A COMPARATIVE STUDY OF NORSE PALAEODEMOGRAPHY IN THE
NORTH ATLANTIC

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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 (c. 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 (Wilson 1976; Fitzhugh and Ward 2000; Price 2015). 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 (Dixon 1998; Edwards et al. 2005; Church et al. 2013). In the late 10th century these colonising activities continued into parts of Greenland and North America (Persson 1969; Fitchugh and Ward 2000; Davy 2020; Hoerder 2020). 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 (Derry 2000; Bagge 2013; 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 (Krogh 1967; Jochens 1998; 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 1468-69 (Morris 1985). Earliest settlement in Iceland can be reliably dated to the early 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: Lynnerup 1996, 1998, 2014; Kjellström et al. 2005). Of note are two papers by Lynnerup (see 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 a 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), provide 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., see 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 & Masset, 1982; Buikstra, Konigsberg, & Bullington, 1986; Corruccini, Brandon, & Handler, 1989; Johansson & Horowitz, 1986; Konigsberg & Frankenberg, 1994; Milner, Humpf & Harpending, 1989; Paine, 1989; Sattenspiel & 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.

The burials span the 8th to the 14th centuries, a period that includes the Viking Age and subsequent 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; Svanberg 2003; Price 2008). 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 2014: 271), 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 2010). 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.
<table>
<thead>
<tr>
<th>Site</th>
<th>Region</th>
<th>Homeland/ Frontier</th>
<th>Date (century CE unless otherwise stated)</th>
<th>Source</th>
<th>D0-14</th>
<th>D total</th>
<th>D0-14/D (2 d.p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birka, Sweden</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>9th-10th</td>
<td>Gräslund 1981</td>
<td>91</td>
<td>308</td>
<td>0.30</td>
</tr>
<tr>
<td>Cnip</td>
<td>Scotland</td>
<td>Frontier</td>
<td>9th-10th</td>
<td>Welander et al. 1987; Dunwell et al. 1995</td>
<td>3</td>
<td>7</td>
<td>0.43</td>
</tr>
<tr>
<td>Fjällinge</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>10th-11th</td>
<td>Helgesson &amp; Arcini 1996</td>
<td>80</td>
<td>128</td>
<td>0.63</td>
</tr>
<tr>
<td>Frösön</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>11th-14th</td>
<td>Benedictow, 1996</td>
<td>210</td>
<td>364</td>
<td>0.58</td>
</tr>
<tr>
<td>Galgedil</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>9th-11th</td>
<td>Price et al. 2014</td>
<td>8</td>
<td>57</td>
<td>0.14</td>
</tr>
<tr>
<td>Hríðbrú</td>
<td>Iceland</td>
<td>Frontier</td>
<td>10th-11th</td>
<td>Byock et al., 2014</td>
<td>3</td>
<td>21</td>
<td>0.14</td>
</tr>
<tr>
<td>Keflavík</td>
<td>Iceland</td>
<td>Frontier</td>
<td>10th-12th</td>
<td>Zoëga &amp; Murphy 2020</td>
<td>22</td>
<td>46</td>
<td>0.48</td>
</tr>
<tr>
<td>Keldudalur</td>
<td>Iceland</td>
<td>Frontier</td>
<td>10th-12th</td>
<td>Zoëga &amp; Murphy 2016;</td>
<td>24</td>
<td>53</td>
<td>0.45</td>
</tr>
<tr>
<td>Location</td>
<td>Province</td>
<td>Region</td>
<td>Time Period</td>
<td>Reference(s)</td>
<td>N</td>
<td>Count</td>
<td>Width</td>
</tr>
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<tr>
<td>Mälaren Valley</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>8th-12th</td>
<td>Zoëga &amp; Murphy 2020</td>
<td>17</td>
<td>136</td>
<td>0.13</td>
</tr>
<tr>
<td>Newark Bay</td>
<td>Scotland</td>
<td>Frontier</td>
<td>Mid-6th/late-7th century to the 14th/early 15th century</td>
<td>Molleson &amp; Owen 2005</td>
<td>118</td>
<td>208</td>
<td>0.57</td>
</tr>
<tr>
<td>Pierowall*</td>
<td>Scotland</td>
<td>Frontier</td>
<td>9th-10th</td>
<td>Redmond 2007; Thorsteinsson 1968; Canmore Westray, Pierowall Links</td>
<td>0</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>PKbank</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>1050-1100</td>
<td>Benedictow, 1996</td>
<td>12</td>
<td>200</td>
<td>0.06</td>
</tr>
<tr>
<td>Sandnes</td>
<td>Greenland</td>
<td>Frontier</td>
<td>Pre-mid 14th</td>
<td>Lynnerup 1998</td>
<td>24</td>
<td>88</td>
<td>0.27</td>
</tr>
<tr>
<td>Sigtuna</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>12-14th</td>
<td>Steckel et al. 2018</td>
<td>94</td>
<td>382</td>
<td>0.25</td>
</tr>
<tr>
<td>Skaill House</td>
<td>Scotland</td>
<td>Frontier</td>
<td>11th-14th</td>
<td>James et al. 1999</td>
<td>15</td>
<td>27</td>
<td>0.56</td>
</tr>
<tr>
<td>Site</td>
<td>Region</td>
<td>Type</td>
<td>Period</td>
<td>Reference</td>
<td>N</td>
<td>ND</td>
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<tr>
<td>Skeljastaðir,</td>
<td>Iceland</td>
<td>Frontier</td>
<td>Pre- 12th</td>
<td>Richter 2005</td>
<td>7</td>
<td>66</td>
<td>0.11</td>
</tr>
<tr>
<td>St Stefans</td>
<td>Scandinavia</td>
<td>Homeland</td>
<td>11th-12th</td>
<td>Benedictow, 1996</td>
<td>77</td>
<td>258</td>
<td>0.30</td>
</tr>
<tr>
<td>Thjodhild's Church</td>
<td>Greenland</td>
<td>Frontier</td>
<td>11th</td>
<td>Lynnerup 1998</td>
<td>24</td>
<td>144</td>
<td>0.17</td>
</tr>
<tr>
<td>Waterford</td>
<td>Ireland</td>
<td>Frontier</td>
<td>11th-13th</td>
<td>Hurley et al. 1997</td>
<td>9</td>
<td>55</td>
<td>0.16</td>
</tr>
<tr>
<td>Westness*</td>
<td>Scotland</td>
<td>Frontier</td>
<td>8th-11th</td>
<td>Sellevold 1999</td>
<td>5</td>
<td>29</td>
<td>0.17</td>
</tr>
<tr>
<td>Wood Quay</td>
<td>Ireland</td>
<td>Frontier</td>
<td>12th</td>
<td>O'Donnabhain 2010</td>
<td>10</td>
<td>23</td>
<td>0.43</td>
</tr>
</tbody>
</table>

*See notes on these series in the SI.
Figure 1. Location of each site used in this study
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 (see Table 3). The resulting two-tailed p value was $p = 0.1332$ 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 (see 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 \( \chi^2 (1, N=2616) = 53.78, p= < 0.00001 \) and there is a significant relationship between region and the proportion of preadults (D0-14/D).

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.

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

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 (see 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.

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

<table>
<thead>
<tr>
<th>Region</th>
<th>D0-14</th>
<th>D&gt;14</th>
<th>Marginal Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenland</td>
<td>48 (74.54) [9.45]</td>
<td>184 (158.46) [4.47]</td>
<td>232</td>
</tr>
<tr>
<td>Iceland</td>
<td>53 (53.01) [0.00]</td>
<td>112 (111.99) [0.00]</td>
<td>165</td>
</tr>
<tr>
<td>Ireland</td>
<td>9 (18.67) [4.25]</td>
<td>46 (38.33) [2.01]</td>
<td>55</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>589 (604.96) [0.42]</td>
<td>1294 (1278.04) [0.20]</td>
<td>1883</td>
</tr>
<tr>
<td>Scottish Isles</td>
<td>118 (66.83) [39.19]</td>
<td>90 (141.17) [18.55]</td>
<td>208</td>
</tr>
<tr>
<td>Marginal Column Totals</td>
<td>817</td>
<td>1726</td>
<td>2543 (Grand Total)</td>
</tr>
</tbody>
</table>
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 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 & 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 (Filipsson & Nordberg 2010; Asteman & Nordberg 2018). 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 (Filipsson & Nordberg 2010; Asteman & Nordberg 2018). 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). Part of the cultural negotiations was a change in religious belief, the pre-Christian Scandinavian religion and religious practices, including furnished graves, were abandoned as the Hiberno-Scandinavian culture developed (Downham 2012), and the domination of inhumation burials even before the adoption of Christianity have been interpreted as early Christian influence on Viking burial rites (Harrison and Ó Floinn 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 in the 870s AD 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 to decide on legislation and dispense justice, in the year 999 or 1000 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 (Krogh 1967; Miller 1990; Pentikäinen 1990; Bragg 1997; Wicker 1999; Jones 2001; Wenman 2005; Grønlie 2006;
Barrett 2008; Wicker 2012; Lawing 2013). 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: 87-88) 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 1,000 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 (McFadden and Oxenham 2017) and a low rate 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 Easters 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 2,000 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 commodity was 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. 2014). This coincides with worsening and more unpredictable climatic conditions following the onset of the Little Ice Age from the late 13th century, and probably a decisive factor in the abandonment of the Western settlement in the 14th century (Schoefield et al. 2022). Norse farming practices in Greenland where 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) than in the 14th century (Sandness). At face value this might suggest a suboptimal demographic environment centuries prior to eventual abandonment of the country while the uptake in the fertility rate at Sandness 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 & Buikstra 1981; Mays et al. 2007; Manifold 2012). Many studies have identified two significant factors to preadult skeletal preservation as being pH levels and the presence of groundwater (Gordon & Buikstra 1981; Mays et al. 2007; Nielsen-Marsh et al. 2000; Manifold 2012; Damiata et al. 2013).

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 3.0-3.5 (Rutherford 1995) which is in the marginal pH range for preadult bone preservation (Gordon & Buikstra 1981). Further, Sandnes is known to experience sporadic permafrost (Christiansen & Humlum 2000; Wallroth et al. 2010) which is associated with elevated rates of bone diagenesis (Nielsen-Marsh et al., 2000; Manifold, 2012; Hollesen et al., 2016; Lee, 2019). Furthermore, site erosion has been identified at Sandnes with part of the original church (and potentially part of the graveyard) now being submerged (McGhee 1984; Lynnerup 1996).

As for Thjodhild’s Church, the pH level falls between a rather acidic 3.9-4.4 (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) and 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; Sellevold 1999; Molleson & Owen 2005). 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 & Owen 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 & Owen 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 with 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 (c. 1200 AD) and Historia Norwegiae (c. 1220 AD) 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 AD 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 (Goodcare 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: 568-569), 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 on 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, but in this instance increased rates of fertility that 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.
Supplementary Materials

1. 8.1 Homeland

1. 8.1.1 Scandinavia

8.1.1.1 Birka

The Birka cemetery appears to have been in use during the 9th and 10th centuries with 308 individuals having been excavated from that period, with 91 of those individuals being aged between 0-14 (Gräslund 1981).

8.1.1.2 Fjälkinge

The Fjälkinge cemetery site is dated to between the 10th and mid 11th centuries with 128 individuals being excavated, with 80 of those being aged 0-14 (Helgesson & Arcini 1996).

8.1.1.3 Frösön

The cemetery of Frösön is dated from the middle of the 11th century to the middle of the 14th century (Benedictow, 1996). In this assemblage there are 364 individuals, with 210 of those being aged between 0-14 (Benedictow 1996).

8.1.1.4 Galgedil

The cemetery of Galgedil is dated between the 9th and mid 11th centuries and 57 individuals were excavated, with 8 of those being aged between 0-14 (Price et al. 2014).
8.1.1.5 Mälaren Valley

The Mälaren Valley skeletal assemblage is dated from the 8th to the 12th century (Kjellström, 2016). This assemblage, comprising a collection of homesteads, contains 136 individuals, and 17 of those individuals are dated to being less than 12 years old (Kjellström 2016).

8.1.1.6 Pkbank

The site of Pkbank is dated from the middle of the 11th century to the beginning of the 12th century (Benedictow 1996). In this assemblage there are 200 individuals, with 12 of those being aged between 0-14 (Benedictow 1996).

8.1.1.7 Sigtuna

The Sigtuna sample for this study is dated to between 1100 and 1300 which slightly post-dates the Viking period for Scandinavia, in this sample there were 382 individuals and 94 of those individuals were aged between 0-14 (Steckle et al. 2018).

8.1.1.8 St Stefans

The cemetery of St Stefans is dated from the middle of the 11th century to the beginning of the 12th century (Benedictow, 1996). In this assemblage there are 258 individuals, with 77 of those being aged between 0-14 (Benedictow 1996).
2. 8.2 Frontier

1. 8.2.1 Greenland

8.2.1.1 Sandnes

In this assemblage that predates the abandonment on the Western settlement in the middle of the 14th century there were 88 individuals with 24 of the being aged between 0-15 (Lynnerup 1998).

2. 8.2.1.2 Thjodhild’s Church

In this assemblage that has been roughly dated to around the 11th century there were 144 individuals, with 24 of them being aged between 0-15 (Krogh 1976; Lynnerup 1998).

3. 8.2.2 Iceland

4. 8.2.2.1 Hrísbrú

The Hrísbrú cemetery is dated to have been used between the 10th and 11th centuries CE (Byock & Zori, 2014). 21 sets of skeletal remains were recovered during the excavation and three of those were specifically identified as being children (Eng 2014).

5. 8.2.2.2 Keflavík

The Keflavík cemetery in Northern Iceland is regarded as being late Viking to early Medieval (10th to 12th centuries) (Zoëga & Murphy 2020). This cemetery contained the remains of 46 individuals, 26 of which were aged between zero to twelve years old (Zoëga & Murphy 2020).
8.2.2.3 Keldudalur

The Keldudalur cemetery in Northern Iceland is regarded as being late Viking to early Medieval (10th to 12th centuries) (Zoëga & Murphy 2016; Zoëga & Murphy 2020). This cemetery contained the remains of 53 individuals, 24 of which were aged between zero to twelve years old (Zoëga & Murphy 2016).

8.2.2.4 Skeljastaðir

The Skeljastaðir cemetery site has been dated to being pre-12th century (Richter, 2005). Due to poor preservation only 51 of the 59 adult individuals excavated were able to be analysed for age and sex estimations along with seven children and infants (Richter 2005).

6. 8.2.3 Ireland

8.2.3.1 Waterford

The Waterford cemetery site has recovered 285 individuals from six different time periods (Hurley et al. 1997). For the purpose of this study only periods I and II (11th to 13th centuries) were used as they were identified as being Hiberno-Norse/ Norman (Hurley et al. 1997). This meant that there were 55 individuals from this site included in this study with nine of those being preadults aged between zero to fifteen years old (Hurley et al. 1997).
8.2.3.2 Wood Quay

The site of Wood Quay is attributed to the Hiberno-Norse culture of Dublin in 12th century (O’Donnabhain 2010). In this sample there were 23 individuals, with 10 of those being preadults in the 0-14 category (O’Donnabhain 2010).

7.  8.2.4 Scottish Isles

8.2.4.1 Cnip

The Cnip cemetery is dated to have been in use in the 9th and 10th centuries with a total of 7 individuals having been found thus far and 3 of those individuals being ages 0-14 (Welander et al. 1987; Dunwell et al. 1995).

8.2.4.2 Newark Bay

The assemblage at Newark Bay is dated between the mid 6th/late 7th century to the 14th/early 15th centuries although Ashmore (2003) suggests most postdate the late 8th century. Some 208 individuals have been excavated, and of those 118 are considered to be between the ages 0-14 (Molleson & Owen 2005). It should be noted that this cemetery includes an early pictish component. Some, 20/39 (51.3%) directly dated individuals derive from the late 10th/early 11th century to the 13th century. A further eight have date ranges that include the 12th century, while only 5/39 (12.8%) of the upper ranges of dated individuals fall into the early 10th century or earlier (see Toolis et al. 2009). The assumption is that while predominantly Christian and Norse, a relatively small proportion (perhaps <15%) of the cemetery are Pictish burials.
8.2.4.3 Pierowall

The Viking cemetery at Pierowall is dated from the mid 9th to the mid 10th centuries (Sikora 2003) and is comprised of 16 individuals, with none being aged under 14 years (Redmond 2007; Thorsteinsson 1968). See also the following for a summary of Thorsteinsson’s burial descriptions: https://canmore.org.uk/site/2768/westray-pierowall-links.

8.2.4.4 Skaill House

The Skaill House skeletal assemblage is comprise of 27 individuals, 15 of which are aged between 0-14 (James et al. 1999). The skeletal remains have been dated to between the 11th and 14 centuries (James et al. 1999).

8.2.4.5 Westness

The Westness cemetery site was used by the Viking settlers during the 8th to 11th centuries (Sellevold, 1999) although more recent dating suggests the earliest burial may date to between the 5th and 7th centuries (Barrett et al. 2000; Ashmore 2003). In this assemblage there were 29 individuals with 5 of those being between the ages of 0-14 (Sellevold, 1999). As with Newark Bay, this is a mixed cemetery and includes 11 individuals identified as pre-Norse or Pict (Ashmore 2003; Sellevold 2010). The question of whether Westness should be treated as a single demographic unit is debateable. Furnished (and particularly oriented graves) have been identified as Viking (n= 8, 7 adults and 1 preadult). Similarly, dating suggests 11 burials are pre-Norse (see Sellevold 1999; Barrett 2003). However, the interpretation of other unfurnished, and otherwise oriented, graves as non-Viking Christian (Pict) would seem to be open to debate. Ashmore (2003: 37), with specific reference to the situation at Wetness, notes
that the presence or absence of grave goods is not necessarily useful in determining one’s religious status. Further, Barrett et al. (2000: 12) notes that “Westness provides the earliest archaeological evidence for Christian-pagan relations”. It would seem Westness may be better seen as a Viking-Pict community for some significant period of its existence at least. Perhaps this is why Sellevold (1999) treats the cemetery as a single unit for the purposes of demographic description. Given the relatively small size of the cemetery, and the potential for this being a cohesive (albeit mixed) community, we believe the case is robust for following Sellevold in treating the cemetery as a single unit for the purposes of demographic modelling.
Acknowledgements

British Academy Global Professorship GP2\190224. The authors would like to thank Ricky Craig, Independent GIS Specialist and Cartographer, Scotland, for preparing Figure 1, the map.
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