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Cover Photograph: Two female burials from Newark, Deerness, Orkney, photographed in 1970. A predominantly Christian and Norse cemetery with a relatively small proportion (perhaps <15%) being Pictish burials. The cemetery is dated between the mid-6th/late 7th century to the 14th/early 15th centuries although most burials likely postdate the late 8th century. This image is courtesy of the Orkney Museum (slide collection accession number 2019.050).

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A Comparative Study of Norse Palaeodemography in the North Atlantic

Britta J. Van Tiel[1, 2], Clare McFadden[1, 3], Charlotta Hillerdal[4,] and Marc F. Oxenham[1, 4*]

Abstract - Our core aim is to compare the population dynamics of homeland and diaspora Norse communities in the North Atlantic through the lens of preadult representation. Our approach is to use the D0/14 palaeodemographic index to compare and contrast data sourced from twenty-one archaeological sites in the North Atlantic, including Scandinavia, Scotland, Ireland, Iceland, and Greenland that represent both homeland and frontier Norse communities including traditional Old Norse and Christian burial practices dated to between the 8th and 14th centuries. We found no statistically significant difference in the proportion of preadults among frontier and homeland communities, while significant differences were found regionally, particularly between Greenland and the Scottish Isles. We conclude that demographic similarities between frontier and homeland communities may have been influenced by general improvements in the climate during this period and/or the maintenance of very close lines of communication and continuity of cultural ties and behaviour between homeland and frontier settlements. Regarding relatively smaller proportions of preadults in Greenland in comparison to the Northern and Western Scottish Isles, the inferred elevated levels of fertility in the latter region may have been associated with a more stable resource base, relatively seamless integration of local and migrant populations, particular and potentially good yield farming, marine adapted subsistence practices, and integration into vibrant maritime trading networks. The situation in Greenland, on the other hand, is consistent with a short-term colonisation event.

Introduction

The Viking Age (ca. 750–1050 CE) is a dynamic period in Scandinavian history, and one that sees a previously unprecedented movement of Scandinavians into regions outside their homelands. While perhaps most famous for raiding, this period saw extensive settlement and colonisation of what has more recently been coined the 'Viking Diaspora' (a term introduced by Judith Jesch in 2008, and that has since been well established in Viking Age research), a vast geographical area including Great Britain and Ireland, and the North Atlantic, the Baltic Sea area, and the rivers systems of Russia, Belarus, and Ukraine.

In its most narrow definition, "Viking" is a term referring to seafaring individuals of northern European origin who engaged in raiding from the 8th to the 11th centuries CE (Baten et al. 2021, Ellis 2021). However, the term Viking is often used as a convenient label for all Norse peoples living between the 8th and 11th centuries in the Scandinavian homelands and Viking diaspora alike (Croix 2015) and it is in this sense that we use the term Viking in this paper. As for the term "Norse", we employ it as a collective noun for people from Old Norse speaking agrarian communities in Scandinavia (the homelands) and Viking Diaspora settler communities originating from these areas.

Norse settlement in and colonisation of the North Atlantic was a gradual process that spanned several centuries, with the first records indicating that raiding activity commenced in Great Britain and Ireland at the end of the 8th century CE (Roesdahl 1998). The first known Norse colonies are believed to have been established in the Northern and Western Isles of Scotland in the 9th century as bases for raiding activities in Great Britain by Vikings from Southern Scandinavia (Fitzhugh and Ward 2000, Price 2015, Wilson 1976). However, more recent evidence suggests that it would take at least a century before these communities in the Northern Isles had taken on a clear Norse character, suggesting a long period of adjustment to, and negotiation with, local populations (Griffiths 2019). In the 9th century further settlements were established in the islands of Britain and Ireland, in addition to the colonisation of the Faroe Islands, Iceland, as well as parts of northern continental Europe (Church et al. 2013, Dixon 1998, Edwards et al. 2005). In the late 10th century these colonising activities continued into parts of Greenland and North America (Davy 2020, Hoerder 2020, Fitzhugh and Ward 2000, Persson 1969). While there was some further Norse expansion during the 11th century, it was during this period that Viking activities started to diminish. Scandinavia officially converted to Christianity and the Kingdoms of Norway, Sweden, and Denmark were established

[1]School of Archaeology and Anthropology, Australian National University, Canberra, ACT 2601, Australia. [2]Tübingen Institute for Archaeological Sciences, University of Tübingen, 72074, Tübingen, Germany. [3]BirthRites Independent Max Planck Research Group, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany, Department of Human Behavior, Ecology and Culture, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany. [4]Department of Archaeology, School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UF, United Kingdom. *Corresponding author: marc.oxenham@abdn.ac.uk.

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(Bagge 2010, Derry 2000, Dougherty 2014). Notwithstanding, within the diaspora these early Nordic states continued to have an important role for some centuries, particularly the kingdom of Norway which had a significant cultural and economic influence over Norse colonies in Greenland, Iceland, and the Orkney Islands (Jochens 1998, Krogh 1967, Short 2010).

Following the early period of Scandinavian settlement, the Earldom of Orkney was established under the Kingdom of Norway (Graham-Campbell and Batey 1998). Formally, medieval Orkney remained under Scandinavian rule until 1468–1469 (Morris 1985). Earliest settlement in Iceland can be reliably dated to the 870s due to a tephra layer covering the earth just before the landnám (settlement) period began. Most settlers of Iceland came from Norway and the British Isles and Ireland, and while Iceland was established as an independent state it became part of the Norwegian kingdom in 1264 (Durrenberger 1992). It would take until 1918 before Iceland was a sovereign state again. Greenland was colonised in the late 980s and subjected to the Norwegian king in 1261. European contact with the Greenland settlements stopped completely in the first half of the 15th century (Magerøy 1993).

In the modern period, Norse cultures have been a source of significant interest, from both a historical and popular culture perspective (Barnes 2015). Archaeological investigations have significantly contributed to a wider understanding of how these people lived. Norse research in the last decade has seen an emphasis on trade and urban networks, mobility and interaction, and a renewed focus on the North Atlantic region (Barrett 1995, Lucas et al. 2009, Sindbaek 2020, Lund and Sindbaek 2022). However, there has been little in the way of modelling the past population dynamics of such communities, thus limiting our understanding of demographic trends and population health in this region and period. See the following for early palaeodemographic research: Kjellström et al. (2005), Lynnerup (1996, 1998, 2014). Of note are two papers by Lynnerup (1996, 2014) that explored population modelling to better understand the composition and eventual demise of the Norse communities in Greenland. The recent publication of a suite of palaeodemographic tools that have been demonstrated to more accurately model past demographic parameters, such as total fertility rates and rates of natural population increase when using archaeological cemetery datasets (McFadden and Oxenham 2017, 2018), provides an opportunity to revisit the issue of Norse palaeodemography from a fresh perspective.

The aim of this paper is to compare the population dynamics of homeland and diaspora Norse communities in the North Atlantic through the lens of preadult representation utilising the D0–14 palaeodemographic index. It is believed such an approach will facilitate a better understanding of the demographic characteristics of homeland and frontier Norse populations. Previous work using such approaches and looking at the demographic dynamics of colonising and established populations in the Pacific (e.g., McFadden et al. 2021) have suggested elevated rates of natural population growth (as evidenced by elevated proportions of preadults in cemetery samples) during initial colonisation and a levelling out effect once populations become established. As such, our working hypothesis with respect to Norse demography is that there will be better representation of preadults, indicative of higher levels of fertility and rates of natural population growth, in frontier relative to homeland communities.

Material and Methods

When dealing with cemetery datasets, there is a considerable amount of evidence (which at face value appears counterintuitive) for the role of fertility, rather than mortality, in shaping a mortality (or cemetery) distribution (Bocquet-Appel and Masset 1982, Buikstra et al. 1986, Corruccini et al. 1989, Johansson and Horowitz 1986, Konigsberg and Frankenberg 1994, Milner et al. 1989, Paine 1989, Sattenspiel and Harpending 1983). Moreover, while there is clearly a relationship between infant mortality and infant representation in any given cemetery sample, there is a much stronger correlation between fertility rates, in distinction to infant mortality rates, and the proportion of children in a cemetery sample (McFadden et al. 2021). Indeed, the proportion of preadults to adults in cemetery assemblages can be very effectively used to estimate demographic parameters such as total rates of fertility and rates of natural population increase (McFadden and Oxenham 2017, 2018). Currently, we lack models that would allow the estimation of infant mortality rates from cemetery data with a detailed discussion of the complexities involved provided in McFadden et al. (2022). In this study we are particularly interested in the proportion of preadults as a potential measure of demographic flux or stability between and/or among homeland and frontier (or colony) sites during the Viking Age and subsequent medieval period.

Published data were sourced from twenty-one archaeological sites in the North Atlantic, including Scandinavia, Scotland, Ireland, Iceland, and Greenland. Assemblages were only included in this analysis if they contained unit or summary data on age-at-death for the cemetery samples of interest.

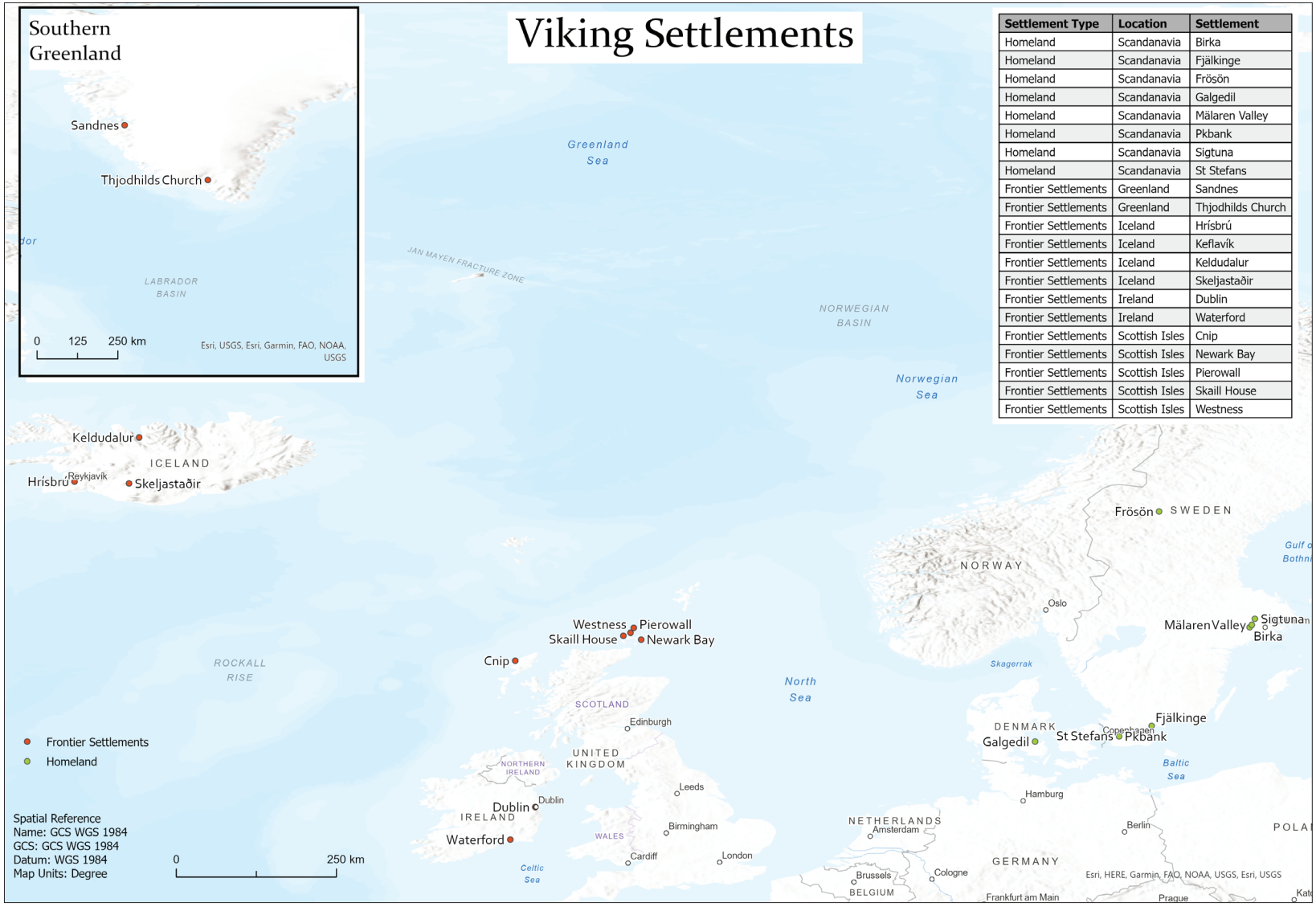
This has meant the exclusion of up to five sites representing Norse colonies established in the United Kingdom and mainland Europe, modern England, mainland Scotland, and Wales. Table 1 provides the sites, region, homeland/frontier, period, source, the number of individuals aged ≤ 14 years (D0–14), the total number of individuals in the cemetery (D total), and the proportion of preadults in the cemetery (D0–14/D). See Figure 1 for the location of each site used in this study while a description of each site is supplied in the Supplementary Materials (see Supplemental File 1, available online at www.eaglehill.us/JONAonline2/supplemental-files/jona-045-Oxenham-s1.pdf).

The burials span the 8th to the 14th centuries, a period that includes the Viking Age and subsequent

Table 1. Samples utilised in this study.

Site	Region	Homeland/ Frontier	Date (century CE unless otherwise stated)	Source	D0-14	D total	D0-14/D (2 d.p)
Birka, Sweden	Scandinavia	Homeland	9th–10th	Gräslund 1981	91	308	0.30
Cnip	Scotland	Frontier	9th–10th	Welander et al. 1987; Dunwell et al. 1995	3	7	0.43
Fjälkinge	Scandinavia (Sweden)	Homeland	10th–11th	Helgesson and Arcini 1996	80	128	0.63
Frösön	Scandinavia (Sweden)	Homeland	11th–14th	Benedictow, 1996	210	364	0.58
Galgedil	Scandinavia (Denmark)	Homeland	9th–11th	Price et al. 2014	8	57	0.14
Hrísbrú	Iceland	Frontier	10th–11th	Byock et al., 2014	3	21	0.14
Keflavík	Iceland	Frontier	10th–12th	Zoëga and Murphy 2020	22	46	0.48
Keldudalur	Iceland	Frontier	10th–12th	Zoëga and Murphy 2016; Zoëga and Murphy 2020	24	53	0.45
Mälaren Valley	Scandinavia (Sweden)	Homeland	8th–12th	Kjellström 2016	17	136	0.13
Newark Bay	Scotland	Frontier	Mid-6th/late-7th century to the 14th/early 15th century	Molleson and Owen 2005	118	208	0.57
Pierowall*	Scotland	Frontier	9th–10th	Redmond 2007; Thorsteinsson 1968; Canmore Westray, Pierowall Links	0	16	0
PKbank	Scandinavia (Sweden)	Homeland	1050–1100	Benedictow, 1996	12	200	0.06
Sandnes	Greenland	Frontier	Pre-mid 14th	Lynnerup 1998	24	88	0.27
Sigtuna	Scandinavia (Sweden)	Homeland	12–14th	Steckel et al. 2018	94	382	0.25
Skaill House	Scotland	Frontier	11th–14th	James et al. 1999	15	27	0.56
Skeljastaðir,	Iceland	Frontier	Pre- 12th	Richter 2005	7	66	0.11
St Stefans	Scandinavia (Sweden)	Homeland	11th–12th	Benedictow, 1996	77	258	0.30
Thjodhild's Church	Greenland	Frontier	11th	Lynnerup 1998	24	144	0.17
Waterford	Ireland	Frontier	11th–13th	Hurley et al. 1997	9	55	0.16
Westness*	Scotland	Frontier	8th–11th	Sellevold 1999	5	29	0.17
Wood Quay	Ireland	Frontier	12th	O'Donnabhain 2010	10	23	0.43

*See notes on these series in the SI.



Settlement Type	Location	Settlement
Homeland	Scandanavia	Birka
Homeland	Scandanavia	Fjälkinge
Homeland	Scandanavia	Frösön
Homeland	Scandanavia	Galgedil
Homeland	Scandanavia	Mälaren Valley
Homeland	Scandanavia	Pkbank
Homeland	Scandanavia	Sigtuna
Homeland	Scandanavia	St Stefans
Frontier Settlements	Greenland	Sandnes
Frontier Settlements	Greenland	Thjodhilds Church
Frontier Settlements	Iceland	Hrísbrú
Frontier Settlements	Iceland	Keflavík
Frontier Settlements	Iceland	Keldudalur
Frontier Settlements	Iceland	Skeljastaðir
Frontier Settlements	Ireland	Dublin
Frontier Settlements	Ireland	Waterford
Frontier Settlements	Scottish Isles	Cnip
Frontier Settlements	Scottish Isles	Newark Bay
Frontier Settlements	Scottish Isles	Pierowall
Frontier Settlements	Scottish Isles	Skaill House
Frontier Settlements	Scottish Isles	Westness

Figure 1. 1 Location of each site, homeland and frontier, used in this study. See Supplementary Materials for a description of each of these sites. Figure prepared by Ricky Craig.

medieval period. During this period burial practices went through significant changes following the conversion in Scandinavia, most significantly a shift from predominantly cremation to inhumation burials (Price 2008). The dataset compiled here includes pre-Christian and Christian burials, as well as two likely transition period cemeteries in Orkney: Westness and Pierowall. Pre-Christian funerary rites were highly variable and localised, and whilst being recognisably Scandinavian within a generalised burial tradition, it is impossible to identify a standard orthodoxy of burial practice common to the whole Viking Diaspora (Callmer 1991, Price 2008, Svanberg 2003). A significant difference between homeland and diaspora Viking burials is that the dominance of cremation practice is not present in the North Atlantic settlements. Only one cremation burial can be securely confirmed in Ireland (Harrison and Ó Floinn 2015), only two possible cremation graves have been identified in Scotland (Nordstein 2020), and cremation is also extremely rare in Iceland (Price 2008). No pre-Christian graves have been identified in Greenland (Gjerland and Keller 2009). Representation in the selection of pre-Christian sites from the homeland is therefore necessarily limited by available inhumation burials, a factor which needs to be considered when interpreting the results of this analysis.

Comparison of D0–14/D proportions between homeland and frontier samples was undertaken with fisher's exact tests, two-tailed, with significance set at $p<0.05$. Two fisher's exact tests were undertaken with the first including all samples, and the second only including samples with 30 individuals or more to investigate whether the inclusion of sites with smaller sample sizes would affect the results. Furthermore, two chi-squared tests of independence were undertaken to investigate levels of preadult representation by region, as there may have been differences in a regional analysis that would not be present in an analysis that focused predominantly on combined frontier and homeland samples. Similarly, two chi-squared tests of independence were undertaken with the first including all samples and the second only including sites with 30 or more individuals. While it would be preferable to assess preadult representation against time since settlement or colonisation, this was not possible given the available temporal and archaeological resolution of the published data available. As such, this analysis is not able to test if the demographic parameters of interest have changed over the short, or longer, term within each site of interest.

Results

The first Fisher's Exact Test was performed to examine whether there was a significant relationship between the type of settlement (homeland or frontier) and the proportion of preadults in the combined samples (D0–14/D), as a predictor of various demographic variables for all available samples. Table 2 below summarises data that were utilised. The resulting two-tailed p value was $p=0.4390$ with the results not statistically significant, which does not support the working hypothesis that fertility and rates of natural population increase would be relatively higher in the frontier communities.

The secondary Fisher's Exact Test was performed in order to examine whether there was a significant relationship between the type of settlement (homeland or frontier) and the D0–14/D proportion for samples where there were 30 or more individuals (Table 3). The resulting two-tailed p value was

Table 2. Homeland and Frontier sample D0-14 and D>14 values.

	D0-14	D>14	Marginal Row Total
Homeland	589	1244	1833
Frontier	264	519	783
Marginal Column Total	853	1763	2616 (Grand Total)

Table 3. Homeland and Frontier samples with sample sizes of 30 individuals or more.

	D0-14	D>14	Marginal Row Total
Homeland	589	1294	1883
Frontier	228	432	566
Marginal Column Total	817	1726	2006 (Grand Total)

p = 0.1332 with the results again not statistically significant and again which do not support the working hypothesis, even when only looking at sites with larger sample sizes.

The first chi-squared test of independence (Table 4) was performed to investigate whether there was a significant interaction between region and the D0–14/D proportion. Essentially, this assesses whether the actual number of preadult individuals in a sample reflects the predicted number. The first test does not take into account the size of the samples. The interaction between these variables was significant: X^2 (1, N = 2616) = 53.78, p<0.00001, and there is a significant relationship between region and the proportion of preadults (D0–14/D).

In the D0–14 column for Iceland, Ireland, and Scandinavia (Table 4) the actual numbers are similar to the predicted, meaning the contributions of these samples to the overall chi square value are low. For Greenland the D0–14 value predicted is substantially higher than the actual numbers, and for the Northern and Western Scottish Isles the predicted number is substantially lower than the actual number of individuals in the D0–14 category, meaning that the contributions of these samples to the overall chi square value are high.

A further chi-square test of independence was performed (Table 5) on the same data set with the exception that samples with less than 30 individuals were excluded. The relationship between these variables was also statistically significant X^2 (1, N = 543) = 78.55, p<0.00001 indicating a significant interaction between region and the proportion of preadults (D0–14/D). As can be observed, the D0–14 column for Greenland again depicts a lower-than-expected number of preadults, and the Northern and Western Scottish Isles again indicates a higher-than-expected number of preadults with Iceland, Ireland, and Scandinavia having values quite similar to predicted.

Discussion

When comparing combined homeland and frontier assemblages we find little difference in terms of preadult representation. However, when comparing by regions there are clear and significant differences in preadult representation. A number of factors are discussed that may be relevant with respect to both the homogeneity in preadult representation when comparing homeland and frontier communities on the one hand and the heterogeneity in preadult representation between specific regions on the other hand.

Frontier versus homeland: Exploring the similarities in preadult representation

There are clearly climatic extremes in terms of homeland and frontier sites with Greenland and Ireland representing either end of this climate cline. Environmental aspects such as climatic

Table 4. Chi-square test of independence for region and D0-14 ratio. Note, the values in parentheses indicate the predicted number of individuals for each age category by region, while values within the square brackets detail the individual contribution to the chi square value.

	D0-14	D>14	Marginal Row Totals
Greenland	48 (75.65) [10.11]	184 (156.35) [4.89]	232
Iceland	56 (60.65) [0.38]	130 (125.35) [0.17]	186
Ireland	19 (25.45) [1.63]	59 (52.57) [0.79]	78
Scandinavia	589 (598.69) [0.13]	1244 (1235.31) [0.06]	1833
Scottish Isles	141 (93.58) [24.03]	146 (193.42) [11.62]	287
Marginal Column Totals	853	1763	2616 (Grand Total)

Table 5. Chi-square test of independence for region and D0-14 ratio for samples of 30 individuals or more.

	D0-14	D>14	Marginal Row Totals
Greenland	48 (74.54) [9.45]	184 (158.46) [4.47]	232
Iceland	53 (53.01) [0.00]	112 (111.99) [0.00]	165
Ireland	9 (18.67) [4.25]	46 (38.33) [2.01]	55
Scandinavia	589 (604.96) [0.42]	1294 (1278.04) [0.20]	1883
Scottish Isles	118 (66.83) [39.19]	90 (141.17) [18.55]	208
Marginal Column Totals	817	1726	2543 (Grand Total)

conditions and site location are factors that could have a significant flow-on effect for preadult survival and subsequent preservation of preadult skeletal remains which directly impact on their representation (Goodman and Armelagos 1989). From a climatic perspective, according to the Köppen Climate Classification system, there is quite a range from temperate in Ireland, through to polar in Iceland (Beck et al. 2018). Notwithstanding, all sites included in this study have at least been partly attributed to what is commonly referred to as the Viking Age/Medieval Climate Anomaly (VA/MCA) where average temperatures increased from the middle of the 9th century CE until the middle of the 13th or 14th centuries depending on the region (Asteman and Nordberg 2018, Filipsson and Nordberg 2010). While there were fundamental and substantive differences in climate by region, generally both homeland and frontier communities experienced somewhat and relatively improved climatic conditions during the same period (Asteman and Nordberg 2018, Filipsson and Nordberg 2010). It is unclear if the general trend toward improving climates, despite otherwise quite different local climatic conditions, may be a contributing factor to the general similarities in terms of preadult representation.

Whilst these diaspora communities appear culturally similar, a closer inspection reveals significant socio-political, economic, and ecological differences that might be able to explain demographic variability. The Norse met very different conditions when settling in the diaspora. Scandinavians who settled in Scotland and Ireland were immigrants into existing communities and had to negotiate their way into these communities, whilst colonisers of Iceland settled a previously uninhabited land, settlers in Greenland were concentrated in isolated communities with what seems little interaction with the native inhabitants of the island and in ecologically very challenging conditions.

Norse settlements in Ireland are found mainly in coastal locations and have a pronounced focus on international trade. They were successful polities within what Clare Downham (2015) refers to as a 'militarised trade diaspora' in a politically fragmented Irish landscape. A hybrid identity seems to have evolved rather quickly among these Norse settlers; they are noted as their own cultural group, "foreign Gaels" in the Irish Chronicles in the late 850s. Intermarriage between the Norse and Gaels is also recorded from the 9th century, probably an important strategy for the political and economic success of Viking settlement in Ireland (Downham 2015). Hiberno-Scandinavian culture did not persist long beyond AD1200 in Ireland following the English conquest of Viking trading ports in the 1170s (Downham 2015). It has been claimed by Downham (2015) that Hiberno-Scandinavians maintained their hybrid culture in merchant communities in Ireland to facilitate their role in trade in a transnational Viking network.

Iceland was settled from the 870s CE as a farming community relying mainly on animal husbandry, but also some agriculture. The settlers brought with them domestic animals and established themselves along the coast. Icelandic society was made up of single farms. Villages or towns never developed in Viking Age and Medieval Iceland. Iceland was a thriving settler society. Politically and legally, Iceland was dominated by a few wealthy chieftains and their families until 1264 when the leading families of Iceland swore fealty to the Norwegian king (Sigurðsson 2007).

The conversion of the Icelanders to Christianity was surprisingly uneventful. It was decided in the Althing, the annual assembly where the community leaders met in the year 999 or 1000, to decide on legislation and dispense justice, that Iceland should adopt Christianity (Vésteinsson 2000). Despite over a century of pre-Christian burial customs practiced in Iceland, cremation burials are extremely rare (Byock et al. 2005).

Regional differences in preadult representation

Greenland. The two regions that stand out in terms of lower or higher proportions of preadults relative to adults are Greenland and Scotland respectively. With respect to Greenland there are a number of factors that could result in a relatively lower proportion of preadults observed in the regional analysis. These factors are both cultural (differential burial practices and low fertility) and environmental (taphonomic) in nature. Various primary and secondary sources indicate that infanticide was a common custom for a number of reasons such as preferences for male offspring, societal hardship, and physical and mental disabilities (Barrett 2008; Bragg 1997; Grønlie 2006; Jones 2001; Krogh 1967; Lawing 2013; Miller 1990; Pentikäinen 1990; Wenman 2005; Wicker 1998, 2012). Notwithstanding, Pentikäinen (1990) notes that Norse infanticide/abandonment practices come to an end with the adoption of Christianity, although some lag and regional differences in the timing of the abandonment of the practice is seen. Interestingly, while Greenland was settled by Christian Scandinavians, Pentikäinen (1990) suggests there is some indirect evidence that the practice may have occurred in Greenland, but to what extent is impossible to say.

Another consideration that may contribute to a relatively lower proportion of preadults in the Greenland regional sample is low fertility. As noted above, the proportion of preadults in a cemetery sample is highly predictive of fertility rates, but not of mortality rates which will be otherwise hidden. While each and every infant in a cemetery sample represents a mortality event (as does every individual for that matter), the mortality 'rate' for any given community is a function of infant deaths per 1000 live births. As such, and without a predictive model for societies without historical records for births and deaths, we cannot calculate infant mortality rates without some knowledge of the number of live births. See discussion in McFadden et al. (2021). The combined data for the two cemeteries from Greenland indicate moderate rates of fertility and low rates of natural population increase (McFadden and Oxenham 2017).

The Greenland settlement is a true frontier community. The Norse established three communities in the late 10th century; the Western and the Eastern Settlements, and a smaller Middle Settlement which is often treated as part of the Eastern Settlement (Arneborg 2008). Population was small, estimated at no more than 2000 at its peak in the 12th century (Lynnerup 1998). Reasons for settling Greenland are debated (c.f. Arneborg 2008), but one agreed upon factor is the marine resources offered by this otherwise challenging environment. The most sought-after commodities were walrus ivory and hides, which made its way into the northern European trade system via the Norwegian market (Frei et al. 2015). This is most probably a contributing factor to the eventual abandonment of Norse settlement in Greenland during the 15th century. Even though Greenlandic farms seem to have been self-sufficient on a subsistence level (Arneborg 2008), the communities were relying on the overseas trade for essential raw materials such as iron (Frei et al. 2015). Changing trading patterns and a lowered demand for walrus ivory on the European market meant Norwegian merchants stopped sailing to Greenland in the 15th century, and with the lack of homeland supplies, the Greenland communities were too small and too specialised to survive (Dugmore et al. 2012). This coincides with worsening and more unpredictable climatic conditions following the onset of the Little Ice Age from the late 13th century, and was probably a decisive factor in the abandonment of the Western Settlement in the 14th century (Schofield et al. 2022). Norse farming practices in Greenland were highly adapted to the specific and challenging environment, but this also made them vulnerable to changing conditions resulting from climate change (Dugmore et al. 2012, Jackson et al. 2018). While the ultimate reason for the abandonment of Greenland is still unknown, in the lead up there were periods of food scarcity which would have negatively impacted fertility rates. Interestingly, when looking at the two Greenland sites for which we have cemetery data separately, fertility rates based on the preadult proportion were lower during the 11th century (Thjodhild's Church). At face value this might suggest a suboptimal demographic environment centuries prior to eventual abandonment of the country, while the uptick in the fertility rate at pre mid-14th century Sandnes may simply be representative of the volatility of demographic variability, although such a potential increase in fertility rates a century prior to abandonment is intriguing.

An alternative suggestion for lowered fertility rates is provided by Lynnerup (1996) who suggests that the emigration of younger individuals out of Greenland was a key contributor. Indeed, a significant exodus of individuals of childbearing and rearing age would undoubtedly have negatively impacted on fertility rates and would additionally have contributed to the development of an aging population. Either of the explanations for lowered fertility are viable and may have worked in tandem, contributing to a lower proportion of preadults in the archaeological record for Greenland.

The final consideration that may have contributed to a lower proportion of preadults relative to adults in the Greenland sample is taphonomic conditions. Preservational skeletal bias in the archaeological record has long been identified as a significant issue, particularly in relation to preadults (Gordon and Buikstra 1981, Manifold 2012, Mays et al. 2007). Many studies have identified two significant factors to preadult skeletal preservation as being pH levels and the presence of groundwater (Damiata et al. 2013, Gordon and Buikstra 1981, Mays et al. 2007, Manifold 2012, Nielsen-Marsh et al. 2000).

Both Sandnes and Thjodhild's Church have taphonomic conditions that are not ideal for preadult skeletal preservation. The site of Godthåb, at the beginning of the fjord where Sandnes is located, has pH levels varying between 3.0 and 3.5 (Rutherford 1995), which is in the marginal pH range for preadult bone preservation (Gordon and Buikstra 1981). Further, Sandnes is known to experience sporadic permafrost (Christiansen and Humlum 2000, Wallroth et al. 2010) which is associated with elevated rates of bone diagenesis (Hollesen et al. 2016, Lee 2019, Manifold 2012, Nielsen-Marsh et al. 2000). Furthermore, site erosion has been identified at Sandnes with part of the original church (and potentially part of the graveyard) now being submerged (Lynnerup 1996, McGhee 1984).

As for Thjodhild's Church, the pH level falls between a rather acidic 3.9 and 4.4 (Rutherford 1995). Mays et al. (2007) suggest the optimal pH level for preadult bone preservation is between 8.3 and 8.5. Unlike Sandnes, Thjodhild's Church is situated in one of the rare southern permafrost free zones (Wallroth et al. 2010), suggesting that the site does not flood with groundwater and there is no noted erosion at the site. It would appear at face value that preadult bone preservation should be better at Thjodhild's Church in comparison to Sandnes.

The two sites represent two different communities both geographically and in time. Sandnes is the largest farm of the Western Settlement, which was abandoned in the second half of the 14th century, about a century before the final depopulation of Norse Greenland (Arneborg 2008). The burial data thus represents the last phases of a community before abandonment, which might explain the underrepresentation of pre-adults. Thjodhild's Church, on the other hand, belongs to the longer lasting South-Eastern Settlement, and the burial data dates to the earlier centuries of settlement in Greenland.

Scotland. In contrast to Greenland, the Northern and Western Scottish Isles were characterised by relatively higher proportions of preadults in the observed cemetery samples. As most of these sites are located in the Northern Isles, with the exception of the small cemetery of Cnip on the Isle of Lewis, the focus of discussion is on Orkney. As noted previously with respect to the samples from Greenland, any given age-at-death distribution is much more reflective of past fertility rates rather than infant mortality rates (McFadden et al. 2021). Collectively, Orcadian sites indicate high rates of fertility (McFadden and Oxenham 2017) and high rates of natural population growth (McFadden and Oxenham 2018), but why would this be the case? At face value it might be argued that resource abundance will often lead to an increase in carrying capacity and associated increase in fertility (Hassan 1978). Indeed, there is considerable evidence for arable land management from the Neolithic onwards in Orkney (Guttmann et al. 2006) while various forms of manuring appear to have intensified from the 10th century (Simpson 1993, Simpson et al. 2005). Arable land improvements with probable increases in returns, coupled with evidence for an increased focus on marine resource exploitation during the Viking Age (Nicholson 1997), would arguably set the scene for increases in fertility, if not rising rates of population increase on these islands.

It should also be noted that issues with predicting infant mortality rates aside, fertility rates do in fact correlate with infant mortality rates, among other things (McFadden et al. 2021). While infant mortality rates cannot be directly estimated, there is evidence that preadult morbidity was somewhat elevated in Orkney. The osteological reports for Newark Bay, Skaill House, and Westness all summarise evidence of periostitis, cribra orbitalia, and other childhood-specific pathological conditions (James et al. 1999, Molleson 2005, Sellevold 1999). At Newark Bay, of the 51 infants and neonates included in the assemblage, nearly half of them (24) demonstrate signs of chronic skeletal pathology, and older preadults also displayed evidence of pathological conditions (Molleson 2005). Such evidence for infant morbidity might be understood in the context of relatively large communities with poor sanitation, living in close quarters with livestock, and cultural practices such as swaddling and early weaning (Barrett et al. 2000, Molleson 2005).

Whether we are seeing evidence for resource abundance, increased bio-social stresses, or a combination of the two, as might be expected in high density, thriving albeit small communities situated within maritime trading networks, it is worth taking a closer look at what is known of Norse settlement and interaction in the region. Larger scale Norse settlement in Orkney can be dated archaeologically to the mid-9th century at the earliest (Barrett 2003, Griffiths 2019). Despite what the Orkneyinga Saga (ca. CE 1200) and Historia Norwegiæ (ca. CE 1220) would have us think, there is no archaeological evidence in Orkney for a violent takeover by the Norse. Instead, the changes in culture and economy are subtle and suggest a gradual adaptation to Norse culture and way of life (Owen 2004). The more far-reaching changes, such as settlement patterns and resource exploitation, occur around CE 1000 (Griffiths 2019). Therefore, one cannot consider Orkney a fully 'Norse' society until this date, possibly coinciding with the establishment of the Earldom of Orkney. Genetic evidence from the modern population suggests that the arrival of Scandinavians was significant, but that they were still a clear minority (Goodacre et al. 2005). There are therefore good grounds to argue for a mutual negotiation and integration of immigrants into the native population in the early stages of settlement. There is even some archaeological evidence suggestive of a settlement decline in Orkney prior to Norse settlement (Harrison 2020). Whether such a decline can be confirmed is debated. However, it could support an argument that an influx of new people would be a welcome addition to some native communities that had seen population declines. Undoubtedly, the archaeological evidence does increasingly suggest a period of Pictish/Scandinavian intermixture rather than a clear

break of tradition (i.e., Griffiths 2019, Morris 2021), which would also be supported by a continuity in the burial evidence (Hillerdal 2020).

Conclusion

This study aimed to shed more light on the demography of Norse communities in the North Atlantic by investigating levels of preadult representation with respect to frontier and homeland communities on the one hand and with regard to specific regions or countries on the other hand. It has been demonstrated that there are no significant differences in preadult representation between homeland and frontier communities which suggests similar demographic characteristics, in terms of fertility and rates of natural population increase, among these communities. An important factor may have been the improving climatic conditions in general despite otherwise quite disparate local climates and environments experienced by frontier and homeland communities during the Viking Age and subsequent medieval period. A further homogenising factor would appear to be the maintenance of very close lines of communication and continuity of cultural ties and behaviour between homeland and frontier settlements.

Contrarily, at an inter-regional level there was a lower proportion of preadults relative to adults in Greenland, and higher proportions of preadults in the Northern and Western Scottish Isles. This is noteworthy in as much as it suggests important demographic differences within and between Viking communities that would have impacted fertility and its corollary preadult survival. Regarding Greenland, the most plausible key explanatory factor for relatively lower preadult proportions is low levels of fertility associated with the general decline and eventual abandonment of these Norse communities. Notwithstanding, less than ideal preservation conditions also need to be considered. With respect to the Northern and Western Scottish Isles, the reverse trend of a greater proportion of preadults in these cemeteries is also most plausibly linked to fertility. However, in this instance inferred increased rates of fertility may have been associated with a more stable resource base, relatively seamless integration of local and migrant populations, particular and potentially good yield farming, marine adapted subsistence practices, and integration into vibrant maritime trading networks.

This is the first large scale palaeodemographic analysis of Viking Age through to subsequent medieval communities in the North Atlantic. Future research into preadult representation in other regions of the world and time periods would contribute to the currently limited research in this area.

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