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Building a high-resolution chronology for northern Hokkaido – A case study of the Late Holocene Hamanaka 2 site on Rebun Island, Hokkaido (Japan)

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A B S T R A C T

Archaeological radiocarbon dating in coastal northern Hokkaido is challenged by the marine reservoir effect and the scarcity of materials with terrestrial carbon sources. This has contributed to gaps and general uncertainty in the timing of the region's culture-historical periods. The Late Holocene site of Hamanaka 2 on Rebun Island, featuring a stratified shell midden context with excellent preservation of organic remains, provides an ideal setting for addressing this issue. A Bayesian chronological model was deployed to study the timing of the site using a series of radiocarbon-dated macrobotanical samples. This resulted in narrowed-down estimated age-ranges in eight of thirteen phases examined, providing the site with a more accurate radiocarbon chronology than before. These temporal data were consequently integrated with local palaeoecological evidence, revealing synchrony between cultural chronology and human-induced landscape transformations. The study demonstrates that the technique should permit more efficient building of archaeological chronologies in similar maritime environments.

1. Introduction

Marine dietary contributions have been demonstrated to vary greatly among aquatic organisms in the coastal areas in northeast Asia, leading to high reservoir offsets and reduced efficiency with the radiocarbon (^{14}C) dating technique (Kuzmin et al., 2007; Miyata et al., 2016). Consequently, in a region marked by maritime-adapted communities, terrestrial materials suitable for reliable dating are oftentimes scarce in cultural assemblages. Chronological inference is further complicated by the atmospheric radiocarbon calibration curve plateauing at critical times in the region's cultural sequence, introducing calibration uncertainty to radiocarbon dates in the first millennium BCE and first millennium CE (Reimer et al., 2020).

These factors have resulted in increased uncertainty and chronological gaps in the culture history of Late Holocene northern Hokkaido (~1800 BCE–1250 CE). The period is marked by prehistoric communities, such as the final-stage Jomon, Susuya, Okhotsk and Satsumon Cultures, that had different subsistence economies and source origins (Oba and Ohyi, 1981; Ono and Amano, 2008; Crawford, 2011). However, further work is required to understand how these cultures relate to each other and what kind of impact they had on their respective ecosystems. Estimating the timing of these cultures is a critical aspect of this work.

Recognized as a unique setting for exploring hunter-gatherer lifeways and human ecodynamics in Hokkaido, the Hamanaka 2 site has been subject to multiple interdisciplinary studies in the past ten years (Sato et al., 2009; Naito et al, 2010; Leipe et al., 2017; Lynch et al., 2018; Schmidt et al., 2019; Junno et al., 2020). The site features a stratified >3000-year occupation sequence extending from the Late Jomon to the Historical Ainu period, where a favorable burial environment has

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supported the preservation of organic materials (Hirasawa and Kato, 2019).

Present at the site is also a shell midden-type sequence attributed to the maritime Okhotsk Culture, emerging in the region around 400–500 CE (Ono and Amano, 2008). The Okhotsk show a diverse cultural background traced to Sakhalin Island and the lower Amur region in Russia (Sato et al., 2009). The Okhotsk were engaged in long-distance trading activities, expanding out to the northern and eastern coasts of Hokkaido during a climate cooling period (Büntgen et al., 2016), and interacting with multiple native prehistoric groups over the course of the second half of the first millennium CE (Hudson, 2004; Ono, 2008). Divided into four main stages on the basis of changing pottery traditions in northern Hokkaido, the Okhotsk typology is frequently used as an important chronological tool and a source of reference for archaeologists in northeast Asia (Ono, 2008). This typological dating, however, should be further investigated and refined using a robust radiocarbon chronology (e.g. Long et al., 2017).

To take advantage of the study site's stratigraphic sequence and well-preserved material record, a Bayesian model (Buck et al., 1996; Benz et al., 2012) was deployed using a series of radiocarbon-dated macrobotanical samples (Leipe et al., 2018). The objective of the present study was therefore to improve our understanding of the cultural chronology from the final-stage Jomon to the Satsumon period in northern Hokkaido. This approach, it was postulated, should result in increased chronological accuracy for the site's settlement sequence, while also providing a temporal estimate on the duration of its occupation gap following the Epi-Jomon phase.

Improvements in dating precision were anticipated especially for assemblages in the second half of the first millennium, where multiple chronological priors are applicable to the well-stratified Okhotsk Culture shell midden concentration. In addition, the modeled ages were compared with the existing chronological framework outlined for Late Holocene northern Hokkaido. Finally, these chronological data were compared to local palaeoenvironmental evidence to explore human ecodynamics on Rebun Island.

2. Study site and material culture

Rebun is a wedge-shaped and hilly island in the Sea of Japan, located ~ 50 km west of the northernmost tip of Hokkaido (Cape Nosappu) and ~ 90 km south of Sakhalin Island (Figs. 1 and 2). It has a maximum length and width of 20 km and 6 km, respectively, and a land area of ~ 80 km^2. The island's highest point is Mt. Rebun (490 m), which is surpassed in elevation by Mt. Rishiri (1718 m), a conical volcano located on Rishiri Island ~ 10 km to the southeast from Rebun. The region is characterized by temperate climate and predominantly controlled by the East Asian Monsoon System, which secures year-round moist conditions (Igarashi, 2013). The summers are warm, and the winters cold and stormy, with the effects of the Tsushima Warm Current and the East Asian Winter Monsoon circulation producing heavy snowfall and

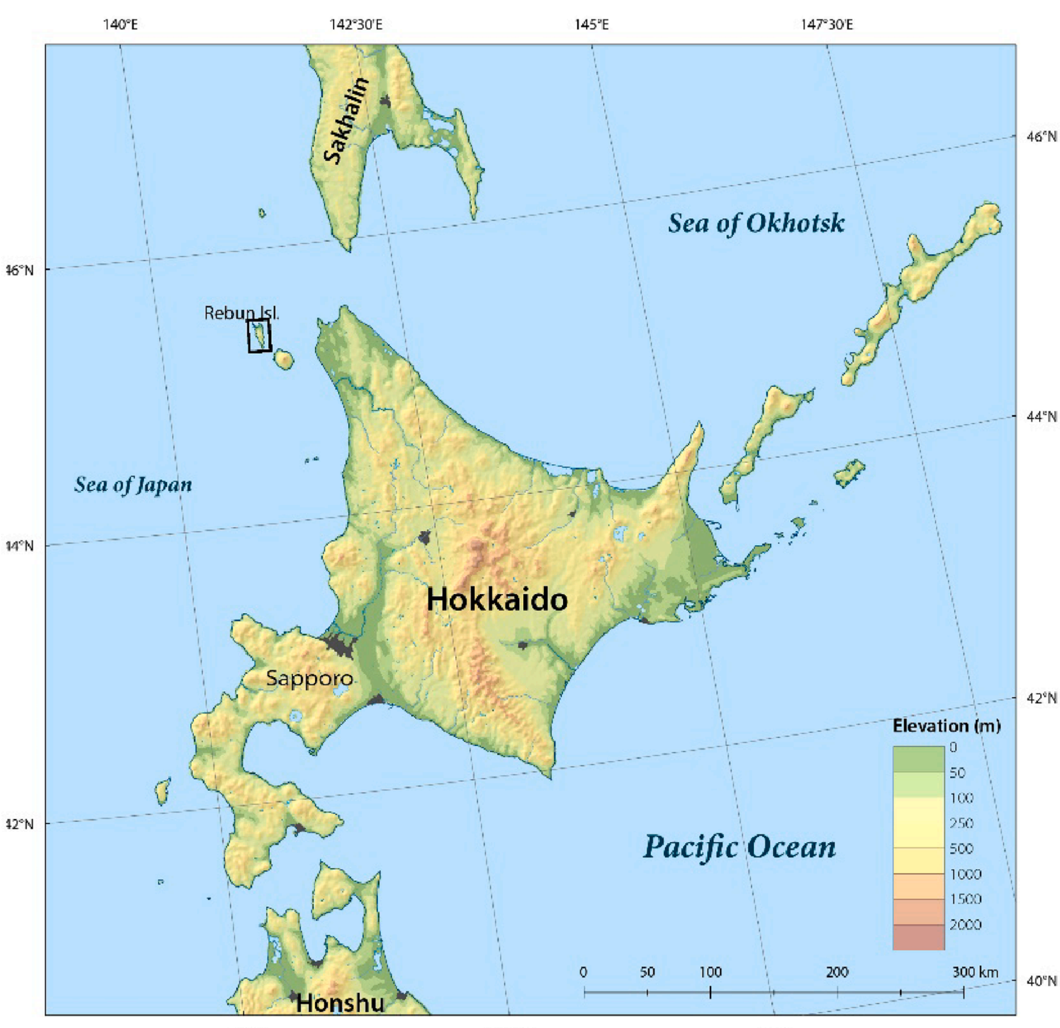

Fig. 1. Location of Rebun Island in northern Hokkaido, Japan.

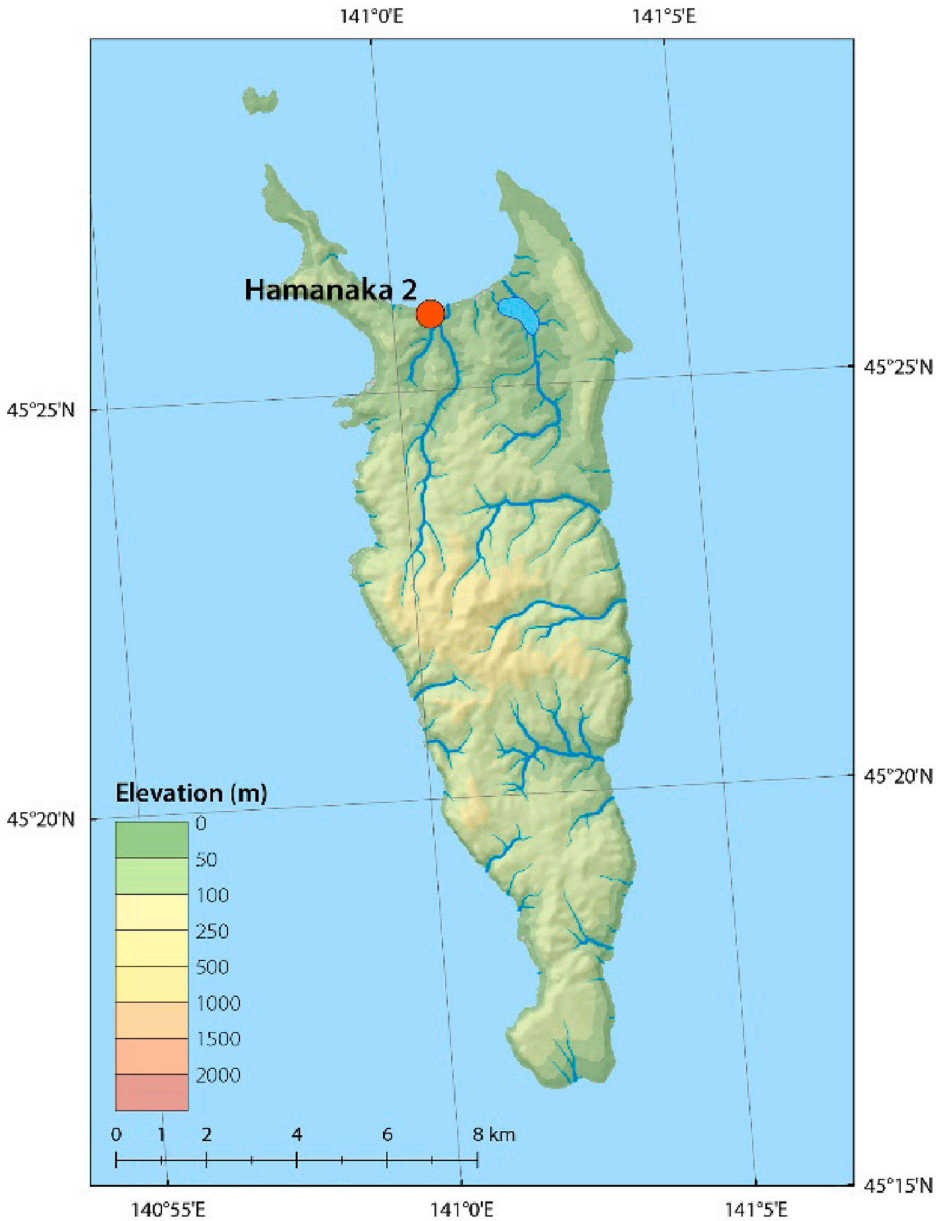

Fig. 2. Location of the Hamanaka 2 site on Rebun Island.

preventing the formation of sea ice (Nikolaeva and Shcherbakova, 1990; Müller et al., 2016).

The island lies within the cool mixed forest biome (COMX) zone (Gotanda et al., 2002), where the natural vegetation cover comprises cool temperate and boreal woody plants (Igarashi, 2013). Rebun Island has a low biodiversity and does not support large terrestrial mammals, such as the brown bear (*Ursus arctos*) or deer (*Cervus nippon*). By contrast, the island offers access to abundant aquatic offshore resources, such as marine fish, sea mammal and shellfish, that are complemented by salmonid and freshwater fish in Rebun's lake and river systems.

The Hamanaka 2 site is located at Funadomari Bay on the northern coast of Rebun Island, ~1500 m to the east from Lake Kushu. The site complex consists of shell-midden type deposits on top of a coastal sand dune (Hirasawa and Kato, 2019). It was formed as a result of human activity accumulating sediment, ecofacts and cultural materials for more than 3000 years (Sakaguchi, 2007a, 2007b; Schmidt et al., 2019). The present study is focused on the excavation area at the Nakatani locality (Fig. 3), where a unique succession of nine stratigraphic units (I–IX) dating back to ~ 1350 BCE from the Final Jomon to the Historic Ainu period (Fig. 4) was documented between 2011 and 2019 (Hirasawa and Kato, 2019).

The study site was formed on the southern slope of a sand dune extending more than 100 m along the coast. To the south of the site there are periglacial hills ca. 40 m asl (meters above sea level), and eroded marine terraces ca. 15–20 m asl. To the east, Osawa river forms a small delta, but its shape has been disrupted by modern construction works. The site sediment, including at the Nakatani locality, is mainly composed of eolian sands. The horizontal distribution of archaeological objects at Hamanaka 2 is uneven because of natural sand sedimentation processes and different intra-site activities. Therefore, no generalizations can be made with regards to the site occupation intensity and site function, as these appear to shift from one phase to another (Nishimoto, 2000; Maeda and Yamaura, 2002; Hirasawa and Kato, 2019).

In turn, the subsistence at Hamanaka appears to have been predominantly focused on the marine resources, with bone harpoon heads, hooks and other tools typical of Northern Pacific maritime communities recorded across the occupation sequence. By contrast, during the Epi-Jomon and Okhotsk Culture periods terrestrial animal species, mainly

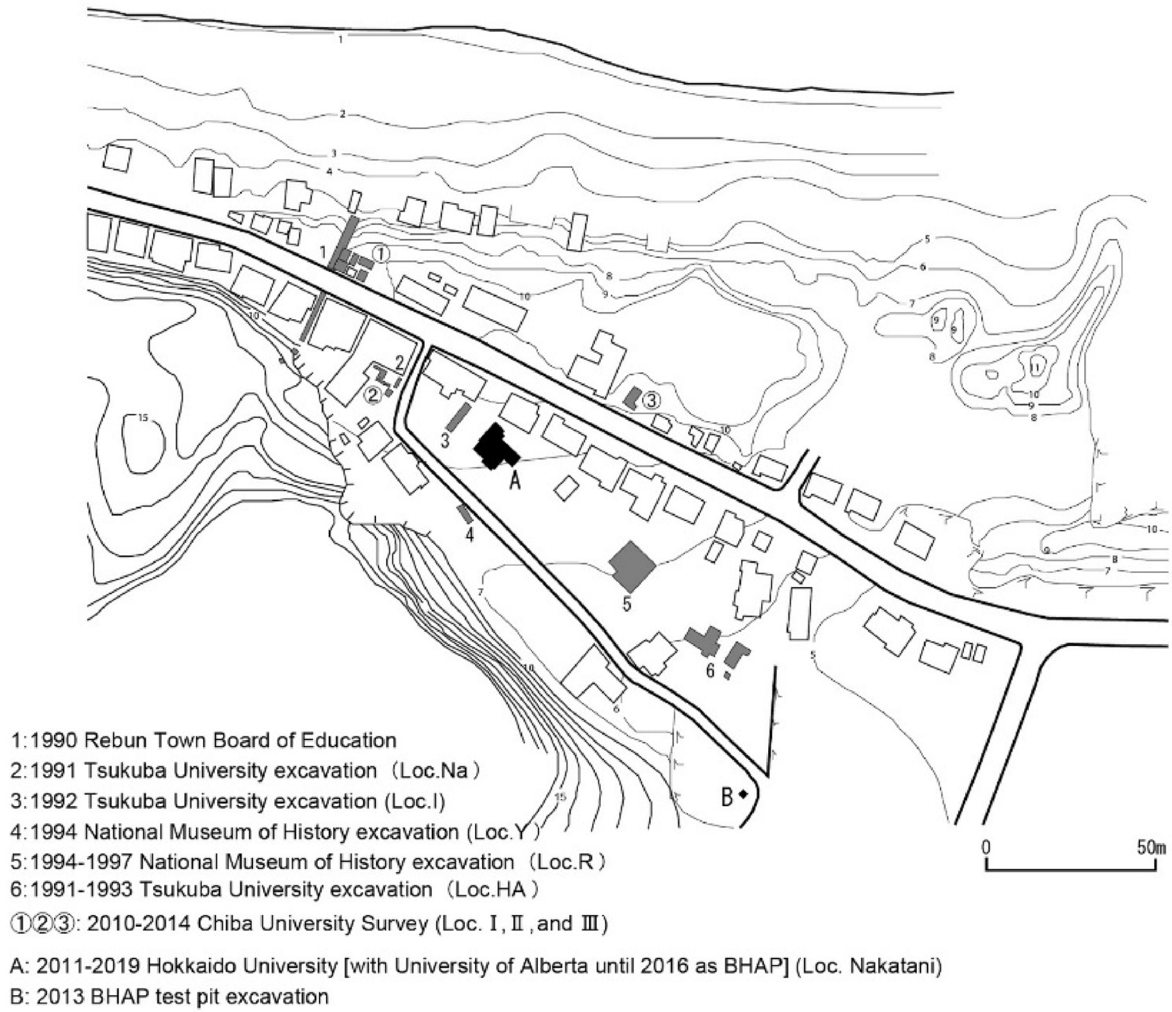

Fig. 3. Study site map of Hamanaka 2 showing the location of the excavated area at the Nakatani locality (A) (Hirasawa and Kato, 2019).

dog (*Canis domesticus*), pig (*Sus scrofa inoi*) and bear (*Ursus arctos*) were consumed sporadically at the site, with wild and domestic plants serving as complementary food sources (Crawford, 2011; Leipe et al., 2018; Hirasawa and Kato, 2019).

The Final Jomon, Epi-Jomon, and the early-stage Okhotsk assemblages (units V–IX) at Hamanaka 2 reflect cultural activity zones associated with food processing and consumption, and lithic production. Human burials were also found in these cultural layers, as well as evidence of ritual activities, such as sea mammal worship (Figs. 5 and 6). In the Middle Okhotsk occupation, and in the ensuing Late and Final Okhotsk, and Historical Ainu phases (IV–II), the excavated Nakatani location at Hamanaka 2 transforms into a shell midden site dominated by marine fauna (Fig. 7). Human burial and the practice of animal rituals, however, persist throughout the site's settlement history, extending from the Okhotsk between the fifth and the tenth century CE, to the Historical Ainu period between the 16th and 19th century (I). The Satsumon occupation at Hamanaka 2 takes place between these two cultural periods, approximately in the 12th and 13th centuries (Hirasawa and Kato, 2019). Due to limited material assemblages and very thin cultural layer (Fig. 4) associated with this occupation, it is unclear what subsistence economy was adopted by the Satsumon on Rebun Island.

3. Materials and sampling

Radiocarbon dates used in the present chronological study were obtained from samples selected from thirteen stratigraphically and typologically distinguishable cultural layers (Table 1). In addition, with the marine reservoir age offset manifested in the marine organisms present in the Hamanaka 2 archaeological record, materials with carbon derived from the aquatic food web were disregarded. Indeed, marine reservoir effects have been demonstrated to vary greatly among aquatic organisms in coastal Hokkaido due to the complex carbon cycle present in the oceanic food web (Kuzmin et al., 2007; Miyata et al., 2016). Consequently, at a site occupied by maritime-adapted communities, the marine carbon contribution to human bone samples could not be estimated, and therefore these materials were also excluded (Okamoto et al., 2016). Likewise, dates from charred pottery crusts were omitted from the model as they may contain carbon introduced from either the marine or the freshwater food webs (Kunikita, 2016; Miyata et al., 2016; Kunikita et al., 2017). Therefore, sample selection was focused only on organic materials with carbon known to have been sourced from the atmospheric reservoir.

However, while exclusive use of terrestrial plant macroremains eliminates the uncertainty associated with the marine reservoir offset, there are other aspects that need to be considered. For instance, wood charcoal is susceptible to the "old wood effect" that makes a sample appear more ancient than the context it is deposited in. By contrast, seeds and other short-lived remains (e.g. twigs) of terrestrial plants are optimal for dating purposes in that the temporal difference between the moment the organism ceased to exchange carbon with the environment, i.e. the dated event, and the activity that generated the archaeological event, is likely much shorter.

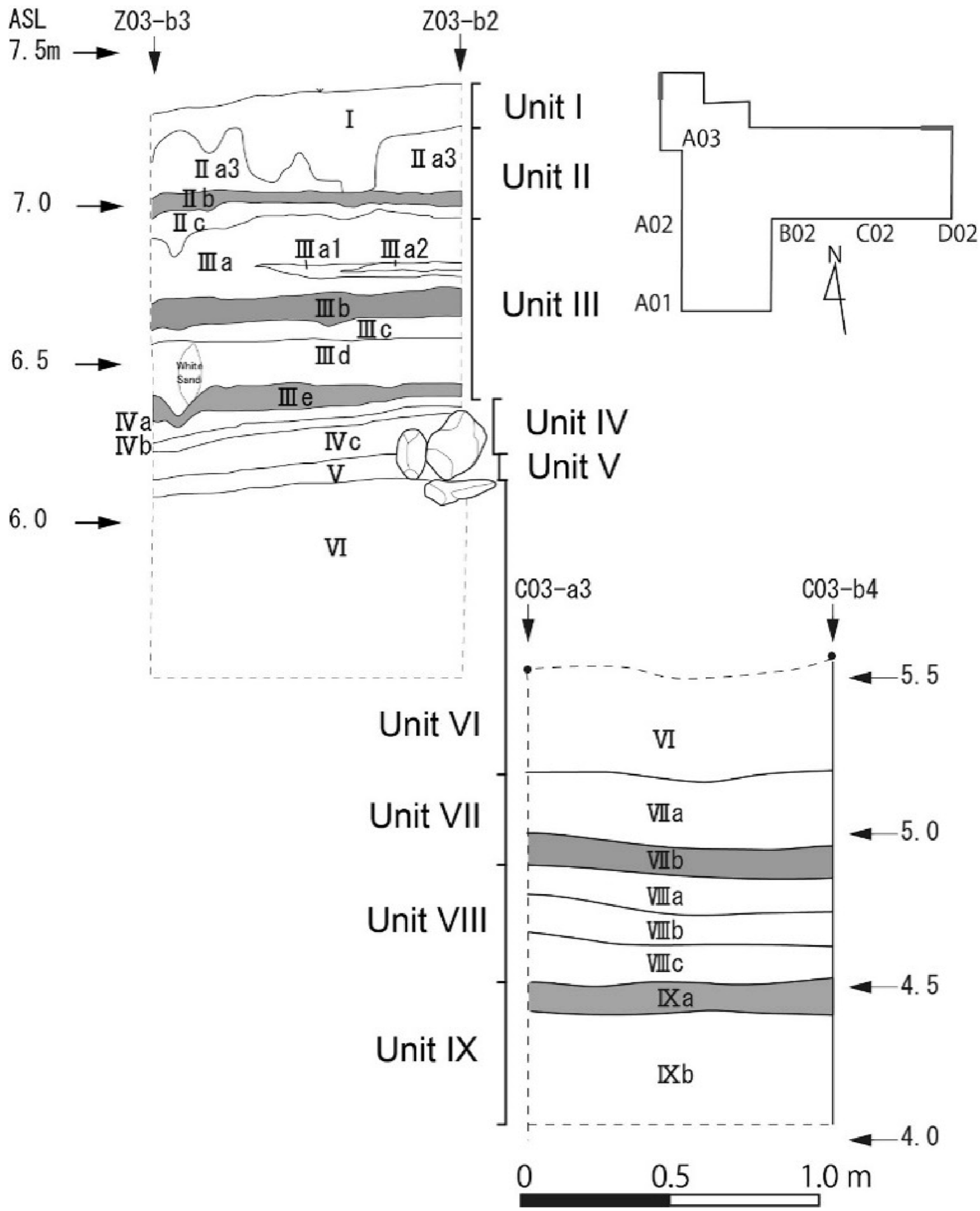

Fig. 4. Cross section indicating the stratigraphic succession of the Hamanaka 2 site, Nakatani locality, including the stratigraphic units and subunits, the excavation grid system and elevation in meters above sea level (ASL) (Hirasawa and Kato, 2019).

That said, their recovery in archaeological excavations requires additional labor investment and material availability can be limited depending on the context of cultural deposits. After assessing the sources of uncertainty associated with the ^{14}C-dates available from Hamanaka 2, a Bayesian chronological model was built with priority given to dates based on seed samples. These materials were complemented by dates derived from charcoal and twigs. Hence the study was carried out using a total of 34 charred seed, 10 wood charcoal samples and one twig sample. All macrobotanical remains were obtained through flotation of soil samples, where the location of each sample is documented at 1 × 1 m accuracy, with also either the main stratigraphic unit or its subunit recorded (Müller et al., 2016; Leipe et al., 2017, 2018).

No datable materials meeting the selection criteria could be recovered from Unit IX (Final Jomon), and therefore this layer is not included in the modeling. Unit VIII comprises three subunits a-c, which are characterized by dim yellow and brownish sandy sediments, corresponding to the Final Jomon and Epi-Jomon cultural phases (see Fig. 8 for final-stage Jomon-type pottery). Two dated samples were collected from this layer, however, their corresponding subunits could not be recorded. Unit VII is characterized by brownish sand and corresponds to the Epi-Jomon culture phase. A total of nine dates were derived from this context. Unit VI is a thick ~ 60–80 cm layer of white sand, it is not

Fig. 5. Sea lion crania deposited next to a hearth in Unit VIII at the Hamanaka 2 site, Nakatani locality, showing evidence of ritual treatment.

Fig. 6. Sea lion cranium with large perforations in Unit VIII at the Hamanaka 2 site, Nakatani locality, possibly resulting from ritual treatment.

Fig. 7. Profile picture taken of the study site's Unit III shell midden context at the Hamanaka 2 site, Nakatani locality, shown are also the units directly below (IV) and above (II-I) it.

attributed to any archaeological culture or settlement and no archaeological dates were available from this unit.

Above the sterile layer VI are the Early Okhotsk-phase (i.e. Towada-style, see Fig. 9 for northern Hokkaido Okhotsk pottery types) units V and IV. Unit V is divided into two subunits Va and b, marked by brownish and black brownish sandy sediments, respectively. The sediment in Unit IV is characterized as white and sandy. These previously undated units were age-estimated with three macrobotanical samples, two from Unit V (subunit not recorded) and one from Unit IV.

Unit III is assigned to the Middle, Late and Final Okhotsk phases by pottery typology, and divided into six stratigraphic subunits IIIa-f. Sediment in units IIIa-f is characterized as brownish and black brownish sand featuring high concentrations of marine fauna and charcoal deposits. Three ^{14}C-dates were obtained from samples collected from the bottom-most subunit IIIf that corresponds to the Kokumon/Enoura B pottery tradition phase. Further four dates were obtained from IIIe, defined as the Kokumon–Chinsenmon transitive phase. This is followed by subunits IIIb-d, which are assigned to the Chinsenmon phase. Four samples were collected from the subunits IIIc-d. However, no stratigraphic distinction could be made between them and therefore they were modeled as one stratigraphic unit. In total, six dates were selected from the transitive Chinsenmon–Motochi subunit IIIb, while three samples were recovered from the Motochi-phase "Motochi 1" subunit IIIa.

Unit II breaks down to subunits IIa-c, found directly on top of Unit III. Two radiocarbon ages were recovered from subunit IIc, which is marked by yellow and dark brownish sandy sediment, and assigned to the Late Motochi phase of the Final Okhotsk period. On top of this layer is subunit IIb with an unidentified cultural component and black brownish sand sediment type. One dated sample was obtained from this layer. In addition, two radiocarbon dates from subunit IIa, assigned to the Satsumon Culture (Fig. 10) phase and characterized by yellow sandy sediment, were available for the present study. The thin units IIa, b and c are close to the modern surface and compared to the layers below less well stratified (Fig. 4), which might be the result of disturbance. This would explain the anomalously young ages of some of the small-sized charred seeds dated from these layers (Table 1), which were likely redeposited from overlying (sub)units. Finally, a total of six dates were obtained from Unit I corresponding to the Historical Ainu period. The layer features a high concentration of abalone sea shells, with a sediment characterized by gray and blackish sand. The samples from Unit I also contain one date with an anomalous age that is likely much older than the conventional Historical Ainu period (1550–1900 CE).

4. Methods

A Bayesian chronological model (Bronk Ramsey, 1995) was built using OxCal v.4.4.2 (Bronk Ramsey, 2017), making use of the site stratigraphy (Benz et al., 2012) and the IntCal-20 atmospheric curve (Reimer et al., 2020). The model (Model 1) was constructed on a simple stratigraphic principle that samples recovered from deeper layers must be older than those from above. The stratigraphic phases were therefore categorized as either sequential or contiguous depending on their stratigraphic relationship to one another (Bronk Ramsey, 1995).

Where the two layers were in contact, a contiguous relationship was defined. This means that the 'end boundary' of one layer and the 'start boundary' of the next share a single 'transition boundary'. When this was not the case (i.e Epi-Jomon and Early Okhotsk units VII and V), a simple sequential relationship was modeled, where separate start and end boundaries were defined. Considering possible redeposition of the dated macrobotanical remains by bioturbation, as well as the potential for the old wood effect present in the charcoal samples, each sample's place within the model was strictly subject to the agreement index of the calibrated date and the OxCal outlier analysis function. Sample exclusion was in line with criteria set out in Bronk Ramsey (2009) and samples that did not meet the 60% agreement threshold in the outlier analysis were omitted. Charcoal samples were modelled against a more flexible charcoal outlier model to allow for inbuilt age difference (Dee and Bronk Ramsey, 2014). Moreover, all samples reported here were dated via AMS (Accelerator Mass Spectrometry), conducted either at the Poznan Radiocarbon Laboratory, or at the Institute for Space-Earth Environmental Research (ISEE) at Nagoya University, following

Table 1
List of ^{14}C-dates from Hamanaka 2 used in the Bayesian models. Samples that were manually excluded in the second model are marked by an asterisk. The following data are expressed; sample code, species, stratigraphic unit (layer) and location data (grid), cultural affiliation (phase), archaeological context, radiocarbon age in uncalibrated "BP" years, measurement error, sample δ^{13}C level and sample reference/publication status.

Code	Material	Layer	Grid	Phase	Context	BP	Error	δ13C (‰)	Reference
Poz–60760*	*Sambucus sieboldiana*	I	A02–d2	Historical Ainu	Shell deposit	165	30	–28.7	Müller et al., 2016
Poz–60761*	*Aralia* sp.	I	A02–d2	Historical Ainu	Shell deposit	115	30	–30.3	Müller et al., 2016
Poz–60762*	Charred twig (unidentified sp.)	I	A02–d2	Historical Ainu	Shell deposit	210	30	–25.0	Müller et al., 2016
Poz–73796*	Wood charcoal (unidentified sp.)	I	A02–d2	Historical Ainu	Shell deposit	120	30	–28.9	Leipe et al., 2018
Poz–91168*	*H. vulgare* v. *nud.*	I	Z02–c3	Historical Ainu	Grid sub–sample	80	30	–33.8	Leipe et al., 2018
Poz–91169*	*H. vulgare* v. *nud.*	I	Z02–c3	Historical Ainu	Grid sub–sample	1175	30	–31.7	Leipe et al., 2018
Poz–73797*	Wood charcoal (unidentified sp.)	IIa	A04–d4/ Z04–c3	Satsumon	Grid sub–sample	215	30	–28.1	Leipe et al., 2018
Poz–91167*	*H. vulgare* v. *nud.*	IIa	A04–d4/ Z04–c3	Satsumon	Grid sub–sample	1245	30	–29.7	Leipe et al., 2018
Poz–73798*	Wood charcoal (unidentified sp.)	IIb	Z04–c3	Unidentified	Grid sub–sample	210	30	–28.9	Leipe et al., 2018
Poz–91165*	*H. vulgare* v. *nud.*	IIc	Z03–b3	Motochi Phase 2	Grid sub–sample	130	30	–32.2	Leipe et al., 2018
Poz–73799	Wood charcoal (unidentified sp.)	IIc	Z04–c3	Motochi Phase 2	Grid sub–sample	1165	30	–28.3	Leipe et al., 2018
Poz–73801*	Wood charcoal (unidentified sp.)	IIIa	Z04–c3	Motochi Phase 1	Grid sub–sample	170	30	–26.0	Leipe et al., 2018
Poz–84278	*H. vulgare* v. *nud.*	IIIa	Z04–c3	Motochi Phase 1	Grid sub–sample	1170	30	–29.7	Leipe et al., 2017
Poz–84277	*H. vulgare* v. *nud.*	IIIa	Z04–c3	Motochi Phase 1	Grid sub–sample	1215	30	–31.4	Leipe et al., 2017
Poz–81342	*H. vulgare* v. *nud.*	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1180	30	–24.0	Leipe et al., 2017
Poz–60768	*Toxicodendron* sp.	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1215	30	–30.9	Müller et al., 2016
Poz–81341	*H. vulgare* v. *nud.*	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1215	30	–23.5	Leipe et al., 2017
Poz–81340	*H. vulgare* v. *nud.*	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1220	30	–25.4	Leipe et al., 2017
Poz–60767	*Vitis coignetiae*	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1265	30	–28.8	Müller et al., 2016
Poz–60766	*Toxicodendron* sp.	IIIb	Z04–c3	Chinsenmon–Motochi	Grid sub–sample	1305	30	–27.6	Müller et al., 2016
Poz–84281	*H. vulgare* v. *nud.*	IIIc	Z04–c3	Chinsenmon	Grid sub–sample	1275	30	–29.6	Leipe et al., 2017
Poz–84280	*H. vulgare* v. *nud.*	IIIc	Z04–c3	Chinsenmon	Grid sub–sample	1285	30	–30.7	Leipe et al., 2017
Nuta2–21213	*H. vulgare* v. *nud.*	IIIc	Z02–b3	Chinsenmon	Shell midden	1320	40	N/A	This study
Poz–73802	Wood charcoal (unidentified sp.)	IIIc	Z04–c3	Chinsenmon	Grid sub–sample	1455	30	–26.7	Leipe et al., 2018
Poz–84285	*H. vulgare* v. *nud.*	IIId	B03–a3	Kokumon–Chinsenmon	Pit 1	1275	30	–32.4	Leipe et al., 2017
Poz–84282	*H. vulgare* v. *nud.*	IIId	Z03–b3	Kokumon–Chinsenmon	Grid sub–sample	1295	30	–25.9	Leipe et al., 2017
Poz–84283	*H. vulgare* v. *nud.*	IIId	Z03–b3	Kokumon–Chinsenmon	Grid sub–sample	1335	30	–29.6	Leipe et al., 2017
Poz–84284	*H. vulgare* v. *nud.*	IIId	B03–a3	Kokumon–Chinsenmon	Pit 1	1475	30	–30.9	Leipe et al., 2017
Nuta2–21216	*H. vulgare* v. *nud.*	IIIe	z02–b3	Kokumon	Shell midden	1154	45	N/A	This study
Poz–84286	*H. vulgare* v. *nud.*	IIIe	Z03–b3	Kokumon	Grid sub–sample	1350	30	–19.3	Leipe et al., 2017
Poz–84287	*H. vulgare* v. *nud.*	IIIe	Z03–b3	Kokumon	Grid sub–sample	1520	30	–30.6	Leipe et al., 2017
Poz–102824	*Vitis coignetiae*	IV	A02–b4	Towada Phase 2	Pit	1535	30	–23.6	This study
Poz–102853	*Vitis coignetiae*	V	A02–a3	Towada Phase 1	Hearth	1540	30	–29.2	This study
Poz–102825	*Vitis coignetiae*	V	A02–a3	Towada Phase 1	Hearth	1550	30	–28.0	This study
Poz–91170	*H. vulgare* v. *nud.*	VII	A03–a3	Epi–Jomon	Hearth 2	1555	30	–30.7	Leipe et al., 2018
Poz–91177	*Toxicodendron* sp.	VII	A03–a3	Epi–Jomon	Hearth 2	2115	30	–36.3	Leipe et al., 2018
Poz–91175	*Vitis coignetiae*	VII	A03–d2	Epi–Jomon	Hearth 2	2170	30	–28.9	Leipe et al., 2018
Nuta2–21214	*Toxicodendron* sp.	VII	A03–b2	Epi–Jomon	Hearth	2176	43	N/A	This study
Poz–73803	Wood charcoal (unidentified sp.)	VII	A03–c2	Epi–Jomon	Hearth 1	2195	30	–25.5	Leipe et al., 2018
Poz–73804	Wood charcoal (unidentified sp.)	VII	A03–c2	Epi–Jomon	Hearth 1	2200	35	–26.3	Leipe et al., 2018
Poz–73805	Wood charcoal (unidentified sp.)	VII	A03–c2	Epi–Jomon	Hearth 1	2220	30	–27.7	Leipe et al., 2018

(*continued on next page*)

Table 1 (*continued*)

Code	Material	Layer	Grid	Phase	Context	BP	Error	δ13C (‰)	Reference
Poz–73806	Wood charcoal (unidentified sp.)	VII	A03–b4	Epi–Jomon	Hearth 1	2220	30	–27.7	Leipe et al., 2018
Poz–91171	*H. vulgare* v. *nud.*	VII	A03–a3	Epi–Jomon	Hearth 2	2220	30	–30.8	Leipe et al., 2018
Poz–91179	*Sambucus sieboldiana*	VIII	B03–c2/ B03–b3	Final Jomon/Epi-Jomon	Pit	2200	30	–32.0	Leipe et al., 2018
Poz–91178	*Vitis coignetiae*	VIII	B03–b3/ B03–b4	Final Jomon/Epi-Jomon	Pit	2240	30	–28.2	Leipe et al., 2018

current pretreatment methods for AMS ^{14}C-dating (Brock et al., 2010).

Finally, based on the results of the model covering the site stratigraphy between units VIII–I, another model with identical specifications (Model 2), save for less strict sample selection criteria, was run to obtain a robust estimate for layer IIc – associated with the end of the Okhotsk period. This could not be achieved with the primary model using all available dates from units IIb and IIc, given how some of the samples in these layers (Fig. 4) have anomalously young ages compared to their stratigraphic position (Table 2).

5. Results

The chronology of the Hamanaka 2 site (Table 2) was investigated with a sample set comprising 45 radiocarbon dates across thirteen cultural layers. To optimize the accuracy of the chronological model developed, outliers in the dataset were first identified and eliminated. In total, eight dates (NUTA2-21216, Poz-73799, Poz-73802, Poz-84284, Poz-91167, Poz-91169, Poz-91170, Poz-91177) were found to be inconsistent with Model 1 parameters.

Initially, an OxCal model (Fig. 12(a)) was run with a total of 37 dates from thirteen stratigraphic units (Fig. 11). The two earliest layers corresponding to the Final Jomon/Epi-Jomon phase VIII, and the Epi-Jomon culture phase VII, showed little variation and exhibited overlapping temporal distributions. The timing of Unit VIII was modeled between 299 and 276 BCE followed by the successive Epi-Jomon phase in Unit VII modeled between 276 and 258 BCE. A phase duration is a relationship between two separate events expressed here as the likeliest modeled start and end dates using mean point estimates (Michczyński, 2007). Maximum phase durations with 2-σ confidence intervals are provided in Table 2. Therefore, these occupations likely had a combined duration of ca. 100 years. This time frame, however, coincides with a plateau in the calibration curve at 335–215 BCE, resulting in extended date ranges. Since priors could not be introduced on both sides of the phases modeled, a timeline with sub-centennial accuracy cannot be provided.

On top of these strata is Unit VI, devoid of archaeological features or datable materials. Above is Unit V, corresponding to the earliest Okhotsk phase, "Towada 1", and timed between 489 and 538 CE. It is followed by another, contiguous phase in Unit IV ("Towada 2"), modeled between 538 and 573 CE. From these results we can infer the presence of an occupation hiatus corresponding to the naturally formed Unit VI at Hamanaka 2, extending from 258 BCE to 498 CE, on the basis of the mean end and start date estimates for units VII and V, respectively.

The age-modeling for the ensuing Okhotsk Culture shell midden succession at the study site was supported by stratigraphic priors available for both phase start and end boundaries. This resulted in higher dating precision and insulating the age estimates from the effects of the plateauing calibration curve at 440–525 and 695–760 CE. The Middle, Late and Final Okhotsk phases in Unit III are divided into six "fishbone layer" subunits IIIa-f. At the bottom is IIIf, corresponding to the Middle Okhotsk Kokumon/Enoura B type pottery, modeled between 573 and 678 CE. Layer IIIe, in turn, is a transitive subunit associated with the Kokumon–Chinsenmon typologies, modeled between 678 and 712 CE.

This is followed by the main Late Okhotsk phase subunits IIIc-d, marked by Chinsenmon-style pottery and dated between 712 and 749 CE, and the transitive Chinsenmon–Motochi subunit IIIb, dated between 749 and 817 CE. The uppermost layer of Unit III is the Final Okhotsk-phase subunit IIIa, i.e. "Motochi 1", dated between 817 and 1710 CE. This is followed by the latest Okhotsk occupation at Hamanaka 2 in the subunit c ("Motochi 2"), pertinent to Unit II, and modeled between 1710 and 1744 CE. It is followed by subunit IIb (unidentified cultural component), timed between 1744 and 1773 CE using only one date (Poz-73801). Likewise, subunit IIb is modeled using one date (Poz-73799).

Since layers IIIa and IIb-c are successive, i.e. contiguous, in the Hamanaka 2 stratigraphy, the Final Okhotsk period (Motochi Phases 1 and 2) is stretched and cannot be estimated with acceptable accuracy without adding more dates. In turn, subunit IIa (Satsumon) was dated between 1773 and 1797 CE, which, similar to the Motochi phase, postdates the conventional time range of this culture at Hamanaka 2 by greater than 500 years. Finally, Unit I (Historical Ainu) was modeled between 1797 and 1853 CE.

To assess the efficiency of the model used, the modeled phase durations (at the 95.4% confidence interval) were compared with unmodeled age-ranges of individually calibrated dates from each phase. These comparisons indicate that the model improved the dating precision of eight of the thirteen phases examined. Dating precision improved the most in contiguously ordered layers where both start and end dates were constrained by chronological priors and from which multiple dates were available. The dating precision in units IIIa-f improved 42–439%. Likewise, the dating precision of units VIII and VII – ordered contiguously with a single prior – improved by 15% and 52%, respectively. In turn, the chronological model did not improve the dating precision of phases IV-V – constrained by a single prior – where 8% and 22%, respectively, was added to the modeled phase durations.

Similarly, the timing of phases IIa-c likely did not improve, given that the model highlighted as outliers most of the older dates from these stratigraphic units. Though these phases were each constrained by both start and end boundaries, the low number of samples (each of the three phases were modeled using one date, since two dates from this unit were identified as outliers) and potential issues with bioturbation likely also contributed to suboptimal dating precision. In turn, the modeled age-range for phase I improved compared to the distribution of its constituent individual dates, with the age-ranges for this phase decreasing by 63%. This phase, however, was only constrained by a single (start boundary) prior.

Finally, since accurate dating of the phases IIa-c was not achieved with the existing samples and model used, a second chronological model (Model 2, see Fig. 12(b)) was run in order to establish a historically realistic age-range for layers IIIa and IIc (Motochi Phase 1 and 2), i.e. the Final Okhotsk period at the study site. In this version of the model, the layers above Motochi Phase 2 were not modeled. The samples Poz-73801 and Poz-91165 were removed from layers Motochi Phase 1 and 2 respectively, considered to be the reason for the archaeologically inconsistent age-estimate for the Motochi period. An outlier function was applied to test the statistical fit of the remaining samples. Samples Poz-91170, Poz-73802 and NUTA2-21216 were removed due to their agreement indices relative to the other samples in the same stratigraphic phase. Sample Poz-91175 (Epi-Jomon, layer VII) with a below-threshold agreement index (25%) was retained, as the end date of its stratigraphic

Fig. 8. Examples of Final-stage Jomon pottery recorded at the study site (Hirasawa and Kato, 2019).

Fig. 9. Okhotsk-type pottery recovered at the study site in units IV, III and IIc (Hirasawa and Kato, 2019)

phase was not constrained by a contiguous phase, and more flexibility could be allowed for. The calibrated dates of this second model demonstrate that by carefully omitting samples due to their poor fit with existing chronologies, the model is able to provide reliable age-estimates for layers VIII–IIc. Therefore, Motochi Phase 2 (IIc) is assigned, based on modeled mean point estimates, an age-range of 847–880 CE (see Appendix for full results of Model 2).

6. Discussion

A probabilistic chronological model was deployed using a series of radiocarbon dates of terrestrial macrobotanical samples for investigating the timing of the Hamanaka 2 site's occupation sequence. This technique responded as anticipated, narrowing down age-ranges in contexts where multiple temporal priors and dates were available, resulting in the first reliable chronology for the study site and its cultural components. Consequently, the model further refines parts of the existing chronology for northern Hokkaido (Hudson, 2004; Weber et al., 2013; Abe et al., 2016; Kumaki et al., 2017), corroborating the notion that the Hamanaka 2 sequence captures the region's cultural dynamics. This is the case, in particular, with the Okhotsk Culture, estimated to have settled Hamanaka 2 from the fifth to the end of the ninth century CE (Figs. 11 and 12), which is consistent with the conventional chronology for this culture in northern Hokkaido (Oba and Ohyi, 1981; Amano, 2003; Ono and Amano, 2008; Deryugin, 2008).

The two earliest occupation phases corresponding to the Final Jomon and Epi-Jomon culture periods, and the Epi-Jomon culture period, respectively, appear to have been shorter than previously assumed, amounting to a combined occupation duration of ca. 100 years. Hamanaka 2, therefore, appears to partially track the evolutionary trajectory of final-stage Jomon cultures in northern Hokkaido. In turn, the final-stage Jomon horizon is separated from the Early Okhotsk (Towada) phase by a natural sediment formation spanning from the mid-third century BCE to the fifth century CE.

The inferred occupation hiatus between the Epi-Jomon phase and the Early Okhotsk (Towada) phase overlaps with the Susuya cultural period, which is absent from the Hamanaka occupation sequence, but present on Rebun Island and other parts of Hokkaido ca. 100–500 CE (Oba and Ohyi, 1981; Kumaki et al., 2017). Consequently, the ensuing Towada period occupation at Hamanaka was estimated to have occurred during the second half of the fifth century CE, which is in line with chronologies posited in Ono (2008), Ono and Amano (2008) and Deryugin (2008).

Moreover, pollen-based vegetation records were intersected with the modeled ^{14}C-data to examine the Rebun Island human and vegetation dynamics during the Okhotsk Culture sequence (Fig. 12). The modeled onset of the Middle Okhotsk (Kokumon) stage ca. mid-sixth century CE coincides with the first evidence for human-induced forest clearing activities in Rebun ~ 550 CE (Leipe et al., 2018). This age-estimate for the Middle Okhotsk is supported by previous studies on the Kokumon/Enoura B assemblages in northern Hokkaido (Hudson, 2004; Ono, 2008; Ono and Amano, 2008; Deryugin, 2008), dated to around the mid-sixth century and occurring in concert with the so-called Late Antique Little

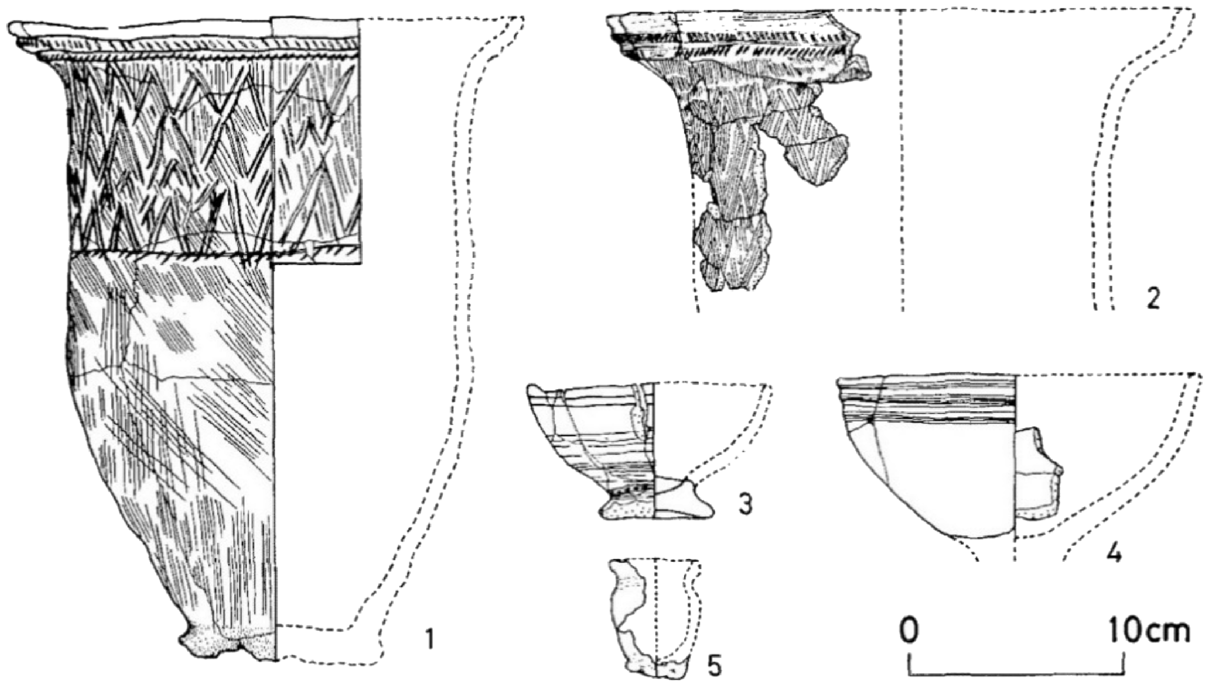

Fig. 10. Drawing of Satsumon-type pottery recorded at a nearby Okhotsk settlement, the Kafukai 1 site on Rebun Island (Oba and Ohyi, 1981).

Table 2
Results of Model 1. Age-ranges modeled for the archaeological cultural sequence at the Hamanaka 2 site, expressed in mean and maximum (2-σ) date estimates for phase start and end dates. Compared with conventional chronologies for northern Hokkaido. (Deryugin, 2008; Ono, 2008; Tashiro, 2017; Hirasawa and Kato, 2019).

Culture period	Typology	Unit	Inferred site activities	Conventional chronology	Modeled phase boundaries (mean values)	Modeled phase boundaries (2-σ range)
Historical Ainu		I	Shell midden	1550–1900 CE	1797–1853 CE	1750–1933 CE
			Animal rituals			
Satsumon		IIa		1100–1200 CE	1773–1797 CE	1737–1852 CE
Unidentified cultural component		IIb			1744–1773 CE	1697–1800 CE
Final Okhotsk	Motochi Phase 2	IIc	Shell midden	800–900 CE	1710–1744 CE	1669–1788 CE
	Motochi Phase 1	IIIa	Animal rituals		817–1710 CE	772–1761 CE
Late Okhotsk	Chinsenmon	IIIb	Human burials	650–800 CE	749–817 CE	687–878 CE
		IIIc			712–749 CE	671–797 CE
		IIId				
Middle Okhotsk	Kokumon/Enoura B	IIIe		550–650 CE	678–712 CE	645–765 CE
		IIIf			573–678 CE	513–751 CE
Early Okhotsk	Towada Phase 2	IV	Stone working	400–550 CE	538–573 CE	445–637 CE
	Towada Phase 1	V	Food processing		489–538 CE	373–588 CE
			Animal rituals			
			Human burials			
Sand layer (no findings)		VI	Natural formation		258 BCE–489 CE	356 BCE–570 CE
Epi-Jomon	Unclassified Epi-Jomon pottery	VII	Stone working	350 BCE– 350 CE	276–258 BCE	362–177 BCE
Final Jomon/ Epi- Jomon	Hamanaka-Omagari, Nusamai	VIII	Food processing	350–1050 BCE	299–276 BCE	391–202 BCE
			Animal rituals			

Ice Age ~ 536–660 CE (Büntgen et al., 2016). The sudden cooling period may have favored the maritime-adapted Okhotsk Culture, whose subsistence should have benefited from extended sea ice coverage and longer marine hunting and fishing seasons due to prolonged winters. These dynamics likely lead to a population increase and a southward Okhotsk expansion to coastal Hokkaido in the second half of the sixth and the seventh century CE (Amano, 2003; Ono, 2008).

That said, the forest clearing activities according to palynological data appear to intensify during or slightly before the transition from the Middle to the Late Okhotsk (Chinsenmon) phase in the first half of the eighth century CE as suggested by the model. This trend, however, is reversed and a full recovery in forest coverage to pre-Okhotsk levels is reached ca. 800 CE, coincident with the modeled onset (847–880 CE) of the Final Okhotsk Motochi Phase 2 (Fig. 12).

The Motochi (Phase 2) layer above the shell midden sequence marks the end of the Okhotsk occupation at the study site in the ninth or tenth century CE, during which the culture entered a terminal decline in Hokkaido (Hudson, 2004; Ono and Amano, 2008). This age-estimate could not be achieved with strict adherence to a mathematical set of principles in chronological modeling (Model 1), but rather required the sample selection criteria to be relaxed, and based on prior archaeological evidence. This was necessary due to the ambiguous provenance of some of the dated samples in the upper layers IIIa and IIa-c associated with the Okhotsk, Satsumon and a yet-to-be identified cultural assemblages. Indeed, four of the eight macrobotanical samples recovered from these layers have ^{14}C-age distributions falling within the age-range of

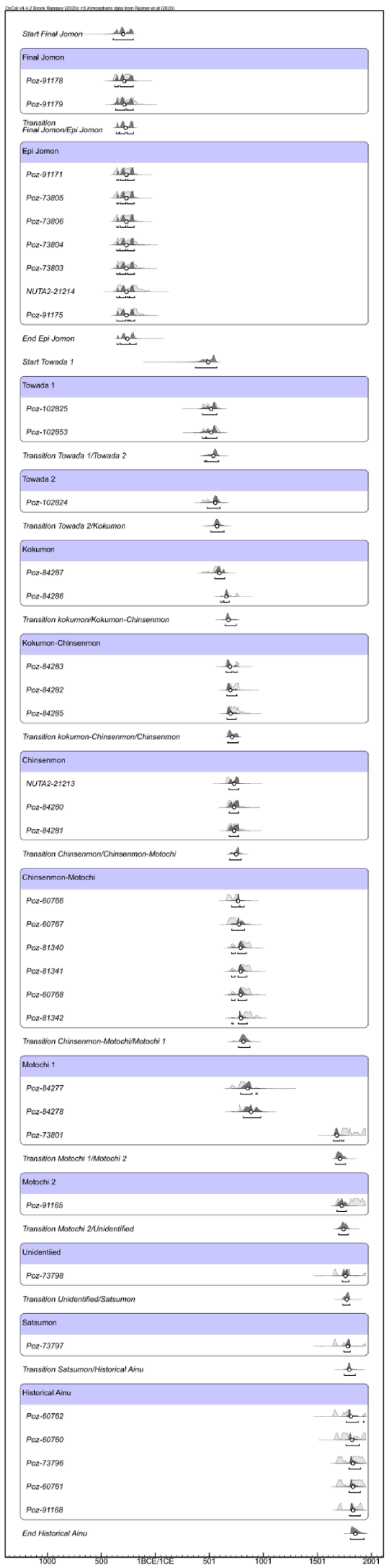

Fig. 11. Results plot of Model 1. A Bayesian age-modeling of 37 radiocarbon dates in thirteen archaeological phases, using the OxCal 4.4.2 calibration software (Bronk Ramsey, 2017). Sequences 1 and 2 are not in direct contact. Sequence is a term defining the modeled order of temporally distinguishable groups of samples, modeled as 'phases' (in this case stratigraphic layers). These are found in a particular order, and as such are constrained by chronological priors (boundaries).

the Historical Ainu period (1550–1900 CE), suggesting that these materials were either redeposited or that at Hamanaka 2 the Ainu cultural layers intersect in places with the Satsumon and uppermost Okhotsk layers. These dates, however, were not highlighted as statistical outliers, resulting in extended age-ranges (from the 9th to the 18th century CE) for the Final Okhotsk layers IIIa and IIc.

To provide a reliable age-estimate for the Final Okhotsk period in northern Hokkaido, an alternative age-estimate was defined using a second OxCal model for the stratigraphic sequence VIII–IIc. This resulted in a more plausible age-range of 847–880 CE for the topmost Okhotsk layer (IIc) at the study site. Indeed, this age-range being the upper limit for the Okhotsk occupation at Hamanaka 2 is consistent with prior chronological estimates for the end of Okhotsk Culture in northern Hokkaido, generally assigned to the ninth or tenth century (Weber et al., 2013). However, further samples representing this cultural phase are required to increase the accuracy of the age-estimate for this context.

Pending the addition of further samples, the timing of the Satsumon occupation at Hamanaka 2 remains an open question, though the Satsumon activities may have been ephemeral and less intensive at the study site – and on Rebun Island in general – since few materials associated to this culture are found there, and since no changes in local forest coverage corresponding to the centuries following the Okhotsk phase (10th-13th CE) are inferred in the terrestrial pollen sum diagram.

Eight dates in total proved inconsistent with the full site-sequence Model 1 and were treated as outliers. The fact that the ^{14}C dates of the samples do not comply with the model constraints does not mean that the radiocarbon dates are not chronologically valid. Given that no complications with the analytical work concerning the dating of the samples were reported, systemic issues with contamination, i.e. the introduction of modern carbon in the sample materials appears unlikely. However, the Hamanaka 2 site is a multi-phase setting at a beachfront where redeposition of macrobotanical remains by disturbances, such as human activities, bioturbation, marine influence (flooding and wave action) and wind erosion (deflation) should be expected.

Though the primary disadvantage of dating small, short-lived botanical materials in a stratified succession is the potential loss of contextual predictability, it can be managed with a high number of samples, rigid quality control, and proper elimination of outliers. In spite of this challenge, however, the modeling presented here in general yielded a robust chronology for the Hamanaka site complex that provided an opportunity to avoid the issues associated with ^{14}C-dates derived from materials affected by marine reservoir offsets. Further work to validate this approach should be conducted with an expanded dating programme in a similar context. This is possible, for instance, at the nearby Kafukai sites on Rebun Island (Oba and Ohyi, 1981), or at Kuznetsova I in Sakhalin Island (Vasilevski et al., 2010) – both contemporaneous multi-phase settlements – where human ecodynamics and archaeological chronologies could be further investigated and compared with Hamanaka 2 site's cultural succession.

7. Conclusions

In this paper we tested the applicability of radiocarbon-supported Bayesian chronological modeling at a multi-phase site in northern Hokkaido, where a high-resolution timeline of the Late Holocene period is becoming increasingly necessary for a network of interdisciplinary researchers. The region, however, is marked by maritime-adapted communities and a complex oceanic carbon cycle, impeding ^{14}C-dating due to unpredictable reservoir offsets among different aquatic organisms. The settlement sequence of the Hamanaka 2 site on Rebun Island was thus examined with a probabilistic stratigraphic model, focusing on ^{14}C-dated macrobotanical remains from a total of thirteen cultural layers. This technique narrowed down the estimated age-ranges in eight phases examined, providing the site with a more accurate radiocarbon timeline than before, and allowing the timing of its cultural succession to be compared with that of the rest of northern Hokkaido.

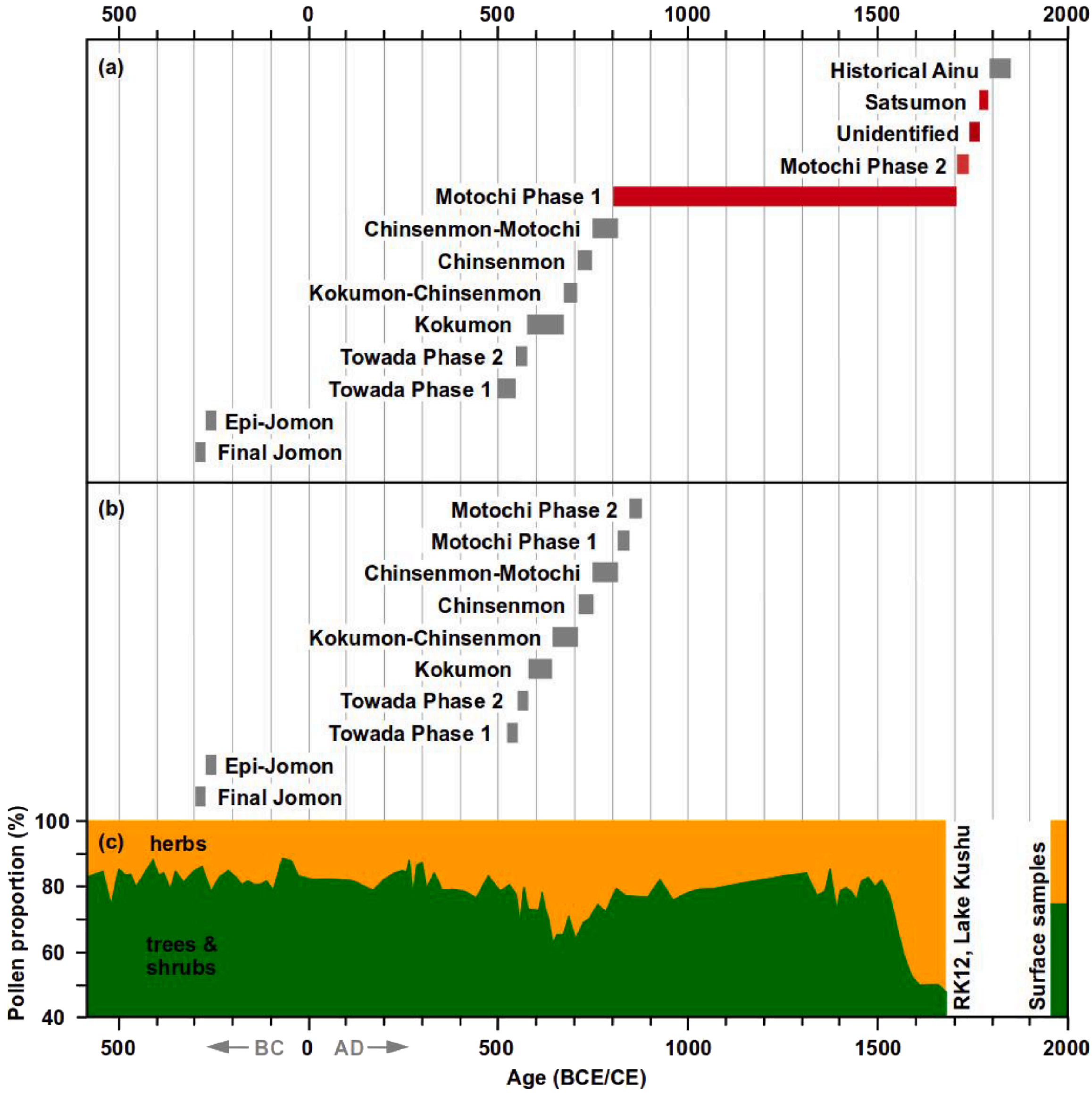

Fig. 12. Archaeological radiocarbon data integrated with palaeoenvironmental evidence. Mean age-ranges for all modeled phases – (a) results of Model 1 (units VIII–I), (b) results of Model 2 (units VIII–IIc) – in comparison with the terrestrial pollen sum diagram for the RK12 sediment core from Lake Kushu (Leipe et al., 2018). Bars representing age-ranges found to be in clear conflict with the conventional chronology are marked in red.

This approach should prove effective in similar maritime environments to overcome dating issues caused by marine reservoir effects. In addition, the resulting cultural chronology in comparison with local palaeoenvironmental evidence reveals that Middle and Late Okhotsk (ca. 570–900 CE) populations were engaged in substantial forest clearing activities that lead to large-scale landscape transformations on Rebun. More work is necessary to further test this technique in a comparable setting in northeast Asia, while also assessing the impact of the Okhotsk Culture to its local ecosystems.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2021.102867.

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