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The Norse Awakens:

A palaeodemographic study of Viking and Norse homeland and frontier communities during the Viking and following Medieval period in the North Atlantic.

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Britta Van Tiel

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I hereby declare that, except where it is otherwise acknowledged in the text, this thesis represents my own original work.

All versions of the submitted thesis (regardless of submission type) are identical.

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Abstract

While there has been a significant amount of interest in the lives of Viking and Norse populations in the modern era through historical representations, archaeology, and representation in popular culture; the knowledge surrounding the population health and dynamics of these people is limited. This is due to a lack of palaeodemographic and palaeoepidemiological investigations. It is widely recognised that palaeodemography can significantly improve our understanding of population health and dynamics of past populations. For this reason, this thesis aimed to apply existing palaeodemographic methods for fertility, population increase and maternal mortality, and adjust a new method for mortality in early infancy. This was in order to develop a better understanding of population health and dynamics of homeland and frontier Viking and Norse communities, which would greatly contribute to the currently limited knowledge.

The results of the analyses undertaken in this thesis indicate that there were no significant differences in the subadult representation in homeland and frontier Viking and Norse communities and on an intra-regional level. However, there were significant differences in the level of subadult representation at an inter-regional level with Greenland appearing to demonstrate subadult under-representation and the Scottish Isles appearing to demonstrate a higher-than-expected number of subadults. Unfortunately, the maternal mortality estimator results were not able to be utilised due to a lack of available data, however, there are hopes to undertake these analyses at a future date when more site-

specific data becomes available. The newly developed infant and neonate mortality estimator appears to require some more work, however, is showing considerable promise. These results contribute to increasing the collective understanding of population health and dynamics in Viking and Norse homeland and frontier communities.

Chapter 1 Introduction

In the modern period the Viking and following Norse cultures have been the source of significant interest for many decades, from both a historical and popular culture perspective (Barnes, 2015). Archaeological investigations have significantly contributed to the wider understanding of how these people lived (Barrett, 1995; Lucas *et al*., 2009). However, palaeodemographic investigations into these communities, which could significantly contribute to furthering our understanding of the lives of these people, has been limited (Lynnerup, 1996; Lynnerup, 1998; Kjellström *et al*., 2005; Lynnerup, 2014).

This thesis study seeks to utilise and develop contemporary palaeodemographic methods to evaluate and compare the population dynamics of towns and settlements colonised by the Vikings or Norse with samples from the Scandinavian homeland. The aim of this thesis is to develop a better understanding of the population dynamics of homeland and frontier Viking and Norse populations and to understand whether there are any significant differences between these groups.

1.1 Introduction to Bioarchaeology and the Role of Palaeodemography in Assessing Past Populations.

The discipline of bioarchaeology broadly focuses on the study of human skeletal remains in an archaeological context (Larsen, 2014). Specific sub disciplines within bioarchaeology have started to emerge which focus on particular aspects of estimating health, population dynamics, death, and culture from individual skeletal remains in order to provide inferences about the health of the specific individual, and the health of wider populations.

Palaeodemography is one of the sub disciplines of bioarchaeology which significantly contributes to the wider understanding of population health in ancient communities. Palaeodemography is an interdisciplinary field which applies demographic methodology in an archaeological context to reconstruct past population structures and dynamics (Buikstra & Konigsberg, 1985; DeWitte, 2018). Variables such as sex and age-at-death are used to study aspects of population dynamics including structure, growth rates, fertility, mortality and migration (DeWitte, 2018; McFadden & Oxenham, 2018a; McFadden & Oxenham, 2018b; McFadden, 2019). This allows researchers to interpret how past populations adapted in response to significant environmental and social changes such as climate change, warfare, and migration (McFadden, 2019). As a whole, palaeodemography seeks to demonstrate how individuals and populations respond to intrinsic and extrinsic factors.

1.2 The Vikings and Norse

The Vikings are often referred to as Norse individuals from Southern Scandinavia who during the 8th to 11th centuries raided and established colonies in mainland Europe, the British Isles, Iceland, Greenland, and North America (Roesdahl, 1998; Holman, 2003). However, it is also important to note that individuals from the regions that were raided and colonised also participated in these activities and the cultural practices that originated in Scandinavia and they too were referred to as Vikings (Goodacre *et al*., 2005; Margaryan *et al*., 2020). Thus, for the purpose of this study the term "Viking" will refer to those individuals who were either from Scandinavia or who undertook cultural practices that were brought out from the Scandinavian homeland. During this time of raiding and colonising the Vikings had a considerable influence, and in the Medieval period following the Viking period the Norse cultures still held considerable influence over regions that they had colonised, particularly where regions had previously been sparsely inhabited such as in Greenland and Iceland.

1.3 Research Aims

1. To compare the population dynamics of homeland Viking and Norse communities and frontier Viking and Norse communities, specifically investigating subadult representation and maternal mortality. This comparison will be undertaken to see whether there are differences in the health of populations that potentially experience different environmental and cultural conditions based on their geographical location.
2. To implement the revised maternal mortality estimator developed by McFadden *et al*. (2020) in order to see whether this estimator is applicable in an archaeological setting outside of ancient Southeast Asia which will provide a better understanding of the maternal

experience in Viking and Norse communities during the Viking and following Medieval period.

3. To develop a new palaeodemographic and palaeoepidemiological method to estimate the number of neonates and infants in a sample using the McFadden and Oxenham (2018a) fertility equations and the newly developed infant and neonate estimators (McFadden et al., in prep.). This is in order to assess whether the expected number of infants and neonates, which are thought to be vulnerable to underrepresentation in a sample can be predicted using more stable demographic information.

1.4 Thesis structure

The following chapter (Chapter 2) is a literature review discussing the role of palaeodemography and palaeoepidemiology in assessing past populations. This is undertaken by evaluating palaeodemographic methodologies and the Osteological Paradox. Chapter 3 discusses the archaeological and historical background of the establishment of Viking and Norse colonies and previous investigations. Chapter 4 outlines the materials and methods which were used to analyse the population demographics and introduces a new palaeodemographic framework, which is then followed by the results of these analyses in Chapter 5. Finally, Chapter 6 provides a discussion of the results in the context of the broader literature, and Chapter 7 draws conclusions and provides directions for future research.

Chapter 2 Literature Review

2.1 Introduction to Literature Review

The evaluation of skeletal materials for palaeodemographic and palaeoepidemiological purposes has significantly improved since the early 1990s when the Osteological Paradox by Wood *et al*. (1992) was first published. There has been an emphasis only recently placed on improving the methodologies influenced by theoretical frameworks to improve the reliability of the data interpreted in the fields of palaeodemography and palaeoepidemiology (McFadden & Oxenham, 2020).

This chapter aims to explore the current literature surrounding Viking palaeodemography and frontier demography in addition to demographic representation in the archaeological record. Furthermore, this chapter will assess the methods that have been developed for the purpose of palaeodemographic analyses, in addition to critically evaluating the Osteological Paradox in relation to its role in palaeoepidemiological and palaeodemographic studies.

2.2 Palaeodemography

2.2.1 Viking Palaeodemography

Whilst there has long been interest in the lives of Viking and Norse individuals and their cultural practices, there have been a limited number of demographic studies undertaken which would provide more information on the societal structure. Previous studies of Norse and Viking palaeodemography have been quite limited, with specific studies undertaken by Lynnerup (1996, 1998, 2014) and Kjellström *et al*. (2005). The paper by Kjellström *et al*. (2005) provided a number of demographic composition tables, similarly the 1998 thesis by Lynnerup provided age-at-death demographic distributions. However, it was the 1996 and 2014 papers by Lynnerup that attempted to undertake population modelling in order to better understand the composition and eventual demise of the Norse communities in Greenland.

2.2.2 Viking and Frontier Paleodemography

The demographic requirements of frontier and colony populations has long been a source of interest for palaeodemographers and academics in the wider fields of archaeology and biological anthropology. This is because aside from the cultural and environmental factors, the number and demographic make-up of the individuals who were involved in establishing these populations had a significant impact on whether or the colony would survive and thrive. In the case of the Viking colonists, there are some sources of evidence which provide rough estimates of how many individuals were involved in some of the colonisation events. The 2019 book by Bernharðsson estimates based on literary and archaeological evidence that in the colonisation of Iceland there were between 311-436 colonists. There is also some evidence from the colonisation of Greenland which indicates that there were 25 ships of colonists that left Iceland but only 14 of them arrived (Brown, 2000). The evidence that is available indicates that approximately 500 individuals left on the 25 ships, which if divided equally means that only 280 individuals arrived (Morcken, 1988). It is important to consider that in the majority of cases it would not have been individuals moving, but households (Goodacre *et al*., 2005). Based on the statements of Benedictow (1996) the average size of a Viking household was 4.25 individuals. This means that for the colonisation of Iceland it is calculated that between 73 and 103 households would have made the journey, and around 65 households would have successfully arrived in Greenland (Morcken, 1988; Benedictow, 1996; Brown, 2000).

A modern demographic calculator was created by the anthropologist John Moore (2001) to calculate the smallest number of individuals required to provide enough genetic diversity for a multi-generational space journey, the results from this modelling is also applicable to other colonisation events such as the Viking colonisation of uninhabited landmasses. Moore's estimate was that a starting population of between 80 to 150 individuals would be required in order to undertake a successful multi-generational endeavour (Smith, 2019). This estimate was supported by the academics Marin and Beluffi (2018) who indicated that a minimum number of 98 individuals would be required to ensure a 100% success rate for a population to last multiple generations and preserve genetic diversity at the same time. These estimates would indicate that in the colonies of both Iceland and Greenland there were enough individuals to ensure that genetic diversity could be preserved, and communities would flourish for multiple generations, provided that the environmental and cultural conditions were favourable.

Similar to the hypothesised familial colonisation of Iceland and Greenland, the Northern Isles appear to have been settled by families according to the genetic studies undertaken by Goodacre *et al*. (2005). However, the familial settlement pattern does not appear to have been the standard across the board, there is a wealth of genetic testing that hypothesises that the Western Isles, Ireland, and parts of England were subject to a higher number of male Viking colonists (Goodacre *et al*., 2005). This concept has also been supported by literary and archaeological evidence (Curtis, 1921; Klæsøe, 2010). The benefit to this would be that not as many colonists would be required to establish new communities

2.2.3 Demographic Representation in the Archaeological Record

The perception that different demographic groups are not always equally represented has long been supported within the archaeological record. This can be attributed to a number of factors, but particularly differential burial practices and poor osteological preservation. The demographic groups that tend to be underrepresented are subadults, the elderly and females (Stojanowski *et al*., 2002). This section aims to highlight various reasons for the lack of equal representation and try to identify if there are demographic groups that are less represented than others.

Differential burial practices are a considerable concern when investigating reasons for under-numeration of different demographic groups. For various cultural reasons demographic groups may be isolated and inhumed in a manner that deviates from the norm. In many cultures infanticide was a common practice due to various socio-cultural reasons such as sex preference, lack of available resources, the inability to care for disabled offspring, and population control (Wrightson, 1975; Minturn *et al*., 1982; Scott, 2001; Caldwell, 2006; Scott, 2017). In the cases where infanticide was undertaken, the child often had no social identity, and thus was not buried in the common cemetery as the parents did not return to collect the child's remains. Another common theme in many cultures was human sacrifice. These sacrificial offerings often contributed to a cosmological belief system where a human would be killed to honour deities in the hopes that a particular outcome would be achieved such as bringing end to a drought or allowing victory in battle (Allan, 1984; Sutter *et al*., 2005; De Anda Alanis, 2007). These individuals would often be sacrificed in temple complexes or other natural areas of religious significance and would not be included in a normal cemetery complex. An additional differential burial practice that is well documented is the practice of subadult clustering within cemeteries and burying children in different cemeteries (Bennike *et al*., 2005; Donnelly & Murphy, 2016). If during excavations the clustering of subadults were not recovered, or a child cemetery separate to a community's main cemetery was not recovered, it would also contribute significantly to the under-numeration of subadults.

Another factor that has the ability to significantly influence the representation of different demographic groups within skeletal samples is the type of taphonomic conditions associated with the burials. According to Stojanowski *et al*. (2002) in a marginally preserved skeletal assemblage, the demographic groups that are more likely to be underrepresented are subadults, females, and the elderly. This is due to the reduced resiliency of less dense bone when exposed to taphonomic conditions that are not conducive to bone preservation (Stojanowski *et al*., 2002). Taphonomic conditions such as acidic pH levels, presence of water, and shallow burial depth all contribute to these demographic groups being underrepresented in the archaeological record (Gordon & Buikstra, 1981; Stojanowski, 2002).

Whilst there are a plethora of factors that may contribute to the under-numeration of particular demographic groups, a significant issue arises when trying to understand how archaeologists or researchers interpret if a demographic group is over or underrepresented and how they fare in comparison to other demographic groups. Unless there are cultural practices or significant taphonomic conditions known to impact particular demographic groups, it should be assumed that there is equal representation (Buckberry, 2000).

2.3 Evaluation of Palaeodemographic Methods

Whilst a significant number of palaeoepidemiological methods are based on modern epidemiological studies, palaeodemography can only relate to modern demography to a certain extent. This is due to the nature of the data that is collected, in that it is only a sample rather than an entire population. The

Osteological Paradox (which is addressed later in the chapter) brings forth this issue but doesn't make an effort to address this. By developing palaeodemographic methods, it starts to address this issue as it provides new methods that are specifically catered to skeletal populations which produce more reliable palaeodemographic information. This section aims to identify key biological methods which provide data for palaeodemographic analyses (age-at-death and sex estimation), and to evaluate some of the palaeodemographic methods that have been developed such as subadult ratios and the associated calculation for fertility rates, in addition to the maternal mortality rate estimator.

The key biological methods which provide data for the palaeodemographic analyses have the ability to significantly impact the outcome of palaeodemographic investigations. The data utilised in this thesis has been collected and revisited recently enough that the biological methods for age and sex estimation are up to date and applicable for the geographic origins of the individuals involved. The main issue that is presented is that the samples from Greenland and Iceland are known to be poorly preserved which may influence the interpretation of the skeletal remains. However, it is important to note that the researchers who complied the biological profiles of the Norse individuals in Greenland and Iceland predominantly undertook observations of the skeletal remains during the excavation process and compiled the biological profile prior to the remains being lifted. This allows for a better understanding the skeletal positioning (for example of the pelvis) which can significantly influence interpretations.

2.3.1 Age-at-death Estimation methods

Age-at-death estimation is an essential aspect of creating a biological profile from skeletal remains and is integral when undertaking palaeodemographic analyses. It involves observing the morphological features from skeletal remains, comparing them with features from other individuals in more recent populations with a known age, and then estimating whether there are any sources of variability between the source and comparison population. It is important to note that not all age-at-death estimation methods are applicable to all age groups, thus this section is divided into subadult and adult age-at-death estimation methods. This is because there are known stages of development for subadults which makes them relatively easy to age, compared to adults where the methods employed to try and estimate the age-at-death can be influenced by a variety of factors.

2.3.1.1 *Subadult age-at-death estimation methods*

Estimating the age of subadults, until approximately the age of 14 years is a relatively straightforward task. This is due to the plethora of known developmental stages for long bone growth, epiphyseal fusion, and dental development. The relative reliability of the aging methods for subadults provides some certainty when undertaking demographic analyses on subadult groups.

Of the aging methods available the one that is regarded as the most reliable is dental analysis (Ubelaker & Khosrowshahi, 2019). As is illustrated in the publications by White & Folkens (2005) and AlQahtani *et al.* (2010), there is a known pattern to subadult dental development and eruption. The 2010 study by AlQahtani *et al.* is unique in that it acknowledges the often-problematic Eurocentric approach to biological methods, and the authors opted to include individuals from Bangladesh to provide a better representation of individuals from multiple geographic regions (Halcrow *et al*., 2007; AlQahtani *et al*., 2010). By identifying the stage of development and eruption for each tooth, a relatively accurate age range can be provided for an individual. Problems do arise when there is missing dentition, there are congenital abnormalities affecting the dentition, or when developmental delays occur due to factors such as poor nutrition (Ubelaker & Khosrowshahi, 2019). However, dental analyses should always be undertaken where possible due to the widely regarded reliability of the method.

Other methods for estimating the age of subadults are through measuring long bone length and assessing the closures of epiphyseal closures and fontanelle closures (Cunningham *et al*., 2016). These methods are generally reliable, however, there can be a considerable amount of individual variation based on genetic or environmental determinants (Cunningham *et al*., 2016; Ubelaker & Khosrowshahi, 2019).

In the majority of cases a multimethodological approach is undertaken to estimate age in order to provide the most accurate representation of the individuals age when the died. This is because often due to abiotic and biotic taphonomic factors not all skeletal aspects may have preserved, and this approach will hopefully increase the accuracy and precision of the age-at-death estimate.

2.3.1.2 *Adult age-at-death estimation methods*

In comparison to subadults, the age-at-death estimation for adults can be considerably more challenging. This is because after the known developmental stages have passed, the majority of signs of aging in skeletal remains are quite subtle and can be influenced significantly by lifestyle. The most common methods for estimating age-at-death for adults are the fusion of cranial sutures, the amount of dental wear, and the morphologies of the pubic symphysis and the sternal rib end.

Dental wear is based on sample seriation, arranging the samples from least to most worn (Lovejoy *et al*., 1985; Buikstra & Ubelaker, 1994; White & Folkens, 2005; Cave & Oxenham, 2016). By arranging the samples this way, it should order the individuals from youngest to oldest and age categories can be applied based on the amount of wear (Buikstra & Ubelaker, 1994). It is important to note that some cultural activities may intentionally or unintentionally increase the rate of dental wear, which if aging an individual exclusively based on their dentition can lead to age-at-death over estimation (Molnar, 1971; Vieira *et al*., 2015).

Cranial suture closure is also another method for aging adult individuals. The method explained by Meindl and Lovejoy (1985) requires scores to be assigned to 9 different cranial sutures based on the stage of closure. These scores are then added together and the outcome is compared with a table which will assign an age to the individual (Meindl & Lovejoy, 1985). Unfortunately, this method can only provide an age estimate until and individual is in their early 50s, meaning that if an individual was considered elderly they would not necessarily be accurately represented by this method.

The public symphysis and sternal rib end both undergo morphological changes as the age of an individual increases (Todd, 1920; Suchey & Brooks, 1990; White & Folkens, 2005). The pubic symphysis in particular undergoes a known progression of metamorphosis as age increases, however, there are some sex-based differences which means that it is extremely important to estimate sex prior to commencing age estimation methods (Suchey & Brooks, 1990; White & Folkens, 2005). The sternal rib end is also indicative of age, with the surface porosity increasing with age, in addition to the surface becoming more concave as an individual's age increases (Işcan *et al*., 1984; Işcan *et al*., 1985; White & Folkens, 2005).

In the majority of cases a multifactor assessment is undertaken to estimate age-at-death in order to provide the most accurate representation of the individuals age when they died. This is done by taking into account the most accurate of the methods (based on the type of population the method was based on), and if different methods produce similar results. This is because often due to abiotic and biotic taphonomic factors not all skeletal aspects may have preserved and this approach will hopefully increase the accuracy and precision of the age-at-death estimate.

2.3.1.3 *Sex estimation methods*

Another integral aspect of creating a biological profile which is essential to palaeodemographic analyses is estimating the sex of an individual. The most reliable way to confirm the sex of an individual is to undertake molecular analyses, however, this is a destructive and costly exercise which may not be successful depending on the level of skeletal preservation (Skoglund *et al*., 2013). Instead, in most cases the skeletal morphology is qualitatively and quantitatively assessed for sexually dimorphic traits. For qualitative traits used to estimate sex, the pelvis is often quite a reliable source due to significant morphological differences. Methods have been developed and explained by authors such as Phenice (1969), Işcan & Derrick (1984), and White & Folkens (2005) (Krishan *et al*., 2016). Some of these methods are based on a scale of femininity to masculinity, and others are based on the presence or absence of feminine or masculine features. Similar qualitative methods have been developed by authors such as Loth & Henneberg (1996, 1998), Graw *et al*.

(1999), and Walker *et al*. (2008), for the cranium where scores are assigned based on robusticity or gracility and then tallied (White & Folkens, 2005). Quantitative methods involve measuring the long bones and various cranial and sub cranial landmarks and considerably vary in their levels of reliability (White & Folkens, 2005; Nikita & Michopoulou, 2018). In most cases a multifaceted approach is undertaken in order to provide the most accurate estimation of sex. This is because often due to abiotic and biotic taphonomic factors not all skeletal aspects may have preserved, and this approach of combining methods will hopefully increase the accuracy and precision of the biological sex estimate.

Prior to the development of these biological methods the estimation of sex was often restricted to inferences based on the type of grave goods associated with a burial. This method of estimating sex has been proven to be unreliable, often producing mixed results (Weglian, 2001; Stratton, 2016). This is because grave goods are more a representation of gender and identity of an individual within a society, which is a very different concept (Sofaer & Sørensen, 2013).

It is also important to note the lack of reliable methods for subadult sex estimation. Whilst there have been some attempts to sex subadult individuals using pre-existing methods and developing new methods as yet these approaches have not been successful at accurately sexing pre-pubescent individuals or have only been tested limited samples (Franklin *et al*., 2007; Stull *et al*., 2017; Klales & Burns, 2017). For this reason, most bioarchaeologists will avoid attempting to sex a subadult due to the lack of reliable biological methods.

2.3.2 Palaeodemographic Indices

The first palaeodemographic method to be evaluated are the ratios associated with subadult representation. For many years the under-numeration of infants in the archaeological record has been assumed to be a significant issue, to the extent that individuals aged between 0 and 4 years are often excluded from palaeodemographic analyses (Milner *et al*., 2008; Seguy & Buchet, 2013, McFadden & Oxenham, 2018a).

The Juvenility Index created by Bocquet-Appel and Masset (1977, 1982, 1996) was developed as a palaeodemographic tool to help palaeodemographers make inferences about the dynamics of past populations. The equation for this index was:

$$D5 - 14/D20 +$$

The equation was based on a subadult to adult ratio which avoided both the high error rate associated with a continuous or multicategory age-at-death distribution and the issues associated with infant under-numeration (Bocquet-Appel & Masset, 1977; Bocquet-Appel & Masset, 1982; Bocquet-Appel & Masset, 1996; McFadden & Oxenham, 2018a). Demographic variables such as mortality and fertility were then predicted using polynomial regression with the assistance of information from life tables and known fertility rates (Bocquet-Appel & Masset, 1977; Bocquet-Appel & Masset, 1982; Bocquet-Appel & Masset, 1996; McFadden & Oxenham, 2018a). This method was only updated by Bocquet-Appel in 2002 when the equation was modified to:

$$D5-19/D5+$$

This update is often referred to as the $_{15}P_5$ Index, however, it did not significantly improve the correlation between estimated and known fertility rates (Bocquet-Appel, 2002; McFadden & Oxenham, 2018a). It should be recognised that in this version of the equation more distinct age categories were identified, making it easier to implement (Bocquet-Appel, 2002; McFadden & Oxenham, 2018a).

Following these equations, McFadden and Oxenham (2018a) developed the D0-14/D Ratio: A new palaeodemographic index and equation for estimating total fertility rates (McFadden & Oxenham, 2018a). This study aimed to develop a new subadult/adult ratio for application to sites with good infant representation, additionally to develop an equation to estimate the fertility rate for a population based on the new age-at-death ratio (McFadden & Oxenham, 2018a). The ratio developed was the number of individuals aged 0-14 divided by the total number of individuals in the sample:

$$D0-14/D\ total$$

In an uncommon move the authors chose to include in their ratio the 0-4 age category which is representative of infants. However, by including individuals aged 0-4 in the equation, the correlation between the ratio and actual fertility rates was significantly higher ($p < .05$) compared to the Juvenility Index and the ${}_{15}P_{5}$ Index (McFadden & Oxenham, 2018a). It is important to note that the authors have acknowledged that there may be a degree of error with their method based on inaccuracies with aging methods (McFadden & Oxenham, 2018a).

A follow up study by McFadden & Oxenham (2019b) indicated that this new ratio maintains its accuracy in the both the fertility calculations when either 25% of the infants or elderly individuals were missing from the sample. However, in the case that both infants and elderly individuals were underrepresented up to 75% of these age categories could be removed before the accuracy was significantly compromised (McFadden & Oxenham, 2019b). This means that the fertility rate equation can realistically still be used on sites where infants are lacking in representation. Thus, the McFadden and Oxenham (2018a) D0-14/D ratio appears to be the most reliable of the palaeodemographic indices and should be implemented until another method is developed that is deemed to improve the accuracy further.

2.3.3 Fertility

In palaeodemographic investigations fertility rates are often estimated as a means to better understand the dynamics of a population. Whilst there have been attempts to develop equations for estimating fertility rates of past populations, prior to the publication of the McFadden and Oxenham (2018a) equation the previous methods were all based on the previously developed Juvenility Index and $_{15}P_5$ Index (Jackes, 2011). By basing fertility calculations on these indices, it removes the demographic group that is highly sensitive to changes in fertility rates (i.e. the sub 5 year olds) (McFadden & Oxenham, 2018a).

The paper by McFadden and Oxenham (2018a) provides a standardised equation for calculating the total fertility rate for a population based on the age-at-death ratio. This equation was developed from United Nations data and produced significant levels of correlation ($p < .05$) (McFadden & Oxenham, 2018a). This fertility equation is able to estimate the average number of children born to a woman over her lifetime, assuming that she survived until the end of her reproductive span (McFadden & Oxenham, 2018a). Simple linear regression produced the following equation:

$$Fertility\ rate = (7.734\ \times\ D0 - 14/D\ ratio) \pm 2.224$$

One of the main benefits to this equation other than it including the age group that is most sensitive to changes in fertility rates, is that it standardises the fertility rates of different populations (McFadden & Oxenham, 2018a). This allows the fertility rates of populations to be compared regardless of their temporal or geographical origins (McFadden & Oxenham, 2018a).

2.3.4 Maternal Mortality

The final palaeodemographic method to be evaluated is the Palaeodemographic measure of maternal mortality (McFadden & Oxenham, 2019a). This study develops a method to estimate the maternal mortality rates of past populations in order to improve the understanding of the maternal experience. The equation that was devised takes into account the number of females and males in their key childbearing years. The equation that was devised is:

$$Maternal\ morality\ rate = \left(333.33 \times \frac{dF20-24}{dM20-24}\right) - 76.07$$

The issue with this equation is that it does not take into account different sex distributions within populations, in addition to the key childbearing age period being very narrow and hard to identify in skeletal remains. These issues were then addressed in the McFadden *et al*. (2020) update which adapted and stabilised the maternal mortality rate equation. The new equation is as follows:

$$Adapted\ maternal\ mortality\ rate = 333.33 \times \left(\frac{d_{F20-29}}{d_{F\ Total}} \div \frac{d_{M20-29}}{d_{M\ total}}\right) - 76.07$$

This updated equation stabilises the sex distribution by dividing the number of deaths in the childbearing years by the total number of deaths for both females and males and removes the requirement for an equal sex distribution in the populations being studied.

This method not only demonstrates the importance of developing new methods, but also being able to critically reflect upon one's own work to improve it where necessary. The innovation displayed by McFadden & Oxenham (2019), and later McFadden *et al*. (2020) means that we are not limited to looking at individual stories, instead we are able to see the significance of those stories on a larger scale, and where they fit within geographical or temporal trends

2.4 Osteological Paradox

One of the primary theoretical frameworks that has the ability to influence palaeoepidemiological and palaeodemographic investigations is the Osteological Paradox. Since the dissemination of the 1992 paper by Wood *et al.* researchers have been forced to reconsider the way in which they evaluate the concepts of morbidity and mortality. This publication has not only been controversial and polarising but has also forced researchers to critically reflect upon the way in which they interpret and evaluate morbidity and mortality in skeletal remains and how this may influence palaeodemographic analyses.

The Osteological Paradox was first proposed by Wood *et al.* in 1992 and outlines three fundamental problems for skeletal evaluation and interpretation: demographic non-stationary, hidden heterogeneity in risk, and selective mortality. The concept of demographic nonstationary refers to the assumption in palaeopathological, palaeoepidemiological, and bioarchaeological studies that the populations being evaluated are stationary (Wood *et al.*, 1992; DeWitte and Stojanowski, 2015). A stationary population infers that there was no migration in or out and that the fertility and mortality rates were constant, so the intrinsic rate of increase was equal to zero (Wood *et al.*, 1992; DeWitte and Stojanowski, 2015). This is an assumption that is unrealistic for the majority of human populations. Hidden heterogeneity in risk refers to the issue that not every individual within a population shares an equal risk of being susceptible to contracting a disease or dying due to the fact that a population is comprised of a mixture of individuals with varied backgrounds (Wood *et al.*, 1992; DeWitte and Stojanowski, 2015). Lastly, the concept of selective mortality is that the only definitive information we have about a skeletal population is that they are dead (Wood *et al.*, 1992). This means that they are a biased representation of health and disease across the age-at-death distribution of the population they represent (DeWitte and Stojanowski, 2015). Wood *et al.* (1992) presented the argument that these fundamental problems are inherent in bioarchaeological and other skeletal contexts and there is the possibility that they may influence interpretations and introduce bias.

Essentially, the Osteological Paradox proposes that the individuals who present bony lesions that on initial interpretation would be considered as having experienced compromised health, are actually healthier than the individuals in the sample who do not show any evidence of bony lesions (Wood *et al.*, 1992; Siek, 2013). This is because in order for bony lesions to develop, an individual must have lived and survived a chronic health condition for a considerable period of time (Wood *et al.*, 1992). Depending on the condition and the severity, it can take between a year to a decade for noticeable bony lesions to develop (Roberts and Manchester, 2007). This would mean that an individual whose skeletal remains demonstrate evidence of disease cannot be considered unhealthy, as they have obviously lived with this condition for a considerable period of time (Siek, 2013). By comparison, an individual whose skeletal remains do not display evidence of skeletal lesions may have been an individual who contracted a disease but succumbed to the disease prior to the formation of bony lesions (Siek, 2013). Therefore, the absence of bony lesions does not necessarily denote the absence of disease and neither does the presence of a lesion present evidence of poor health (Wood *et al.*, 1992; Siek, 2013). The Osteological Paradox has significant implications for the interpretation of frailty and resilience within skeletal populations as it means that lesions are not able to be interpreted at face value.

The Osteological Paradox has received a significant amount of attention since its publication, and in the fields of bioarchaeology, palaeopathology, and palaeoepidemiology it has been a polarising subject. The fundamental problems identified have been received positively by some academics who thought that it was beneficial for the analysis of individual populations, however, the Osteological Paradox has also garnered a substantial amount of criticism (McGrath, 1992; Cohen, 1994). Upon its initial release a number of academics argued that it is was oversimplified, it ignored a number of well-evidenced theories such as the increase in infection associated with sedentism, and that it was not as paradoxical as what was proposed (Cohen, 1992; Goodman, 1993; Cohen, 1994). A valid concern that has been presented in more recent times by Siek (2013) is that the Osteological Paradox tries to force researchers investigating morbidity in skeletal remains into categorising individuals as being either healthy or unhealthy. Siek (2013) argues that health is a spectrum and thus should not be interpreted in a binary fashion. Finally, a number of academics are unable to agree on whether the presence of lesions is an indicator of frailty and compromised health, or whether instead the presence of lesions is suggestive of resilience as they survived long enough for the lesions to form (Wood *et al.*, 1992; Armelagos and Gerven, 2003; Hoover and Hudson, 2016; Kyle *et al.*, 2018; McFadden and Oxenham, 2020). These criticism and disagreements highlight the need for the development of new frameworks which are able to take into account the problems highlighted as a result of the Osteological Paradox.

Whilst the literature surrounding the Osteological Paradox primarily focuses on palaeoepidemiology and palaeopathology, it also has significant implications for palaeodemography. The concepts of hidden heterogeneity in risk and selective mortality in particular have the ability to influence the approach to palaeodemographic studies. This is because not all individuals experience the same risk of mortality based on their age or sex.

One of the ways in which the Osteological Paradox can be overcome from a palaeodemographic perspective is by investigating cohorts instead of entire populations. For example, childbearing aged females and infants and neonates are cohorts that may be investigated to see if they are in line with expected mortality rates or if they exceed the expected rates. If the mortality rates are found to be excessive, inferences may be made about population health issues being present. The approach of investigating cohorts partially addresses hidden heterogeneity and selective mortality. This is because this approach investigates whether there are any unusual mortality occurrences in a confined part of the sample, or that there are any indications of a particular group being at a higher risk of mortality based on their age or sex.

Chapter 3 Historical Background

3.1 Historical Background of Viking Expansion

In Europe the period of time between the 8th and 11th centuries CE is commonly referred to as the Viking Age (Barrett, 2008; Baug *et al*., 2018). This is the period in which Norse individuals from Southern Scandinavia (Norway, Sweden, and Denmark) raided and colonised a number of regions in mainland Europe, the British Isles, Iceland, Greenland, and North America (Roesdahl, 1998; Holman, 2003). This section aims to provide a brief overview of the raiding and colonisation activities undertaken by the Vikings. Figure 1 below provides a colour coded system to assist the reader with understanding the chronology of Viking expansion.

The first Viking raid is recorded to have been undertaken by a group of Norwegian Vikings in 793CE on the island of Lindisfarne in what is now Northern England (Fitzhugh, 2000; Lawler, 2016). Over the rest of the 8th century the raids by the Vikings became seasonal and predominantly targeted monasteries in the Northern Isles of Scotland (Orkney and Shetland) and the Western Isles (Outer Hebrides), but also venturing across to Ireland and further down into Northern England (Fitzhugh, 2000, Starkey; 2004). Following the success of the seasonal raiding, colonies were established by the end of the 8th century by these Norwegian Vikings in the Northern and Western Isles of

Scotland as bases for further raids on mainland Scotland, Western England, and Ireland (Wilson, 1976; Fitzhugh, 2000; Price, 2015).

Following into the 9th century it appears that there was a continued effort for raiding with literary evidence of raids occurring in Wales, Ireland, mainland Scotland, and England along with a number of areas in mainland Europe including Normandy and the Baltic region (Kurrild-Klitgaard & Svendsen, 2003; Ashby, 2015). It appears that these raids were better organised and with more individuals being involved, which resulted in a larger number of inland settlements with better resources being targeted (Cróinín, 2016). It was during the middle of the 9th century that the Great Heathen Army descended upon what is now England, the aim of this endeavour was to claim land and steal riches and they were mostly successful (Hadley, 2008a; Raffield, 2016). After just over a decade of rampaging and pillaging a treaty was finally signed which resulted in the establishment of the Danelaw, whereby the Viking raiders were able to retain control over a significant portion of Northern and Eastern England (Hadley, 2008a). This resulted in the establishment of new towns such as Cork, Dublin, and Lymerick; and the transition of established towns such as York to Viking rule.

It was also during the 9th century that the Vikings established colonies in the Faroe Islands and in Iceland (Edwards *et al*., 2005; Church *et al*., 2013). The colonisation of Iceland occurred due to chance, when a crew of sailors were blown off course on their journey to the Faroe Islands and upon their safe return to their Scandinavian homeland decided to bring their families back and establish communities (Pálsson, 2014). These colonists survived in the harsh conditions and these colonies were used as resupply and trading points when colonies started being established further abroad (Wallace, 2003; Kendall, 2014). It was in the late 10th century that Vikings from the Icelandic colonies set out and established new colonies in Greenland and North America (Persson, 1969; Fitzhugh, 2000). Unfortunately, the colony sites from Greenland and North America did not survive, with the one colony site located in modern day Canada not appearing to have been inhabited for very long and the colonies of Greenland collapsing in the 15th century (Brown, 2000; Fitzhugh, 2000; Wallace, 2003).

In the same century as the Western colonies expanded, Viking colonies were established throughout the European mainland following over a century of raiding activities and small encampments. The majority of what is now known as Normandy was colonised following a treaty being established with a Frankish King which handed over the regions that were already being raided seasonally (Davy, 2020). Additionally, a significant portion of what is now Eastern Europe was settled, from Finland down to the Black Sea (Hoerder, 2020). There were some smaller colonies that had been established in this region during the 9th century, but in the 10th and 11th centuries the Vikings who in this region were known as Varangians made a concerted effort to expand (Dixon, 1998).

Eventually in the middle of the 11th century the influence of the Viking culture diminished as Christianity was introduced to Scandinavia and the kingdoms of Norway, Sweden, and Denmark were established (Derry, 2000; Bagge, 2013; Dougherty, 2014). This effectively brought a close to the period of Viking dominance with communities transitioning away from their traditional pagan practices and cultural systems, instead adopting the Christian practices of the newly established kingdoms. These kingdoms did appear to still have a significant influence, with the kingdom of Norway in particular having significant cultural and economic influence over the previously Viking colonies in Greenland, Iceland, and the Orkney Islands (Krogh, 1967; Jochens, 1998; Short, 2010).

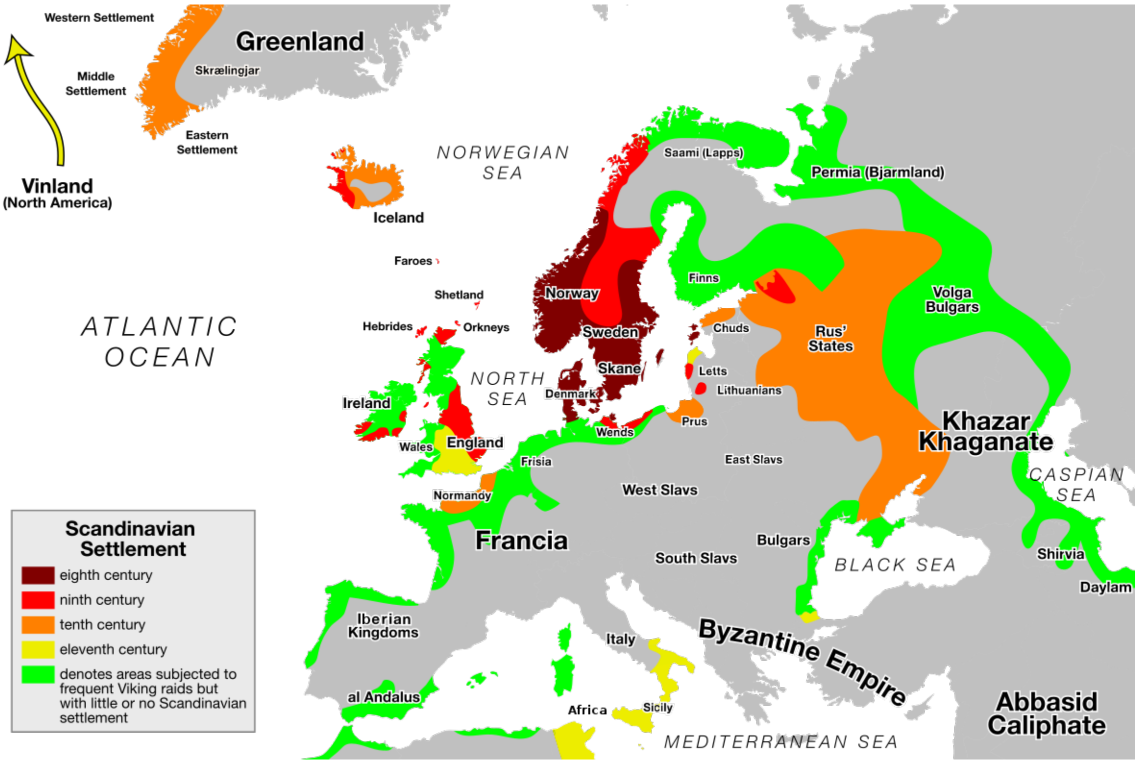

Figure 1: Map depicting Viking expansion from the 9th to 11th centuries. Source: https://en.wikipedia.org/wiki/Viking_expansion

3.2 Previous Palaeoepidemiological and Palaeodemographic Studies

Previous palaeoepidemiological and palaeodemographic studies by scholars such as Lynnerup (1996, 1998), Sharpe (2002) and Kjellström *et al*. (2005) have revealed a wealth of knowledge relating to the health of individuals and populations in specific regions which Vikings colonised, and the population dynamics within Scandinavia that are thought to have been the catalyst for Viking expansion. There tends to be a large number of individual case studies that look at specific Viking burials from regions that are known to have been raided or colonised, however, there are not as many comparative population-based studies. This is surprising considering the impact that the Vikings have had on history and the reputation that has been established in modern culture. This disproportionate number of studies undertaken can be explained by a number of challenges associated with gathering the skeletal data. Some of the challenges associated with finding appropriate data include taphonomic conditions, burial practices, the utilisation of pre-existing cemeteries, and lack of accessibility to site reports and remains.

The first challenge stems from the taphonomic conditions associated with many burial sites that are not conducive to the preservation of skeletal remains. A significant number of site reports have indicated that due to abiotic and biotic taphonomic factors the skeletal remains that are located are often in extremely poor condition. For example, there have been at least six Viking cemetery sites located in Greenland around known colony sites, however, there is next to no pathological data available from any of the sites due to the poor preservation of the skeletal material (Lynnerup, 1998; Quigley, 2001). The excavation and assessment work undertaken by Lynnerup (1998) as part of their doctoral thesis hypothesises that the poor preservation was due to a combination of the soil acidity, lack of grave depth, and root action. There are a number of similar cases where there is a lack of skeletal material due to poor preservation from known Viking cemeteries in France (Jaubert, 2000), Iceland (Callow, 2006; Damiata *et al*., 2013; G. Zöega, personal communication, July 17, 2020), the United Kingdom (Ritchie *et al*., 1981), and Scandinavia (Sundman & Kjellström, 2013; Price *et al*., 2018).

Another issue that is presented when trying to collect data stems from the burial practices of the Vikings. A biotic taphonomic factor that significantly affects the integrity of the bone is cremation. By cremating the bone, it denatures the collagen which makes it easier for the bone to break down and destroys almost all data that would be compiled in a biological profile (Castillo *et al*., 2013). There are a number of examples of the Vikings cremating their dead, both in the Scandinavian homeland (Price *et al*., 2018) and in the colonies (Speed & Rogers, 2004; Bond & Worley, 2006). Whilst there are some isotope analyses that can be undertaken on cremated remains, realistically it is almost impossible to collect data that would be usable in either palaeoepidemiological of palaeodemographic analyses (Harvig *et al*., 2014; Price *et al*., 2018).

A further challenge stems from reviewing the readily available literature where it appears that the majority of Viking skeletal finds are attributed to pre-existing cemeteries rather than exclusive Viking cemeteries (Hadley, 2008b). The reason for this is that there was a tradition during the raiding and colonisation period of burying the dead in pre-existing cemeteries where possible (Hadley, 2008b; Trynoski, 2008). This tradition accounts for the large number of singular Viking burials that appear at cemetery sites from other cultures such as Balnakeil (Sutherland), and Adwick-le-street (South Yorkshire); and also for the mixed cemeteries such as Westness (Northern Isles) and Kilmainham (Dublin, Ireland) where Viking colonisation and cultural hybridity took place (Sellevold, 1999; Speed & Rogers, 2004; Trynoski, 2008; Batey & Paterson, 2012).

The final significant challenge comes in the form of accessibility to excavated remains and site reports. A number of Viking cemeteries and burials have been excavated by consulting groups as part of salvage operations or they were excavated prior to the establishment of professional standards that archaeologists and bioarchaeologists are now expected to uphold. The work undertaken by private consulting firms has meant that a number of reports that provide the biological profile are not available for academic use due to a lack of publication which unfortunately significantly limits our ability to better our understanding of these past populations. Furthermore, the excavations that have taken place during the 18th, 19th, and parts of the 20th centuries have resulted in a significant loss of data (Hedges, 1983; Batey,1993; Montgomery *et al*., 2014). This is due to professional standards being nearly non-existent with a number of antiquarians who excavated Viking cemeteries keeping the skeletal materials that they uncovered and they have since been lost (Hedges, 1983). Additionally, the methods that have been developed over the last five decades to improve the biological profile and the knowledge surrounding pathological conditions was not available when a number of excavations were undertaken and reports written.

These challenges have all created significant limits on the amount and type of Viking skeletal data that can be collected for the purpose of this study, nonetheless the benefits to undertaking this analysis far outweigh any concerns caused by these limitations. This is because undertaking analyses comparing the palaeodemography of Viking samples from Scandinavia with that of Viking colony samples is a novel concept which aims to greatly improve the understanding of the population health and dynamics of frontier colonies during the Viking period.

Chapter 4 Materials and Methods

The following chapter will outline and discuss the materials and methods used in this analysis. To begin, the skeletal samples utilised in this study will be detailed, including the total number of individuals and the number of individuals aged 0-14. Additionally, notes will be made if any age categories required for analysis needed to be expanded due to the type of data that was available. To follow on from this the methods that were used to analyse the demographic data will be outlined, and the new method for estimating infant and neonate mortality will be explained.

4.1 Materials

The samples utilised in this study are described below and depicted on the map located at the bottom of this section (figure 2). The samples are split into homeland and frontier samples with those located in Scandinavia being classed as homeland, and the samples from other regions being classed as frontier.

4.1.1 Homeland

4.1.1.1 *Scandinavia*

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)

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). The male and female 20-30 age categories had to be expanded out to 20-40 based on the data that was available in the publication.

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).

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).

Mälaren Valley

The Mälaren Valley skeletal assemblage is dated from the 8th to the 12th century (Kjellström, 2013). This assemblage contains 136 individuals, and 17 of those individuals are dated to being less than 12 years old (Kjellström, 2013).

Pkbank

The cemetery 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). The 20-30 age category for males and females in this sample had the be expanded out to 18/20-35/40 due to the type of data that was published.

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). The 20-30 age category for males and females in this sample had the be expanded out to 20- 34 due to the type of data that was published.

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). The 20-30 age category for males and females in this sample had the be expanded out to 18/20-35/40 due to the type of data that was published.

4.1.2 Frontier

4.1.2.1 *Greenland*

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).

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).

4.1.2.2 *Iceland*

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).

Keflavík

The Keflavík cemetery in Northern Iceland is regarded as being late Viking to early Medieval (10th to 12th centuries) (Zoëga & Murphy, forthcoming). This cemetery contained the remains of 46 individuals, 26 of which were aged between zero to twelve years old (Zoëga & Murphy, forthcoming). The 20-30 age category for males and females in this sample had the be expanded out to 18- 29 due to the type of data that was published.

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, forthcoming). This cemetery contained the remains of 53 individuals, 24 of which were aged between zero to twelve years old (Zoëga & Murphy, 2016). The 20-30 age category for males and females in this sample had the be expanded out to 18- 29 due to the type of data that was published.

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).

4.1.2.3 *Ireland*

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 subadults aged between zero to fifteen years old (Hurley *et al*., 1997).

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 subadults in the 0-14 category (O'Donnabhain, 2010).

4.1.2.4 *Scottish Isles*

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).

Newark Bay

The assemblage at Newark Bay is dated between the 8th and 14th centuries with 208 individuals having been excavated thus far, and of those 118 are considered to be between the ages 0-14 (Molleson & Owen, 2005).

Pierowall

The Viking cemetery at Pierowall is dated from the mid 9th to the mid 10th centuries and is comprised of 16 individuals, with none being aged under 14 years (Redmond, 2007).

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). The 20-30 age category for males and females in this sample had the be expanded out to 18- 30 due to the type of data that was published.

Westness

The Westness cemetery site was used by the Viking settlers during the 8th to 11th centuries (Sellevold, 1999). In this assemblage there were 29 individuals with 5 of those being between the ages of 0-14 (Sellevold, 1999). The 20-34 age category for males and females in this sample had the be expanded out to 18- 29 due to the type of data that was published.

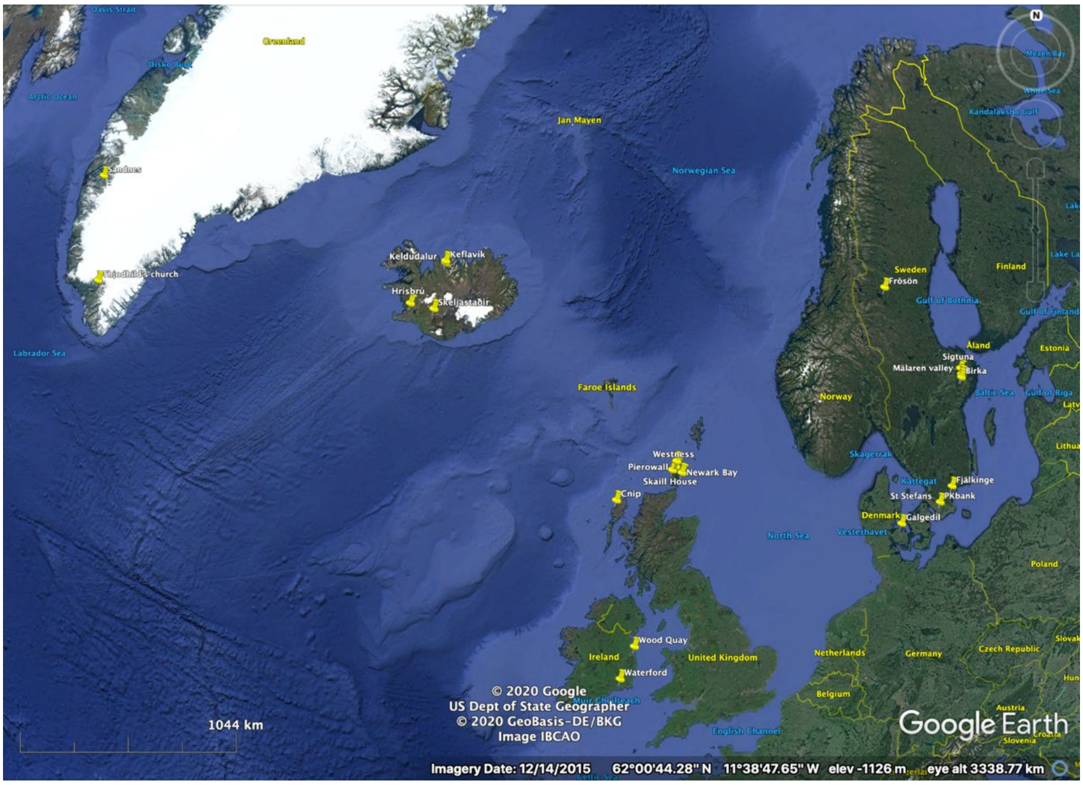

Figure 2: Map depicting location of samples used in this study. Source: Google Earth 2020.

4.2 Methods

4.2.1 Data Collection

Data was collected from existing published datasets that have been described above and for which there is a full table of data in the results. The data that were recorded across all sites were the number of individuals whose age was estimated to be between 0-14 and the total number of individuals in the sample. In a small number of cases this age frame varied slightly as the authors may have combined age categories making the older end of the spectrum unsuitable for inclusion e.g. age categories 12-18, or alternatively creating an age category 0-15. This has been noted in the sample description in the materials section provided above. Additional data that was recorded if it was available was the number of females aged 20-30, the total number of females, the number of males aged 20-30, and the total number of males. Similar to before, in some cases the age range was extended based on the data that was made available in the publications.

4.2.2 Methods of Analysis

The primary analyses undertaken on the data collected are demographic analyses. Fertility, Neonate Mortality, and Infant Mortality were calculated using the most recent equations developed by McFadden & Oxenham (2018 a & b), and McFadden et al. (in prep.). Furthermore, where the age and sex estimation data were available the McFadden *et al*. (2020) Maternal Mortality equation was applied. Additionally, a new equation for Infant and Neonate Mortality Estimation was developed which is able to work in conjunction with the McFadden et al. (in prep) method to estimate the neonate and infant (years 0-1) mortality for each sample.

4.2.2.1 *D0-14/D ratio*

The D0-14/D ratio is used as a subadult to adult ratio which can be applied to better estimate birth-based relationships such as fertility and rate of natural population increase (McFadden & Oxenham, 2018a). The equation is as follows:

$$D0-14/D = number\ of\ individuals\ aged\ 0 - 14/\ total\ number\ of\ individuals$$

A correlation of 0.848 was achieve between the D0-14/D ratio and actual fertility rates (McFadden & Oxenham, 2018a). This correlation was significantly higher ($p < .05$) than what was achieved by the other ratios such as the D5-14/D20+ ratio developed by Bocquet-Appel and Masset (1977,1982,1996) and the $_{15}P_5$ Index developed by Bouquet-Appel (2002). Hence, this juvenility index has been selected for use, rather than the others mentioned here, and described in Chapter 2.

4.2.2.2 *Fertility*

The fertility rate equation which is based on the D0-14/D ratio estimates the total fertility rate (number of births per woman) for a sample or population based on the D0-14/D ratio (McFadden & Oxenham, 2018a). This equation estimates the number of births per woman (McFadden & Oxenham, 2018a). The equation is as follows:

$$Fertility\ Rate = (7.734 \times D0 - 14/D\ ratio) + 2.224$$

A limitation to this equation, is that to date there has been no way of comparing the fertility rates calculated with the actual number of offspring. This has been a challenge adopted by the author of this thesis who aims to develop a palaeodemographic equation that is able to estimate the number of infants and neonates within a sample based on the results of the McFadden and Oxenham (2018a) fertility equation.

4.2.2.3 *Infant Mortality and Neonate Mortality*

The infant and neonate mortality equations estimate the number of infants and neonates in a sample based on the D0-14/D ratio (McFadden et al., in prep.). This equation allows for a comparison between the estimated and actual number of infants and neonates in a sample to see whether there are any deviations from the expected rate (McFadden et al., in prep.). The infant mortality equation is as follows:

$$Infant\ mortality\ rate = 115.7\ (D0 - 14/D) + 5.0969.$$

The neonate equation is as follows:

$$Neonate\ mortality\ rate = 71.949\ (D0 - 14/D) + 3.5602.$$

These equations are very useful for the estimations that they provide, however, they should be recognised as interim equations. This is because individually the results are not useable. Instead, an equation needs to be developed to estimate the number of live births for the cemetery sample in order to investigate whether the estimated number of infants and neonates in a sample deviates from the actual (McFadden et al., in prep.).

4.2.2.4 *Maternal Mortality*

The stabilised maternal mortality equation developed by McFadden *et al*. (2020) was applied to the samples where appropriate demographic data was available. By applying the data to the equation provided below the number of maternal deaths per 100000 births was able to be estimated for each sample. The equation is as follows:

$$Maternal\ Mortality = 333.33 \times \left(\frac{F20-30}{F\ total} \div \frac{M20-30}{M\ total}\right) - 76.07$$

This updated equation (McFadden *et al*., 2020) achieved a similar correlation to the original 2019a McFadden and Oxenham equation (r=0.884 and r=0.894 respectively). Even though the differences in correlations in marginal when being used on United Nations data, the McFadden *et al*. (2020) equation is able to better overcome a relatively common issue of there being sex biases within archaeological skeletal samples.

4.2.2.5 *Infant and Neonate Mortality Estimator*

For this thesis a new equation was developed in order to standardise the number of infant and neonate deaths that we expected to see in each sample based on the number of females in the sample and the estimated fertility rate. This method does assume that women are well represented in the sample, or that there is at least equal representation of women and children in the sample. This assumption is based on the academic literature surrounding taphonomic processes and demographic representation in the archaeological record, which was explored in Chapter 2. This equation will estimate the number of live births for the dead women and from that, estimate the number of infants that we expect to see in the same deceased population.

The United Nations 2002 World Population Monitoring report indicates that in less developed regions the reproductive lifespan for chid bearing in women is between 18 to 40 years of age (Frank *et al*., 1994; United Nations, 2004). Considering the lack of access to modern contraceptives and the potential for nutritional deficiencies this range of fecundity is likely very similar to what would have been observed in the Viking and Medieval periods. However, it is widely accepted that the birth intervals and fertility rates of women are not consistent over time.

Modern studies have indicated that in developing countries a significant factor to having shorter birth intervals (approximately 22 months) is age (Aleni *et al*., 2020). In the study by Aleni *et al*. (2020) it was hypothesised that younger women experienced shorter intervals as they did not necessarily have the same ability to make independent decisions regarding the number of children they wished to have, and older women were coming close to the family sizes that they wanted. These results have been seen across a number of developing countries such as Uganda, Bangladesh, and the Democratic Republic of Congo (Saha & van Soest, 2013; Chirwa *et al*., 2014; Aleni *et al*., 2020). The increased birth intervals with age could also be attributed to fertility reducing with age. Modern studies in IVF technology in countries where there is adequate access to healthcare and a low likelihood of malnutrition acknowledge that the rates of embryo survival decline gradually after 30 years of age, but by more than two thirds after 40 years of age and in women with reduced ovarian capacity (Hull *et al*., 1996).

Another United Nations study investigating the fertility of women in developing countries supports the hypothesis that fertility rates decline for older women (United Nations, 2002). The study indicates that in most cases the age group 35+ contributes a nominal amount to the total fertility rate (at most close to 30%) as is displayed in Figure 2 below (United Nations, 2002).

Region	Average date of estimate	Percentage of total fertility contributed by ages		
		15-24	25-34	35+
Northern Africa and Western Asia................	1975	30.4	46.3	23.3
	1994	25.5	49.3	25.2
Sub-Saharan Africa..	1970	30.1	41.3	28.6
	1992	34.2	41.8	24.0
South-central and South-eastern Asia.............	1975	30.1	45.0	24.8
	1994	37.7	46.8	15.7
Latin America and the Caribbean....................	1976	35.1	43.7	21.3
	1995	40.8	42.3	17.0

Figure 3: Percentage of Total Fertility contributed by ages 15-24, 25-34, 35+ from selected regions. Source: United Nations, 2002.

This equation utilises the fertility rate calculated using the McFadden and Oxenham (2018a) equation. To estimate the total number of births for a sample the number of females in the 20-30 age category were multiplied by 70% of the fertility rate. The rate of 70% was decided upon following careful consideration of a number of academic studies and United Nations reports outlined above.

The equation is as follows:

$$Total\ Birth\ Estimator = \big(F\ 20 - 30 \times (fertility \times 0.7)\big) + \big((F\ total - F\ 20 - 30) \times fertility\big)$$

To then estimate the infant and neonate mortality for the sample, the total birth rate estimator result is then divided by 1000. The result of this is then applied to the previously calculated infant mortality rates and neonate mortality rates respectively. The estimated infant mortality rate and estimated neonate mortality rates are then added together to provide the estimated mortality rate for individuals aged 0-1 in the sample.

$$Birth\ Rate\ Estimator\ result / 1000$$

$$estimated\ infants = result\ \times\ infant\ mortality$$

$$estimated\ neonates = result\ \times neonate\ mortality$$

$$\begin{aligned} Estimated\ mortality\ 0 - 1\ years \\ &= estimated\ infant\ mortality \\ &+ estimated\ neonate\ mortality \end{aligned}$$

Due to the limitations of the data, namely that in some cases there were only age ranges provided, rather than specific age categories, quantitative assessments of the results were undertaken and interpreted in a qualitative manner. To undertake the quantitative analyses of the data and produce standardised results, for sites where there was an age range provided (Keldudalur (0-3), Sandnes (0-5), Waterford (0-5), Fjälkinge (newborns + 0-3), St Stefans (0-6), Pkbank (0-6)) the total number in the age group was divided evenly by the number of age categories i.e. for Keldudalur there were 3 age categories so the total was divided by 3. The author recognises that this is a crude measure, however, there is no specific data available which would allow for a more accurate division individuals within these categories.

The actual number of individuals in the sample aged 0-1 was then compared to the estimated number of individuals in the sample aged 0-1 as was calculated using the Birth Rate Estimator for Neonates and Infants. There were three different types of comparisons undertaken: percentage difference, proportion (actual/estimated), and the numerical difference between the actual number of individuals and the estimated number of individuals.

4.2.3 Statistical Analyses

4.2.3.1 *Fisher's Exact Test*

The first null hypothesis for the Fisher's exact test was that there would be no significant difference in the D0-14 ratios between homeland and frontier samples regardless of sample size. The second null hypothesis for the Fisher's exact test was that there would be no significant difference in the D0-14 ratios between homeland and frontier samples where smaller samples (less than 30 individuals) were excluded due to their small size.

There are a number of different ways in which to calculate a p value from a contingency table; one of the more common is a chi-square test of independence, the issue with this method is that it only calculates an approximated p value (Motulsky, 1995-2020). Often a Yate's continuity correction is applied to small samples to improve the approximation of the p value, however, the difference is negligible in larger sample sizes (Motulsky, 1995-2020). The Fisher's Exact test is an alternative nonparametric method of calculating a p value, it is well regarded as it calculates the actual p value rather than an approximate (Motulsky, 1995-2020). A Fisher's Exact Test is often applied to smaller samples where a chi-squared test of independence is not appropriate, however, even with a large sample size the accuracy of this test incentivises the application of it in this context (Motulsky, 1995-2020). In this analysis a two-tailed p test was undertaken at a $p < .05$ significance level in conjunction with the Fisher's Exact test. The reason for choosing a two-tailed P test is that there is the potential to have differences both larger and smaller, which would make a one-sided p test inappropriate as it only factors in fluctuations in a singular direction.

4.2.3.2 *Chi Square Test of Independence*

A chi-squared test of independence is a non-parametric method that is used to evaluate whether there is an association between two categorical variables (McHugh, 2013). This method allows for each variable to have two or more categories (McHugh, 2013). In this analysis the two categorical variables are region (5 categories) and age group (2 categories).

The first null hypothesis for the chi-squared test of independence was that there would be no significant difference in the D0-14 ratios between regions regardless of sample size. The second null hypothesis for the chi-squared test of independence was that there would be no significant difference in the D0-14 ratios between regions when smaller samples (less than 30 individuals) were excluded due to their small size.

4.2.3.3 *Range Analysis*

The range between the largest and smallest D0-14/D ratio data values in each intra-regional sample will also be calculated to produce intervals that contains all of the data values for each region independently. This method allows for the understanding of how extensive the data is dispersed in each sample. As the D0-14/D ratio can be a value between 0 to 1 the range value will be between 0 and 1. A small range indicates that there is less data variation, whereas a large range indicates that there is a lot of data variation. An inter-quartile range was not utilised due to there being a small number of samples within each region.

4.2.3.4 *Unpaired T-Test*

An unpaired t-test compares the means of two assigned groups (Fabri & Knierim, 1988). In this case it was applied in the context of comparing the estimated maternal mortality rates from homeland samples to the estimated maternal mortality rates from frontier samples. The null hypothesis for this test was that there would be no difference between the two groups at a $p < .05$ significance level.

Chapter 5 Results

This results chapter aims to present and explain the results from the statistical analyses undertaken on the Viking and Norse homeland and frontier samples. The results will be split into multiple sections: Infant and Neonate Mortality Estimator Interpretations, Fisher's Exact Test interpretations, Chi Squared Test of Independence interpretations, Intra-Regional D0-14/D Range Observations, and Unpaired T-test Interpretations for maternal mortality.

Table 1 below outlines all of the data used in the study in addition to providing the numerical results from the demographic calculators used which is particularly important for the Infant and Neonate Mortality Estimator Interpretations.

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Table 1: Data utilised in this study

	Frontier Settlements													Homeland							
	Iceland				Greenland		Ireland		Scottish Isles					Scandinavia							
	Keldudalur	Keflavík	Skeljastaðir	Hrísbrú	Thjodhild's Church	Sandnes	Wood Quay	Waterford	Westness	Skaill House	Cnip	Newark Bay	Pierowall	Sigtuna	Birka	Mälaren Valley	Galgedil	Fjälkinge	St Stefans	Pkbank	Frösön
Number of D0-14	24	22	7	3	24	24	10	9	5	15	3	118	0	94	91	17	8	80	77	12	210
D Total	53	46	66	21	144	88	23	55	29	27	7	208	16	382	308	136	57	128	258	200	364
Females 20-30	3	2	8	1	5	19	1	6	5	0	0	3	NA	36	NA	NA	NA	3	44	47	NA
Females Total	14	11	25	4	20	35	8	22	12	5	2	49	NA	80	NA	NA	NA	24	92	93	NA
Males 20-30	2	5	5	1	7	3	1	2	1	1	0	5	NA	61	NA	NA	NA	12	40	42	NA
Males Total	10	13	24	9	37	16	3	20	9	3	2	42	NA	149	NA	NA	NA	23	89	83	NA
D0-14/D (2dp)	0.45	0.48	0.11	0.14	0.17	0.27	0.43	0.16	0.17	0.56	0.43	0.57	0	0.25	0.30	0.13	0.14	0.63	0.30	0.06	0.58
Fertility (2dp)	5.73	5.92	3.04	3.33	3.51	4.33	5.59	3.49	3.55	6.52	5.54	6.61	2.22	4.13	4.51	3.19	3.31	7.06	4.53	2.688	6.69
70% fertility (2dp)	4.01	4.15	2.13	2.33	2.46	3.03	3.91	2.44	2.49	4.56	3.88	4.63	1.56	2.89	3.16	2.23	2.32	4.94	3.17	1.88	4.68
Maternal Mortality (2dp)	281.07	81.50	435.92	673.92	364.40	889.00	54.85	23.61	1173.92	NA	NA	95.36	0	290.32	NA	NA	NA	3.79	278.64	256.83	NA
Neonate Mort (2dp)	36.14	37.97	11.19	13.84	15.55	23.18	34.84	15.33	15.97	43.53	34.40	44.38	3.56	21.26	24.82	12.554	13.658	48.53	25.03	7.88	45.07
Infant Mort (2dp)	57.49	60.43	17.37	21.63	24.38	36.65	55.40	24.02	25.05	69.37	54.68	70.73	5.10	33.57	39.28	19.559	21.335	77.41	39.62	12.04	71.85
Total Birth Rate Estimator (2dp)	75.01	61.60	68.80	12.32	124.36	126.96	41.24	70.49	37.35	32.60	NA	318.02	NA	285.60	NA	NA	NA	163.03	357.14	212.09	NA
Total Birth Rate Estimator / 1000 (2dp)	0.08	0.06	0.07	0.01	0.12	0.13	0.04	0.07	0.04	0.03	NA	0.32	NA	0.29	NA	NA	NA	0.16	0.357138 0	0.21	NA
Infant and Neonate Mortality Estimator Neonate (2dp)	2.71	2.34	0.77	0.17	1.93	2.94	1.42	1.0	0.60	1.42	0	14.11	0	6.07	NA	NA	NA	7.91	8.94	1.67	NA
Infant and Neonate Mortality Estimator Infant (2dp)	4.31	3.72	1.19	0.27	3.03	4.65	2.26	1.69	0.94	2.26	NA	22.49	NA	9.59	NA	NA	NA	12.62	14.15	2.55	NA

Infant and Neonate Mortality Estimator Infant + Neonate (2dp)	7.02	6.06	1.96	0.44	4.97	7.60	3.72	2.77	1.53	3.68	0	36.61	0	15.66	NA	NA	NA	20.53	23.09	4.22	NA
Actual 0-1	7	20	5	0	15	2	0	0.6	4	10	0	51	NA	19	NA	NA	NA	91.3	9	3	NA
Percentage difference (2dp)	0.34%	106.97%	85.19%	NA	100.51%	116.02%	NA	127.86%	89.39%	91.80 %	NA	32.45%	NA	104.42%	NA	NA	NA	126.10%	88.15%	33.96%	NA
Proportion (2dp)	1.00	3.30	2.54	0	3.02	0.26	0	0.22	2.61	2.72	0	1.39	0	1.21	NA	NA	NA	4.45	0.39	0.71	NA
Difference (actual-estimated) (2dp)	-0.02	13.94	3.04	-0.44	10.03	-5.60	-3.72	-2.17	2.47	6.32	NA	14.39	NA	3.34	NA	NA	NA	70.80	-14.09	-1.22	NA

5.1 Infant and Neonate Mortality Estimator Interpretations

As previously mentioned in Chapter 4 these data were analysed qualitatively rather than quantitatively due to limitations surrounding the type of data available meaning that tests of significance were not appropriate to undertake. It appears that in the majority of cases there are deviations of the actual number of infants and neonates from the expected number of infants and neonates. The proportions data appears to indicate that in most cases the estimated number of infants and neonates deviates from the actual number of infants and neonates as nine of 13 proportions available were either larger or smaller than (six of the nine were above 2.0, and three of the nine smaller than 0.5), four of the 13 were within 0.5 of 1. It is also important to note that only three of the percentage difference figures were within 50%, and the other 10 percentage difference percentages indicated that there was a percentage difference of more than 50%.

As displayed in Table 1, it appears that the way in which the estimated number of infant and neonates is being compared with the actual number of infants and neonates in many cases produces a seemingly substantial difference due to the small number being estimated. When comparing the percentage difference and proportions with the numerical difference, there are a number of samples such as Skeljastaðir, Waterford and Westness where there are high percentage differences and large proportions, however, the numerical difference is far smaller than those seen in other larger samples. The percentage difference and proportions appear to highlight more acutely the differences in smaller samples, and do not appear to highlight large actual differences in bigger samples. By standardising and qualitatively analysing the available data it indicates that there are some issues with this new method, or rather the way in which the results are being analysed. By reapplying this method with data that is better suited to quantitative analyses or working out a way to better standardise the data, it may allow for analyses to be undertaken that will allow us to better estimate the infant and neonate mortality from a sample.

At present taking the results at face value could be explained by two main factors: either female representation within the sample, or infant representation within the sample. Alternatively, if the number of infants in the sample is lower than the estimate this could be indicative of infant underrepresentation, or if the number of infants is higher than the estimate it could be indicative of high infant mortality. This concept and the reasons for differences between Frontier and Homeland samples will be further discussed in Chapter 6.

5.2 Fisher's Exact Test Interpretations

The first Fisher's Exact Test was performed to examine whether there was a significant statistical relationship between the type of settlement (homeland or frontier) and the D0-14 ratio, as a predictor of various demographic variables, for all available samples. Table 2 below summarises the data that were utilised. The resulting two-tailed p value was $p = .4390$. This means that the results are not significant at the assigned level, meaning that we can accept the null hypothesis that there is no difference in the D0-14 ratios between homeland and frontier samples.

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

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

A secondary Fisher's Exact Test was performed to examine whether there was a significant statistical relationship between the type of settlement (homeland or frontier) and the D0-14 ratio for samples where there were more than 30 individuals. The data that was used is displayed in Table 3 below. The resulting two-tailed p value was $p = .1332$. This means that the results are not significant at the assigned level, meaning that we cannot reject the null hypothesis that there is no difference in the D0-14 ratios between homeland and frontier samples when there are acceptable sample sizes.

Table 3: Homeland and Frontier samples with acceptable sample sizes.

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

The reason why two tests were undertaken, one with all of the samples and not just including samples with more than 30 individuals is that there are a number of small samples that have less than 30 individuals. This does not necessarily mean that the data in these samples is invalid or not of any use, instead it is a factor to be aware of and it is interesting to see whether there are any differences seen in the results of the statistical analyses.

5.3 Chi Squared Test of Independence Interpretations

The first chi-square test of independence was performed to examine the relationship between regions and the D0-14 ratio, in this case not taking into account the size of the samples. The relationship between these variables was significant X^2 (1, N=2616) = 53.78, p= < .00001. In this case it appeared that there was a significant relationship between region and the D0-14 ratio.

Referring to Table 4 below, the circular brackets show the predicted number of individuals for each age category by region, while the square brackets detail the individual contribution to the chi square value. The D0-14 categories for Iceland, Ireland and Scandinavia the actual numbers are similar to the predicted, meaning the contributions of these samples to the overall chi square value are low. In the case of Greenland, the D0-14 value predicted is substantially higher than the actual numbers, and in the case of the Scottish Isles the predicted number is substantially lower than the actual number of individuals in the D0-14 category.

Table 4: Chi-square test of independence for region and D0-14 ratio.

Results			
	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 (597.69) [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)**

A second chi-square test of independence was performed to examine the relationship between region and the D0-14 ratio, this time taking into account whether the samples were too small (less than 30 individuals). The relationship between these variables was also significant X^2 (1, N=543) = 78.55, p = < .00001.

As depicted in table 5 of all the samples the Scottish Isles D0-14 appeared to have significantly higher numbers of individuals in the D0-14 category than estimated, and Greenland having lower numbers than estimated, with the other three samples appearing to be relatively close to the estimated numbers. These results further highlights that there is something different about the D0-14 ratios in the Scottish Isles.

Table 5: Chi-square test of independence for region and D0-14 ratio for samples of an acceptable size.

Results			
	D0-14	**D>14**	**Marginal Row Totals**
Greenland	48 (74.54) [9.45]	184 (157.46) [4.47]	232
Iceland	53 (53.01) [0.00]	112 (111.99) [0.00]	165
Ireland	9 (17.67) [4.25]	46 (37.33) [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)**

Similar to the Fisher's Exact Test, two tests were undertaken to understand whether the inclusion of smaller samples intervals influenced the results of the statistical analyses in any way.

5.4 Intra-Regional D0-14/D Range Observations

From the chi-squared analyses that have been run and explained above it appears that there is inter-regional variability in the D0-14/D ratios in the case of the Scottish Isles and Greenland. Due to the D0-14/D ratio values available, a range analysis was undertaken to assess the intra-regional variability. The variability within the regions is as follows: Greenland= 0.10 (0.17-0.27), Iceland= 0.37 (0.11-0.48), Ireland= 0.27 (0.16-0.43), Scandinavia= 0.57 (0.06-0.63), and Scottish Isles= 0.57 (0.00-0.57). In most ranges examined there appears to be a high degree of variability in the D0-14/D ratios. Admittedly some of these regions only have two samples due to the lack of available of data, however, the ranges for the D0-14/D ratios appear to demonstrate quite considerable variation in some regions such as Scandinavia and the Scottish Isles. There are a variety of reasons that can explain the intra-regional variability which will be identified in Chapter 6.

5.5 Unpaired T-test Interpretations

The unpaired t-test that was undertaken in order to assess whether there was any significant difference mean maternal mortality rates between homeland and frontier samples produced a two-tailed p value of 0.2811. This p value indicates that the results from this test were not statistically significant, and that the null hypothesis that there is no significant difference can be accepted. However, there are some issues with this test. Whilst there were a large number of regions being looked at, there are too few case sites being observed which stems from insufficient data availability. Whilst results have been produced for this test, due to the nature of the data analysed, the author has chosen not to pursue this avenue of investigation any further for the time being. Instead opting to hopefully return at a future date when more datasets are available for comparison in order to produce more results that better represent the cultures that are being investigated.

Chapter 6 Discussion

This chapter will discuss and interpret the results from the infant and neonate mortality adjustment method and the results from the comparative demographic analyses which were presented in the previous chapter. This discussion will provide insights and explanations for the observed results of the statistical analyses of the demographic materials. These results significantly contribute to the presently limited understanding of comparative population demographics in Viking and Norse frontier and homeland communities in the North Atlantic.

6.1 Infant and Neonate Mortality Adjustment Method

The Infant and Neonate Mortality Adjustment Method appears to have been relatively successful from a qualitative perspective. The quantitative statistical tests that would compare how close the estimated numbers were to the actual were not suitable considering that some of the data were denoted by age group, rather than allocating specific ages and/or categories for neonates and infants.

Whilst this new method does assume that the proportions of females and infants/neonates are represented equally in every sample, this is not always the case which can influence the results; potential sources of error are discussed further below. The results from the qualitative analyses indicated that 9 or the 13 proportions were either above 2.0 or smaller than 0.5. This in conjunction with the knowledge that 10 of the 13 samples had a percentage difference of more than 50%. At first glance this may seem like the estimator is considerably out, however, as is discussed below sample size needs to be taken into consideration. There are some issues with the results produced from the estimator thus far, however, this appears to be a promising tool when some of the issues identified below are overcome.

While the percentage difference and proportional analyses undertaken were used to standardise the data making the samples comparable and indicating that in most cases there were higher than expected numbers of infants and neonates, it also highlighted a significant issue. When samples of a smaller size were standardised, the estimated number of neonates and infants were more likely to be interpreted as being considerably larger or smaller than the actual on a relative scale (e.g. Newark Bay had 51 infants represented and 36.61 estimated making a 32.45% difference, compared to Waterford where there were 0.6 infants represented and 2.77 estimated creating a 127.86% difference). Similarly, the samples with a larger sample size were often not identified as being considerably different based on the methods that aimed to standardise the results, even though the raw numerical difference indicated otherwise.

As was mentioned in Chapter 5, it would be extremely beneficial to undertake analyses of a similar nature to see how accurate and reliable this new method is but ensuring that the data being worked with would allow for quantitative analyses to be undertaken e.g. larger sample sizes and year by year data. This would allow for increased reliability of the method as it would negate the current requirements for qualitative interpretations of the results; instead, judgements of reliability would be procured from statistical significance. Notwithstanding, the following guide to interpreting the results from the Infant and Neonate Mortality Method are offered in anticipation of further testing and application of this method, based on the promising preliminary results in this thesis.

There are two main contributing factors to the equation that can influence the results: female representation within the sample, and infant representation within the sample. The first factor, female representation within the sample can influence the final result in two different ways. If there is an over representation of females within a sample, meaning that the proportion of females represented within the skeletal assemblage is higher than the portion of infants and neonates (e.g. 10% of females who lived in the population vs 5% of neonates and infants who lived in the population) it artificially inflates the estimated number of neonates and infants. This means that the estimated number of infants and neonates in the sample is too high. Similarly, if there is an under representation of females within a sample, meaning that the proportion of females represented is less than the infants and neonates (e.g. 5% females vs 10% of neonates and infants that lived in the population) it artificially deflates the estimated number of neonates and infants. This means that the estimated number of infants and neonates is too low. There are a variety of reasons for varying levels of female representation in skeletal samples. In some Christian communities the death of a pregnant woman would result in her not being allowed to be buried in consecrated ground due to "unclean" state (Lahtinen & Korpiola, 2015). Additionally, if a female individual had been sentenced to death for criminal activities, instead of being buried in a regular fashion they were either burnt or buried on consecrated ground (Lahtinen & Korpiola, 2015).

The second factor that can influence the results is infant representation. There are also two components to this factor, and they are infant and neonate under representation and high infant and neonate mortality. Infant and neonate under representation can occur for a variety of reasons, such as differential burial practices and poor taphonomic conditions (Gordon & Buikstra, 1981; Wicker, 1999; Jones, 2001; Wenman, 2005; Grønlie, 2006; Mays *et al*., 2007; Barrett, 2008; Manifold, 2012; Wicker, 2012; Lawing, 2013). This results in an inaccurate representation of the infants and neonates within the sample, where the estimated number is higher than the actual. These reasons can also apply to subadult under representation, which is discussed further in this chapter. High infant and neonate mortality are a significant issue as well, and this can lead to the actual number of infants and neonates exceeding the estimated number (Goodman & Armelagos, 1989; Lewis & Gowland, 2007).

The method assumes that the proportions of females and infants and neonates in each skeletal sample are equal. This means that unless there are known cultural practices that may influence proportions (e.g. pregnant women not being buried in consecrated ground, child cemeteries, or infanticide), when the estimated and actual figures do not come close to one another there is either infant and neonate under representation or there are elevated levels of infant and neonate mortality.

Whilst there have been issues identified with this method and its application on the current dataset, by utilising a different dataset that can be standardised and have quantitative statistical methods undertaken to analyse the results this method has the potential to redefine the way in which infant and neonate mortality is interpreted in the archaeological record. This method will allow for a greater understanding of neonate and infant representation at different sites and will potentially be able to provide us with greater insights into population health and cultural practices. Although this study has been significantly limited by the data available, it has proven promising in spite of such limitations and offers and exciting avenue for future research.

6.2 Settlement Type

The Fisher's Exact Tests did not produce significant results for the samples that included all of the sites ($p = .4390$), and the second test that excluded the sites that had less than 30 individuals ($p = .1332$). There are a variety of factors that could contribute to these results which will be discussed below, including environmental conditions and cultural practices.

Regardless of whether these were homeland or frontier sites, they appear to be environmentally similar. Environmental aspects such as climatic conditions and site location are factors that could have a significant flow on effect for subadult survival and preservation of subadult skeletal remains (Goodman & Armelagos, 1989). For the first significant environmental factor: climate, whilst there are some slight regional variations based on geographic positioning, according to the Köppen Climate Classification system these sites are exposed to harsh weather conditions, whether it be short summer seasons or cold winters (Geiger, 1954). A number of these sites are quite inhospitable in today's environment; however, all of these sites have at least been partly attributed to what is commonly referred to as the Viking Age/ Medieval Climate Anomaly (VA/MCA) as is demonstrated in Table 1 below. The VA/MCA is where average temperatures increased in the period from the middle of the 9th century (850CE) until the middle of the 13th or 14th century (1250/1350CE) depending on the region (Filipsson & Nordberg, 2010; Asteman & Nordberg, 2018). This meant that whilst geographically there were slight variations, generally all of these sites experienced better climatic conditions during the same period of time (Filipsson & Nordberg, 2010; Asteman & Nordberg, 2018). As there were similar favourable climatic conditions for both the homeland and frontier groups, it is unlikely that there would have been differing levels of subadult mortality between them. The lack of climatic differences likely contributed to the lack of differences in subadult representation between the homeland and frontier samples.

Another environmental consideration that could have had a significant impact on subadult representation is the location of these sites and whether they are inland or coastal. As is observed in Table 1 in both the homeland and frontier groups there are a mix of coastal and inland sites, for the purpose of this study sites are regarded as coastal if they are within 5km of the coastline. Whilst there are a mix of site types, it is important to note that the sites regarded as inland are all close to freshwater systems that would provide additional sources of food to compensate for the lack of marine resources due to the distance from the coast (Cristi Nicu & Romanescu, 2016). It is hypothesised here that the mix could be attributed to colonising populations opting to settle in environmentally similar areas as they know that they are able to survive there based on their previous experiences. This could be an explanation as to why there are a mix of site types, and again, why there are no significant differences in the representation of subadults in the two groups.

From a cultural perspective, the frontier and homeland communities do not appear to have been disparate. According to historical sources the Scandinavian homeland had a significant influence on frontier communities, both during the Viking period and the following Medieval period (Jochens, 1998; Holman, 2001; Short, 2010). Viking chieftains and Scandinavian monarchs had considerable influence enforcing religious ideals and introducing new laws to change cultural practices to align the frontier colonies more closely with the homeland (Krogh, 1967; Jochens, 1998; Short, 2010). This was beneficial to the frontier colonies, even if they had been established many generations prior, as there were financial and social benefits to staying culturally aligned, such as continued trade and diplomatic relationships (Gräslund, 2009; Smith, 2014; Frei *et al*., 2015).

The lack of significant differential cultural practices is interesting considering that there were multiple regions where frontier communities were established, some of whom had a pre-existing local population and culture (Bjarnason *et al*., 1973; Ebenesersdóttir *et al*., 2018). Even though some of the frontier regions were established through violent take overs, the settlers integrated with the local populations and in a number of cases took a local spouse (Bjarnason *et al*., 1973; Ebenesersdóttir *et al*., 2018). By having a mixed population, it would have been beneficial to adopt a number of local cultural practices so as to not alienate inhabitants who now came under the Viking or Norse rule (Hadley, 2002; Abrams, 2012). However, Scandinavian settlers still maintained a Viking or Norse social identity, and there were fundamental cultural practices and social systems that they implemented in their new communities (Hadley, 2002). This was supported by the continual contact with other individuals from the Scandinavian homeland who came out to the frontier colonies for raiding, trading, or settling purposes (Abrams, 2010; Peschel, 2014). This means that realistically it is unlikely that there would have been significantly different cultural practices surrounding burial and death resulting in dissimilar representation of subadult individuals within the cemetery assemblages of these groups.

Both the frontier and homeland groups experienced favourable climatic conditions, had sites that varied in their positioning in relation to the coast, and regardless of whether they were mixed populations, both had very similar cultural conditions surrounding burial and death. Therefore, it is not unusual to see that there is not a significant difference in the number of subadults observed in the samples.

6.3 Inter-Regional Analysis

The second round of analyses undertaken were to compare the D0-14/D ratios of each region using Chi-Squared Tests of Independence to investigate whether there were different levels of subadult representation between regions. It is important to investigate subadult representation considering the influence that it is known to have on our understanding of fertility rates and rates of natural population increase (McFadden & Oxenham, 2018a; McFadden & Oxenham, 2018b). Two tests were undertaken, one that included all of the sites and the other only included sites with a large enough sample size (large than 30). Significant results were produced for Greenland and the Scottish Isles in both the analyses; where all the samples were included in addition to the analysis where only large samples (30 individuals or more) were included. The results indicated that the levels of subadult representation in Iceland and Scandinavia were approximately what was expected, while Greenland and the Scottish Isles deviated significantly. The section below will discuss the significant results seen in the regional samples from Greenland and the Scottish Isles.

6.3.1 Greenland

In both of the Chi-Squared Tests of Independence the results indicated that in the Greenland sample there were lower numbers of subadult individuals aged 0-14 than predicted. The under-numeration of subadults could be attributed to subadult misrepresentation where the actual proportion of adults and subadults is not accurately represented or there is the presence of low fertility. The inaccurate representation could be attributed to factors such as differential burial practices, low fertility, or taphonomic processes.

6.3.1.1 *Differential Burial Practices*

A potential explanation for the under-numeration of subadults in Greenland could be attributed to differential burial practices, particularly relating to infants. A number of primary and secondary sources have indicated that infanticide was a common practice in Viking and Norse culture (Wicker, 1999; Jones, 2001; Wenman, 2005; Grønlie, 2006; Barrett, 2008; Wicker, 2012; Lawing, 2013). There have been a number of explanations for why infanticide was undertaken such as preferences for male offspring, societal hardships, and physical and mental disabilities (Pentikäinen, 1990; Bragg, 1997; Wenman, 2005; Wicker, 2012; Lawing, 2013). An alternative hypothesis suggested by Krogh (1967) and Miller (1990) postulates that infanticide was a form of population control as the number of infants being born due to a lack of birth control were disproportionate to the food resources that were available. It is possible that a combination of the aforementioned factors played a significant role in choosing to commit infanticide in Viking and Norse cultures.

In Viking and Norse culture, when infanticide was practiced, it was usually implemented through exposure of infants. According to *Finnboga's Saga* the unwanted infant was laid between two stones with a third on top, then it was left to its fate with a piece of pork in its mouth to keep it alive for as long as possible (Krogh, 1967). By leaving the infant with some food it apparently allowed for the parents to feel that they played no part in their offspring's death, as they had left the child with some food and there was the potential that an individual of better means may come across the child and take them in (Krogh, 1967). While the sagas try to portray infanticide as being a rare occurrence, this idea is betrayed by a variety of historical sources which make note of the pagan practices that were still temporarily allowed to be undertaken in frontier colonies (Krogh, 1967; Wicker, 1998; Wicker, 2012). The pagan practice of infanticide was still allowed to be lawfully undertaken in Iceland for two decades at the very beginning of the 11th century following the regional conversion to Christianity (Jochens, 1998; Short, 2010). However, by the second decade of the 11th century the new Norwegian king Óláfr was informed that infanticide was still being undertaken in the colonies and outlawed the practice (Krogh, 1967; Jochens, 1998; Short, 2010).

As both of the sites in the Greenland sample have been associated with later Norse Christian periods and practices, it seems quite unlikely that infanticide would be contributing to the lower than expected numbers of subadults (Halffman *et al*., 1992; Enghoff, 2003). Furthermore, as this is a differential burial practice where the parents of the infant release themselves of the responsibility of the child upon their death these infants would not be brought back to be buried within the church graveyard, which would result in lower than expected numbers of infants and neonates. It does not appear that infanticide was a significant contributing factor to the lower subadult numbers at Thjodhild's Church with 15 infants being included in the assemblage when the number based on the Infant and Neonate Mortality Adjustment Method was five. For the Sandnes sample, it could be a consideration where there were only two infants when the estimated number of infants and neonates in the sample was between seven and eight, however, due to the historical knowledge this seems unlikely and other factors should be taken into consideration.

6.3.1.2 *Low Fertility*

Another consideration that may contribute to the under-numeration of subadults in the Greenland regional sample is low fertility. Low fertility in populations can arise from a variety of factors but inadequate maternal nutrition can be a significant contributing factor (Neela & Raman, 1997; Fall *et al*., 2003; Bhutta *et al*., 2012). During pregnancy the foetus receives the nutrients required for development from the mother, and even though spontaneous abortions are known to be multifactorial, studies have indicated that there is a relationship between serious under nutrition during pregnancy and spontaneous abortions (Neela & Raman, 1997; Fall *et al*., 2003; Helgstrand & Andersen, 2005; Bhutta *et al*., 2012). These studies have also indicated that inadequate maternal nutrition during pregnancy also elevates the risk of maternal mortality (Bhutta *et al*., 2012).

The reason that inadequate nutrition is identified in this section is based on the historical context of the Norse communities in Greenland. There is archaeological evidence to suggest that during the 15th century the Norse communities in Greenland collapsed (Buckland *et al*, 1995). There are a number of hypotheses for the collapse of the Norse communities in Greenland such as climatic instability leading to famine, poor agricultural practices leading to arable soil erosion, and the declining price of ivory (Buckland *et al*., 1995; Dugmore *et al*., 2007). Whilst the ultimate reason for the collapse is still unknown , in the lead up there were definitely periods of food scarcity which would have negatively impacted fertility rates.

Lynnerup (1996) provides another suggestion for lowered fertility rates. His hypothesis is that the emigration of younger individuals out of Greenland would have also contributed reducing the fertility rate (Lynnerup, 1996). An exodus of younger individuals would definitely lower the fertility rates and create an aging population, as unless there were additional young people to supplement those that had left, more younger individuals would need to look further afield for potential suitors.

Regardless, there are a number of viable explanations which would have contributed to reducing the fertility rates in the Greenland Norse communities, which would subsequently result in the lowered representation of subadults in the mortuary record.

6.3.1.3 *Taphonomic Conditions*

The final significant consideration that may explain the under-numeration of subadults in the Greenland sample is taphonomic conditions. Preservational skeletal bias in the archaeological record has been identified as a significant issue, with a number of studies aiming to provide more information to better understand the conditions which are conducive to the preservation of subadult skeletal remains (Gordon & Buikstra, 1981; Mays *et al*., 2007; Manifold, 2012). Many studies such as those undertaken by Gordon & Buikstra (1981) and Mays *et al*. (2007) have both identified that acidic pH levels have a detrimental effect on the preservation of subadult skeletal remains in the archaeological record. Additional to soil pH levels, another taphonomic factor that may significantly influence whether or not subadult skeletal remains are preserved in the archaeological record is water. The presence of groundwater is believed to be the most influential contributor to bone diagenesis, particularly in areas where the presence of water is not constant as it increases the bone porosity and allows it to break down at a faster rate (Nielsen-Marsh *et al*., 2000; Manifold, 2012; Damiata *et al*., 2013). This is a significant issue in the preservation of human remains in Greenland due to the permafrost. In some cases, the continual presence of permafrost has served to protect the archaeological remains beneath, however, there are also cases where there is sporadic permafrost which has led to soils being inundated with water sporadically (Logan, 2005).

The taphonomic conditions at Sandnes are not ideal for bone preservation, especially for subadults. The 1995 publication by Rutherford sampled the soil from some of the Norse settlements in Greenland, with the pH levels in Godthåb (which is located at the entrance of the fjord system where Sandnes is located) varying between 3.0-3.5. This is very acidic and in the marginal pH range that Gordon & Buikstra discuss in their 1981 paper which they identify as being detrimental to subadult bone preservation. Furthermore, the study by Hollesen *et al*. (2016) indicated that compared to more Northern sites that experienced continuous permafrost the moisture levels at Sandnes were lower, which could be attributed to the sporadic permafrost conditions it experiences. Figure 2 from Christiansen & Humlum (2000) and Wallroth *et al*. (2010) presents the modern regional distribution of permafrost in Greenland, which supports the claim that the permafrost at the site of Sandnes is not continuous. This is significant as a continual permafrost is generally beneficial to the preservation of osteological materials as stable taphonomic conditions are created through the low temperature which freezes the groundwater and inhibits a number of biological processes that otherwise result in bone degradation (Von Endt & Ortner,1984; Nielsen-Marsh *et al*., 2000; Manifold, 2012; Hollesen *et al*., 2016; Lee, 2019). Fenger-Nielsen *et al*. (2020) highlight that the thawing of the permafrost allows for abiotic and biotic taphonomic processes to occur which results in the degradation of osteological materials.

Additionally, the sporadic permafrost allows the ground to flood and the water to stabilise on multiple occasions, which as mentioned previously results in faster bone diagenesis. A further taphonomic condition that may contribute to the under-numeration of subadults at Sandnes is the erosion that has been noted at the site in conjunction with part of the original church site (and potentially part of the graveyard) now being submerged (McGhee, 1984; Lynnerup, 1996). This combination of taphonomic conditions at Sandnes appear to have had the potential to play a significant role in the preservation and recovery of skeletal materials, which would likely have an effect on subadult representation within the sample.

The taphonomic conditions at Thjodhild's Church were also a potential source for the subadult under-numeration observed. According to Rutherford's 1995 paper, the pH level for the site varied between 3.9-4.4 which is more alkaline than what was recorded for the location close to Sandnes. However, these figures are still too acidic for good osteological preservation based on the Mays *et al*. (2007) paper which indicates that the optimal pH level for preserving subadult bone would be somewhere between 7.3 and 8.5. There are a few explanations why even though the pH levels are not ideal for bone preservation, there is still a higher representation of subadults (and particularly infants). The first reason could be the lack of permafrost in the region (as is depicted in Figure 1), this may mean that the site does not flood with ground water as often. Another reason could be the lack of erosion that has occurred at the site, which may have led to more of the remains being recovered during excavations.

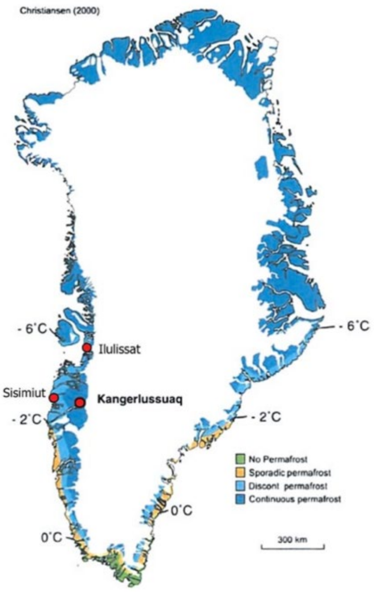

Figure 4: Permafrost distribution in Greenland. Source: Christiansen & Humlum, 2000; Wallroth et al., 2010.

6.3.1.4 *Greenland Conclusions*

Of the potential factors that may have influenced subadult representation in the Greenland regional sample based on the historical context of the site, differential burial practices seem like an unlikely contributor to the under-numeration. Instead, the evidence suggesting that there were low fertility levels and poor taphonomic conditions at both of these sites is quite convincing. Therefore, it seems that in this case the low fertility rates and poor taphonomic conditions may have resulted in subadult remains not being present or preserved in the archaeological record and thus presenting as being underrepresented.

Considering that low fertility rates were also a factor to be considered, it would be interesting to undertake further investigations if more data becomes available to see whether there may be a relationship between high levels of maternal mortality and low levels of subadult representation.

6.3.2 Scottish Isles

The Scottish Isles sample indicated in both of the Chi-Squared Tests of Independence that there were a higher number of individuals in the D0-14 age category compared to what was predicted. As has been mentioned in the settlement type analyses and demonstrated in Table 1, there does not appear to be a homogenous set of environmental and cultural factors for each site, which means that it is not likely that either of those would have played a significant role in the higher representation of subadults. Instead, factors that could significantly contribute to or be associated with the high levels of subadult representation in the Scottish Isles is the presence of pathological conditions and/or high fertility within the populations.

6.3.2.1 *Pathological Conditions*

A significant contributing factor to the high subadult representation could be the presence of pathological conditions or more generalised poor subadult health. The osteological reports for Newark Bay, Skaill House, and Westness all indicate that there is evidence of periostitis, cribra orbitalia, and other childhood specific pathological conditions (James *et al*., 1999; Sellevold, 1999;

Molleson & Owen, 2005). Especially 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 subadults also displayed evidence of pathological conditions (Molleson & Owen, 2005). It is important to note, however, as has been outlined in the review of the Osteological Paradox that there may have been other types of pathological conditions that may have not developed any skeletal lesions but would still contribute to compromised health and others may have died prior to developing lesions (Wood *et al*., 1992). Additionally, fertility has a greater influence on the proportion of subadults in a sample than mortality (Sattenspiel & Harpending, 1983; Milner *et al*., 1989; Konigsberg & Frankenberg, 1994).

Firstly, periostitic bony lesions are commonly observed in skeletal populations and are regarded as being an important indicator of poor health (Kim *et al*., 2013; Klaus, 2014). Periostitis usually refers to the inflammation of the periosteum due to infection which leads to new woven bone deposition (Roberts, 2019). There are two types of periostitis, specific and non-specific, with known and unknown causes of periosteal inflammation respectively (Roberts, 2019). Whilst periostitis is not a childhood specific disease, osteomyelitis which is the inflammation of bone due to infection is particularly common during childhood (Peltola & Pääkkönen, 2014). It is important to note that even in the modern period unless this condition is identified and treated at an early stage, there is a high likelihood of mortality (Peltola & Pääkkönen, 2014). Therefore, in a period where modern medical treatments were not available, for any individual but particularly a child to have developed periostitis it likely would have been fatal.

Another commonly observed pathological condition is cribra orbitalia (CO) which is characterised by porotic lesions in the orbital region of the frontal bone (Walker *et al*., 2009, McFadden & Oxenham, 2020). These lesions can only develop in children from 6 months of age until approximately 12 years of age and are widely regarded as being an indicator of stress during childhood (Obertová & Thurzo, 2008; Brickley, 2018; Cole & Waldron, 2019). The reason that these lesions can only develop during childhood is based on the proposed aetiology of the condition and the physiological requirements for the lesions to develop. It has been widely accepted that many different forms of anaemia may contribute to the aetiology of CO, with the primary concept being that different types of anaemias result in ineffective erythropoiesis in the red bone marrow, also known as ineffective red blood cell production (Oxenham & Cavill, 2010, McFadden & Oxenham, 2020). In the case of iron-deficiency anaemia the red blood cells that are not effective due to a lack of haemoglobin are destroyed within the marrow and red blood cell production is increased (Oxenham & Cavill, 2010). This process results in bone marrow hyperplasia which is the expansion of the red marrow as the number of hematopoietic cells that produce red blood cells increase (Oxenham & Cavill, 2010). The reason that this condition can only develop in children is due to the type of marrow that is present in the body at different stages of life. According to Brickley (2018) the red bone marrow that is required for erythropoietic activity is only present in the orbital region until the age of 12. It is important to note that CO can return after this age in extreme cases, but only where there has been previous cribrotic activity (Brickley, 2018).

There are a number of other proposed aetiologies for CO in addition to non-specific anaemias which are predominantly related to metabolic stress and congenital abnormalities (Sandford *et al*., 1983; Walker *et al*., 2009; Smith-Guzman, 2015; Rivera & Mirazón Lahr, 2017). The disputed aetiology aside, it is accepted by the majority of researchers and academics that the presence of these lesions in childhood indicates physiological stress and poor health (Obertová & Thurzo, 2008; Koesbardiati *et al*., 2018; McFadden & Oxenham, 2020). It is important to note that CO would not directly result in individual mortality, instead the presence of this condition is indicative of a compromised immune system and general poor health, so it is likely that the individual would have contracted another disease or condition that would have directly resulted in their death (Fairgrieve *et al*., 2000; Koesbardiati *et al*., 2018; McFadden & Oxenham, 2020).

There were also other types of pathological conditions present in these samples that were not observed elsewhere such as Legg-Calvé-Perthes disease, additional cranial fenestrations, infantile rickets, and Barlow's disease (Sellevold, 1999; Molleson & Owen, 2005). The aetiology of Legg-Calvé-Perthes disease is still debated considerably with different academics proposing it be a genetic condition or alternatively a condition associated with malnutrition (Loder & Skopelja, 2011; Perry *et al*., 2012). However, the other conditions are widely recognised as being a result of nutritional deficiencies (Clemetson, 2002; Holick, 2006).

6.3.2.2 *High Fertility*

An alternative reason for the higher than expected number of subadults observed in the Scottish Isles could be attributed to there being high fertility rates. There is substantive evidence that negative fluctuations in resource abundance reduce the maximum carrying capacity, and an abundance in resources increases the carrying capacity of a population and thus increasing the fertility rates (Hassan, 1978). Whilst the Scottish Isles are not known for their fertile soils there is evidence to suggest that during the period of Viking and Norse occupation the lands were fertilised using seaweed and manure (Simpson, 1993; Montgomery *et al*., 2014). It is also important to take into account the abundance of marine resources available to coastal populations, and the fact that the Scottish Isles were a common trading stop when sailing across the North Atlantic (Barrett, 1995; Simpson *et al*., 2005). The abundance of resources available to communities and individuals would have likely reduced that pressure, and potentially would have improved maternal health resulting in higher fertility rates.

6.3.2.3 *Scottish Isles Conclusion*

In comparison to the other regions where the osteological and site reports make mention of a few cases, it appears that the samples from the Scottish Isles, particularly those larger in size, were more affected by pathological conditions. This may be a result of having large communities without proper sanitation, living in close quarters with livestock, cultural practices such as swaddling and early weaning (Barrett *et al*., 2000; Molleson & Owen, 2005). It is likely that a combination of these factors would have resulted in the increased presence of pathological conditions within communities, and as a result increased subadult mortality.

Unfortunately, whilst there are often mentions of pathological conditions at the sites from all the regions, the reports often fail to provide a full biological profile for each individual. In some cases, this is because of the age of the excavations and reports when the modern biological profile had not yet been established, and in other cases academics have opted not to be specific. The lack of specific data has meant that an in depth palaeoepidemiological analysis has not been undertaken due to the lack of available data. This would be a future area of study that would significantly contribute to our understanding of the health dynamics of subadults in frontier Viking communities, and more specifically the health of subadults in Viking communities in the Scottish Isles and in the wider North Atlantic region.

It is also important to additionally acknowledge the potential for high fertility rates in the Scottish Isles. If there were high fertility rates, they would have also contributed to the higher levels of subadult representation.

6.4 Intra-Regional Analysis

From an intra-regional perspective, there appears to be a high degree of variability when it comes to subadult representation. The variability within the regions is as follows: Greenland= 0.10 (0.17-0.27), Iceland= 0.37 (0.11-0.48), Ireland= 0.27 (0.16-0.43), Scandinavia= 0.57 (0.06-0.63), and Scottish Isles= 0.57 (0.00-0.57). This variability in the intra-regional subadult representation can likely be attributed to a variety of cultural, environmental, and representational differences. These factors have been acknowledged in Table 6 below and have also been discussed in the settlement type discussion above. Several factors have been taken into consideration such as whether it was a large or small sample, distance to the coast, and climatic conditions. Purely based on observation, there does not appear to be a distinct pattern of factors that result in either a high or low D0-14/D ratio. The relationship between such factors and high or low D0-14/D is complex and cannot be easily defined. Whilst a variety of factors have been named here, there are other influential factors that are not able to be included due to the lack of knowledge available which may hold the key to better understanding of why some sites experience higher or lower levels of subadult representation. It appears that there is a multifactor and dynamic relationship between variables and subadult representation, thus multiple lines of evidence and a multidisciplinary approach provides the most promise to better understanding the relationship.

Table 6: Environmental and Cultural information for each site.

	Frontier Settlements												
	Iceland				Greenland		Ireland		Scottish Isles				
	Keldudalur	Keflavík	Skeljastaðir	Hrísbrú	Thjodhilds Church	Sandnes	Wood Quay	Waterford	Westness	Skaill House	Cnip	Newark Bay	Pierowall
D0-14/D	**0.45**	**0.48**	0.11	0.14	0.11	0.27	**0.43**	0.16	0.17	**0.56**	**0.43**	**0.57**	0
Time period	10^{th} -12^{th} C	10^{th}-12^{th} C	Pre-12^{th} C	10^{th} -11th C	11^{th} C	Pre 14^{th} C	12^{th} C	11^{th}-13^{th} C	8^{th}-11^{th} C	11^{th}-14^{th} C	9^{th} & 10^{th} C	8^{th}-14^{th} C	9^{th}-10^{th} C
Small (n<30) or Large (n>30) Sample	**Large**	**Large**	**Large**	Small	**Large**	**Large**	Small	**Large**	Small	Small	Small	**Large**	Small
Preservation Good/ Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	**Good**	**Good**	**Good**	**Good**	**Good**	Poor
Mixed or singular	**Mixed**	**Mixed**	**Mixed**	**Mixed**	Singular	Singular	**Mixed**	**Mixed**	Singular	**Mixed**	Singular	Singular	Singular
Costal vs Inland (kms to the coast)	Inland (8km)	**Coastal (1km)**	Inland (60km)	**Coastal (3km)**	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (4km)**	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (<1km)**
Elevation	18m	82m	**162m**	58m	21m	35m	4m	10m	11m	10m	13m	14m	7m
Climatic conditions	VA/MCA	VA/ MCA	VA/MCA	VA/ MCA	VA/MCA	**VA/MCA – start of LIA**	VA/ MCA	**VA/MCA- start of LIA**	**VA/MC A- start of LIA**	VA/ MCA	VA/ MCA	**VA/MC A- start of LIA**	VA/MCA

	Homeland						
	Scandinavia						
	Sigtuna	Birka	Mälaren Valley	Galgedil	Fjälkinge	St Stefans	Pkbank	Frösön
D0-14/D	0.25	0.3	0.13	0.14	**0.63**	0.3	0.06	**0.58**
Time period	12^{th}-14^{th} C	9^{th}-10^{th} C	8^{th}-12^{th} C	9^{th}-11^{th} C	10^{th}-11^{th} C	11^{th}-12^{th} C	11^{th}-12^{th} C	11^{th}-14^{th} C
Small (n<30) or Large (n>30) Sample	**Large**	**Large**	**Large**	**Large**	**Large**	**Large**	**Large**	**Large**
Preservation Good/ Poor	Poor	Poor	Poor	**Good**	**Good**	**Good**	**Good**	**Good**
Mixed or singular	Singular	Singular	Singular	Singular	Singular	Singular	Singular	Singular
Costal vs Inland (kms to the coast)	**Coastal (<1km)**	**Coastal (<1km)**	**Coastal (<1km)**	Inland (6km)	Inland (9km)	Inland (9km)	Inland (9km)	Inland (150km)
Elevation	22m	14m	10m	6m	25m	41m	36m	**353m**
Climatic conditions	**VA/MC A-start of LIA**	VA/ MCA	VA/ MCA	VA/ MCA	VA/MCA	VA/ MCA	VA/ MCA	**VA/MC A- start of LIA**

Bolded data highlights differences in each row.

6.5 Chapter Summary

The Viking and following Norse culture of establishing frontier colonies provides a unique opportunity to undertake palaeodemographic analyses comparing subadult representation within these homeland and frontier communities. While there are other cultures that established frontier communities such as the groups that peopled the Pacific region; there is a strong written history of the Viking and Norse cultures, there are a number of datasets available, and there are not the same cultural sensitivities which may limit access to osteological remains. This means that it is possible to explore how environmental and cultural factors may influence our understanding and perception of subadult representation in the archaeological record.

Climatic and settlement data has indicated that similar climatic conditions were observed in all of the samples, and that the settlement types were environmentally diverse. This is reflected in the diversity of subadult representation in the intra-regional analysis, and the fact that there are no significant differences between the homeland and frontier groups. Furthermore, whilst historical sources indicate that there were high levels of infanticide occurring during the Viking period, the results indicating that there tended to be higher than expected numbers of infants and neonates in samples contradicts this hypothesis (Enghoff, 2003; Short, 2010). If differential burial practices were being undertaken the numbers of infants and neonates within the samples should be considerably lower than expected which would bring down the level of subadult representation. However, this does not appear to be the case and there do not appear to be any statistically significant differences in subadult representation between settlement types or on an intra-regional level. This could be attributed to there being a wide variety of environmental conditions and similar cultural practices being undertaken.

However, the inter-regional analyses that indicated that there were lower than expected representations of subadults in Greenland and higher than expected representations of subadults in the Scottish Isles is slightly harder to explain. Understandably, the poor taphonomic conditions have likely played a role in the under representation of subadults within the Greenland samples, however, that is not to rule out the potential role of low fertility in the low numbers of subadults within the region (Lynnerup, 1996; Lynnerup, 1998). The high level of subadult representation in the Scottish regional sample is likely the result of a combination of increased pathological presence and high fertility rates (James *et al*., 1999; Sellevold, 1999; Molleson & Owen, 2005). However, it is important to note that the specific factor or factors that triggered the increased presence of pathology is still undetermined, and we can only hypothesise the potential reasons for high fertility.

Future research directions could aim to investigate and better understand the types of pathologies that are observed in these samples. This may better the collective understanding of intrinsic and extrinsic factors that may influence subadult representation in homeland and frontier communities, and more specifically why there are regional variations in subadult representation.

Conclusions and Future Directions

This thesis sought to undertake a palaeodemographic study investigating subadult representation in Homeland and Frontier Viking communities in the North Atlantic during the Viking and following Medieval Period. There have been few previous palaeodemographic analyses investigating the population dynamics of Viking and Norse communities, and none have undertaken an analysis on this scale. This thesis therefore presented a unique opportunity to undertake palaeodemographic investigations on a scale never before.

This thesis has successfully addressed each of the aims outlined in the Chapter 1 (Introduction). By doing so, it provides insights into population health and dynamics of Viking and Norse communities during the Viking and following Medieval period. This chapter outlines each of the conclusions reached from the original aims, in addition to suggestions for future research. The aims outline in the Introduction were:

1. To compare the population dynamics of homeland Viking and Norse communities and frontier Viking and Norse communities, specifically investigating subadult representation and maternal mortality. This comparison will be undertaken to see whether there are differences in the health of populations that potentially experience different environmental and cultural conditions based on their geographic location.
2. To implement the revised maternal mortality estimator developed by McFadden *et al*. (2020) in order to see whether this estimator is

applicable in an archaeological setting outside of ancient Southeast Asia which will provide a better understanding of the maternal experience in Viking and Norse communities during the Viking and following Medieval period.

3. To develop a new palaeodemographic method to estimate the number of neonates and infants in a sample using the McFadden and Oxenham (2018a) fertility equations and the newly developed infant and neonate estimators (McFadden et al., in prep.). This is in order to assess whether the actual number of infants and neonates in a sample can be predicted using known demographic information.

The population dynamics of homeland Viking and Norse communities were compared with frontier Viking and Norse communities. Analyses were undertaken that investigated subadult representation between frontier and homeland groups, on an inter-regional level, and on an intra-regional level. The results indicated that there were no significant differences in the levels of subadult representation between homeland and frontier groups, which can be attributed to a combination of similar environmental and cultural factors. However, there were significant differences noted in the inter-regional analysis with Greenland results indicating that there were lower levels of subadult representation than expected and the Scottish Isles results indicating that there were higher levels of subadult representation than expected. These inter-regional differences can be attributed to a combination of intrinsic and extrinsic factors. Additionally, the range analysis of intra-regional variation indicated that there is a large amount of diversity in the ranges of subadult representation observed. This can be attributed to a multifactorial and dynamic relationship between variables and subadult representation. For future investigations multifactorial and multidisciplinary approaches appear to provide the most promise for better understanding these complex relationships.

The revised maternal mortality estimator was applied to the sample in order to investigate whether there were any differences in the maternal mortality rates of homeland and frontier populations. Unfortunately, there was not enough appropriate data available to run a sizable analysis comparing the homeland and frontier maternal mortality rates. Once enough appropriate data becomes available it would be highly beneficial to run these analyses again. An additional avenue of investigation that has been mentioned briefly in the previous chapters would be to undertake regional comparisons. To take the concept further, statistical analyses could be run to investigate whether there is a relationship between the number of infants and neonates and the maternal mortality rates. This type of analysis would provide a greater insight into the Viking and Norse maternal experience.

A new palaeodemographic method was developed in order to assess whether the actual number of infants and neonates in a sample can be predicted using known demographic information. The method developed needs to undergo further development and testing, however, it does show considerable promise.

This thesis used existing palaeodemographic methods and developed a new one in order to analyse and compare the demography of homeland and frontier Viking and Norse communities, specifically investigating subadult representation and maternal mortality. Although this research was limited in scope, it is hoped that the demographic results may still be used to deepen our understanding of subadult representation in homeland and frontier Viking and Norse communities and inspire future demographic research. The Viking and Norse homeland and frontier skeletal samples still hold opportunities to further investigate population health during the Viking and Medieval period which should be the focus of future research. For example, the discussion aspect of this thesis only looked at subadult representation and how known intrinsic and extrinsic factors may have impacted this representation, however, it was not able to fully account for pathological conditions due to the lack of available data. This research, however, has also highlighted a number of voids in our knowledge of Viking and Norse palaeodemography in the North Atlantic. While only subadult representation was able to be utilised in this discussion, it has highlighted the complexity of subadult representation in the archaeological record, and the complexity of estimating infant and neonate numbers based on known demographic information. This thesis has therefore illustrated a complex relationship between population health and demography of homeland and frontier communities during the Viking and Medieval period.

Chapter 7 Bibliography

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