and in local socio-ecological contexts, local challenges and conditions are inextricably tied to these global processes and therefore share potential solutions. The local context also potentially reveals local solutions for resilience and sustainability that might be transferable to other communities facing similar challenges caused by the same global processes (Mintz and Du Bois, 2002).

Attempts to integrate natural and social sciences concerning ecological and environmental issues (Scoones, 1999) and food systems (Ericksen, 2008) have been conducted in the fields of anthropology and ecosystemic studies. These studies suggest the importance of perceiving food and environment as potentially unbalanced and complex, requiring a broad framework to understand the systems. Ericksen's model of food system components is especially significant when we consider bridging local and global and environmental and social food-related issues (Ericksen, 2008: Fig. 1). However, these prior studies did not include Indigenous and minority cultures, food resources, and regional diversity of available resources, due to colonial contexts (Whyte, 2016). Upon the above-mentioned background and scope of the research questions, we built a working framework, Food Life History (FLH), which embraces food-related issues such as security, sovereignty, and foodways, but also ecological and climatological viewpoints (Martens et al., 2016; McMichael, 2014; Polis et al., 1997). Below, we discuss three aspects of the framework.

The first aspect of FLH is the life history of food resources. Plants and animals, both wild and domesticated, are food resources for human beings but have their own individual life histories. In other words, each species has its own habitat, seasonality and phenology, and population size, influenced by current conditions and affected by the changes in the natural and social environments. These conditions vary from region to region, from time to time, and include the activities of human and non-human entities (i.e., plants, animals, and in many worldviews, spirits). Therefore, human food resources and the cultural activities related to food are greatly influenced by various environmental factors surrounding the resources, such as climate, landscape, ecology, and sociality. For this aspect, natural science approaches such as animal and plant ecology, geography, climatology, and oceanography play important roles in the investigation of the status of food resources.

The second aspect of FLH is human food life, i.e., food traditions and their history. This aspect emphasizes the life history and activities of human beings, such as the sociocultural effects of spiritual ties between specific food resources and human groups, and group identity represented by food, in addition to food safety and distribution traditions, which have already received much attention (Jolles, 2003; Loring and Gerlach, 2009; Olstad et al., 2023). Cultural anthropology and archaeology, among other social sciences, have conducted comprehensive studies on food histories and practices of specific cultures (Chrzan, 2022a, 2022b; Jaine, 2014; Klein and Watson, 2016; Mintz and Du Bois, 2002). When discussing the food system for humanity (i.e., production, processing, transportation, distribution, and consumption), the issues tend to be simplified or overly generalized, and the perspective is often biased toward the global (Office of Assistant Director-General (Economic and Social Department), 1999). The examinations of local histories and evaluations of food systems need to be considered equally, such as how food is acquired, processed, transported, stored, distributed, exchanged, consumed, and disposed of, the spiritual practices and traditions involved, and the education (skill-building and other cultural knowledge) required to pass this knowledge onto the next generation (Nyéléni 2007 International Steering Committee, 2007; ICC-AK. 2015, 2020).

The third aspect of FLH emphasizes a theoretical shift toward a postmodern paradigm of scholarship and thought. It has been argued that a departure from the dichotomous ways of thinking generated by modernity is necessary (Descola, 2013; Scott, 2009). This includes such dichotomies as those between academic knowledge based on Western frameworks of thought and Indigenous knowledge, between state and people, or nature and culture, or city (metropole) and periphery, and so on. We are aware that it is impracticable to solve a problem created by modernity within a modern academic framework of thought. Thus, we need to critique modern academic dichotomous thinking, as well as to seek diverse solutions that address the fundamental elements of the problems.

Since FLH is a newly developed concept intended to address food culture issues and the causes of related changes, in non-dichotomous ways, it is necessary to determine the validity and applicability of the concept by examining specific cases and by conducting detailed theoretical verification through research such as that described in this paper.

2.4. Interdisciplinary approaches

This project cooperatively uses field techniques, combining social and natural science approaches, and is informed by local, traditional, and Indigenous knowledge. The expertise of our group includes cultural anthropology, archaeology, preservation ecology, permafrost science, and climatology. These are augmented by learning and comprehending, within local worldview contexts, local traditional Indigenous knowledge.

Researchers prepared for the regional and national institutional and/or administrative requirements to conduct research activities. These procedures vary in the four study areas. In Alaska, it is required to obtain written consent from the potential participating communities, and to be authorized by the Institutional Review Board (IRB) for ethical compliance prior to conducting the field study. Our Alaska research team communicated through phone calls and emails to contact potential study communities to identify partnering communities. We met Alaska Native tribal councils, city governments, and Alaska Native corporations to exchange ideas and learn about their interests in the project to inform us prior to writing and submitting the research proposal, which was authorized by IRB of the University of Alaska Fairbanks. In Siberia (Sakha), special permission to conduct sociological surveys among the population other than special contingents (minors, prisoners, military personnel, intelligence officers) is not required according to the legislation of the Russian Federation. The researcher is given complete freedom for scientific creativity; everything depends on the capabilities of the scientist and the goodwill of the respondents. It is similar in Mongolia. In Japan, no institutional or administrative authorization is required. Access to the study sites were granted through the support of the local researcher, Professor Iwao Takei.

2.4.1. Social science methods

The social science approach includes community-based participatory research, oral history interviews, participant observation, and sociocultural surveys. Because of the differences in the human-concerned research environment and conditions among the study areas, the methods are described separately for each area below.

Our Alaska research team has used community-based research (CBR), and community-based participatory research (CBPR). A principle of community-based engagement is to establish trust with the partner community. Engaging with community research participants (e.g., knowledge-holders such as Elders) helps researchers to gain insider perspectives and enhance the community's well-being by encouraging the study community to identify and pursue their own goals for the project (Koskey, 2020; Kugo, 2021). Through this engagement, the goals of the community and the goals of the academic researcher are brought into alignment through the efforts of the research project itself. CBPR lends itself well to pursuit of the three goals of the project on cold storage under climate and social change. Researchers engage with local practices by watching and participating in regular activities (participant observation), while interacting with community members through interviews, community meetings, and conversations with knowledge-bearers at the site of cold storage facilities enhances the depth and breadth of the knowledge recalled and discovered. A CBPR approach allows researchers and study communities to co-benefit from developing the research design collaboratively, as well as by conducting the research and analysis as cooperative research partners (Cochran et al., 2008; Norton and Manson, 1996). This method, then, increases the likelihood that the research furthers community interests and benefits the community while co-producing the knowledge and strategies for more feasible future facilitation and partnerships for research.

In Alaska, we conducted participant observation and oral history interviews with knowledge-holders in four communities: Gambell (11 respondents), Savoonga (5 respondents), Point Hope (9 respondents), and Anaktuvuk Pass (10 respondents), using a CBPR approach. Our open-ended interview questions focused on the use of underground food storage practices that have changed due to rapid environmental fluctuations, such as permafrost thawing and changes in moisture conditions, and the arrival of non-local education, technologies, and economy (Koskey and Kugo, 2023). Their interviews are transcribed verbatim, and words from Indigenous languages are translated by local language translator(s).

In Siberia, the first surveys by questionnaires (sociological surveys) were conducted on the use of underground cold storage in two inland districts in the Sakha Republic, namely Tattinsky (143 respondents) and Verkhnevilyuisky (74 respondents) *uluses*. Before compiling the questionnaire, several pilot interviews were conducted with ice cellar owners. These interviews identified key issues related to the use of ice cellars, as well as emerging problems with food storage due to various reasons, including climate change. Based on the information received, the structure and questions of the sociological questionnaire were compiled. The survey was conducted using Google forms using the snowball sampling method. A respondent who took part in the survey reposted the link to another owner of a *buluus*, and they, in turn, forwarded the questionnaire to their next friend. Personal social networks were also used to look for suitable respondents from their village. Paper questionnaires were also used among focus group participants.

In Mongolia, no systematic field investigation of cold storage facilities was conducted before this project. Information on the previous use of large ice cellars (*mozon zoori*) were investigated by literature review. A preliminary visit was made in the northern highlands of Mongolia to document a family-managed cellar (*zoori*) that is still in use.

In Japan, we surveyed the cases of the traditional *himuro*, both active and abandoned, for historical and geographical aspects, and current conditions. The research team visited the restored snow house in Yuwaku Onsen, Kanazawa, Ishikawa Prefecture (#2 in Table 2) to establish a relationship with the local stakeholders to conduct a future investigation; however, no social scientific investigation was conducted during this period of the study in Japan.

2.4.2. Natural science methods

The natural science methodology includes (1) monitoring of the physical conditions (e.g., temperatures, humidity, and light intensities) and chemical compositions (e.g., carbon dioxide), (2) field survey for geometry, micro-topography, and geography of the facility and the surrounding environment in permafrost regions, and (3) sampling of ground cores within and outside of the cold storage facilities. Below we describe the overall observation plans in the project and the details of investigations conducted during this period.

The physical conditions of the subterranean food storage facilities are monitored by sets of loggers and sensors. During this period of the study, we installed temperature sensors and loggers in the cellars or their surroundings with permission from the facility owners in the project villages of Alaska (2 in Gambell, 3 in Point Hope, and 1 in Anaktuvuk Pass) and Siberia (6 in Tattinsky *ulus*, 4 in Verkhnevilyuisky *ulus*, 2 in Megino *ulus*, 2 in Churapchinsky *ulus*, and 2 in Yakutsk, Sakha Republic). The equipment was either temperature/light intensity loggers (MX2202, Onset) or temperature/relative humidity/light intensity loggers (MX1104, Onset) to measure at one-to-ten-minute intervals and to record the hourly statistics (maximum, minimum, average, and standard deviation). In Mongolia, data was collected from a logger (UX120-006 M, Onset) that was installed in advance to monitor temperatures inside of the cellar in Ulaanbaatar.

Table 2
List of the Snow houses and snow pits visited in Kanazawa and Kaga Cities, Japan.

#	Day[a]	Location	City	Remark
1	1	Kenroku-en	Kanazawa	Relict snow pit (Fig. 5a). #5 in Table[b]
2	1	Yuwaku Onsen	Kanazawa	Restored *himuro* (Fig. 5b). #25 in Table[b]
3	1	Tsukiura-cho	Kanazawa	Relict snow pit (Fig. 5c). #23 in Table[b]
4	2	Rendai-ji Mountain Castle	Kaga	Relict snow pit (Fig. 5d).
5	2	Hase-dani	Kaga	Relict snow pit (Fig. 5e). Snapshots from the 3D model are shown in Fig. 5l-m.
6	2	Yamashiro Ex-military hospital	Kaga	Relict snow pit (Fig. 5f).
7	2	Daisho-ji Station	Kaga	Relict snow pit on a hill behind the station (Fig. 5g).
8	2	Daisho-ji Ogiu-machi	Kaga	Relict snow pit (Fig. 5h). #2 in Table[b]
9	2	Daisho-ji Bell tower	Kaga	Restored *himuro* (Fig. 5i). #23 in Table[b]
10	2	Hashidate Izumi Shrine	Kaga	Relict snow pit (Fig. 5j). #7 in Table[b]
11	2	Hashidate fishery port	Kaga	Relict snow pit (Fig. 5k). #5 in Table[b]

[a] : Day 1: February 27, 2022. Day 2: February 28, 2022.
[b] : Table 1 in Takei et al. (2009). Number (#) is taken from the list for respective cities.

LiDAR (Light Detection and Ranging) and SfM (Structure from Motion)/MVS (Multi-View Stereo) with handy scanners and aerial photographs are used to capture the three-dimensional structure of the cold storage facilities, where possible, so that the physical conditions, dimensions (depth, width, shape), building techniques, and geographic orientation can be compared. In 2022, a preliminary aerial survey using an unmanned aerial vehicle (UAV) was conducted at the Hasedani snow pit in Ishikawa Prefecture, Japan, in addition to photographic documentation of the relict pits and restored snow houses listed in the literature (Takei et al., 2009; Takei, 2022. See Table 2).

The project also includes plans to collect frozen sediment samples at some representative locations around the project communities in the permafrost region (near subterranean cold storage or intact land near the communities) to understand the constituents of permafrost, which will be released into the atmosphere or surrounding aquatic system. The collected permafrost samples are used to analyze water geochemistry and identify ice, greenhouse gas, and organic matter contents. The monitoring system for ground temperature is also installed into the boreholes made by the sampling activities. However, it was not conducted at any sites during this period of the study.

3. Results and discussions

This section reports the results and discusses our preliminary research conducted from 2021 to 2023 for each of the four project regions, with a focus on social science analyses due to ongoing data collection conducted by the project's natural scientists. Social science data collection and analyses are based on interviews from Alaska, household surveys from Sakha (Siberia), and cultural observations in Alaska, Sakha, Mongolia, and Japan. In Alaska, social scientists conducted oral interviews with the knowledge-holders on the use of underground food storage practices while natural scientists investigated permafrost conditions and the likelihood of thawing in areas critical to existing or future underground cold storage facilities, and in these they installed temperature sensors. In Siberia, the sociologist with local assistants conducted surveys by questionnaire on the use of underground cold storage in two inland districts in the Sakha Republic, and installed temperature monitoring in several ice cellars. The Mongolian researcher performed temperature monitoring in an ice cellar in Ulaanbaatar, Mongolia, and visited for a preliminary investigation a new cold storage structure in northern Mongolia that is still in use today. The Japanese team visited some relict pits and restored snow houses in Ishikawa Prefecture, Japan, to document them by photography and aerial survey using a UAV. An overall discussion regarding comparisons across the regions follows at the end of this section.

3.1. Alaska

Through the interviews and community meetings in Gambell, Savoonga, Point Hope, and Anaktuvuk Pass in 2022 and 2023, community members reported difficulties maintaining the cellars due to the landscape changes (erosion and permafrost thawing) and the arrival of modern freezers and transportation (snowmobiles replacing dog teams). The time of the arrival of modern technology was similar across communities, and respondents reported similar changes in lifeways, such as how people started working in wage labor jobs that limited their access to hunting and seasonal camping, but which were needed to purchase modern equipment and gasoline for hunting and fishing.

In 2021 and 2022, we conducted a total of nine interviews (three in Anaktuvuk Pass and six in Gambell). The community respondents included two females and seven males between their late 60s and early 90s in age. Some of the responses from the respondents' stories indicate the changes in food lifeways, and these are directly tied to the global climate and economic changes discussed above. One Gambell Elder reported that "[She] grew up with it [*siqlugaq*]." However, many Elders recognized that "the weather is getting warmer and warmer" and winter has been getting short (from multiple Gambell Elders interviews, May 2022). A Point Hope whaling captain reported that electric freezers keep the whale meat tasting good, but it does not have the *si ġ ḷuaq* taste that we like (Point Hope whaling captain, interview, June 2023). While Saint Lawrence Islanders maintain their *siqlugaq* (underground meat cache. Fig. 2b) within family and clan systems, whaling captains and their families maintain and use *siġḷuat* (sg: *siġḷuaq*) in Point Hope. The Inland Iñupiaq (*Nunamiut*) of Anaktuvuk Pass possessed three community cellars, abandoned in the 1980s and now inundated, and explained that different cellars were used for different kinds of storage items (e.g., caribou meat, other land animals, sea animals, and berries), and/or were used by specific families. Our preliminary analyses led to a revision of our interview questions, and we returned to the Alaskan communities in 2023 to seek answers to new questions emerging from the data. Among other topics, these included discussions on how the results of the research could be best utilized by each community, and what might be done to revitalize underground cold storage traditions in some communities, while working to ensure their continued healthy use in other communities, including concerns about inorganic contaminants.

During fieldwork conducted in the spring and summer of 2023 for approximately two to three weeks in each community, we conducted oral history interviews, followed up with respondents concerning their previous interviews, observed and participated in local activities, and presented our preliminary findings at the community halls and local school classrooms. Based on our previous visits, we approached the four communities according to their cultural protocols for cooperative research, including their specific community goals for the research. We introduced a community-based approach alongside variations necessitated by place-specific differences. In Point Hope, fieldwork was conducted during the *Qagruq* (Whale Feast), including oral interviews, and we learned about local traditions and customs through participation in food preparation and gathering during the feast. During and after *Qagruq*, whaling captains who own or use cellars to store whale meat and whale tails in *siġḷuat* expressed concerns about the current conditions of *siġḷuat* because of erosion, permafrost thawing, rodents, or other small burrowing animals. The coastal Iñupiat (*Taġiuġmiut*) prefer to store the blubber and meat in *siġḷuat* to age and/or ferment for the flavor that Elders prefer, rather than storing them in modern freezers, which does not allow for obtaining of the preferred flavor since it often overfreezes and dries the meat (freezer-burn), losing the natural flavor acquired by aging and fermentation. Maintaining and repairing a *siġḷuaq* is the whaling captains' and *siġḷuaq* owners' responsibility, and it culturally and physically ties to community well-being through meat sharing at seasonal feasts. In Anaktuvuk Pass, upon receiving permission from local Elders and board members of the City and Native Village of Anaktuvuk Pass, water (drained from thawed permafrost, melted ice, and rain leakage) was removed by an electric pump with the help of local assistants. Water was removed from one of the remaining community cellars in July 2023 to examine the possibility for repairing or constructing a new ice cellar in the community.

During the preliminary period, the project's natural scientists started observations in Alaska, but no results have been collected. The data of ongoing measurements conducted at 2 cellars in Gambell, 3 in Point Hope, and 1 in Anaktuvuk Pass will be collected and analyzed in 2024.

Employment of a community-based, ideally participatory, approach, and working with community research assistants, helped us learn local perspectives on the value of local resources, practically and symbolically, through oral history interviews and participating in activities such as cutting whale intestines, eating whale, walrus, and seal meat with Indigenous people in these communities, and by harvesting local food with them (participant observation). When we asked respondents questions about how they have used and still use underground storage caches, they often talked about how the changes of the weather, ice, snow, water, and other factors have changed the land, and therefore the use of underground cold storage facilities have also changed. Also, some respondents noticed how using all-terrain vehicles along new routes might be affecting the landscape as a whole.

The social science portion of the investigation of the food life history of the four Alaskan study communities has revealed that though similar concerns and changes in food traditions stem from climate change and the effects of increasing dependency on the global economy, the manifestation of the consequences of these changes from the local and human perspectives can vary widely according to local values, ethics, and worldviews. Local values, ethics, and worldviews can only be learned through interaction with community members, both formally (as in interviews) and informally (as by participating in local events and informal conversations). In some communities, there is ongoing and active use of cold storage, in some form, while in others, cellars are no longer used. However, in all communities we found that interest in their continued use or revitalization was supported by many. This is in part due to the role played by cold storage facilities in these communities, in which they serve practical purposes such as the storage and fermentation of meat. Whether actively used or not, they remain an artifact of cultural identity, a symbol of the knowledge and activities of their ancestors, and those that continue to be used are done so with the pride that comes from inheriting and practicing one's culture in ways that improve community resilience. Monitoring the physical condition of a cleaned cellar in each partnering community, including its deterioration, will provide a substantial basis for determining where the community might retain the current cellars or build a new cellar.

3.2. Siberia

The sociological survey conducted in Tattinsky *ulus* and Verkhnevilyuisky *ulus* showed that use of the ice cellar is relatively more popular in the former (66.7% of respondents) compared to the latter (46.2%). The census of households in two selected villages of these *uluses* shows a somewhat different picture. In the Cherkekh village of Tattinsky *ulus*, 78.2% of the inhabitants constantly use *buluus*, and in the village of Nam, Verkhnevilyuisky *ulus*, only 6.5% of the inhabitants constantly use them. The census also shows that 13.2% of *buluus* owners in Cherkekh and 90.3% of *buluus* owners living in Nam stopped using them (note that not every inhabitant owns their ice cellar). This large difference in the ratio between the villages results from geographical features and illustrates the major purpose of the ice cellar usage in the region. The village of Nam in the Verkhnevilyuisky *ulus* is located very close to the Vilyui River, where it is easy for residents to obtain drinking water in the summer, decreasing the reliance on ice cellars. By comparison, the village of Cherkekh, Tattinsky *ulus,* has no large water sources, such as rivers. The residents depend largely on ice cellars to secure drinking water of good quality in summer, by storing ice collected in winter.

The most common reason for not using *buluus* was because "chests/freezers (are) more convenient, easier to use" (43.6% in Tattinsky *ulus* and 59.0% in Verkhnevilyuisky *ulus*). The second reason for abandoning the ice cellar included problems such as, "(o)ur *buluus* is in poor condition, has fallen into disrepair" (41.0% and 30.8%, respectively). The most frequently mentioned problem that worsens the condition of *buluus* was water-related in Tattinsky *ulus* ("rainwater flooding," 22.7%), while it is temperature-related in Verkhnevilyuisky *ulus* ("high temperature, does not keep cold well," 19.8%). For other reasons similar responses were delivered in both *uluses*: "high humidity, mold" (13.6% and 14.6%), "groundwater flooding" (13.6% and 14.1%), and "wall deformation" (9.9% and 9.7%). Only 12.4% of respondents in Tattinsky *ulus* and 19.8% of respondents in Verkhnevilyuisky *ulus* perceived no problems with the ice cellar. As for the external reasons for these issues with *buluus* are "hot summer, thawing permafrost" (22.0% in Tattinsky *ulus* and 26.3% in Verkhnevilyuisky *ulus*) and "heavy, prolonged rains" (23.4% and 18.4%, respectively). Interestingly, respondents from the Tattinsky *ulus* are three to four times more likely than respondents from the Verkhnevilyuisky *ulus* to choose subjective reasons for the deterioration of the *buluus* such as "wrong choice of building site for *buluus*" (13.9% and 3.9%) and "violation of *buluus* construction rules" (10.0% and 2.6%).

Water penetration into the ice cellar is the most significant problem that makes it difficult to store food in the summer. Residents of the Tattinsky *ulus* recognize this problem more often: 48.4% of the respondents answered that water gets into the *buluus* "only when it's a rainy summer," while 15.6% answered that water intrudes "every summer, even if the summer isn't rainy." On the contrary, the Verkhnevilyuisky owners acknowledge such phenomena much less frequently, that is, 24.3% and 11.6%, respectively. 35.9% (Tattinsky) and 63.9% (Verkhnevilyuisky) answered that water does not penetrate their *buluus*.

As a result of the above-mentioned factors and the widespread use of chest freezers, residents of Tattinsky and Verkhnevilyuisky *uluses* stopped storing the following products in the ice cellar: "domestic meat" (39.7% and 44.6%, respectively), "hunting trophies" (39.3% and 42.9%), "butter" (39.7% and 52.4%), "berries'' (27.2% and 29.7%), and "homemade jam" (27.9% and 30.2%). Spoilage due to mold formation was suspected as one of the important reasons for stopping use of *buluus* for these products, since some residents reported that there has been a lot of mold in recent years. In earlier times food could be stored for a long time without mold, but now everyone is forced to store meat, butter, berries and homemade jam in freezers, which provide a better preservation condition at a lower temperature than ice cellars do. Chest freezers are widely used; more than 90% of respondents in both *uluses* answered that they use them. 28.8% (Tattinsky) and 40.3% (Verkhnevilyuisky) answered that they completely abandoned use of ice cellars in favor of freezers. However, more than half of the respondents continue to use *buluus* despite the simultaneous use of a chest freezer: 65.5% in Tattinsky *ulus* and 51.4% in Verkhnevilyuisky *ulus*. In such a case, a *buluus* is usually used to store ice while other food items are stored in the freezer.

As for the outlook for use of their *buluus*, 85.8% (Tattinsky) and 65.2% (Verkhnevilyuisky) of the respective respondent-owners plan to use their ice cellars in the next five-to-ten years. Of these, 40.3% and 25.8% of respondents, respectively, plan to store only ice for drinking-water. Similarly, 45.5% and 39.4% will continue to use *buluus* to store both food and ice, respectively.

An example of continuous monitoring of physical conditions in an ice cellar (at Chuya, Megino *ulus*, Sakha Republic, Russia) is shown in Fig. 4. The cellar temperature follows the change in air temperature during the winter (Oct–Feb 2022/2023), while the cellar temperature in summertime shows stable negative temperatures with the cellar door closed. The record of light intensity in the cellar clearly shows the timing of the access door closure when the intensity went close to zero. The cellar temperature was kept below or at 0 °C even when the air temperature was above the freezing point.

This sociological study showed a contrasting difference in cold storage practices of ice-cellar users between the two surveyed districts. In the Tattinsky *ulus*, the ice cellars are more actively used, and chest freezers are less popular than in the Verkhnevilyuisky *ulus*. The geographical condition of availability of drinking-water of good quality in summer suggests an important factor for continuation of ice cellar use. The Tattinsky *ulus* respondents complained more about water-related problems while Verkhnevilyuisky *ulus* respondents complained more about temperature-related ones. At the same time, there are fewer owners in Verkhnevilyuisky *ulus* who recognize problems with the ice cellar. This may imply that overall permafrost degradation is less intense in the Verkhnevilyuisky *ulus* than in the Tattinsky *ulus*. However, it also suggests that the *buluus*-owners in Tattinsky are more conscious of the management and maintenance issues of *buluus* likely because the Tattinsky owners rely more on the cold storage facilities. In both *uluses*, spoilage of food due to mold formation is suspected as an important factor to stop use of *buluus* for food. The analyses on the measurement data from the ongoing observations of temperatures, humidity, and light intensity at both sites provides a physical basis to substantiate the discussion. The full analyses of this issue will be reported in a separate article.

3.3. Mongolia

The research team confirmed that large ice cellars (*mozon zoori*) built in large cities and used under the Soviet regime were mostly abandoned after the regime changed. Most of the ice cellars have been destroyed in the last three decades, and few of them are currently in use. Two of them are located in Ulaanbaatar. The temperatures measured at four different locations on the floor of one of the two cellars range between -4 °C and −10 °C (Fig. 3c) and relative humidity between 90 and 98% during winter. Similar to the cases reported in Chukotka (Maslakov et al., 2020), it appears difficult to keep and manage large ice cellars built under the Soviet regime due to their energy, cost, and labor demands

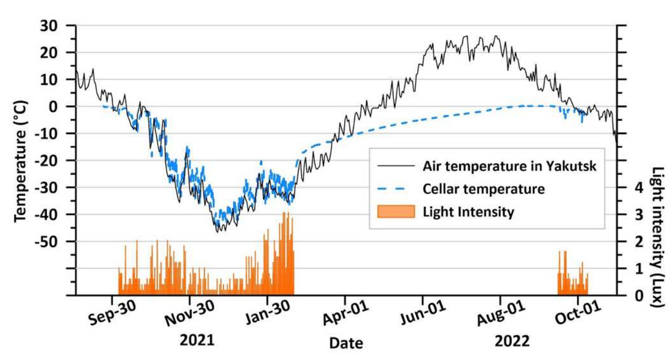

Fig. 4. Air temperature (Yakutsk, Russia, Station ID: RSM00024959), and ambient temperature and light intensity in a 50-year-old ice cellar at Chuya, Megino *ulus*, Sakha Republic, Russia.

(Vanchig et al., 2012).

In contrast, a family-managed cellar (*zoori*. Fig. 3b) found in Tsagaannuur, Hövsgöl, in the northern highland area, shows continuity from the Siberian practice in terms of family-sized management and active use currently. The local Indigenous people dig in the permafrost under the floor of their houses and use it to store food. In this preliminary study, only one case was visited for a short time, but it was learned that there are other cellars in the district. In a future part of the project, further investigations will be conducted to document the extent of usage, as well as geometric and physical surveys on the facilities in this area, to be compared with practices in other cities and regions, within the FLH perspective.

3.4. Japan

Two restored *himuro* and nine relict snow pits were visited in Kanazawa and Kaga in February 2022 (Fig. 5, see locations and related information in Fig. 1b–c and Table 2). The restored *himuro* in Yuwaku Onsen is actively used for local rituals and as a tourist attraction (Fig. 5b–Table 2 #2). Every year on July 1st, the *himuro* festival organizer opens the snow house to celebrate the day of *himuro*, which has its traditional roots in the ancient imperial ritual where the ice house was opened and the stored ice was distributed to the subjects of the emperor (Kawamura, 2008). In the next stage, temperature, humidity, and light sensors will be installed to monitor the physical conditions between the closing and opening of the *himuro*.

The other restored *himuro* in Daisho-ji exemplifies the relationship between *himuro* and residents (Fig. 5i–Table 2 #9). It was built inside of a bell tower in 2003. The original bell tower was built in 1667 and had been one of the symbolic and monumental buildings in the area until it was lost to fire in 1934. The restored *himuro*, however, is not functional, possibly due to some construction failures. It illustrates two aspects of a *himuro* in the present day: that it functions as a symbol of the history and culture of the area, and that the necessary building techniques of *himuro* and their inheritance were lost after a long intermission, limiting the capacity to rebuild a *himuro* adequately.

All the nine snow pits we visited were relict, used until the WWII era, then abandoned (Fig. 5a, 5c-k. Table 2 #1, #3–8, #10–11). The major function was to store coolants for fishery transportation, except for Yamashiro's case (Fig. 5f. Table 2 #6), which was used as a military hospital (Takei, 2022). The locations of the pits were also similar. They were constructed at a flat place on tree-rich hills either close to the target

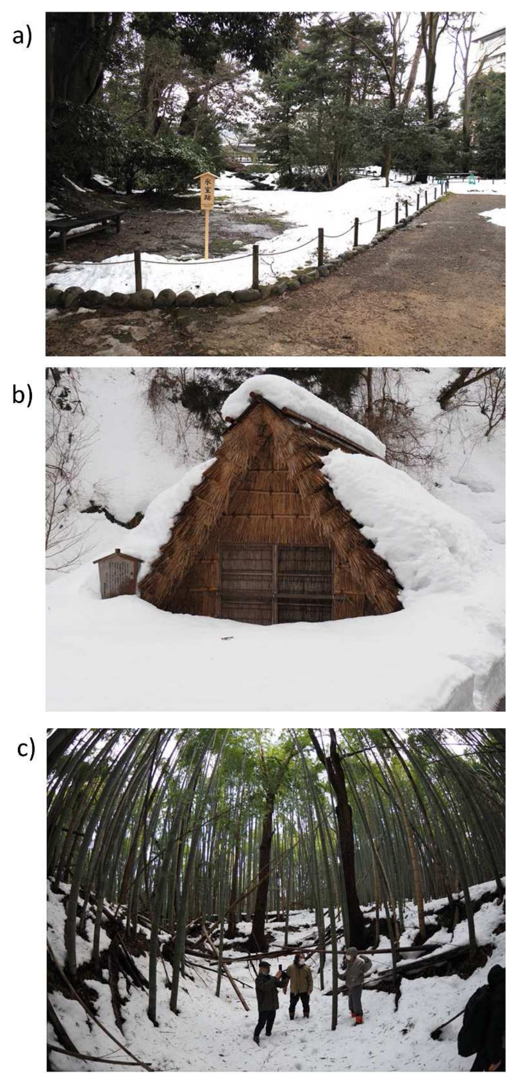

Fig. 5. Ice (snow) houses in Japan. a) Kenroku-en garden (Kanazawa City, #1 in Table 2). b) Yuwaku Onsen (Kanazawa City, #2). c) Tsukiura icehouse (Kanazawa city, #3). d) Rendai-ji snow pit (Kaga City, #4), e) Hase-dani (Kaga City, #5). f) Yamashiro ex-military hospital (Kaga City, #6). g) Pit found on a hill behind the Daisho-ji Station (Kaga City, #7). h) Daisho-ji Hagio-cho (Kaga City, #8). i) Restored icehouse under the bell tower of Daisho-ji (Kaga City, #9). j) Hashidate Izumo Shrine (Kaga City, #10). k) Pit found on a hill behind fishery port of Hashidate (Kaga City, #11). l) A 3D model of Hase-dani snow pit (#5) constructed from an UAV survey. m) Same as l) except from a view from a different angle.

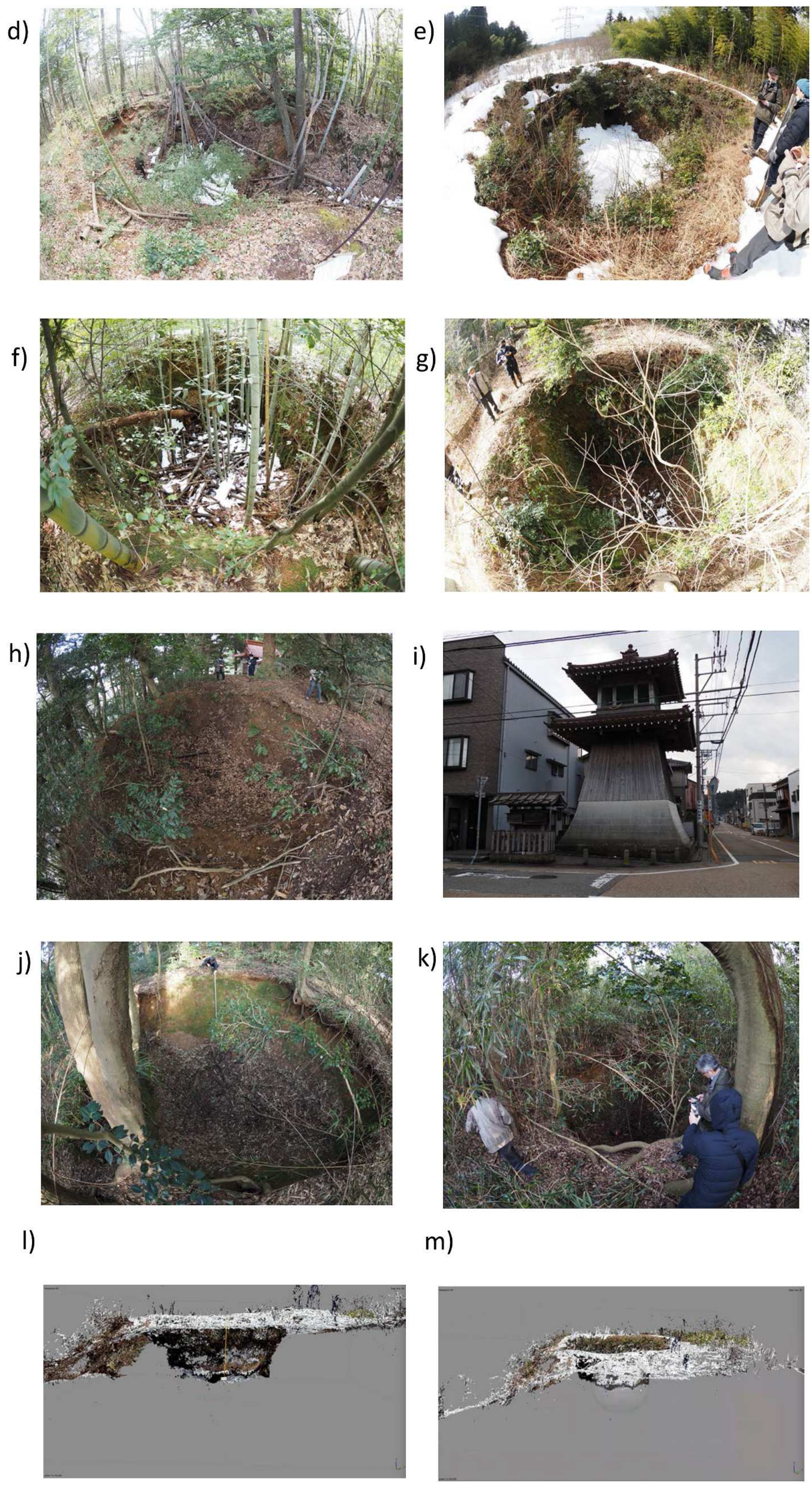

Fig. 5. (*continued*).

places for usage, such as at stations and ports, or at common places such as at castles, temples, and shrines. The structure (i.e., size and shape) are common among the pits (ca. 5 m in diameter and 5 m in depth). A preliminary aerial survey was conducted on the Hasedani pit using an unmanned aerial vehicle (UAV. Fig. 5l-m). Its open location allowed it to be easily seen, in contrast to the other pits that were covered by woods, bamboo, and/or urban constructs. These similarities in structure and the large size of the pits indicate that the collective efforts of community members (especially *seinen-kai*, youth groups) were required to construct the pits and their surroundings (e.g., site and road clearance), and inter-community communications were active in order to share the methods of construction and management among the neighboring areas (Takei Iwao, personal communication, 2022).

3.5. Comparison across the regions

The previous subsections report the individual results of the preliminary investigations conducted from 2021 to 2023 in the different areas in the Greater Beringia region, namely, Alaska (oceanic, coastal, and inland communities), Siberia (inland Sakha Republic villages), Mongolia (a large city and a highland village), and Japan (northwestern coastal area). The regions extend from the northern continuous permafrost zones in the Arctic to the discontinuous and sporadic permafrost zones in the Subarctic to seasonally frozen ground zones in the middle latitudes. In northern areas, frozen ground is the major agent of natural cold, while ice and snow play a more substantial role in the southern areas. It was found that the current situations of the cold storage practices and facilities in the areas reflect many different historical and environmental backgrounds and characteristics, but also common aspects. A summary of comparison of these similarities and differences projected from the FLH perspective is provided in Table 3. Differences are demonstrated in terms of form, functionality, ownership, and usage. Form differences include underground cellars with built structures of different sizes, durability, and construction, the use of surface pits and natural landforms on slopes, and the construction of insulated cabins to store ice or snow. Differences in functionality include seasonal to occasional storage of harvests, game, and ice, aging and fermentation, water resource storage, and ritual and touristic uses. Ownership varies considerably, with ownership and management based on the social unit of clans and families in Alaska, on communities in Japan, and in the case of Soviet-type cellars in Ulaanbaatar, on the society as a whole, while they are more personally owned in Siberia and northern highland Mongolia. Usage differences are also highly variable: some are still in active use while the others are less used or totally abandoned, depending on local climate, ecology, and culture. This reflects the local conditions of climate, ecosystem, livelihood, subsistence, and socioeconomics, and the changes in the control of these factors from internal and external drivers, which act differently in different areas. Still, the community members seem to have common concerns regarding the continuing use of the facilities, maintaining usage traditions, and management for keeping the facility healthy and operable. It was also observed that the cold storage practices are commonly impacted by changes and conditions at a large to global scale, such as warming and wetting of climate, and social changes in response to the effects of globalization.

Our preliminary data gathered through fieldwork and literature reviews show that cold storage practices did or still contribute to nurturing

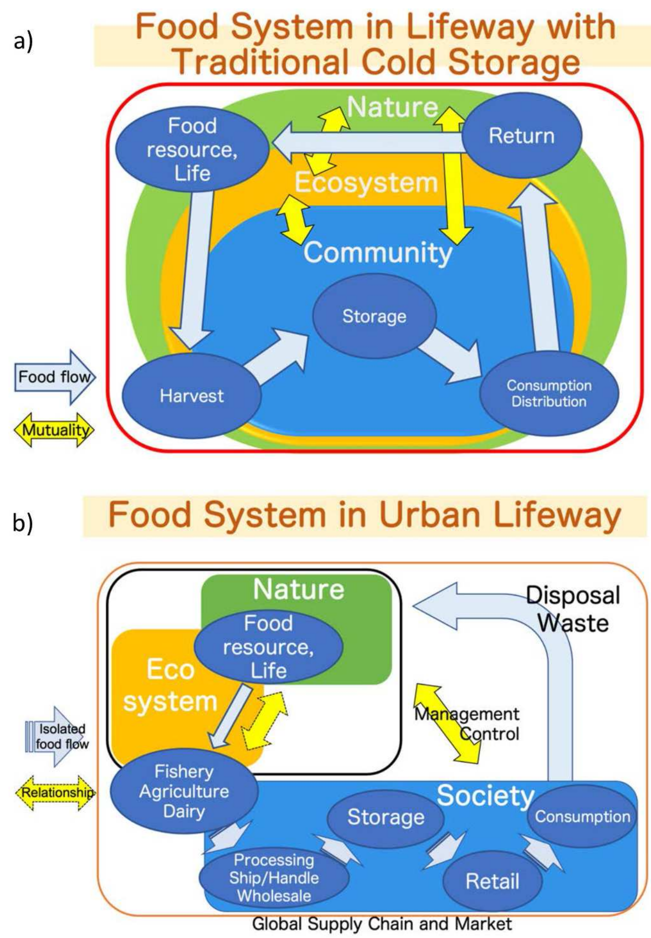

Fig. 6. Schematic of food system and the environment as viewed from the food life history framework for a) communities with lifeway using traditional cold storage, and b) modern urban lifeway.

Table 3
Various types and functions of storage using natural cold energy.

Ground freezing	Permafrost		Seasonally frozen ground		
Region	Siberia	Alaska	Siberia/Mongol	Alaska	Japan
Areas	Northern coasts, Inlands	North/NW coasts, Northern inland	Southern areas	Southern areas (Iliamna Lake)	Hokkaido/Honshu
Forms	Underground cellar/cache		Pit/icehouse		Caves, Ice/snow house
Function	Storage of food and water, Aging and Fermentation, Stock for distribution		Seasonal preservation Temporary storage		Ritual, Sericulture; Food-value addition
Ownership	Society as a shole (large community cellars, Chukotka), Families (Sakha/northern Mongolia)	Social unit of clans and families	Society as a shole (Soviet-type cellars, e.g., Ulaanbaatar)	Social unit of clans and families	Communities
Problems	Malfunction Warming, flooding Mismanagement		Freezer not fully replaceable Interruption of traditions Generation gaps		Maintenance of use within/by communities
Issues	Inheritance of (functional) use and management Maintenance of tradition/culture				Necessity for use; Who and how to maintain

the ties of the local community to their environment and its inhabitants. In some cases, it requires the cooperation of many community members to construct and maintain the facilities (e.g., Alaska, Japan). In other cases, it helps to visualize and maintain common past customs or rituals (e.g., Arafune *fuketsu* in Japan; Shimizu and Sawada, 2015), to serve the local economy as tourist attractions (e.g., Yuwaku Onsen), and to store the foods for later distribution among community members, especially those in need (e.g., oceanic and coastal Alaska). This shows the potential role of traditional cold storage practices to work as a key to maintaining or reviving community ties and energizing local community networks. Restrengthening of local social networks is important for well-being, contributing to overall food security under increasingly uncertain and volatile conditions (caused when current globally networked socioeconomic systems face difficulties, such as indicated by the consequences and impacts of the recent pandemic, and the Russo-Ukrainian War).

Fig. 6a schematically illustrates the process of the food system as compatible to a lifeway with traditional cold storage in relation to the food life history framework, as the research team has induced from the preliminary results from the four regions. In a traditional lifeway, the elements in a food system, from procurement to storage to consumption to disposal, are closely related to each other within the environment where nature, ecosystem, and human society are mutually connected. This contrasts to the modern urban case (Fig. 6b), where the elements of the food system are separated by different sectors (e.g., agribusiness, transporter, wholesale, retail, and household) and the non-human entities (i.e., nature together with ecological resources) are separated from human society as an object of control and management. This urban worldview exemplifies the modern (or Western) dichotomous recognition of the environment. These diagrams guide us in the next stage to investigate functions of and relationships between key elements, and to shape the characteristics and roles of the cold storage practice in each of the four regions. By understanding the role that cold storage plays in local identity, community well-being, and community resiliency, we can better understand the meaning that is produced through the active maintenance and usage of these facilities. The use of cold storage facilities connects the actions of present-day users with those of their ancestors, further strengthens identity-of-place, and reinforces the relationships between the community and the non-human entities of the environment. This further supports resiliency in a time of rapid sociocultural and climatological change. By comparing local strategies for dealing with these rapid changes, and contrasting with others (e.g., modern urban lifeway) through the lens of food life history and its associated artifacts (such as the *siqlugaq*, *siġḷuaq*, *hiġḷuaq*, *lédnik*, *buluus*, *zoori*, *himuro*, and *fuketsu*), adaptation and change-mitigation strategies can be shared more readily and applied more efficiently to local communities, assisting efforts at community planning.

In the next stage of the project, we will continue to work at the current study sites to complete the planned activities of the social and natural science portions of the research (Table 1). Specifically, we will extend scope and continue to monitor the natural environment of the facilities in use, and their surroundings, to analyze the physical and chemical conditions to understand the cold-preserving mechanism and to facilitate better management and future protection against projected warming and wetting. Further, we will expand the project areas and sites to collect additional examples for more comprehensive comparison and considerations of cold storage practices from the FLH framework, as well as for verification and improvement of the concept. In doing this, we seek involvement of additional disciplines that are lacking in the current research project, such as biology, health science, political economy, and history, to further enhance the research.

4. Conclusion

This paper reports the preliminary results of the investigations of cold storage facilities and traditions that use natural cold energy in the Greater Beringia region, namely Alaska, interior eastern Siberia (Sakha), Mongolia, and Japan from 2021 to 2023. Our preliminary findings from 2021 to 2023 demonstrate regional differences in cold storage facilities in size, form, ownership, use-practices, construction, and maintenance. This indicates a strong influence from surrounding local natural and social environmental conditions, and a close connection with the traditional lifeways of the cultures of the communities.

Through preparation for the research activities of the project in each of the study areas, and conducting a preliminary investigation to document and compile local perspectives and knowledge on the history, current conditions, and future issues of cold storage practices, we have successfully built trustful relationships with local residents and/or owners of the storage facilities in some communities, commenced communication to build such relationships in other communities, and learned new aspects and uses of cold storage in other areas. Investigations of the physical aspects of cold storage facilities were initiated during the preliminary investigation period and are currently ongoing. These include monitoring of temperatures and humidity, boring core samples, and climatic assessment of the functionality of the cold storage facilities under the projected future climate change impacts. In the next steps, we will incorporate the results of analyses of collected natural scientific data together with continuing analyses from our social scientific study. Further, we will review and deepen our hypotheses regarding the roles and functions of cold storage practices from the Food Life History perspective. By doing this, we hope to achieve an articulation of scientific, technological, and Indigenous knowledge for the co-production of solutions to protect, learn from, and facilitate local food lifeways, traditions, and practices as keys for understanding and fostering community adaptation to social and natural environmental changes.

CRediT authorship contribution statement

Kazuyuki Saito: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Yoko Kugo:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Michael Koskey:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Go Iwahana:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Yu Hirasawa:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Shirow Tatsuzawa:** Resources, Investigation, Conceptualization. **Yuriy Zhegusov:** Writing – review & editing, Resources, Investigation, Formal analysis, Data curation. **Yamkhin Jambaljav:** Investigation, Formal analysis, Data curation. **Theresa Arevgaq John:** Writing – review & editing, Validation, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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