

Ancient DNA sexing of walrus bones from Alþingisreitur, Iceland

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Icelandic
ZooArch

Icelandic Archaeological Research Reports no. 2021-2

Skýrslur Íslenskra fornleifarannsókna ehf nr. 2021-2

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Icelandic Archaeological Research Reports no. 2021-2/Skýrslur Íslenskra fornleifarannsóknna ehf nr. 2021-2

Publisher: Íslenskar fornleifarannsóknir ehf og Icelandic ZooArch

Place: Reykjavík

ISBN 978-9935-9641-0-6

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Introduction

We earlier reported on the ancient DNA preservation of several archaeological walrus specimens obtained from the archaeological site of Alþingisreitur, Iceland (A. H. Pálsson et al., 2018). The DNA preservation was of such quality, that –with the genomic resources available at that time– limited genetic analyses could be performed.

Recently, a chromosome-resolved version of the Pacific walrus reference genome (Foote et al., 2015) was released using HiC methodology (Dudchenko et al., 2017) on DNA ZOO (<https://www.dnazoo.org/>). This resource allows the determination of genetic sex for samples with extremely poor DNA preservation (Barrett et al., 2020; Bro-Jørgensen et al., 2021; Nistelberger et al., 2019; Schubert et al., 2017). Therefore, we have revisited the specimens from Alþingisreitur, Iceland here, to provide genetic sexing results for those specimens with sufficient DNA preservation for sexing. In addition, we provide more detailed archaeological context information on the bones and an overview of published walrus bone finds from archaeological excavations in Iceland and discussion of the results. For information about laboratory methods and detailed finds information for the bones see the previous report (A. H. Pálsson et al., 2018).

The Alþingisreitur site

The Alþingisreitur site was located in downtown Reykjavík and spanned over 2000 m². It was excavated between 2008-2010 and again in 2012 due to planned expansion of parliamentary office buildings. The site is close to the Reykjavík pond and was only a short distance from the shoreline (Garðarsdóttir, 2010, 2011, 2013). Two other Viking Age sites are only a few meters away, a long house at Aðalstræti 14-18 excavated in 2000-2001 and 2003 (Roberts, 2001, 2003) and Viking Age structures found during construction in 1944 and partially recorded (Grímsson & Einarsson, 1970).

The Alþingisreitur site is divided into four phases, based on tephrochronological, radiocarbon and typological dating methods (Garðarsdóttir, 2010, 2011). During the oldest phase of the site, Phase IV 877-1226¹ AD, the area was used as an outdoor work area and there were also several structures related to iron working and processing, a boundary wall, wooden pathway, mixed use buildings with hearths and small middens formed in parts of the area (Garðarsdóttir, 2011, 2013). During Phase III 1226-1500 AD and Phase II 1500-1800 AD, a large midden formed in the area and some buildings were also present but most of them were severely damaged by the cellars of houses built in the 19th and 20th century. The archaeology of the youngest phase of the site, Phase I 1800-modern, was very fragmentary due to deep cellars, utility cable trenches and such but included some walls, peat ash midden layers and a well among other things (Garðarsdóttir, 2010).

All of the animal bone recovered from the oldest phase of the site has been zooarchaeologically recorded (A. H. Pálsdóttir, 2010, 2013) but only parts of the material from the younger phases of the sites have been analyzed (A. H. Pálsdóttir, 2010). A number of the marine mammal bones from the site were identified to family or species level through ZooMS (Buckley et al., 2014, 2015).

¹ The Landnám tephra layer, that underlies most of the archaeology at Alþingisreitur, was dated to 871±2 AD but was recently re-dated to 877±1 AD based on refinement of ice-core data from Greenland (Schmid et al., 2017). The start date of Phase IV has been changed to reflect these new results.

Walrus skull fragment WLR035 - 877-1226 AD

The walrus skull fragment from Alþingisreitur (WLR035) included in this study was found in a peaty silt layer interpreted as a cultural deposit but could also possibly have been naturally formed. No other animal bones were recorded from this layer. The skull fragment is dated to 877-1226 AD based on tephrochronology and archaeological context. The walrus skull fragment had no DNA and it could therefore not be assigned to a clade or sexed (Table 1; A. H. Pálsdóttir et al., 2018). The bone had been previously confirmed to come from walrus through ZooMS (Buckley et al., 2014).

Walrus pelvis WLR036 - 1226-1500 AD

This specimen is an almost complete pelvic bone (WLR036) that is archaeologically dated –based on context– to between 1226-1500 AD. It was found in a peat ash midden layer along with a large number of animal bones (Garðarsdóttir, 2010; A. H. Pálsdóttir, 2010). The bone had been previously confirmed to come from walrus through ZooMS (Buckley et al., 2014).

There are no published criteria to sex the pelvis bones of walruses morphologically but it was possible to sex the pelvis through aDNA analyses and it clearly comes from a female walrus (Table 1). The age of death of the walrus specimen is somewhat ambiguous, yet the pelvis bone is fully fused without visible fusion lines. Although there is no published data on the order of fusion or ages of bone fusion for walrus postcranial skeletons previous work has used the fusion order for seals (Storå, 2000) as a rough indicator of age (Monchot et al., 2013, p. 22). The acetabulum of the pelvis is an early fusing element in seals and falls into skeletal age group 3 with the earliest age of complete fusion in seals at 5-11 months. Elements that are parts of skeletal age group 1-3 give the minimum age of yearling which is the youngest age group according to Storå (2000). Following this reasoning we can tentatively state that the pelvis comes from an individual that at a minimum falls into the later stages of the yearling age group but could of course be much older. Female walrus become sexually mature between 6 and 8 years and it is possible that the pelvis come from a breeding female (Born, 2001).

Table 1: aDNA sexing results for the walrus bones from Alþingisreitur, Iceland

Sample number	DNA sample number ^a	Element	Aligned reads (n)	X chromosome coverage	Autosomal coverage	Ratio	Genetic sex determination
2008-32-709 #1051	WLR035	Skull fragment	na				
2008-32-685 # 711	WLR036	Pelvis	15189	0,0002	0,0002	0,87	female

Discussion

In the modern period walrus are only occasional visitors to Iceland but it is known that the size of the walrus population was drastically reduced due to overhunting in the 18th-20th century and there are indications of overhunting of the walrus population in Greenland today (Þórðarson & Hauksson, 2004). This in turn has likely reduced the number of walrus vagrants in Iceland. While walrus bone finds are most common in the West coast of Iceland sightings today are most common in Northern and Eastern Iceland (Keighley et al., 2019; Þórðarson & Hauksson, 2004).

Of the 34 walrus samples presented in Keighley et al. (2019), three are radiocarbon dated to after the settlement of Iceland in 871 AD (1079 BP), sample Ic00 from Ytri-Garðar in Snæfellsnes dated to 1129-1282 calAD, sample Ic21 from Reykjavík dated to 1055-1288 calAD and sample Ic13 from Reykjavík dated to 1213-1330 calAD, after correction for marine reservoir effects and calibration² (Keighley et al., 2019, pp. 2658 & Supplementary Material 1).³ All three date to after the Norse settlement of Greenland around 985 AD or the late 10th century (Arneborg et al., 2012; Edwards et al., 2013; Gulløv et al., 2004; Price & Arneborg, 2018). Unfortunately, very little information is provided about the elements sampled⁴ in the Keighley et al. (2019) paper or its supplement and no detail about find context so it is unclear if they are loose finds or that they were obtained from archaeological excavations. The youngest walrus bone from the pre settlement period is radiocarbon dated to 658-781 calAD (1292-1169 BP, sample Ic11) and comes from Breiðavík in the Westfjords. Furthermore, it is interesting that none of the walrus bones from Iceland dated in Keighley et al. (2019) actually date to the settlement period of Iceland (877-939 AD), and only one, sample Ic21 from Reykjavík dated to 1055-1288 calAD, has dates that fall within the Post-Landnám period (939-1104 AD) (Schmid et al., 2017, p. 62). There is therefore a gap with no walrus bone from Iceland during 781-1055 AD based on the material presented in Keighley et al. (2019, pp. 2657–2658 & Supplementary Material 1) and that period exactly overlaps the settlement of Iceland in the late 9th century and the consequent settlement of Greenland by the Norse in the late 10th century.

Of the previously published walrus bones from Iceland which have been sexed using ancient DNA analyses, 10 specimens were from males, one specimen was female (sample XOR_31) and one had no result (sample XOR_99) (Bro-Jørgensen et al., 2021 Supplementary: Table S2). Of these sexed

² There is little mention of the many potential issues regarding the correction of the marine reservoir effect and calibration of radiocarbon dates from walrus bones from Iceland which can be complex due to their feeding habits, potentially very large ranges as well as possible human transportation of bones (Bennike, 1997; Bennike & Andreasen, 2007; Dyke et al., 2019).

³ Dates calAD calculated from calBP dates given in the paper supplement.

⁴ Only element information given is: "Approximately 68% of all 229 find featured single tusks, a further 24% included skulls with tusks and the remaining 8% comprised skulls without tusks or other bones (e.g., mandibles, baculum, ribs)." (Keighley et al., 2019, p. 2657). This seems to indicate that there are very few post-cranial bones among the material sampled for the study but it is not possible to know for sure.

specimens, five male walrus samples pre-date the human settlement of Iceland based on radiocarbon dating and the single female walrus from Hjörtsey in Mýrasýsla is an undated peat bog fossil (Bro-Jørgensen et al., 2021 Supplementary: Table S2; Keighley et al., 2019 Supplementary Material 1). It is unclear if the three reported samples dating to the post-settlement period have been sexed as part of the Bro-Jørgensen et al. (2021) paper which reports some of the walrus bones from Iceland as belonging to the Dorset period (ca 500-1500 AD), a cultural period description which is not applicable to Iceland, and not all the sample numbers in Bro-Jørgensen et al. (2021) can be matched up to the radiocarbon dates reported in Keighley et al. (2019). A single sample XOR_114 from Reykjavík is sexed as a male but it can't be matched up to the dates in Keighley et al. (2019 Supplementary Material 1) so there are three different samples which it could be, including the two samples from Reykjavík dating to after the settlement of Iceland.⁵

The majority of all walrus elements found in archaeological contexts in Iceland are either skull or tusk fragments (Table 2). The exception is the undated possible hunting site in Innri-Hvanney in Breiðafjörður discussed in more detail below. There are two finds of walrus from archaeological contexts dating to the early modern period where no element information is given, one find from the high status site of Bessastaðir, 1600-1895 AD (Amorosi et al., 1992, p. 173) and one find from Svalbarð 1636-1800 AD (Amorosi, 1992, pp. 123–124). All other published walrus finds from archaeological contexts are cranial bones or tusks (Harrison, 2013; Harrison et al., 2008; L. B. Pálsdóttir & Sveinbjarnarson, 2011; *Sarpur.is - Herjólfsdalur 2001 Bein*, n.d.).⁶ Due to the lack of context and element information in Keighley et al. (2019) it is unclear if there is any overlap between the walrus material presented there and the published walrus bones from archaeological excavations in Table 2.

During a small excavation in Innri-Hvanney, Bjarneyjum in Breiðafjörður 49 walrus bones from at least 4 individuals were found. The excavation revealed an irregular spread of rocks with animal bones in-between. No artifacts were found during the excavation and the remains found in Innri-Hvanney have not been dated. While it was clear that this was not a natural rock formation the purpose of the structure was unclear but it could have been a cairn (*i. varða*) or just rocks collected from around the island to make it easier to cut grass (Friðriksson et al., 2013). A total of 462 animal

⁵ The possible sample numbers are: Ic01 350-540 calAD, Ic13 1213-1330 calAD, Ic21 1055-1288 calAD. Sample Ic26 187-415 calAD can probably be ruled out since it had no DNA according to Keighley et al. (2019) and it also dates to before the start of the Dorset period which is the time period reported in Table S2 of Bro-Jørgensen et al. (2021).

⁶ A possible walrus bone was collected from a midden erosion face in Bær I in Kaldrananeshreppur (A. H. Pálsdóttir & Birgisson, 2015). After reviewing photos of bones from the site I no longer believe my initial tentative identification was correct, I would now classify it as marine mammal and most likely it is a cetacean bone. The bone could be more securely speciated through ZooMS or aDNA.

bones (TNF⁷), 370 NISP⁸, were found at this site including bones from an adult polar bear, seal bones, a single neonatal calf bone and some sheep/goat bones, possibly from a single young individual, but most of the bones at the site were from seabirds and marine mammals. The walrus bones at Innri-Hvanney come from at least 4 individuals, most of them are from neonatal animals in the first year of life. There are extensive butchery marks on the bones which come from all parts of the body indicating that whole carcasses were butchered in Innri-Hvanney. The butchery marks indicate that ivory was removed from the skulls but that the walrus were also butchered for meat (Woollet, 2013, pp. 24–25). In addition to the identified walrus bones there are 84 bones identified as large pinnipeds most of which are probably neonatal walrus (Woollet, 2013, p. 25). Due to the unclear use of this site and the fact that the material has not been dated these remains are hard to interpret. They do seem to indicate the site was used for hunting of marine mammals, bird and fish that were at least partially butchered on site (Woollet, 2013). These neonatal walrus could be from a local walrus population in Breiðafjörður or have been the result of spring pack ice in the fjord (Woollet, 2013, p. 26). It is possible that all the bones are from the same hunting event but a number of radiocarbon dates of material from the site are needed to further interpret it and connect it to other archaeological walrus bone finds from Iceland.

All three dated sites in Iceland with confirmed (or highly likely) post-cranial walrus elements, Tjarnargata 4, Aðalstræti 14-18 and Alþingisreitur come from a very small area in what is downtown Reykjavík which was likely one of the earliest settlements in Iceland (Garðarsdóttir, 2011; Grímsson & Einarsson, 1970; Roberts, 2001, 2003; Schmid et al., 2017). The few postcranial walrus bones found in archaeological excavations in Iceland, apart from the undated material from Innri-Hvanney (Friðriksson et al., 2013; Woollet, 2013), all date to the Viking Age, the vertebra from Alþingisreitur, juvenile walrus ribs⁹ from the site of Tjarnargata 4 (Amorosi, 1991, p. 280, 1996, p. 213; Grímsson & Einarsson, 1970; McGovern, 2011) and the scapula and partial vertebral column from the Aðalstræti 14-18 (McGovern, 2011). The one exception is the female walrus pelvis from Phase III (1226-1500 AD)

⁷ Total number of fragments.

⁸ Number of identified specimens, total number of bones identifiable to species/family (Reitz & Wing, 2008, pp. 205–210).

⁹ The original publication does not give element information for the Tjarnargata 4 walrus bones but several publications state that juvenile or even neonatal walrus bones were found in Tjarnargata 4 based on observations of Thomas McGovern (McGovern, 2011, p. 2; Pierce, 2009, p. 59; Vésteinsson et al., 2002, p. 111). I went to the National Museum of Iceland (Þjóðminjasafn Íslands) in late 2016 to look for the walrus bone from Tjarnargata 4 but they were not there. Walrus bone from the site was not included in the boxes at the NMI, all bird and fish bone from the site was also missing. I contacted Zoologisk Museum in Copenhagen and they only had a few great auk bones from the site. Some great auk bone from the site is at Náttúrufræðistofnun Íslands and some is on display in the Landnámssýning in downtown Reykjavík. The walrus bones from Tjarnargata 4 are possibly located in the Hunter College zooarchaeology laboratory.

at Alþingisreitur reported here, which likely post-dates the reported extinction of an endemic Icelandic walrus population as suggested by Keighley et al. (2019).

The sexing of the walrus pelvis from Alþingisreitur which dates to the medieval period gives an important further data point in the discussion of walrus hunting and use in Iceland. This summary clearly shows that limited numbers of postcranial walrus bones have been found in archaeological contexts in Iceland and the majority of archaeological finds are small ivory fragments which could have been imported to Iceland from the walrus hunting grounds in Greenland. Interestingly despite the extensive excavations of Viking Age archaeofaunas from the area around Mývatn, no walrus bones are reported in those collections despite the presence of whale and seal bone in the collections albeit in small quantities (McGovern, 2009; McGovern et al., 2006). More well published and confirmed finds of post-cranial walrus bones and ideally neonatal or juvenile walrus bones from archaeological excavations in Iceland would provide support for the existence of a local walrus population in Iceland during the early settlement period in the late 9th century.

Excavation and zooarchaeological analysis of more Viking Age archaeofaunas from the Reykjanes peninsula, Snæfellsnes and to the Westfjords might help to deepen our understanding of walrus populations in Iceland and walrus exploitation in Iceland from the Viking Age onwards and would be a promising avenue for further research. Further aDNA and ZooMS analysis of marine mammal bones from archaeological excavations in Iceland could also find more walrus bones in fragmented material which can't be speciated securely through morphological methods.

Table 2: Overview of walrus bones and tusks found in archaeological contexts in Iceland, based on published literature.

SITE	ELEMENT	DATE AD	COMMENTS	REFERENCE
Alþingisreitur, Reykjavík	Vertebra	877-1226	Chop marks	(A. H. Pálsdóttir, 2010, 2013; Buckley et al., 2014, 2015; A. H. Pálsdóttir et al., 2018)
Alþingisreitur, Reykjavík	Skull fragment	877-1226		(A. H. Pálsdóttir, 2010, 2013; Buckley et al., 2014, 2015; A. H. Pálsdóttir et al., 2018)
Alþingisreitur, Reykjavík	Pelvis	1226-1500		(A. H., 2010, 2013; Buckley et al., 2014, 2015; A. H. Pálsdóttir et al., 2018)
Aðalstræti 14-18, Reykjavík	Three tusks	Viking Age	Unused craftworking material	(McGovern, 2011)
Aðalstræti 14-18, Reykjavík	Scapula	Viking Age	In base of long house wall	(McGovern, 2011)
Aðalstræti 14-18, Reykjavík	Partial vertebral column	Viking Age	One thoracic vertebra and 4 lumbar. In base of long house wall	(McGovern, 2011)
Tjarnargata 4, Reykjavík	3-4 walrus bones	Viking Age	Possibly neonatal/juvenile walrus ribs, elements present uncertain.	(Amorosi, 1991, p. 280, 1996, p. 213; Grímsson & Einarsson, 1970; McGovern, 2011, p. 2; Pierce, 2009, p. 59; Vésteinsson et al., 2002, p. 111)
Herjólfsdalur, Vestmannaeyjum	Possible tusk	850-1100	Possibly worked. Identification not certain	Sarpur.is - Herjólfsdalur 2001 Bein, n.d.
Gásir in Eyjafjörður	Worked tusk fragment	13-14th century	Sawn tusk root	(Harrison, 2013, pp. 180–181)
Gufuskálar, Snæfellsnes	Ivory fragment	Medieval/Late medieval	Small piece from the root of the tusk	(L. B. Pálsdóttir & Sveinbjarnarson, 2011, p. 25)
Bessastaðir, Álftanesi	?	1600-1895	No published information about element	(Amorosi et al., 1992, p. 173)
Svalbarð	?	1636-1800 CE	No published information about element	(Amorosi, 1992, pp. 123–124)
Eyri in Ísafjörður, Westfjords	Maxilla fragment	19th century layers	No evidence of ivory extraction	(Harrison et al., 2008, p. 5)
Innri-Hvanney, Bjarneyjum in Breiðafjörður	49 bones, majority neonatal and juvenile	Unknown	MNI 4 individuals, extensive butchery marks for meat and ivory removal.	(Friðriksson et al., 2013, Woollet, 2013)

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