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Dating Coastal Archaeological Wood From Pingusugruk (15th–17th CE), Northern Alaska:

Preliminary Results and Methodological Perspectives in Dendrochronology

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Abstract

Along the coasts of northern Alaska, in a treeless tundra environment, the primary wood resource for coastal populations is driftwood, a seasonal and exogenous resource carried by the major rivers of western North America. The potential of Alaskan coastal archaeological wood for tree-ring research was first assessed in the 1940s by archaeologist and tree-ring research pioneer J. L. Giddings. Despite his success, the difficulties of dendrochronological studies on driftwood and the development of radiocarbon dating during the 1950s resulted in the near-abandonment of dendrochronology to precisely date archaeological sites and build long sequences using archaeological wood in Alaska. In this study, we explored the possibilities and limitations of standard ring-width dendrochronological methods for dating Alaskan coastal archaeological wood. We focus on the site of Pingusugruk, a late Thule site (15th–17th CE) located at Point Franklin, northern Alaska. The preliminary results have been obtained from the standard dendrochronological analyses of 40 timber cross-sections from two semi-subterranean houses at Pingusugruk. We cross-correlated individual ring-width series and built floating chronologies between houses before cross-dating them with existing regional 1000-year-long master chronologies from the Kobuk and Mackenzie rivers (available on the International Tree-Ring Databank, ITRDB). Additional work on various dendro-archaeological collections using an interdisciplinary approach (geochemical analyses of oxygen isotopes and radiocarbon dating) will help develop and expand regional tree-ring chronologies and climatic tree-ring sequences in Alaska.

Keywords

dendrochronology – archaeology – northern Alaska – Thule – coastal wood

1 Introduction

Along the coasts of northern Alaska, wood was a key resource in the daily life and subsistence economy of neo-Inuit societies (Giddings, 1941, 1952b; Alix, 2004, 2012, 2016). In this treeless tundra environment, the primary wood resource is driftwood originating from the subarctic boreal forests of North America (Giddings, 1943a, 1952a; Alix, 2005). Wood is carried to coastal areas via major rivers and their tributaries, that is, the Yukon River, Kuskokwim River, or further north, the Kobuk and Noatak rivers (Figure 1). Along the coasts of northern Alaska, around the Birnirk site near Point Barrow, wood can

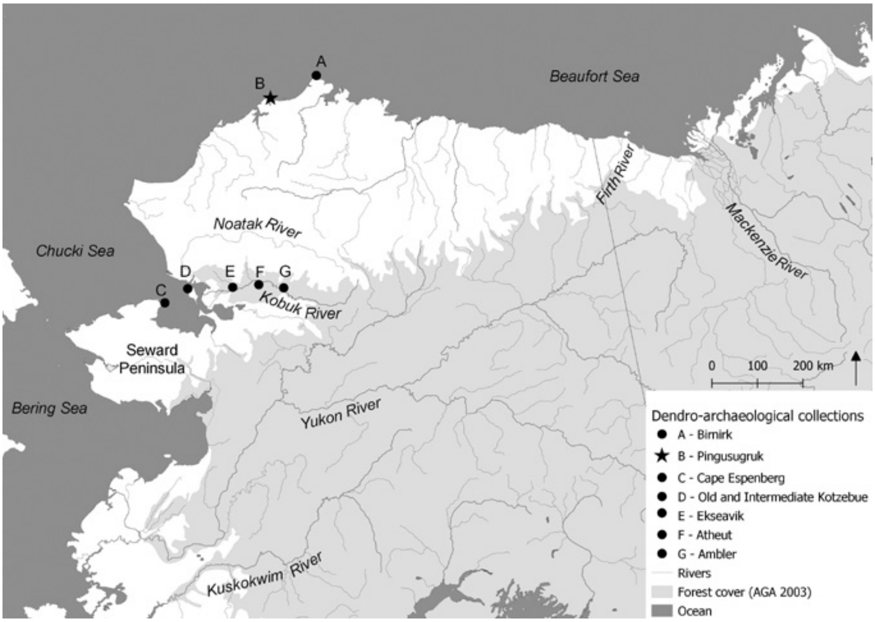

FIGURE 1 Map of Alaska showing locations of archaeological sites with tree-ring sample collections discussed in this article

also arrive from eastward rivers such as the Mackenzie River (Giddings, 1943a, 1952a; Alix, 2005). Driftwood accumulations on beaches are a recurring seasonal resource related to several climatic and environmental factors such as spring thaw, riverbank erosion, wind direction, marine currents, and sea-ice cover (Giddings, 1941, 1952a; Eurola, 1971; Eggertsson, 1994; Dyke, 1997; Alix & Brewster, 2004; Alix, 2005; Hellmann *et al.* 2013, 2017; Hole & Macias-Fauria, 2017; Hole *et al.* 2021; Sander *et al.* 2021).

The main wood species identified in driftwood piles along the northern coasts of Alaska is white spruce (*Picea glauca* (*Moench*) *Voss*), which is a dominant tree in North American boreal forests, regularly growing along valley bottoms, floodplains, and riverbanks (Viereck & Little, 2007; Juday & Alix, 2012; Juday *et al.* 2015). The growth of the white spruce species is sensitive to summer temperature variations — mean June and July temperatures — and regularly provides 200-year-long sequences and, more rarely, up to 400-year-long ones (Giddings, 1943b; Barber *et al.* 2000; Wilmking & Juday, 2005; Viereck & Little, 2007; Juday *et al.* 2010, 2015). Spruce trees growing in different areas of western North America, such as central interior Alaska, northwestern Alaska treeline (*i.e.* the northern latitudinal limit of the boreal forest), and northwestern

Canadian tree-line, bear distinct growth patterns that may allow to provenance them to their source region (Giddings, 1941, 1952a; Barber *et al.* 2000; Alix, 2005; Wilmking & Juday, 2005; Porter & Pisaric, 2011; Juday & Alix, 2012; Juday *et al.* 2015). These spruce trees are well-represented in the coastal archaeological sites of the second millennium CE (Giddings, 1952a; Alix, 2005; Juday & Alix, 2012).

The potential of coastal archaeological wood for tree-ring research was assessed as early as 1938 by Alaska archaeologist and dendrochronology pioneer James Louis Giddings (1938, 1940, 1941, 1944, 1948, 1952b, 1954, 1966; see also Nash 2000). Giddings collected a large number of white spruce tree-ring samples (cores and cross-sections) from various places and contexts (archaeological timbers, driftwood, historic logs, and modern cores) in Alaska. He built a 1000-year-long chronology (978–1941 CE) based on living trees and archaeological wood samples from the Kobuk River valley (Giddings, 1948, 1952b), which allowed the accurate calendar dating of arctic archaeological sites for the first time, prior to the development of radiocarbon dating (Giddings, 1948, 1952b; Nash, 2000). Despite his early success with driftwood from a known river system, cross-dating archaeological timbers from northern Alaskan coastal sites remains challenging. Remnant wood can be too decayed for accurate ring measurement, may belong to species other than white spruce, or the measured tree-ring series can be too short, too fragmented, or too complacent. An additional challenge is that wood remains at archaeological sites are from different and multiple geographic origins. The farther a coastal site is from the source rivers, the more likely the wood remains are from multiple regions of origin. A successful cross-dating of coastal tree-ring series, thus, requires a reference chronology for each possible area of origin of the wood. Moreover, as in any archaeological context, the most recent date obtained is that of the last preserved growth ring of the archaeological wood sample and not necessarily that of its use by people. As a result, the accurate dating of wood does not always provide the exact date of occupation of sites and structures. It is, therefore, necessary to accurately cross-date and determine the provenance of coastal archaeological wood originating from various regions in order to effectively interpret and multiply the chronological information relative to a site, and to correctly extract and interpret the climatic and environmental information according to the regions of origin of the wood. Unfortunately, the difficulties of cross-dating archaeological driftwood from multiple origins along with access to radiocarbon dating starting in the 1950s (Arnold & Libby, 1949; Nash, 2000) resulted in the near-abandonment of dendrochronology to date archaeological sites and build long sequences using preserved archaeological wood

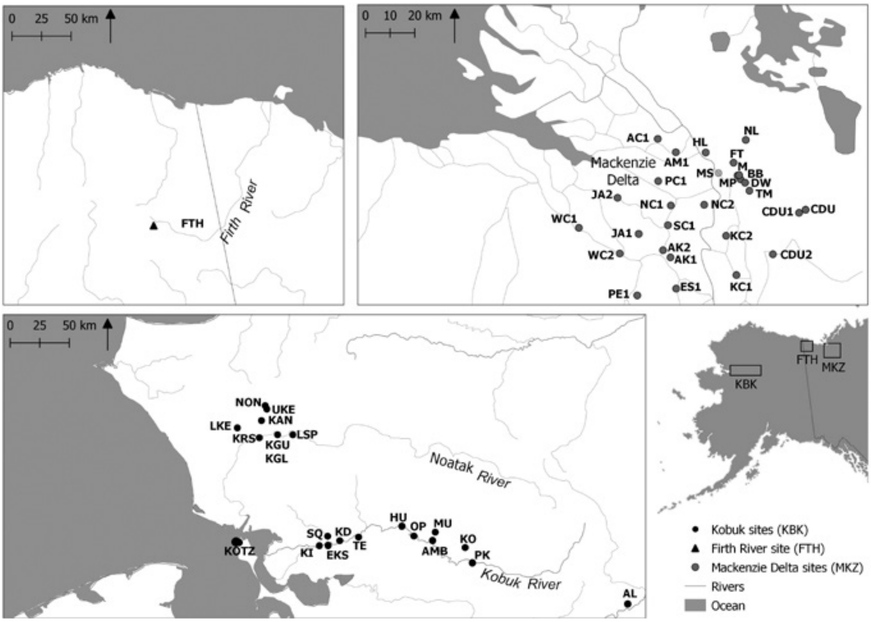

FIGURE 2 Regions of the three millennial regional Master chronologies with the location of the sites and/or tree stands contributing to each chronology: A. Firth River (modified from D'Arrigo et al. 2006), B. Mackenzie Delta (modified from Porter et al. 2013) and C. Kobuk/Noatak rivers (modified from Giddings, 1948, 1952; Graumlich & King, 1997)

in Alaska. Today, the Kobuk River sequence remains the only 1000-year-long chronology in Alaska (Graumlich & King, 1997; Nash, 2000; D'Arrigo *et al.* 2005) that can be used to cross-date coastal wood from northwest Alaskan sites of the first half of the second millennium CE. In addition, two other millennial-length tree-ring sequences were developed for climate studies along the Firth River (1067–2002 CE) in northeastern Alaska and the Mackenzie River drainage (1118–2007 CE) in northwestern Canada (Figure 2) from several sub-fossil and living-trees sites (D'Arrigo *et al.* 2006; Porter *et al.* 2013). Considering the direction of coastal currents, it is possible that archaeological wood remains from northern Alaska may be successfully cross-dated with these master chronologies.

Northern Alaska has remained a crucial region for exploring settlement and population dynamics in the North American Arctic since the beginning of the second millennium CE. The Thule culture, which is directly ancestral to today's Inuit, emerged during the Medieval Climate Anomaly (MCA)

(10th–13th centuries CE) and the transition to the Little Ice Age (LIA) (12th–15th centuries CE) (Mann *et al.* 2009; Raff *et al.* 2015; Mason, 2017; Nicolle *et al.* 2018; Tackney *et al.* 2019; Mason, 2020). In high latitude regions, the slightest climate variations can strongly affect the environment and resources on which people like the Thule subsisted in their daily life. However, the limited resolution of regional environmental proxies in northern Alaska used to characterize the MCA-LIA transition and climate variations, in general, restrains our ability to accurately perceive and understand the complex interactions between climate, resources, and people (Mason & Gerlach, 1995; Mason & Barber, 2003; Jensen 2016; Nicolle *et al.* 2018; Mason, 2020). Following Gidding's initial work (1940, 1941, 1944, 1948, 1952b, 1954), only a handful of researchers took advantage of the exceptional preservation of archaeological wood remains in Thule coastal sites and sampled cross-sections of timbers from semi-subterranean winter houses. This is the case at sites such as Birnirk near Point Barrow (Rye, 1949; Carter, 1966), Pingusugruk at Point Franklin (Sheehan, 1991, 1997), or, more recently, at Cape Espenberg, Seward Peninsula (Hoffecker & Mason, 2010; Alix *et al.* 2017; Alix & Mason, 2018) (Figure 1). As dendrochronology can provide an annual and multi-scalar resolution of climatic and cultural phenomena, these recent collections and legacy of archaeological coastal wood provide the opportunity to build and expand tree-ring master chronologies and climate sequences to document key moments in the development of the Inuit culture in northern Alaska.

In this context, the northern coastal site of Pingusugruk (15th–17th CE) offers some particular advantages. First, because of its geographical location, Pingusugruk is susceptible to having received driftwood from both Alaskan and northwestern Canadian rivers. In addition, the time period of the Pingusugruk site, based on radiocarbon dating (Krus *et al.* 2019), is relatively well-represented in regional master tree-ring sequences, unlike earlier coastal sites. As a result, the wood collection from Pingusugruk is favorable for exploring the potential and limitations of conventional ring-width dendrochronological studies of Alaskan coastal archaeological wood and, in particular, may offer a useful cross-check of the otherwise ambiguous multiple sources of coastal wood. This study aims to build, strengthen, and potentially expand tree-ring master chronologies and climate sequences documenting the second millennium CE and the Thule settlement sequence in northern Alaska.

This paper first presents preliminary findings from conventional dendrochronological analyses (*sensu* Douglass, 1922; Fritts, 1976; Schweingruber, 1988; Cook & Kairiukstis, 1990; Speer, 2012) of Pingusugruk wood samples (Sheehan, 1997; Jensen, 2016). We then examine the potential for related and new techniques to obtain relevant dating information from tree rings.

2 Materials and Methods

2.1 *Site Presentation*

Pingusugruk (WAI-096) was a large whaling village (Sheehan, 1991, 1997: 67–96) located at Point Franklin, south of Utqiaġvik, in an arctic tundra environment far removed from the boreal subarctic forest and tree-line (Figure 1). Established on the shores of the Chukchi sea, the village provided good access to marine resources, such as walruses, whales, and seals. This whaling site was surveyed in 1986 and partially excavated by Glenn W. Sheehan, Anne M. Jensen, and Gregory A. Reinhardt between 1994 and 1996 (Sheehan *et al.* 1991, 1997; Jensen & Sheehan, 2016). Although early aerial photographs of the site indicate that there were originally more than twenty house mounds present, a large part of the village had been subject to erosion by the time the site was excavated in the mid-1990s. Large areas were excavated in three house mounds and smaller units elsewhere on the site. In an unconventional move for Alaskan coastal archaeology at the time, the excavators at Pingusugruk recorded and collected all preserved architectural wood elements from two excavated house mounds identified as SL1 and SL2.

The SL1 excavation revealed a pair of semi-subterranean houses with partially shared entrance tunnels (Figure 3). Unfortunately, there is no publishable map

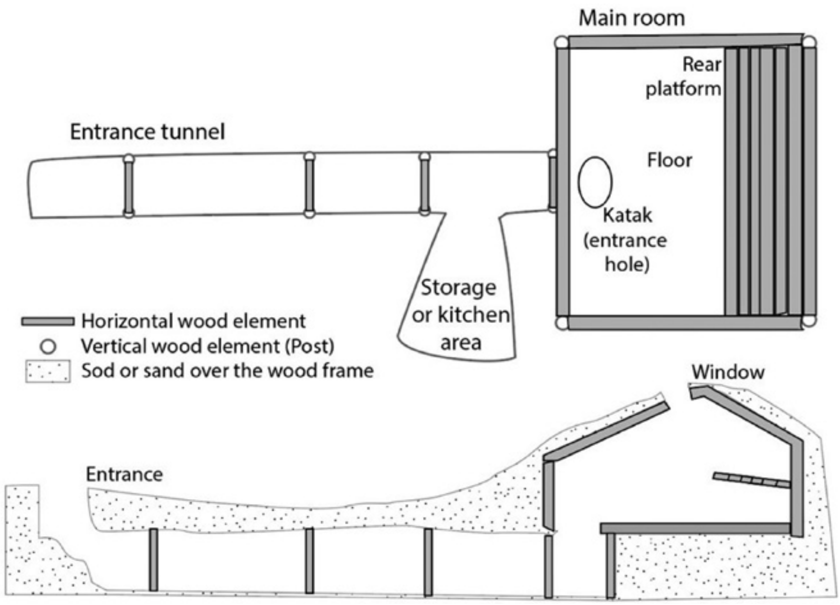

FIGURE 3 Idealized floorplan and general shape of an Iñupiaq semi-subterranean house (modified from Murdoch 1982: 72)

of the Pingusugruk site and its excavated house features at this time. Figure 3, modified from Murdoch 1892, illustrates a typical semi-subterranean wood frame and sod-covered Thule/Iñupiaq house. The main elements of the house are an elongated entrance tunnel leading to a main rectangular room with a rear elevated platform (see Norman *et al.* 2017 for a description and summary of western Thule house architecture). As shown in Figure 3, the floor of the entrance tunnel was usually deeper than that of the main living floor, thus acting as a cold trap (see also Lee & Reinhardt, 2003). The western house appears to have been built and occupied first. The eastern house was constructed at a later date, with its entrance tunnel connecting to the earlier tunnel. The eastern house was larger, with indications of large-scale processing of blubber in the kitchen area. Several wall logs adjacent to the western front corner of the platform had been burned prior to being placed in the position in which they were found (one of the volunteer crew members was a law enforcement officer with training in arson investigation). The wall logs appeared to have been put in place from the inside of the house, suggesting a repair in winter, possibly following a fire that burned them.

The SL2 excavation revealed a single house with a kitchen on the east side of the tunnel. The roof of this kitchen had been used to lay someone to rest, presumably after the house had been last abandoned. The grave goods contained no metal or trade items, and therefore, this was possibly a pre-contact individual (Jensen & Sheehan, 2016). The house had a side platform, which projected from the original footprint of the house on the east side. The reconstruction of the east wall indicated that this platform was an addition to the original structure. This house was certainly built in the footprint of a previous house and may have reused several structural timbers. One indication of this was the human remains that were found beneath the floor of the tunnel, within the tunnel footprint, which were not buried according to the typical pattern (Jensen, 2009). It may have been a burial under exigent circumstances or of someone who had taken shelter and died in the tunnel of an abandoned house. Given the Iñupiat belief system in which houses were abandoned when and where people had died (Reinhardt & Lee, 2003), it is likely that the latest version of the house was built with no knowledge of the human remains resting beneath the tunnel floor. This suggests that a significant amount of time must have passed between the earlier and final periods of use.

With frames of driftwood and whale bones covered with sod, the houses display similarities in building, arrangement, and use of space (Sheehan, 1997), suggesting a temporal continuity from the 13th century until the beginning of the 18th century CE (Sheehan, 1997). In addition, the SL1 house features appeared superposed using the "same footprint" over time, suggesting multiple re-occupations. Based on historical and archival research, Sheehan (1997) suggested that the village was occupied throughout the year, abandoned around 1700 CE (pre-contact period), and re-occupied around 1850 CE (historic period). While the village showed signs of long-term and repeated occupations, recent ^{14}C dating at Pingusugruk provides a time interval of 1410–1640 CE regarding the occupation of the two house mounds (Krus *et al.* 2019).

2.2 *Sample Selection, Preparation, and Measurement*

In 2014, one of the authors spent a week at the Ukpeaġvik Iñupiat Corporation (UIC) archaeology lab at the Barrow Arctic Research Center (BARC) in Utqiagvik, recording, measuring, and sampling the architectural elements collected by Sheehan, Jensen, and Reinhardt during the 1990s' excavation. A total of 110 wood timbers were recorded and inventoried from the two excavation areas (SL1 and SL2), and a total of 93 wood cross-sections were sampled. These disks, from whole or split logs, were sent to the Alaska Quaternary Center at the University of Alaska, Fairbanks, AK, USA (UAF). In 2019, 55 of these samples were selected from the SL1 and SL2 mounds for tree-ring analysis with the goal of contributing additional tree-ring series to the existing millennium-long chronologies, especially for time periods of low sample depth, and to start building floating chronologies with tree-ring series from unknown regions yet to be identified, most likely in the interior Alaskan Yukon River basin (Giddings, 1952a; Alix, 2005). Only six of the 55 selected cross-sections lacked spatial information about their position within the archaeological site.

We used the following criteria to assess the potential of the 55 samples for dendrochronological analyses: (a) species identification, (b) state of preservation, (c) dimensions and shape, (d) length of growth ring series, and (e) presence/absence of wood distortion (compression wood, knots). We prepared and measured the selected cross-sections using standard procedures. We used diluted wood glue to consolidate half of the samples that were fragile and tended to fragment. Cross-sections intended for ring width measurements were sanded to reveal patterns in growth rings (grain size of 50 to 600 grit), marked, and measured using a Velmex measurement table at a precision of 0.001 mm at the UAF Tree-ring laboratory. We scanned all prepared samples with a high-quality image scanner (Epson Expression 10000 XL) to produce an archive of digital copies (Figure 4). In the end, 15 cross-sections were discarded because they belonged to species other than white spruce, contained too much decay or growth distortion (heavy compression wood), or presented an insufficient number of growth rings. As a result, we retained a total of

FIGURE 4 Architectural timber SL2–1986 prior to sampling and cut sampled cross-section

40 white spruce (*Picea glauca*) cross-sections for standard dendrochronological analyses (16 cross-sections from SL1, 21 cross-sections from SL2, and three cross-sections with unknown spatial information).

We measured raw ring widths (RRW) for one to four radii on each disk according to sample shape (whole, half, or quarter disk) and potential distortion. We verified measurement accuracy using the cross-dating program COFECHA (Holmes, 1983). Then, we averaged the measurements of RRW along several *radii* to produce individual tree-ring width series.

2.3 *Detrending, Cross-Correlation, and Cross-Dating Pingusugruk Tree-Ring Samples*

The individual tree-ring series were detrended using the program DplR in R and its default values (Bunn, 2008, 2010) to remove the age trend in growth. For each series, we applied the three traditional curve fitting techniques of negative exponential, horizontal mean, and cubic spline and divided the raw ring-width values by the values of the selected theoretical curve fitting procedure to obtain detrended series of ring-width indices (RWI) (Fritts, 1976; Cook & Kairiukstis, 1990; Sullivan *et al.* 2016). Each detrending technique choice was guided by a visual inspection of each curve fitting technique to the raw tree-ring series and by information specific to each sample. Visual characteristics that were used to select the most appropriate detrending curve included: site, hypothesized environment of growth, length of the series, presence of bark, presence of pith (near <10 rings), type of growth (stable, age trend, unstable) over the entire sequence, and type of growth after the first 20–30 years were truncated. Overall, the negative exponential curve was applied to 33 series, the cubic spline to two series, and the horizontal mean to five series.

We visually observed and statistically compared each RWI individual series of the 40 selected samples (Fritts, 1976; Schweingruber, 1988; Cook & Kairiukstis, 1990; Sander & Levanic, 1996; Speer, 2012) using TSAPWIN (RinnTech, 2000) and COFECHA software (Holmes, 1983). Cross-correlation (in-between site) and cross-dating (with master tree-ring chronologies) were guided by visual comparison and statistical indices commonly used in dendrochronology (Fritts, 1976; Schweingruber, 1988; Cook & Kairiukstis, 1990; Speer, 2012), including:

(1) Baillie-Pilcher *T*-value (TVBP) and Hollstein *T*-value (TVH) indices, which are sensitive to extreme values (Baillie and Pilcher 1973; Sander and Levanic 1996);

(2) Cross-Date Index (CDI) calculated by TSAPWIN based on the T-values and Gleichläufigkeit indices (GLK), which "represents the overall accordance of two series" (RinnTech, 2000).

Cross-correlation and cross-dating are generally considered reliable when tree-ring sequences share a common period of 60 years (Pilcher, 1990). However, because our coastal archaeological wood disks have numerous chances of originating from multiple regions, we set the overlap (OVL) threshold to 70 common years to avoid spurious cross-correlation and cross-dating. When the visual observation and statistical parameters indicated a significant cross-correlation (TVBP and TVH > 4, CDI > 30, and OVL > 70) (Baillie & Pilcher, 1973; Sander & Levanic, 1996), the individual series were averaged into a floating mean chronology (not placed in calendar time).

The floating mean chronologies and sufficiently long individual series (⩾ 70 rings) were then cross-dated (using similar parameters as described above) with the three *ca.* 1000-year-long master chronologies (Figure 1): (a) the Kobuk River valley chronology 978–1992 CE (KBK) (Giddings, 1948, 1952b; Graumlich & King, 1997), (b) the Firth River chronology 1067–2002 CE (FTH) (D'Arrigo *et al.* 2006), and (c) the Mackenzie delta site sequences from 1118–2007 CE (MKZ) (Porter *et al.* 2013), available in the International Tree-Ring Data bank (Zhao *et al.* 2018). According to Porter *et al.* (2013), the Mackenzie delta site sequences were averaged in a master regional chronology (1118–2007 CE). The KBK master chronology was detrended following the same traditional detrending procedure used for the Pingusugruk individual tree-ring series. Because the purpose of this study is cross-dating, which is primarily sensitive to short-term variability, for the FTH and MKZ detrending, we used only the most common (negative exponential) detrending curve form (Speer, 2012). Master chronologies may allow the placement of the floating sequences in absolute time and provide an indication of provenance for the individual trees contributing to the sequences. The lack of chronologies longer than 300 years for the Yukon River drainage in the Interior of Alaska (Juday & Alix, 2012) suggests that floating sequences could not be tested for provenance and potential origin in what is known to be a major source area of Alaskan Arctic driftwood (Giddings, 1941, 1952; Alix, 2005). The cross-dating procedure of

Pingusugruk individual RWI series and floating mean chronologies with the RWI master chronologies was conducted at the regional level for the three master chronologies (KBK, FTH, and MKZ).

3 Results

Disk samples from Pingusugruk were mostly fragmented and did not necessarily retain the first year of growth (FYG) and/or the last year of growth (LYG) due to decay or abrasion of wood layers. If LYG were rarely present (n=1), cross-sections often showed that the last measurable ring was close to the LYG (near bark). FYG was present in 30 of the total disk samples.

3.1 *Cross-Correlation Analysis of Pingusugruk Disks*

Cross-correlation of individual tree-ring series at the site level resulted in two instances of finding parts of the same individual tree used in different areas of the house features in both excavation areas. For example, timbers SL1–3105 (post, eastern house) and Slno-nb3 (missing spatial information) generated such high cross-dating indices (OVL = 80; TVBP = 25.5; TVH = 21; CDI = 215) that the curve similarity suggested it was the same tree. Likewise, timbers SL1–1915 (wall log, eastern house) and SL2–1916 (kitchen area, single house) (OVL = 122; TVBP = 7.0; TVH = 6.4; CDI = 45) showed significant statistical cross-correlation and such strong visual overlap that we accepted them as being from the same tree (Figure 5). At this preliminary stage of the investigation, we decided to

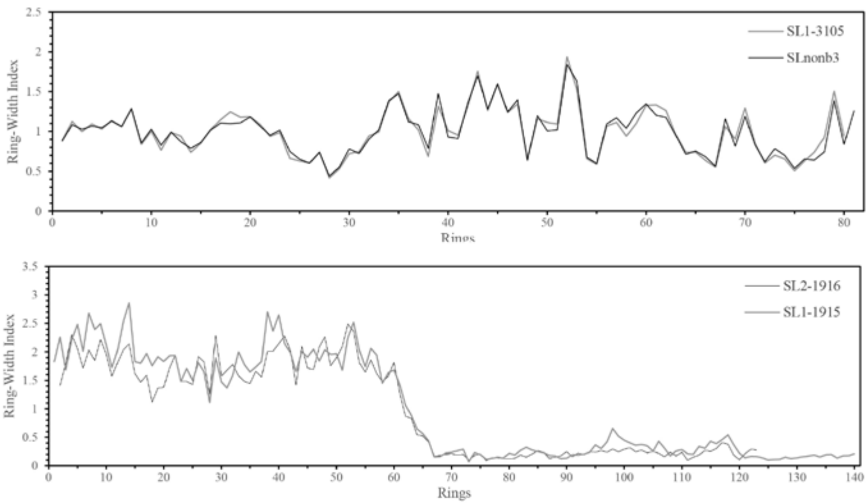

FIGURE 5 Tree-ring series from the same trees

TABLE 1 Description of the floating chronologies built from individual RWI series with associated statistical scores

Floating chronologies	Tree-ring series included	OVL	TVBP	TVH	CDI	Comments
PIN_C1 (2 series)	SL1–1306 SL1–1139	90	5.9	5.2	43	Samples are from SL1 western house.
PIN_C2 (3 series)	SL2–1986 SL2–1456 SL1–2264	65–76	4.5–5.8	6.0–6.3	32–47	Samples are from SL1 eastern house and SL2 single house.
PIN_C3 (2 series)	SL2–1931 SL2–2207	77	4.5	5.0	30	Samples are from SL2 single house.
PIN_C4 (2 series)	SL2–1707 SL1–1915/ SL2–1916	76	5.5	4.9	33	Samples are from SL1 eastern house and SL2 single house.
PIN_C5 (2 series)	SL2–2199 SL1–3130	140	4.8	5.5	36	Samples are from SL1 eastern house and SL2 single house.

OVL: Overlap; TVBP: Baillie-Pilcher T-value; TVH: Hollstein T-value; CDI: Cross Dating Index.

average each same tree pair into mean individual tree series, which left 38 individual tree-ring width series.

Based on the cross-correlation index scores, we built five floating mean chronologies that include 11 of the 38 ring-width series (Table 1). The cross-correlation of the remaining 27 individual series with each other and with the five floating chronologies did not meet our threshold index criteria for successful cross-correlation. The cross-dating of the five floating mean chronologies between each other did not provide any positive results according to our threshold criteria. The five floating mean chronologies were thus kept separated (Table 1).

3.2 *Cross-Dating with Regional Master Chronologies*

Cross-dating of the Pingusugruk individual series and floating mean chronologies with the Kobuk (KBK) and Mackenzie (MKZ) master chronologies provided significant results. However, no floating chronology from Pingusugruk was successfully cross-dated with the Firth River Master chronology (FTH). PIN_C1 cross-dated successfully with KBK master chronology (OVL = 197; TVBP = 12; TVH = 13.3; CDI = 103), placing this chronology between 1429 CE and 1625 CE (Figure 6; Table 2). PIN_C3 cross-dated successfully with KBK master

TABLE 2 Cross-dating indices of individual series contributing to PIN_C1 and PIN_C3 when cross-dated with KBK master chronology

Pingusugruk series	Kobuk chronology	OVL	TVBP	TVH	CDI	Dating
SL1–1139 (Pin_C1)	KBK	90	4.5	4.7	34	1460–1549 CE
SL1–1306 (Pin_C1)	KBK	197	15.9	17.7	138	1429–1625 CE
SL2–1931 (Pin_C3)	KBK	89	4.5	4.5	30	1440–1528 CE
SL2–2207 (Pin_C3)	KBK	93	5.9	4.3	30	1452–1544 CE

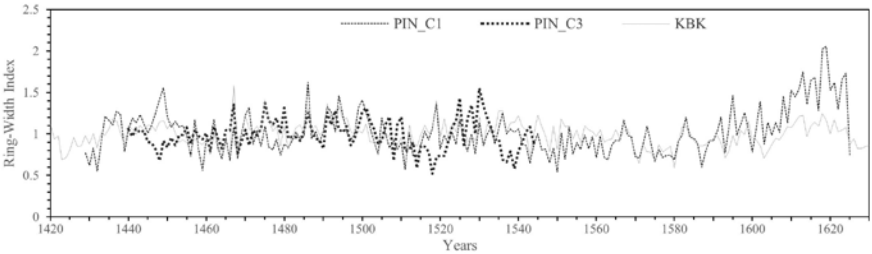

FIGURE 6 Cross-dating PIN_C1 and PIN_C3 with Kobuk (KBK) master chronology

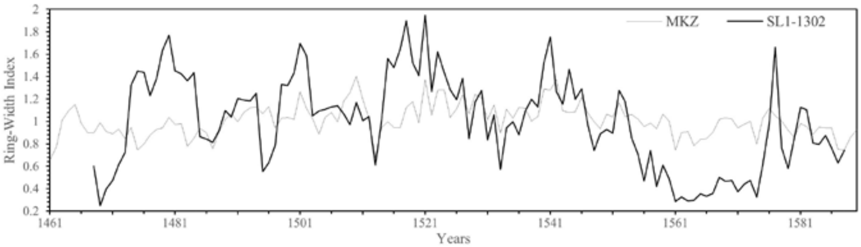

FIGURE 7 Cross-dating of series SL1–1302 (black) with the MKZ master regional chronology (grey)

chronology (OVL = 105; TVBP = 6.2; TVH = 5.0; CDI = 36) placing this chronology between 1440 CE and 1544 CE (Figure 6; Table 2).

Only one of the 27 remaining individual series was successfully cross-dated with one of the three master chronologies. SL1–1302 individual series (from the western house) cross-dated with MKZ master chronology between 1468 and 1588 CE (OVL = 121; TVBP = 4.6; TVH = 5.8; CDI = 33) (Figure 7), suggesting a potential area of origin for this sample (Figure 2).

4 Discussion

4.1 *Dendrochronological Findings from Pingusugruk*

The dendrochronological dates obtained in this study support the archaeological evidence of temporal continuity and/or successive phases of occupations at the Pingusugruk whaling village in the 16th and 17th century CE.

Our standard dendrochronological approach to the 40 selected archaeological cross-sections provided limited but relevant results. The technique applied allowed the identification of cases in which individual trees were cut or split into pieces and used in the construction of more than one house. We identified two pairs of samples corresponding to single trees. In one case, a divided tree was part of house features in both excavation areas SL1 and SL2 (SL1–1915 and SL2–1916). In the other case, one part of a tree came from SL1 (SL1–3105), but the other had no known contextual data (Slnonb3). In general, when sampling and cross-dating archaeological wood, it was found, as might be expected, that splitting and dividing timbers was relatively common in Birnirk and Thule houses (Hoffecker & Mason, 2011; Norman *et al.* 2017; Alix & Mason, 2018). These findings indicating the deliberate placement of wood from a common source in different parts of a structure raise questions regarding when the features were constructed vs. repaired (e.g., recycling of timbers from one area to another). As mentioned earlier, timber SL1–1915 had been burnt before it was placed from the inside in the eastern feature of SL1, which suggested a repair. SL2–1916 came from the fill of the kitchen area in SL2 single house. We have yet to explain how and in what order the two pieces from the same log ended up in the two different house frames. Although there is a possibility that structural elements from the SL2 kitchen area were used to repair SL1, additional contextual and chronological information is needed at this stage to address this further.

The sequence PIN_C1 significantly cross-dated with KBK chronology (Figure 6; Table 2), providing an end date for samples SL1–1139 at 1549 CE and SL1–1306 at 1625 CE. The successful cross-dating of sample SL1–1302 with MKZ chronology provided an end date of 1588 CE. These three dated timbers are from SL1 western house, representing three different end dates for this house feature (1549, 1588, and 1625 CE) over a time period of 76 years. PIN_C3 significantly cross-dated with KBK chronology (Figure 6; Table 2), providing end dates for samples SL2–1931 at 1528 CE and SL2–2207 at 1544 CE. Thus, the SL2 single house has two end dates, only 16 years apart.

The architectural wood elements used in the construction of house features in SL1 and SL2 show limited signs of log reduction, besides longitudinal splitting to obtain two halves or cross-sectioning to obtain two log sections. As a result, it is possible that the missing FYG and especially LYG may be related to post-tree death degradations (biological, climatic, and physical) that would have occurred at any stage of the driftwood cycle and later when the wood was used as timber and subsequently excavated as archaeological material. However, in several logs, the last measured ring shows signs of being close to LYG and can be referred to as near bark. As a result, the absolute dates obtained in this study are very likely close to that of the death of the trees, and the 76 years separating the earliest and the latest dates obtained for the SL1 western house cannot be explained by the absence of LYG. When dating timbers from archaeological houses on the Kobuk River, Giddings similarly found a range of approximately 100 years between the youngest and oldest end dates within a single house (Giddings, 1952b).

The whaling village of Pingusugruk showed signs of temporal continuity and repeated occupations, with a superposition of house features (Sheehan, 1997). These dendrochronological results suggest the potential recycling of timbers taken from earlier structures and/or rebuilding events within SL1 with newly arrived driftwood in the early 17th century. The three end dates for the SL1 western house are consistent with radiocarbon dates obtained at the site (Krus *et al.* 2019) and calibrated between 1460 and 1640 CE. The youngest tree-ring end date (1625 CE) falls toward the end of the radiocarbon interval. This calendar date suggests occupation of the house or a re-occupation of the "footprint" feature in the mid-17th century, consistent with archaeological remains of the late Western Thule whaling village (Sheehan, 1997). So far, we could date no timbers from the SL1 eastern house, which is considered to have been built later than the western house. The two end dates from the SL2 house dated timbers (1528 and 1544 CE) are also consistent with Krus *et al.'s* (2019) radiocarbon dates obtained for the low camp (1440–1630 CE) and the midden (1450–1640 CE). However, additional dates should be obtained to further discuss the relationships and temporality of construction, occupation, and repairs of the three houses.

4.2 *Standard Dendrochronology on Coastal Archaeological Wood from Northern Alaska*

Our cross-dating and provenance findings from Pingusugruk archaeological coastal wood support local Alaskan knowledge and modern tree-ring provenance studies, which indicate that modern driftwood originates from both Alaskan and Canadian large rivers (Giddings, 1952a; Alix *et al.* 2013). However, a larger number of samples and significant correlations will be necessary to fully inform paleo-environmental studies (e.g., the role of sea currents in transporting Alaskan driftwood).

We found convincing matches through the cross-dating techniques for five archaeological timbers (including two of the build chronologies), reinforcing the idea that these chronologies are valid and useful representations of the overall growth trends of northwest North American boreal trees. Our samples have led to the increase in the number of trees contributing ring widths to the reconstruction of 1450–1650 CE, a critical time period in northwest Alaska. The 15th century is considered in the area as the beginning of the LIA, and the 16th and early 17th century represents the most severe period of the LIA. This later period is also when cultural change can be seen in the Kobuk River valley and Thule archaeological sequences from northwestern Alaska (Giddings, 1952b; Giddings & Anderson, 1986; Minc & Smith, 1989; Mason, 2012; Jensen, 2016; Norman *et al.* 2017).

While previous studies demonstrated that some modern driftwood collected at Point Barrow also originated in the Yukon flats and Tanana River (Giddings, 1952a; Alix, 2005; Juday & Alix, 2012), the absence of master tree-ring chronologies exceeding the last 300 years in this area (Alix, 2005; Juday *et al.* 2015) does not yet allow the biogeographic region of tree-ring samples from Thule archaeological sites to be determined. Our cross-dating results using Pingusugruk disk timbers highlight the need to collect additional archaeological tree-ring samples from the Thule coastal sites to build and expand the network of local and regional tree-ring chronologies.

4.3 *A Strategy to Date Alaskan Coastal Wood Using Other Tree-Ring Techniques*

Recent decades have witnessed the development of innovative techniques and tools that are both complementary to each other and/or independent of standard ring-width variation analyses, for example, ^{14}C wiggle-matching, $^{87}Sr/^{86}Sr$ ratio determination, wood density, and carbon and oxygen stable isotopes measurements (Christen & Litton, 1995; English *et al.* 2001; Galimberti &Bronk Ramsey, 2004; McCarroll &Loader, 2004; Kagawa & Leavitt, 2010; Bridge, 2012; Daux, 2013; Rydval *et al.* 2014; Hajj *et al.* 2017; Wilson *et al.* 2017a,b; Loader *et al.* 2019; Domínguez-Delmás, 2020; Domínguez-Delmás *et al.* 2020). Here, we discuss a strategy to supplement and overcome the limitations of standard ring-width dendrochronology applied to archaeological coastal wood in northern Alaska.

First, to estimate and calibrate the floating dendrochronological sequences in calendar time, we are developing a ^{14}C wiggle-matching approach. Wiggle-matching consists of the radiocarbon dating of several individual rings (regularly spaced, every 5 to 20 years) from an individual tree sample belonging to a floating chronology. The radiocarbon signatures of the rings form a curve that is statistically compared to the ^{14}C calibration curve. This method is based on a Bayesian process that consists of calibrating together several ^{14}C dates with unknown exact age but with a known time interval, that is, the number of rings separating each dated ring. This method allows reducing the effect of fluctuations in the ^{14}C calibration curve and considerably refines the calendar interval in which the age of the last ring of the wood is located (Christen & Litton, 1995; Galimberti & Ramsey, 2004; Astrade & Miramont, 2010). Performing wiggle-matching on one sample from the Pin_C2 floating sequence may provide an absolute and precise calendar dating (from centennial to decadal interval) for the three cross-dated floating ring-widths series that represent the Pin_C2 sequence. Ultimately, this wiggle-matching dated sequence could help date other archaeological coastal wood samples from Neo-Inuit sites and build other long master sequences for different source areas in Alaska.

Second, to determine the biogeographic region of origin of Alaskan coastal archaeological wood, we considered two methods: the Blue Intensity (BI) technique and geochemical analyses of $^{87}Sr/^{86}Sr$ isotope ratios. Recently developed, BI is based on the reflectance of blue light on growth ring cells from high-quality tree-ring scans and can improve the provenance-determination of timbers by highlighting a regional signal that is recorded in the trees (Rydval *et al.* 2014; Wilson *et al.* 2014, 2017a,b). BI allows the reconstruction of a summer temperature signal that is less affected by non-climatic effects on tree growth, compared to ring-width variations and Latewood Density analyses, and uses simpler and cheaper equipment (Rydval *et al.* 2014; Wilson *et al.* 2014, 2017a,b). However, this technique is sensitive to wood discoloration that chemical pretreatments (*e.g.* ethanol or acetone baths) cannot yet overcome (Wilson *et al.* 2017a.b, 2019). Such discolorations are common in archaeological and driftwood spruce wood due to fungi and other preservation issues.

Recent applications of geochemical analyses of $^{87}Sr/^{86}Sr$ isotope ratios on archaeological wood provide a precise method to identify the biogeographic region of origin of archaeological wood. Strontium $^{87}Sr/^{86}Sr$ ratios in wood are largely dependent on the geological substrate and, thus, can be characteristic of a tree's growth locality (English *et al.* 2001; Kagawa & Leavitt, 2010; Rich, 2013; Rich *et al.* 2015; Hajj *et al.* 2017). However, recent research has challenged the use of strontium geochemical isotopes to determine the biogeographic origin of wood that has been in contact with seawater (Van Ham-Meert *et al.* 2020; Snoeck *et al.* 2021), as in the case of shipwrecks (Rich *et al.* 2016; Hajj *et al.* 2017), and potentially Alaskan archaeological coastal wood. As seawater has its own $^{87}Sr/^{86}Sr$ signature, wood that has been in its contact can have its $^{87}Sr/^{86}Sr$ signature contaminated and modified within a few weeks/days (Hajj *et al.* 2017; Snoeck *et al.* 2021). As of today, there is no chemical protocol or pre-treatment that can reliably recover the original $^{87}Sr/^{86}Sr$ signature (endogenous) of a tree that has been in contact with seawater. As a result, it is not yet possible to confidently accept provenance results (Van Ham-Meert *et al.* 2020; Snoeck *et al.* 2021).

While further research is needed to assess the levels at which $^{87}Sr/^{86}Sr$ signatures of coastal driftwood logs are modified, another dendro-isotopic method using a series of oxygen isotopic compositions of tree-ring cellulose (Loader *et al.* 2019) might help identify the calendar dating and biogeographic origin of Thule archaeological wood. Isotopic ratios of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) from wood cellulose produced on an annual basis can provide data on temperature and moisture and are, therefore, an independent source of information to characterize climatic signals and reconstruct climatic variations and environmental conditions (McCarroll & Loader, 2004; Daux, 2013; Porter *et al.* 2014; Bégin *et al. 2015;* Csank *et al.* 2016). A recent study in central England developed a new dating approach based on oxygen isotopes ($\delta^{18}O$) for wood from different geographic areas and trees influenced by the same type of climate variability (Loader *et al.* 2019). The annual dating technique is similar to cross-dating using conventional dendrochronology (ring-width), except that it is based on a series of $\delta^{18}O$ annual variations, themselves sensitive to variations in soil water. We are presently testing this approach on five coastal tree-ring samples that we cross-dated with the KBK master chronology and three coastal tree-ring samples whose sequences remain floating. At this preliminary stage, we are investigating whether this technique can provide the annual calendar dating of floating series. We hypothesize that these sequences might provide a strong common $\delta^{18}O$ isotopic signal (strongly sensitive to climate), which would suggest geographic proximity of tree origin, as of yet undetectable with conventional dendrochronology.

We believe that at present, coupling dendro-isotopy (oxygen) and ^{14}C wiggle-matching with standard dendrochronological procedures offers the best potential for building robust regional reference chronologies and expanding them back into the second millennium CE. This interdisciplinary strategy has the potential to resolve important questions of cultural dating, paleoclimate, and environmental change, especially during a time period of important cultural and climate variations during the MCA and the LIA.

5 Conclusion

This paper presented the results of standard dendrochronological analyses of coastal archaeological wood from the Thule houses of excavated areas SL1 and SL2 of the Pingusugruk site in northern Alaska. The cross-correlation of 40 archaeological wood cross-sections has so far allowed the construction of five mean floating chronologies (representing 11 individual tree-ring series). The successful cross-dating of two chronologies and one individual tree-ring series with the Kobuk and Mackenzie master chronologies provide a calendar date for the site in the 16th and 17th century, consistent with the ^{14}C dating and archaeological evidence of a late Western Thule whaling settlement (Sheehan, 1997; Krus & Jensen, 2019). These preliminary results confirm the potential of dendrochronology for a better understanding of the Thule period of climate and cultural change. However, at the present stage of the research, the lack of master chronologies longer than 300 years in Interior Alaska limits the application of our results and requires analyzing additional collections of coastal archaeological wood to build and extend tree-ring master chronologies in different driftwood source areas. Our preliminary results suggest that additional work on various dendro-archaeological collections using an interdisciplinary approach (geochemical analyses of oxygen isotopes and radiocarbon dating) will help develop and expand regional tree-ring chronologies and climatic tree-ring sequences in Alaska.

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