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Environments Explored: An In-Depth Analysis of Soil Movement in Northern Iceland

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ENVIRONMENTS EXPLORED: AN IN-DEPTH ANALYSIS OF SOIL MOVEMENT IN NORTHERN ICELAND

A Thesis Presented

by

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ABSTRACT

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May 2019

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The initial colonization of Iceland in the late 9th century had a profound impact on the fragile environment of the North Atlantic island. Settlement and the introduction of livestock resulted in widespread erosion and the replacement of woodlands with meadows and heaths. Changes in the environment are assumed to have played a role in determining settlement patterning and subsistence strategies. While marginal highland areas were most seriously affected, resulting in farm abandonment, the nature of changes in lowland areas and their impact on the productivity of individual farms is poorly understood. Local patterns of landscape change in Iceland could be highly varied as erosion in one area often resulted in soil accumulation in another. Focusing on the lowland region of Hegranes in northern Iceland, this thesis examines patterns of erosion and sediment accumulation in relation to fluctuations in farmstead size during three periods of occupation: pre-1104 A.D., 1104-1300 A.D., and post-1300 A.D. This study

considers when and where soil erosion and accumulation occurred and its implications for farmstead activity and the long-term viability and productivity of individual farms and households.

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CHAPTER 1: INTRODUCTION

The Scandinavian settlement of Iceland resulted in widespread erosion and land degradation (Arnalds 1987; McGovern et al. 1988; Vésteinsson et al. 2002). Land clearance and livestock grazing profoundly impacted the environment and overall landscape. These anthropogenic practices, combined with the friable soils and marginal climate, lead to widespread deforestation, loss in vegetative land cover, and erosion across the island. These changes have been evaluated by examining patterns of soil movement and changes in vegetation (Arnalds 1987; Dugmore et al. 2005). While researchers have examined these changing soil and vegetation patterns throughout Iceland from a regional perspective, to date, there has been limited investigation that looks at the impact of erosion and soil accumulation on the productivity of individual farms. An examination of localized patterns in sediment accumulation rates, erosion, and farm productivity, from the initial settlement in A.D. 870 through the 19th century, allows us to better understand the environmental impact of the Icelandic settlement and the long-term relationship between ecological change and farm productivity.

The Icelandic ecosystem is fragile – consisting of highly erodible volcanic soils, sparse vegetation sensitive to ecological changes, and a climate that varies in temperature and rainfall (Arnalds 1987). Movement of soils can dramatically impact the environment

through an increased sediment accumulation rate (SeAR) or erosion, which can severely impact vegetation coverage (Arnalds et al. 2001). The effects of erosion can be seen in bare patches of rock or thin layers of exposed soils without vegetation coverage. Erosion is also visible in sediment accumulation, which can result in a variety of effects on the environment including impacts to hydrology, drainage, vegetation types and vegetation productivity. Past studies have examined soil movement in relation to erosion on Iceland to determine how the effects of erosion are reflected in the SeAR (Dugmore and Buckland 1991; Dugmore et al. 2000; Dugmore et al. 2006; Dugmore, Church et al. 2007; Dugmore et al. 2009). This research examines sediment accumulation rate and erosion (SeAR/E) as complimentary processes, simultaneously affecting the environment. On Hegranes, in Skagafjörður, Northern Iceland, the effects on such a delicately balanced ecosystem are reflected in fluctuations in farmstead size and productivity throughout a millennium of continued occupation. Through an exploration of farm production activities and the SeAR/E for seven farms on Hegranes, this thesis demonstrates that the changing landscape affected settlement fluctuations in size and farmstead abandonment. This enquiry also examines the correlations between SeAR/E, amounts of utilizable grazing biomass on farm properties, farm production activities, and change in farmstead size. These correlations were examined from three different periods: pre-1104, 1104-1300, and post-1300.

In this study SeAR/E is considered as a result of natural wearing processes from wind and water, and from human actions like landscape alteration and grazing pressures; environmental changes encompass both direct and indirect effects of variations in the

environment. These variations include changes in the amount and productivity of land available to individual farms, changes in soil depth, differences in the volume of soil coverage over specific areas, and soil accumulation rates. Recorded livestock (cows and sheep) values for each farm within the study area were obtained from the late 19th century records maintained by the Icelandic Farmers' Association (Búnaðarfélagið). These recorded numbers of livestock are considered relative to the carrying capacity of the available land (utilizable biomass). An understanding of environmental pressures and resulting landscape transformation assists in determining the potential influence of SeAR/E on settlement patterning and landscape cultivation.

Friable soils and varying vegetation have been heavily impacted by environmental and anthropogenic stresses, leading to extensive soil movement and reformation of the Icelandic landscape. Studies focused on SeAR/E have examined how the combined natural and anthropogenic actions affect soil instability and degradation, and what this means for the surrounding landscape (Arnalds 1987; Dugmore and Buckland 1991). Settlement abandonment and practices of landscape management, like grazing strategies, appear to be affected by changes in SeAR/E. However, it is difficult to determine the degree to which individual farms were affected from either soil accumulation or erosion (Dugmore, Church et al. 2007; Dugmore et al. 2006; Streeter et al. 2012). Previous research conducted in southern Iceland examined rapid soil accumulation and vegetation changes in the environment as a result of anthropogenic and climatic influence (Erlendsson et al. 2009; Streeter et al. 2012; Thórarinsson 1961). At Ketilsstaðir, effects on changes in SeAR and vegetation coverage were a result of varying factors; where

climate was responsible for pre-settlement birch tree suppression, and volcanic eruptions, in conjunction with livestock grazing, led to greater erosion post A.D. 871 (Erlendsson et al. 2009). In Skaftártunga, later periods of increased livestock management (i.e. limited grazing) (A.D. 1389-1597) are related to a reduction in fluctuations of SeAR/E, despite climate deterioration during this time (Streeter et al. 2012).

While these changes did not always have an immediate, obvious effect on farms, long-term impacts on the landscape contributed to farmstead abandonment and fluctuations in productivity (Thórarinsson 1961). Environmental research is key for understanding how periods of settlement and intensification practices affected local and regional landscapes and their associated environments. Evidence for localized fluctuations in SeAR/E, can identify how and when farms may have reacted to these environmental changes. Similarly, changes in farmstead size could have impacted erosion and soil deposition patterns.

Archaeology provides an opportunity to assess how the environment and landscape is shaped by human actions. The interaction between the environment and anthropogenic actions can be seen through the distribution of farms, current vegetation patterning, and historical documentation of environments and land use practices (Hayashida 2005). This interaction is especially important in contexts of settlement where local soil properties and climate factor into land management decisions (Adderley et al. 2008). Previous studies of adaptation of farm practices have established that both natural qualities of the land and land management practices affect farm productivity like hay

yield and livestock (Adderley et al. 2008; Adderley et al. 2000; Adderley and Simpson 2006; Adderley et al. 2006). However, the research has been limited to a single region. Focusing on a single region allows for an assessment of how farm establishment impacted SeAR/E, and the difference between anthropogenic and natural impacts on varying aspects of the environment. Research on local landscapes can identify why farms were established in specific locations, whether some areas were more suitable for settlement than others, and how localized changes in the environment impacted the productivity and continued existence of farms and the people living at them. Depending on environmental and anthropogenic changes, farms may become more productive, less productive, or have been abandoned altogether. Ideally, studies like this can provide insights into the creation and development of settlement patterns, which can be applied to other regions in the North Atlantic and beyond.

This research specifically examines aspects of the environment in relation to changes in farmland and farmstead size on Hegranes. From an archaeological perspective, Icelandic farmsteads consisted of turf structures, infields, outfields, pastures, and other resources specific to each farm (Steinberg et al. 2016). The core of each farmstead consisted of domestic buildings, kitchen, sleeping quarters, storage areas, and workshops. Surrounding these structures was the homefield where sheep and cattle barns were located. Surrounding the local farmstead landscape were wetlands, meadows, and pasture (Bolender 2006). The farmstead can be measured in the areal extent of turf and midden deposits (Steinberg et al. 2016).

This thesis builds on research conducted by the Skagafjörður Archaeological Settlement Survey (SASS)/Skagafjörður Church and Settlement Survey (SCASS). SASS/SCASS conducted research focused in the study area of Skagafjörður to examine the political relations between settlement patterns and Christian consolidation (Bolender et al. 2008; Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). The research for this thesis seeks to build upon this previous work to explore settlement patterns and farm productivity from an environmental perspective. In considering the prior SCASS data from Hegranes and its interpretations, the overarching question for this research examines how the environment affects settlement on Hegranes, either through natural environmental impacts or anthropogenic influences on the landscape. Stratigraphic data on settlement locations and soil movement was identified through coring conducted across the study area. This coring data allowed for calculations of SeAR/E between identified sediment layers. By examining the cumulative coring data collected over the past two field seasons and correlations between the resulting variables of SeAR/E, amounts of utilizable biomass, farm production activities, and change in farmstead size over time, this thesis considers how the instability of the environment affected farm productivity and stability.

This study revealed that farms appear to respond to environmental and anthropogenic pressures on the landscape on a case by case basis. In terms of available total utilizable biomass, the local farming landscape is predictive of farmstead size and productivity. The amount of soil in the immediate vicinity of a farmstead (an approximately 350-meter radius around a farmstead) impacts the amount of available

utilizable biomass within the area. The amount of utilizable biomass is an important factor in determining the initial size of a farm; greater soil accumulation in the settlement location is indicative of a larger initial farmstead size versus areas with less soil. The amount of utilizable biomass on a regional level influences later fluctuations in farmstead size and productivity. Over time farm production becomes dependent on regionally available resources rather than the immediate local landscape.

The initial size of a farmstead at settlement is related to the initial farmland productivity, and predictive of a farmsteads' growth and productivity throughout its occupational history. The amount of change in SeAR/E within the immediate landscape surrounding a farmstead, affects subsequent fluctuations in farmstead size. Evidence of sustained soil movement within the localized area around a farmstead leads to either an increase in, or stability in, farmstead size; dramatic and sudden influx in the SeAR appear to be associated with farm abandonment. Within the broader landscape, the depth of soil is indicative of the amount of available utilizable biomass.

Chapter 2 begins with an introductory section on the background of Iceland and the study area of Hegranes. In addition to historical information about settlement patterns during the Viking Age, this chapter looks at the physiography of the island, climate, and environmental impacts due to settlement. Previous research conducted on Hegranes is addressed in relation to the current project. Chapter 3 examines the primary method of data collection and the three main variables for this research: farmstead size, SeAR/E, and utilizable biomass. Individual farmstead size for each of the three study periods was

produced by SCASS through identification of cultural deposits in the coring data (Bolender et al. 2016; Bolender et al. 2017). Values for SeAR/E throughout the selected study areas was calculated based on measurements of soil thickness between tephra layers collected during coring. There are two vegetation maps for Iceland that were used to estimate the utilizable biomass associated with the overall region of Hegranes and individual farms. Information from these vegetation maps were incorporated into Búmodel, an environmental simulation model, to calculate the available utilizable biomass amount for each type of vegetation coverage (Thomson 2003). This chapter examines literature that addresses similar research questions, and methodological approaches utilized by previous researchers within Iceland.

Chapter 4 explores how localized patterns of SeAR/E and utilizable biomass affected farmstead size and farm productivity. Possible outcomes within the statistical model are discussed. Chapter 5 addresses the results of the data interpretation for the three main variables and correlations between data. Aside from the correlation between the pre-1104 farmstead settlement size and available utilizable biomass, regionally, farmstead size does not follow a pattern in relation to SeAR/E or utilizable biomass. SeAR/E did not correlate with the variables in a significant way; soil movement is not indicative of amounts of utilizable biomass or changes in farmstead size over the three study periods. The amount of utilizable biomass does correlate with farm production activities during the 19th century, supporting the utilization of the Búmodel vegetation values as an appropriate proxy for vegetation coverage during this time. Relationships between the data are then examined on a farm by farm basis across the seven study areas

on Hegranes. Evidence of SeAR/E relative to changes in farmstead size and productivity appears to vary between each farm, resulting in different outcomes. Chapter 6 concludes this thesis with closing thoughts on the application of SeAR/E and utilizable biomass when attempting to understand environmental effects on farmstead size and productivity in Iceland.

CHAPTER 2: BACKGROUND AND HISTORY

Iceland

To understand the relationship between farmstead settlement size, vegetation availability, and the movement of soils, the Icelandic ecosystem and history of occupation should be examined. The following chapter considers the basic geological background of Iceland, including soil typology, volcanic eruptions, vegetation categories and changing coverage, and climate fluctuations. The initial occupation and settlement of Iceland is reviewed, followed by the history of anthropogenic use of the landscape. This background introduction will assist in introducing the relationship between the environment and human actions on this far north island.

Initial Settlement

Iceland was settled in the late 9th century, in approximately A.D. 870, by people from Scandinavia and the British Isles (Karlsson 2000). During the initial settlement (*landnám*) period, settlements were placed along coastal, lowland, and interior valley locations (Vésteinsson et al. 2002). Following the initial settlement, during the Commonwealth period (ca. A.D. 930-1262) farms and resources were further sub-divided

(Karlsson 2000). Smaller, tenant-occupied farms were established between the larger farms, resulting in the development of a settlement-based hierarchy (Bolender et al. 2008).

The first human impacts on the environment occurred during the Norse settlement of Iceland (Amorosi et al. 1997; Arnalds 1987; Dugmore et al. 2000). While written sources suggest that Irish monks came to the island in the 8th century (Karlsson 2000), prior to the Landnám period, there is no visible trace of human occupation on the Icelandic landscape (Dugmore et al. 2000). The manipulation of the landscape to suit the Norse settlers, led to distinct impacts and environmental change. Within a few generations of the initial settlement, Iceland was transformed from a wooded environment to an open landscape (Catlin and Bolender 2018; Dugmore, Keller, and McGovern 2007). As the Arctic climate was much cooler and the landscape more fragile than Norway, attempts at traditional Norse farming negatively impacted the island. Long term effects of farming practices had definite impacts on the flora, fauna, and natural landscapes (Amorosi et al. 1997; Ashwell 1966; Brown et al. 2012; McGovern et al. 1988; Thórhallsdóttir et al. 2013; Vésteinsson et al. 2002). Overgrazing of pigs and goats damaged the root systems of birch woodlands, encouraging widespread erosion. This combination of anthropogenic actions and resulting environmental effects significantly changed the landscape. Often, severe, localized degradation, especially in the highlands, resulted in farm abandonment (Sveinbjarnardóttir 1992).

Physiography

Located in the North Atlantic, just south of the Arctic Circle, Iceland is approximately 800 kilometers (km) west of Norway and 180 km east of Greenland. Iceland is a relatively temperate volcanic island on the mid-Atlantic ridge (Arnalds 2004; Eythorsson 1949). The island's perimeter landscape was formed into costal fjords and valleys due to glacial processes, while the interior consists of a high barren rocky plateau. A mountainous country, Iceland has an average height of 500 meters (m) above sea level. Glaciers cover approximately 11.5% of the total area, receding in warmer temperatures and advancing in colder (Einarsson 1984). Within these environmental contraints, productive farmland is often restricted to narrow strips between wetlands and steep mountain slopes with thin soil coverage (Bolender 2006).

Soils

Iceland is a volcanic island, producing volcanic eruptions approximately every 4-5 years. These eruptions result in lava flows and volcanic tephra falls, a volcanic glass material consisting of solid basalt glass particles to rhyolitic pumice grains (Arnalds 2004). As a result, Icelandic soils are mainly volcanic, containing parent materials that consist of a mixture of tephra layers and eolian sediments (Arnalds 2004). Most Icelandic soils are classified as Andosols, unique in comparison to other volcanic soils due to their basaltic origin, large amount of eolian sediment, and occurance in locations of low temperatures with a wide range of precipitation (Arnalds 2004). The variability of

amount of eolian materials and presence of tephra potentially provides a significant impact on soil formation. The amount of water and drainage ability of a region impacts the formation of specific types of Andosols. There are six main soil types in Iceland: Histosols, Histic Andosols, Gleyic Andosols, Brown Andosols, Vitrisols, and Leptosols (Arnalds 2004). In general, Andosols are extremely vulnerable to erosion due to their friability when dry.

Erosion

During initial settlement, erosion was an almost guaranteed byproduct of grazing pressures or natural processes of the landscape that affected the environment, like varying weather intensity or volcanic eruptions. Such dramatic movement of soils affects the ecosystem through SeAR/E severely impacting vegetation coverage of the surrounding landscape (Arnalds et al. 2001). Patterns of SeAR/E are important to this research as the changing environment and settlement locations are explored in relation to soil movement.

Highly susceptible to erosion, Iceland's fragile course-textured andosols have been severely impacted by deforestation, grazing, and foraging (Figure 1) (Arnalds 1987; Dugmore, Keller, and McGovern 2007; McGovern et al. 2007). Usually protected and covered by a vegetative root mat, the landscape is more susceptible to erosion in colder seasons when there is diminished plant productivity and the loose textured soils are exposed (Arnalds 1987; Arnalds 2004). The sensitivity of soils may be increased by the presence of tephra beneath the surface, as exposed tephra erodes faster than the general

andosols (Dugmore et al. 2006; Dugmore, Church et al. 2007). Erosion can occur rapidly or slowly over time, a few millimeters per year, as evidenced in the cores and profiles from recent fieldwork. Past erosion is identified as areas of bare rock or deeper soils on lowland farms. Evidence of such erosional activities can be recorded within the soil stratigraphy; deposition of these eroded sediments builds up between tephra layers, identifying periods of erosion through SeAR. Erosion is the product of multiple factors at several scales, including decisions made by the first settlers to Iceland, construction of farmsteads, animal grazing and roaming, and environmental effects like volcanic eruptions, heavy rainfall, and strong winds (Catlin 2016; Ashwell 1966; Arnalds 1987; Dugmore and Buckland 1991; Dugmore et al. 2009; Einarsson 1984).

Figure 1. Eroded landscape on Hegranes, Skagafjörður, Northern Iceland.

Soil erosion has two key phases: a *triggering event*, resulting in the removal of vegetation cover (often due to grazing pressures), and a *propagation phase*, during which natural effects (frost, wind, rainfall) impact the exposed soil (Dugmore, Keller, and McGovern 2007; Dugmore et al. 2009). The type of sediment and accumulation rate indicate the nature and intensity of erosion, while specific tephra layers reveal whether sources of sediment, and hence areas of erosion, are local (from <10m) or regional (from >1km) (Dugmore et al. 2009). To study models of soil erosion from sediment accumulation rates, there are two important assumptions to recognize: first, that rates of sediment accumulation are directly proportional to rates of local wind erosion; and second, that the intensity of erosion reflects erosion patterns within the immediate vicinity (Dugmore and Buckland 1991). This means that soil accumulation rates vary depending on the circumstances of the soils' movement. While some localized soil accumulation rates increase due to nearby vegetation trapping the coarser soil particles as they erode, simultaneously increasing the SeAR during the erosion process, others increase due to a progressively eroding slope, resulting in sediments accumulating at the base. Regionally, the transport of sediments, either alluvial depositions or aeolian movement from highlands to lowlands, can identify patterns of erosion on a broader scale.

Aeolian sediment accumulation is useful as a proxy for the soil erosion that has occurred over the past 1,000 years in Iceland (Dugmore et al. 2000). Búmodel, an environmental simluation model, was created to study past farmland management strategies by modeling utilizable biomass from various vegetation coverage (Thomson

2003). Previous erosion studies applied this grazing model to assess pressures and tephrochronology-based soil accumulation rates as a proxy for land degradation (Brown et al. 2012; Dugmore and Buckland 1991; Thomson 2003; Thomson and Simpson 2007). Thomson and Simpson (2007) examined the capability of available utilizable biomass to support the number of livestock indicated archaeologically and historically. They studied grazing management strategies that supported the recorded number of livestock while avoiding extensive land degradation and erosion. By calculating utilizable biomass based on historic climate, vegetation, and management conditions for northeastern Iceland, Brown et al. (2012) addressed the extent to which shieling-based (pastures for milking livestock) grazing pressures affected land degradation. In addition to the intensity of grazing conducted on the landscape, the seasonality of grazing pressures can impact environmental responses to grazing, like erosion or a rebound in available vegetation. Research on these complex relationships between grazing pressures and landscape response in southern Iceland revealed sufficient utilizable biomass production during the summer season to support historical livestock numbers (Brown et al. 2012; Simpson et al. 2001). Therefore, rather than a lack of available utilizable biomass affecting the on-set of erosion, the error was delayed removal of livestock from grazing areas after the growing season, resulting in land degradation.

Tephrochronology

Environmental research in southern Iceland has examined patterns of SeAR/E through the application of tephrochronology (Dugmore and Buckland 1991; Dugmore et

al. 2000; Dugmore et al. 2006; Dugmore, Church et al. 2007; Dugmore, Keller, and McGovern 2007; Dugmore et al. 2009). Tephrochronology uses identified tephra layers to date periods of human occupation and land use in Iceland (Þórarinsson 1970). Tephra layers are deposits of glassy, silicate-rich sediments from volcanic eruptions that are visible within soil profiles due to their distinct colors, textures, and widths (Figure 2). By using identified tephra layers to determine the amount of sediment accumulation in a location between known periods of time, these studies identified moments of anthropogenic soil erosion due to livestock grazing pressures (Dugmore and Buckland 1991; Dugmore et al. 2009).

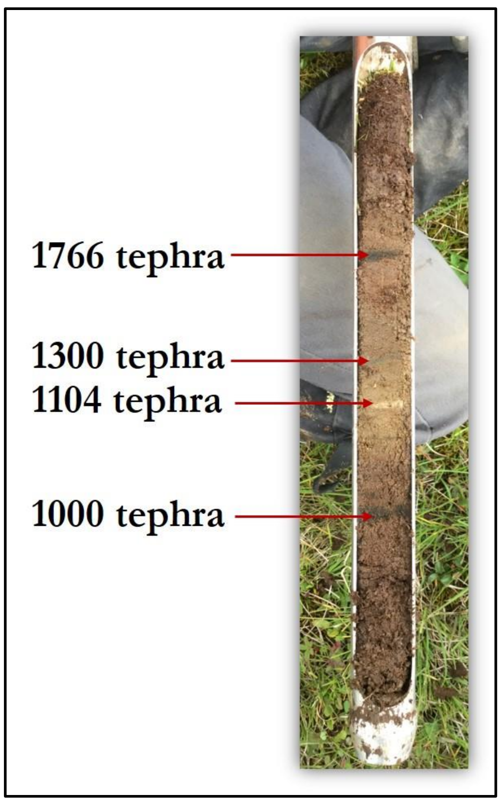

Figure 2. Sample core from SCASS survey, showing tephra layers.

It is estimated that anthropogenically triggered erosion has removed over half of the soils in Iceland, resulting in a 40% loss of land area to erosion (Dugmore and Buckland 1991; Runolfsson 1978). In the Icelandic highlands, massive erosion occurred which led to local and regional farm abandonment. An assessment of the ruins of farm sites in Þórsmörk through tephrochronology, alongside written documentation and artifact evidence, show that site occupation ended with major episodes of localized soil erosion and the loss of significant areas of grazing (Dugmore and Buckland 1991; Dugmore et al. 2006; Dugmore, Keller, and McGovern 2007). Additional farm abandonment occurred because of environmental degradation from the A.D. 1104 and Hekla volcanic eruptions (Dugmore, Church et al. 2007). The potential for studies of soil erosion are significant, and tephrochronological frameworks can greatly assist in focuses on small, constrained areas, such as Hegranes (Dugmore and Buckland 1991).

The combination of the Viking Age tephra sequence and substantial lowland soil deposition found in Northern Iceland makes Skagafjörður an ideal study area (Bolender 2006; Catlin 2011). The tephra layers are thin, and the early sequence visible in Skagafjörður profiles allow for a more exact dating of cultural deposits and environmental events (see Figure 2) (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). Tephras in Skagafjörður include two prehistoric tephras: Hekla 4 (H4), from ~2300 B.C., and Hekla 3 (H3), from 1050 B.C. These tephras are the thickest (up to 10cm) and consist of a yellow/white fine-grained sand. In some cases, H3 and H4 is visible as a single layer due to the small amount of sediment deposition in the 1350 years between the two eruptions (Bolender et al. 2016; Bolender et al. 2017; Steinberg et

al. 2016). The next visible tephra is the Landnám sequence, a deposit consisting of three tephras from the time of initial settlement, often observed with layers of extreme burning (Catlin 2011; Steinberg et al. 2016). The oldest of the three included tephras is a dark black layer, most likely from the Katla eruption, however, the date is inconclusive. This is followed by the Landnám tephra from the Veiðivötn fissure swarm associated with the Torfajökull and Bárðarbunga volcanos, dated to A.D. 871 $\pm$ 2 (Grönvold et al. 1995). This layer is an olive-green tephra over a white tephra, however, in Skagafjörður, only the green layer is visible within soil profiles. The final tephra within the Landnám sequence is a blue-green layer from the 10th century, with a tentative date of around A.D. 950 (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). The next tephra seen in Skagafjörður is a dark tephra layer associated with either the Grímsvötn or Veiðivötn eruption of A.D. 1000. The most consistent and visible layer within almost every core is the Hekla 1 (H1) tephra, from A.D. 1104. This consists of a white tephra of substantial thickness. Two final tephra layers seen in Skagafjörður are from Hekla eruptions in A.D. 1300 and A.D. 1766. Both are relatively thin and vary from grey-blue to dark black depending on location and soil moisture (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016).

Vegetation

A large component of this thesis focuses on understanding the vegetation cover across Hegranes and how this affected the carrying capacity of farmland. The carrying capacity is the ability of a landscape to support livestock grazing. Carrying capacity can

be measured through the amount of utilizable biomass. Utilizable biomass is the amount of vegetation that is available to grazing livestock (Thomson 2003). Prior to settlement, the Icelandic landscape consisted of extensive birch woodlands and fairly consistent vegetation coverage (Lawson et al. 2007). Despite the previously forested landscape, much of Iceland is now cleared farmland (Figure 3).

Figure 3. Cleared farmland on Hegranes, Skagafjörður, Northern Iceland.

Erosion was an unwanted byproduct of the transformation from trees to fields, as the Norse settlers purposefully attempted to raise the productivity of land through practices of intensification (McGovern et al. 1988). The woodlands that previously covered Iceland were not well-suited to the Norse intensive pastoralism. While woodlands produce more *total* biomass than other low vegetation coverage, the percentage of *utilizable* biomass for humans or livestock is relatively small. Grasslands

produce nearly twice as much utilizable biomass, making these environments, and the development of such environments, more desirable to farmers (Catlin and Bolender 2018; Thomson 2003).

Despite the 40% loss of land area to erosion, the doubling of utilizable biomass during the conversion from forest to grassland increased overall land productivity. The least productive farms were often located in the highlands, as they were placed on less arable land with fixed resources that required extensive labor to maintain. These highland farms were the most susceptible to the negative consequences of erosion and deforestation, while lowland farms often saw gains to the productivity of their grazing lands with increased soil deposition (Catlin and Bolender 2018). This is exemplified in past studies of the Mývatn region of Iceland: settlements located on interior, highland lands were largely abandoned during the 13th century, while settlements located in lowland areas continued to thrive. This abandonment was attributed to either widespread depopulation of the area, or negative environmental effects, like soil erosion, resulting from poor landscape management (Vésteinsson and McGovern 2012; Vésteinsson et al 2014).

SeAR/E can be used to determine the amount and timing of vegetation loss and soil erosion (Amorosi et al. 1997; Arnalds 1987). This allows for a distinction of *local* factors of degradation from more widespread *regional* trends. The difference between the two patterns indicates whether erosion and subsequent soil movement was a result of general environmental impacts or localized anthropogenic actions. Livestock played a

significant role in the expansion of erosion and depletion of the landscape (Amorosi et al. 1997). Additional intensification practices, including manuring and local irrigation, affected flora and fauna in ways that are still apparent today (Amorosi et al. 1997).

Climate

In conjunction with anthropogenic factors, the climate in Iceland indirectly impacts soil movement and directly affects vegetation growth. Situated at the meeting point for cold polar air and warm Atlantic air, summers in Iceland are cool, and winters not overwhelmingly cold. Rain falls frequently, and the wind can often make the temperature seem colder. This variable climate is a result of the surrounding seas; the warm Irminger current and cold East Greenland current merge in the open water causing temperature and moisture fluctuations (Einarsson 1984; Eythorsson 1949; Ogilvie 1991). During initial occupation, Iceland's climate may have been favorable, with warmer temperatures than experienced post A.D. 1300, and a relatively stable climate. A warm period occurred between the 9th to the 14th centuries in much of the northern Atlantic, followed by a decline in temperature (Ogilvie and Jónsson 2001; Amorosi et al. 1997; Dugmore, Keller, and McGovern 2007; McGovern et al. 1988; Thórhallsdóttir et al. 2013). After A.D. 1300, a series of colder, wetter years led to glacial expansion and subsequent abandonment of some inner farms (Amorosi et al. 1997). An aspect of the current research explores how these climatic changes would have impacted available vegetation, and subsequent grazing capacity for farms. As erosion is also an indirect

result of climatic effects, climate is therefore a factor in understanding farm productivity and household response to environmental change.

Paleoclimatic data sets from ice-cores in Greenland provide high quality regional environmental data about the Arctic climate (Ogilvie and Jónsson 2001; Amorosi et al. 1997; Dugmore et al. 2006; Dugmore, Borthwick et al. 2007; Dugmore, Keller, and McGovern 2007). The Greenland Ice Cores suggested that the transition from the warm initial settlement period to the Little Ice Age (A.D. 1550 to 1850) was the most dramatic transition in 6,000 years. This resulted in growing seasons shortening considerably, which stressed already over-grazed pastures (Amorosi et al. 1997). Previous research in Iceland has observed the impact of climate on grass growth and hay yield from A.D. 1601 to 1780, products essential for winter fodder and farming (Ogilvie 1984). In northern Iceland, where the current study area of Skagafjörður is located, temperatures in the spring and summer are strongly related to grass growth and harvest. Winter temperatures for grass growth and final harvest are also significantly related (Ogilvie 1984). While temperatures for all seasons are related, lower temperatures have visible negative effects. In the research conducted by Ogilvie (1984), summer rainfall was the only rainfall data examined, as there was a lack of adequate rainfall data for all other seasons. The relationship between rainfall and hay harvest was most significant in the north and west areas of Iceland. The highest statistically significant results appear to be from the northern region, as the southern areas of Iceland seems noticeably less sensitive to changes in climate. Overall, there is a strong crop-climate relationship in Iceland for

almost all variable combinations of seasons, temperatures, and grass growth/hay harvest (Ogilvie 1984; Dugmore, Keller, and McGovern 2007).

Due to Iceland's climatic conditions, the four seasons are not of equal length: spring begins in late April, summer in late June, autumn late September, and winter in late October (Eythorsson 1949). Temperatures in the spring and summer are strongly related to grass growth and harvest in the northern and western regions of Iceland. In the south, the relationship between the summer temperature and growth/harvest is more important than spring. Winter temperatures for grass growth are significantly related in the north and west regions, but not the south, while winter temperatures for the final harvest are related in all regions (Ogilvie 1984). In general, lower temperatures throughout Iceland have visible negative effects. In the research conducted by Ogilvie (1984), the relationship between rainfall and grass growth was strongest in the south, where the relationship between rainfall and hay harvest was most significant in the north and west. The highest statistically significant results appear to be from the northern region, as the south seems noticeably less sensitive to changes in climate. The current study area of Hegranes in located in one of the more sensitive areas of northern Iceland, and therefore more vulnerable to climatic fluctuations. Overall, there is a strong crop-climate relationship in Iceland for almost all variable combinations of seasons, temperatures, and grass growth/hay harvest (Ogilvie 1984; Dugmore, Keller, and McGovern 2007).

This observed annual crop-climate growth cycle potentially speaks to the results of this thesis research, as the amount of utilizable biomass will be considered for four climatic scenarios within the environmental simulation model, Búmodel. These include climate values for a baseline, warm, cold, and extreme cold climate scenario. Búmodel models seasonal productivity and grazing impact on the local and regional landscape within these different climates (Thomson 2003). The regional landscape provides a better examination of the interplay between vegetation and climate and subsequent SeAR/E (Thomson 2003).

Ecological Practices and Land Use

Farm settlements were often situated in fertile lowland fjords, valleys, and coastal plains. Settlements focused on areas where resources such as grass, water, and woodland or peat bogs were accessible for livestock and fuel (Vésteinsson 1998). However, resource availability varied between farm settlements, with some areas more productive than others. To ensure the maximum productivity from the available land, farms worked to enhance the natural quality of the land through practices of intensification. Intensification is the process of improving the land through investing labor and capital to yield a greater production (Brookfield 1984). Intensification in Iceland included the clearance of forests to create pastureland, and the enriching of fields through manuring (Adderley et al. 2008). Other efforts included the maximizing of livestock grazing times and locations, and seasonal labor had to be performed in order to maintain the viability of the land (Catlin and Bolender 2018). By anthropogenically enriching the lands through

deliberate modifications to the landscape, farm yields increased (Brookfield 1984; Adderley et al. 2008; Bolender 2006; Catlin and Bolender 2018).

This thesis addresses changes in farmstead size over the three study periods in relation to production activities, utilizable biomass, and SeAR/E. Past intensification could affect these variables as such practices often resulted in unintentional movement of soil, subsequently impacting the available vegetation and potentially affecting the farm productivity. Previous research in northern Iceland has identified a correlation between higher farmstead size, historical measures of farm productivity, and the early establishment of farms (Steinberg et al. 2016). As such, for this research, farmstead size appears to be a good proxy for household and herd size, in addition to overall farm productivity (Steinberg et al. 2016; Bolender and Johnson 2018).

The subsistence economy in Iceland depended on domestic animals and cereal cultivation, reflecting an adaptation to the different local environments (Amorosi et al. 1997; Ingimundarson 2010). There are two main relationships that existed between the farming household and the land; both are maintained through livestock and available vegetation. In terms of the grazing, Icelandic farmers set limits on the timing of summer grazing, due to the restrictions of their marginal environment. During the summer months livestock was moved to highland pastures to allow grass growth for fodder near the farms to support the animals through the winter. By not exhausting the productivity of the land, farms could increase hay production to increase herd size and livestock benefits (Simpson et al. 2004). Hay production focused on both homefield and outfield production for

winter fodder. The amount of hay available to supply livestock through the winter, in addition to some winter grazing, allowed for a maintenance of herd size, milk production, and fertility (Bolender 2006; Catlin 2011; Thomson 2003; Thórhallsdóttir et al. 2013).

There are two categories of hay production in Icelandic agriculture: *úthey*, a lesser quality grass from outfield areas, like meadows and wetlands, extensively harvested over time, and *taða*, high quality grass that is produced within the cultivated homefields surrounding the main domestic buildings of the farmstead (Friðriksson 1972). These production strategies worked together to accumulate as much hay as possible for winter fodder. This thesis research focuses on examining the SeAR/E within a small localized catchment area that emphasizes homefield areas, in relation to the broader 19th century property boundary that includes areas used for both categories of hay production. Hay harvesting occurred from late July through September. Homefield hay depended on precise timing and ready labor, whereas outfield hay could be harvested throughout late summer. Intensified homefield areas increased both soil fertility and grass quality, enhancing the productivity of a farm (Friðriksson 1972).

Farms were dependent upon transhumant pastoralism, where livestock were moved from lowland to upland locations depending on the season (McGovern et al. 1988). This infield-outfield system allowed farms to be largely self-sufficient. Outbuildings scattered within the homefields contributed to additional production activities (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). The

development of such a widespread farm resulted in significant alterations to the natural environment through creation of a cultural landscape.

Today, many farms remain in the same location where they were first established, while others were abandoned. This initial intensification of farm resources was critical to the survival of the farms and formed lasting resources that the farming household relied on, impacting overall farm productivity and survival (cf. Brookfield 1984). Abandonment of a farm is most likely indicative of some significant change in the landscape.

Study Area: Skagafjörður and Hegranes

The region of Hegranes is located in the northern area of Skagafjörður, North Iceland. It is 16km long by 4km wide (Figure 4). Hegranes is an example of a marginal and varied regional landscape, containing several different types of vegetation coverage, resulting in distinct farm locations. In this lowland region, there are increased areas of bedrock, bog, and heathland (Catlin 2011, 2016; Bolender et al. 2017). The geology consists of Upper Tertiary basic and intermediate extrusive basalts overlain by morainic glacial till (Bolender et al. 2017; Feuillet et al. 2012). The glacial rivers of Héraðsvötn flow on both the west and east sides of the island, separating Hegranes from the rest of the valley (Bolender et al. 2017). There is evidence of localized patterns of soil erosion and deposition throughout the region, although the extent of anthropogenic or environmental effects is indeterminate (Bolender et al. 2017). Soils in the region consist of a brown andosol that, while non-cohesive, has an extremely high-water retention

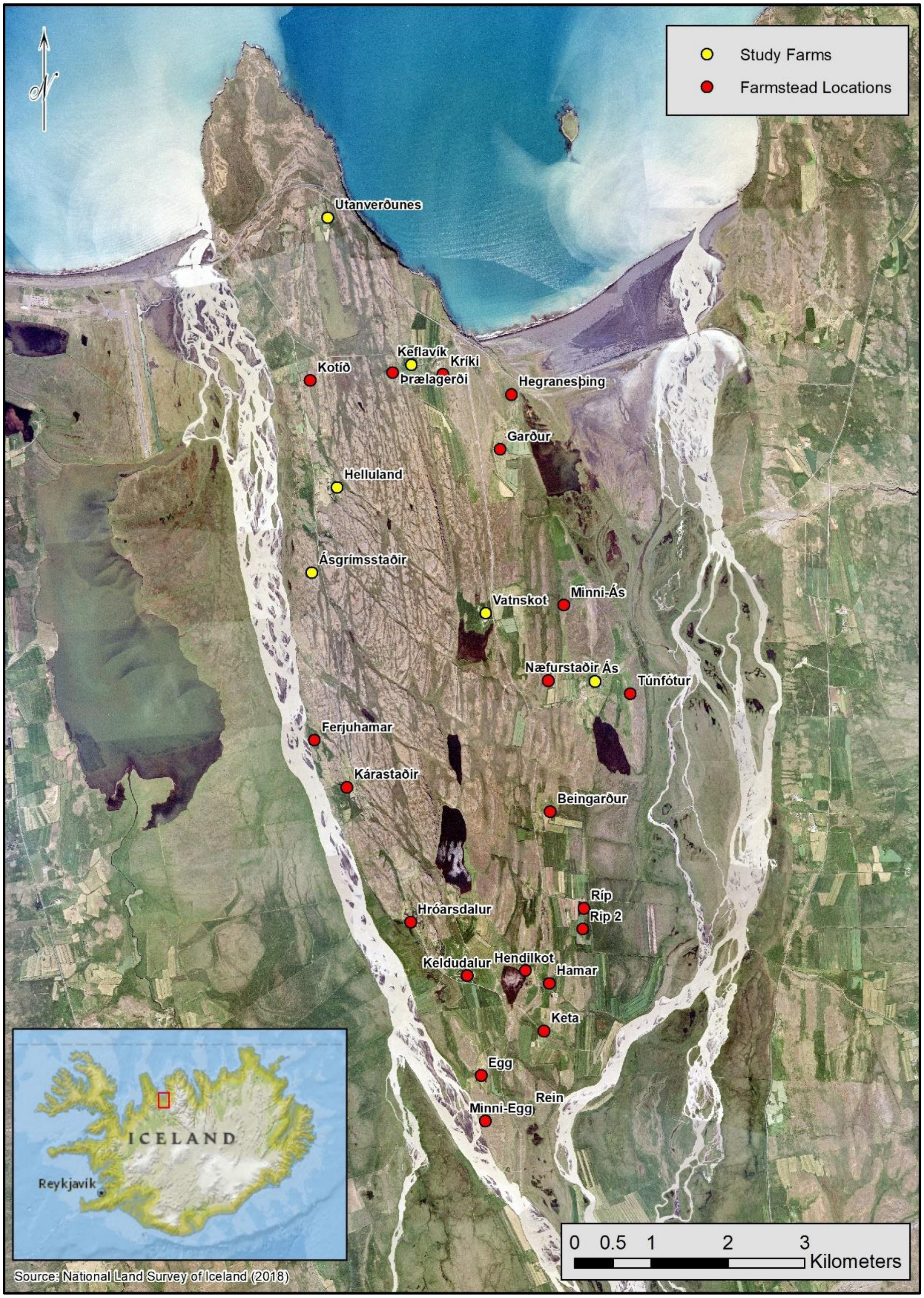

Figure 4. Research location of Hegranes, Skagafjörður, Northern Iceland.

capability and can better support vegetation growth (Arnalds 2008; Bolender et al. 2017). Sediment accumulation is varied, as areas of deep soil can be found immediately adjacent to areas eroded down to glacial gravel and bedrock (Catlin 2016). This is indicative of a location that is exposed to both natural and anthropogenic elements, resulting in erosional activities. Stratigraphy within Hegranes consists of rapidly formed sediment and soils, intermixed with tephra layers, gravel layers, and glacial lenses.

Initially claimed by 22 colonists, Skagafjörður is a valley in north central Iceland (Pálsson and Edwards 1972). As recorded in the Jarðabók Árna Magnússonar (Magnússon and Vídalín 1930) there are 12 primary farms (still active today) on Hegranes: Keflavík, Garður, Ás, Ríp, Hamar, Keta, Egg, Keldudalur, Hróarsdalur, Kárastaðir, Helluland, and Utanverðunes, and two abandoned farms: Ferjuhamar, and Ásgrímsstaðir. This thesis study focuses on seven of these farms: Helluland, Keflavik, Ás, Vatnskot, Utanverðunes, Rein, and Ásgrimsstaðir (see Figure 4).

This research uses data collected from previous surveys by the Skagafjörður Archaeological Settlement Survey (SASS)/Skagafjörður Church and Settlement Survey (SCASS) in 2015 and 2016. SASS/SCASS conducted research to understand the relationship between the Viking settlement hierarchy and Christian consolidation (Bolender et al. 2008; Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). Teams investigated the regions of Langholt and Hegranes during subsequent field seasons in northern Iceland. Applying extensive coring, geophysics, and traditional

excavation, SASS/SCASS conducted a settlement pattern study, creating an inventory of farm sites and their locations. Over 7,000 cores were taken as part of the regional coring survey that covered the region. SASS/SCASS determined three basic archaeological measures: farmstead location, farmstead size at the end of the Viking Age, and farmstead establishment date (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). As the farm is difficult to identify archaeologically due to its dispersed qualities, these surveys concentrated on the farmstead, rather than the farm, as a whole (Bolender et al. 2016; Bolender et al. 2017). Known farmstead sites were systematically cored to estimate their extent at various periods in history.

Farmstead size was determined by calculating the area of continuous spread of cultural layers that occurs under the H1 tephra layer. Cultural materials include building debris, midden, and charcoal deposits. This calculation represents the maximum farmstead size reached by A.D. 1104. Depending on the presence or absence of cultural material, farmstead sizes were calculated for time periods within known tephra layers. Where natural boundaries were present, these were used as farmstead extents. The farmstead establishment date range was based on the lowest peat ash deposit in relation to the surrounding identified tephra layers (Bolender et al. 2016; Bolender et al. 2017; Steinberg et al. 2016). Several farm mounds have been occupied since the initial settlement of Iceland, while some farms were occupied for shorter periods, either due to abandonment or relocation (Bolender et al. 2017).

On Langholt, a region southwest of Hegranes across the Héraðsvötn river, SASS surveyed 22 modern farm properties to understand the settlement pattern within divisions of wealth and hierarchy (Steinberg et al. 2016; Bolender et al. 2008). By looking at farmstead size as a proxy for wealth, size was used to examine the distribution of productivity among farms over time (Steinberg et al. 2016). Larger farms were settled first, and later smaller farms scattered in between. SASS found that many farms remain in the same location as those established during the Viking Age (Bolender et al. 2011; Steinberg et al. 2016). The researchers felt that there were significant advantages for earlier settled farms (Steinberg et al. 2016). Additional research conducted on Langholt examined productivity between farms in relation to political economy (Bolender 2006). The economy was mainly based on livestock, primarily cattle and sheep (Bolender 2006). Results found that differences in productivity were related to homefield size and agricultural intensification. This research touched on the complex relationship between environmental degradation, property, and intensification (Bolender 2006). On Hegranes, SCASS continued the work completed on Langholt, surveying 16 farm properties to determine the relationship between establishment date and farmstead size (Bolender et al. 2016; Bolender et al. 2017). On Hegranes, there was a much greater variation between farmstead sizes with similar establishment dates, and a greater range of farmstead sizes in general. This suggests that some aspect of the landscape was affecting each farm individually, resulting in differences in productivity and subsequent changes in farmstead size. The current research will assist in identifying why farmsteads did not follow a distinct pattern in size on Hegranes.

The *Fornbýli* Landscape and Archaeological Survey (FLASH) on Hegranes was conducted and led by Kathryn Catlin during three subsequent field seasons from 2015-2017 (Catlin et al. 2016, 2017). FLASH examined ruined structures and sites (*fornbýli*) to understand the role of anthropogenic environmental and landscape change on the establishment, abandonment, and reuse of such sites. During environmental profiling, detailed erosion data was difficult to obtain due to the complexity of turf architecture, absence of tephra layers, and significant differences in soil depths within close vicinities. Coring data assisted in timing erosional events at many of the fornbyli due to the presence or absence of tephra layers (Catlin et al. 2016, 2017). This data suggested significant erosion events at numerous sites prior to A.D. 1104, between 1104 and 1300, and again after 1766 (Catlin et al. 2017). It appears that major erosion events occurred either at the same time or just after occupation of the fornbýli ended around 1104. By the late 11th and 12th centuries, the outlying areas of Hegranes were no longer used for settlement but continued to be used as part of seasonal or day-to-day farm management with fornbyli used as infrastructure for livestock (Catlin et al. 2017). After the second round of erosion in the 19th century, the fornbýli ceased to be occupied. While the current study does not consider these smaller sites, they could very well play a role in the fluctuations in farmstead size across Hegranes.

CHAPTER 3: METHODS

Stratigraphy in Iceland is unique given its varying inclusion of tephra layers, resulting in local stratigraphic sequences across the island. Tephra is a layer of sediment that consists of small micro-particles that were released during volcanic eruptions. Due to the distinct variation in color and sequence between each tephra, it is possible to match tephra layers to specific volcanic eruptions. This allows for a precise comparison of occupational periods across farms and the landscape. Information gathered during coring allows for these tephra layers to be quickly and easily examined, identifying levels of anthropogenic activity and depth of soil accumulation. Evidence of human activity within core locations allows for an estimation of farmstead size and area, while SeAR assists in explaining how soil moved around the landscape from both a regional and local perspective. Through dating the soil horizons, tephra presence allows for the ability to connect disparate coring sequences to the farmstead locations and sizes. This information can aid in determining whether soils moved due to natural erosional processes, or as a result of anthropogenic actions.

Further examination of vegetation coverage complements this SeAR/E data, as soil movement can affect the growth patterns and availability of specific types of vegetation. Each type of vegetation coverage corresponds to a unique utilizable biomass

amount which contributes to the amount of resource availability in a certain location. Utilizable biomass is the carrying capacity of each type of vegetation; or, the ability of a specific vegetation within the landscape to sustain livestock. By understanding how vegetation cover equates to utilizable biomass, the resource demands of each farm can be assessed and compared throughout the study area on Hegranes. Local patterns of SeAR/E could have impacted the vegetation coverage, subsequently affecting farmstead size and resulting productivity.

Coring/Data Collection

Coring is applied in archaeological research to determine the location, size, and stratigraphic sequence of buried sites (Steinberg et al. 2016). Easily conducted, coring can be performed relatively quickly and at a low cost, allowing for large swaths of land to be covered in a short amount of time (Catlin 2011). Previous work in Skagafjörður, Northern Iceland, has involved extensive coring to reveal information about site locations, sizes, and times of occupation and abandonment (Bolender 2006; Bolender et al. 2016, 2017; Catlin 2011; Steinberg et al. 2016). During the SCASS field seasons on Hegranes in Skagafjörður, approximately 7,000 total cores were collected by the excavation team (Figure 5) (Bolender et al. 2016; Bolender et al. 2017). SCASS coring was conducted mainly on and around farm mounds, to determine the area and date of farmstead deposits (Bolender et al. 2016; Bolender et al. 2017). This systematic soil coring on Hegranes simultaneously collected tephra data which was examined to date periods of SeAR/E.

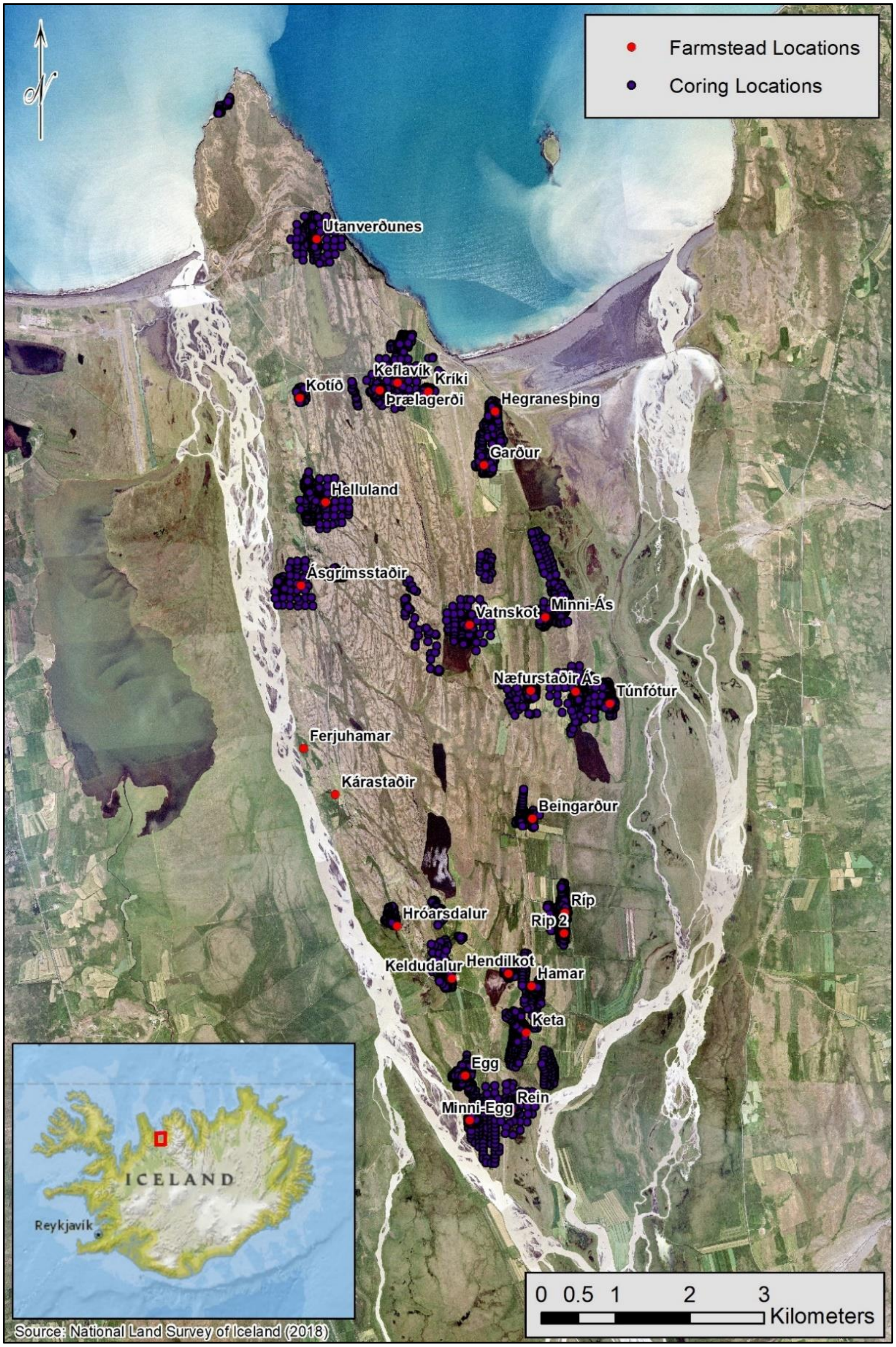

Figure 5. SCASS coring locations on Hegranes.

For this research, additional coring was conducted in 2017 at seven farm locations on Hegranes: Ás, Ásgrímsstaðir, Helluland, Keflavik, Rein, Svanavatn, and Utanverðunes. Each of the seven farms was given a 350-meter buffer in which to core at 50m intervals. This buffer was large enough to include any variations in topography, vegetation, and soil coverage for each farm. The landscape on Hegranes includes high and lowland areas, dense vegetation and sparse, and varying depths of soil, including extensive areas of exposed rock. Coring was conducted where possible within the 350-meter buffers; in areas of exposed rock the coring location was shifted from the designated 50 m grid to a nearby area with greater soil depth. This shift was necessary to collect as much tephra data as possible for each farm and to systematically assess local soil movement. Given the field time and crew available for personal research during the 2017 field season, this buffer also presented a necessary limitation to the research for this thesis.

Cores were collected using the JMC Backsaver soil sampler push probe along an approximate 50m grid. The barrel of the coring device is 18 inches long and 1.25 inches wide, with the ability to extend for a total depth of 120 centimeters. If the core reached subsoil or glacial till before the full 120 cm, the core was terminated. Using an iPad and field notebook, each stratigraphic layer was measured and recorded by type, depth, and width. Stratigraphic layers included tephra layers, soil horizons, and farmstead deposits. Farmstead deposits consisted of middens, turf deposits, and dense cultural layers and floors (Steinberg et al. 2016). If a core was particularly well-stratified, showing clear definition between soil types and tephra layers, or was difficult to interpret for the survey

team, photographs were taken for later analysis and tagged to the coring location. Due to multiple individuals recording field data, potential discrepancy between measurements of stratigraphic layers is to be expected. After extracting the soil and recording the necessary details, the soil was returned to the hole.

Coring locations were captured and updated within Collector for ArcGIS on the iPad. The Collector program allowed survey teams to view field maps in the field and collect spatial data easily and in real time, continually updating the map during fieldwork so other survey teams could view new coring information. Where necessary, core locations were additionally recorded using a differential GPS that provided more accurate location captures. All geographic data was recorded in ISNET93 (Icelandic Land Survey Network), the national Icelandic geodetic reference system. ISNET is used for all GPS measurements taken for Iceland, and regularly re-measured to ensure accuracy due to local distortion from earthquakes and volcanic eruptions (Landmælingar Íslands 2004). Recording data in this system allows for easy integration with additional Icelandic data. The information collected in the field was later entered into a FileMaker relational database where coring data could be compared and further interpreted as needed.

Vegetation Modelling

There are several types of vegetation that cover Iceland's landscape. To study environmental changes and impacts over time, it is important to recognize and understand the variety of available vegetation as a resource. The type of vegetation directly

contributes to the productivity of farms through the amount of utilizable biomass, or the amount of vegetation that is available to grazing livestock. Some vegetation types are more conducive to supporting livestock than others. Several models of vegetation classification have been developed over the years for the Icelandic landscape. This current research uses vegetation classification information from three vegetation models: Búmodel, Nytjaland, and Vistgerðakórt. Búmodel, an environmental simulation model created by Amanda Thomson (2003), utilizes vegetation coverage values from the Icelandic Agricultural Research Institute (RALA) and previous vegetation studies (Guðbergsson 1980; Steindórsson 1980; Thorsteinsson and Arnalds 1992). Thomson's (2003) simulation model allows for calculations of utilizable biomass from available vegetation across the Icelandic landscape during different climatic scenarios. The *Nytjaland* (farmland) database was produced in 2001 by the Agricultural University of Iceland as a GIS landcover database. The database was compiled from satellite imagery to produce a vegetation classification map representing the productivity and land use properties of the Icelandic vegetation (Arnalds n.d.). In 2014, an online vegetation coverage geodatabase, *Vistgerðakórt* (vegetation land map), was developed by the Icelandic Institute of Natural History. Vistgerðakórt includes even greater vegetative detail and was created to make land data for Iceland more accessible to the public for research (Ottósson et al. 2016).

As each of the three models uses a slightly different system of vegetation classification, the vegetation coverage classifications for this research were assigned based upon the values provided in Vistgerðakórt, the most recent and detailed vegetation

model, and then combined and reclassified to fit the classifications in Búmodel. While the vegetation assignments were partially compatible, vegetation in a single location in Iceland may have been under two different classifications in the different models. This reclassification allows the vegetation coverage in Vistgerðakórt to be compatible with the environmental model, Búmodel, to produce values for utilizable biomass on Hegranes (Table 2). By comparing the amount of available utilizable biomass on Hegranes to SeAR/E and farmstead size, variations in landscape fertility and how this relates to the other research variables are examined across the region.

Búmodel

Amanda Thomson (2003) developed Búmodel, an environmental simulation model, for her dissertation on farm management and ecological interactions. Búmodel was created to manipulate the Icelandic vegetation coverage to allow for study of past farmland management strategies. Such manipulations include: modelling utilizable biomass from various vegetation types under varying seasonal and climatic conditions (from warm to cold); considering winter grazing as part of farm productivity rather than limiting to spring/summer grazing; and providing grazing impacts given various stocking levels within the landscape. Thomson's (2003) classifications were influenced by the Icelandic Agricultural Research Institute (RALA) vegetation mapping from 1955-1979, the first complete vegetation classification specific to Iceland (Guðbergsson 1980). Within this method, vegetation was classified by physiographical characteristics, followed by dominant plant species (Steindórsson 1980). Thomson (2003) also examined

Thorsteinsson and Arnalds' (1992) vegetation classifications developed during their research conducted in Þingvallavatn in south-western Iceland. Their classifications consisted of six main plant communities, in addition to an ungrazeable category.

Thomson (2003) reorganized vegetation classifications from these previous vegetation studies into eight grazeable vegetation communities for use in Búmodel. The Búmodel vegetation communities include: hayfield, grassy heath, dwarf shrub heath, moss heath, birch woodland, bog/mire, riverine, sparsely vegetated field, and one category for ungrazeable. These nine total classifications can be run through a grazing simulation designed to assess land management strategies through measuring grazing pressures and carrying capacity of a landscape. Through application of Búmodel, Thomson (2003) predicted spatial and temporal patterns of vegetative biomass, and the amount of utilizable biomass available during specific climates, regions, and landscapes in Iceland. By examining grazing patterns and pressures, landscape vegetation coverage was used as a proxy for amount of land productivity.

Calculations of utilizable biomass from each vegetation community are examined within four climatic scenarios in Búmodel: baseline, warm, cold, and extreme cold (Table 1) (Thomson 2003). These were developed from recorded meteorological observations of temperature from 1845 onwards, in conjunction with documentary sources from earlier dates when meteorological data was not available. Within each climatic scenario, the mean monthly temperature influences the starting date and length of the vegetation growing season and subsequent biomass production. The baseline scenario comes from

Table 1. Utilizable biomass values in Búmodel (Thomson 2003).

Baseline scenario		May	June	July	August	September	October	November	December	January	February	March	April		TOTAL
Hayfield	Baseline	430	2190	3080	2820	1920	1150	780	550	550	550	550	550		15120
Grassland	Baseline	500	2080	3130	3050	2020	1440	940	720	585	585	585	585		16220
Dwarf shrub heath	Baseline	970	1350	1485	1620	1580	1375	1175	970	800	800	800	800		13725
Moss heath	Baseline	60	80	140	120	85	65	60	60	60	60	60	60		910
Bog/mire	Baseline	720	1100	1280	1460	1450	1440	1290	1000	750	750	750	750		12740
Riverine	Baseline	660	2660	3800	3600	2480	1480	950	710	575	575	575	575		18640
Grazed birch woodland	Baseline	1000	2100	2700	2780	2270	1780	1340	1060	870	870	870	870		18510
Sparsely vegetated land	Baseline	50	150	200	190	130	90	60	45	35	35	35	35		1055
Extreme cold scenario		May	June	July	August	September	October	November	December	January	February	March	April		
Hayfield	Extreme co	430	1095	1870	1930	1275	780	390	390	390	390	390	390		9720
Grassland	Extreme co	500	1040	1300	1570	1410	1000	650	500	410	410	410	410		9610
Dwarf shrub heath	Extreme co	800	970	1080	1190	1210	1130	970	800	660	660	660	660		10790
Moss heath	Extreme co	60	70	80	90	65	45	40	40	40	40	40	40		650
Bog/mire	Extreme co	700	750	860	970	1075	1065	955	740	555	555	555	555		9335
Riverine	Extreme co	575	800	1495	2190	2070	1235	790	590	480	480	480	480		11665
Grazed birch woodland	Extreme co	870	1435	1710	1825	1640	1285	970	770	630	630	630	630		13025
Sparsely vegetated land	Extreme co	50	80	100	125	115	80	55	40	30	30	30	30		765
Warm scenario		May	June	July	August	September	October	November	December	January	February	March	April		
Hayfield	Warm	785	2940	4040	3680	2480	1490	1000	810	810	810	810	810		20465
Grassland	Warm	800	2770	4120	3960	2620	1870	1200	980	980	980	980	980		22240
Dwarf shrub heath	Warm	1030	1515	1690	1870	1810	1575	1345	1110	915	915	915	915		15605
Moss heath	Warm	80	100	165	140	95	75	65	65	65	65	65	65		1045
Bog/mire	Warm	800	1220	1450	1680	1660	1640	1470	1140	855	855	855	855		14480
Riverine	Warm	810	3260	4700	4450	3020	1730	1110	830	670	670	670	670		22590
Grazed birch woodland	Warm	1240	2600	3310	3320	2650	2080	1570	1240	1020	1020	1020	1020		22090
Sparsely vegetated land	Warm	90	180	245	230	150	110	75	60	45	45	45	45		1320
Cold scenario		May	June	July	August	September	October	November	December	January	February	March	April		
Hayfield	Cold	430	1545	2670	2530	1630	980	570	490	490	490	490	490		12805
Grassland	Cold	500	1465	2005	2254	1805	1260	820	630	520	520	520	520		12819
Dwarf shrub heath	Cold	800	1160	1283	1380	1395	1253	1073	885	730	730	730	730		12148
Moss heath	Cold	60	75	105	105	75	55	50	50	50	50	50	50		775
Bog/mire	Cold	700	925	1070	1215	1263	1253	1123	870	653	653	653	653		11028
Riverine	Cold	575	1130	2140	2895	2275	1358	870	650	528	528	528	528		14003
Grazed birch woodland	Cold	870	1768	2205	2303	1955	1533	1155	915	750	750	750	750		15703
Sparsely vegetated land	Cold	50	115	147	165	127	85	55	45	35	35	35	35		928

the mean temperature from a 30-year period between 1961-1990; the warm scenario comes from the average of the ten warmest years between 1937 to 1995, and represents a 'typical' warm year; the cold scenario is the average from the ten coolest years between 1937 and 1995, and represents a 'typical' cold year; and the extremely cold scenario is the mean temperature from data recorded during the coolest decade between 1859-1868 (Thomson 2003).

Precipitation was not included in Búmodel as it is difficult to determine the extent of rainfall and impact due to its variability across months and regions (Thomson 2003). This absence of this variable could negatively impact model results for utilizable biomass as rainfall does significantly affect the landscape in some areas of Iceland given the variability in rainfall amounts across different regions on the island (Thomson and Simpson 2006). As seasons and temperature change, there is also a variability in available vegetation and the type of vegetation that the livestock consumes. These changes in dietary composition of sheep have been previously recorded and observed in both Iceland and Scotland (Grant et al. 1976).

Management inputs in Búmodel are the number and type of livestock, and the length of grazing spent in an area within one year (Brown et al. 2012). Despite the Icelandic agricultural systems' dependence on sheep, cattle, and horses, only sheep are accounted for in Búmodel; there is much greater information in past literature regarding basic nutritional requirements and grazing practices for sheep than the other livestock. As sheep are the only livestock accounted for in the model, resulting values of utilizable

biomass and its ability to sustain the recorded amount of livestock could be inaccurate (Thomson and Simpson 2006). For her model, Thomson (2003) utilized the values for the number of livestock recorded in the Jarðabók, which contains a written record of agricultural values between 1702 and 1714. Conducted by Árni Magnússon and Páll Vídalin (1930), this documentation provides insight into aspects of Icelandic farming agriculture. Given that the relative difference in farm productivity seen in the Jarðabók appears to remain fairly consistent over time, it is reasonable to think these recorded counts are representative of earlier periods. The fodder intake in Búmodel is designed to reflect the amount of fodder necessary for an animal to function normally. This value is derived from an estimate of the amount of fodder each farm needs to support livestock through the winter months, in combination with available land for winter grazing (Thomson 2003). The research for this thesis is focused on estimating changes in productivity based on changes in the landscape. Búmodel allows for an approximation of how the amount of available utilizable biomass affects the ability of each of the seven study farms on Hegranes to support these recorded livestock values and maintain productivity.

Nytjaland

To estimate the amount of available utilizable biomass surrounding each farm on Hegranes, vegetation coverage for the region needed to be established and verified. The Agricultural University of Iceland (*Landbúnaðarháskóla Íslands*) developed Nytjaland, a farmland vegetation coverage database. The database was created through classification

of multispectral satellite imagery of the Icelandic landscape (Arnalds n.d.). As satellite imagery can be difficult to interpret, information about aquatic areas was acquired from the National Land Survey of Iceland, and wooded landscapes from the Icelandic Forest Service (Arnalds n.d.). This vegetation database was developed to show the productivity and grazing properties of Icelandic vegetation within farmland areas. In Nytjaland, classifications of vegetation are split into 10 groups: *Ræktað land* (farmland), *Kjarr og skógur* (shrub and woodland), *Graslendi* (grassland), *Votlendi* (wetland), *Hálfdeigja* (semi-wetland), *Rýrt Mólendi* (poorly vegetated heath land), *Ríkt mólendi* (richly vegetated heath land), *Mosi* (mossland), *Hálfgróið* (partially vegetated land) and *Líttgróið* (sparsely vegetated land) (Nytjaland 2006).

The data in Nytjaland is organized by dividing the whole of Iceland into eight regions: Austurland, Höfuðborgarsvæðið, Norðausturland, Norðvesterland, Suðurland, Suðurnes, Vestfirðir, and Vesturland. Each region is further divided into *hreppar* (municipalities). Norðvesterland, where Skagafjöður is located, has been divided into 12 *hreppur* (adiminstrative unit/communities organized around common grazing resources). Each hreppur was responsible for managing the access to common grazing lands, livestock numbers, and the fall round up of livestock (Arnalds 1987). Within each hreppur is an extensive list of all of the known farms in that area. Under each farm is an approximate measurement (in hectares) of the farm with subsequent measurements of each vegetation category within the farm boundary. The information was formatted into a GIS database for easy manipulation and exploration of the Icelandic landscape. To ensure

the best accuracy for the vegetation layer on Hegranes, the values provided in Nytjaland were compared to a more recent vegetation coverage model, Vistgerðakórt.

Vistgerðakórt

Nytjaland provides a database of the farmland vegetation coverage in Iceland, but there were some overarching issues with the classification system (Arnalds n.d.). Within the Nytjaland model, it was difficult to determine the actual boundaries of vegetation types on Hegranes between what was shown on the database coverage layer versus on the actual landscape. Additionally, the applied vegetation classifications were restrictive, including a high diversity of vegetation types within a single Nytjaland classification (Arnalds n.d.). The development of Vistgerðakórt, a vegetation classification model for all of Iceland, served to further distinguish the Icelandic vegetative landscape (Figure 6) (Ottóson et al. 2016). Developed by the Icelandic Institute of Natural History (*Náttúrufræðistofnun Íslands)* utilizing digital graphics with the assistance of infrared imagery, Vistgerðakórt displays the limits of vegetation and landscapes within a selected location.

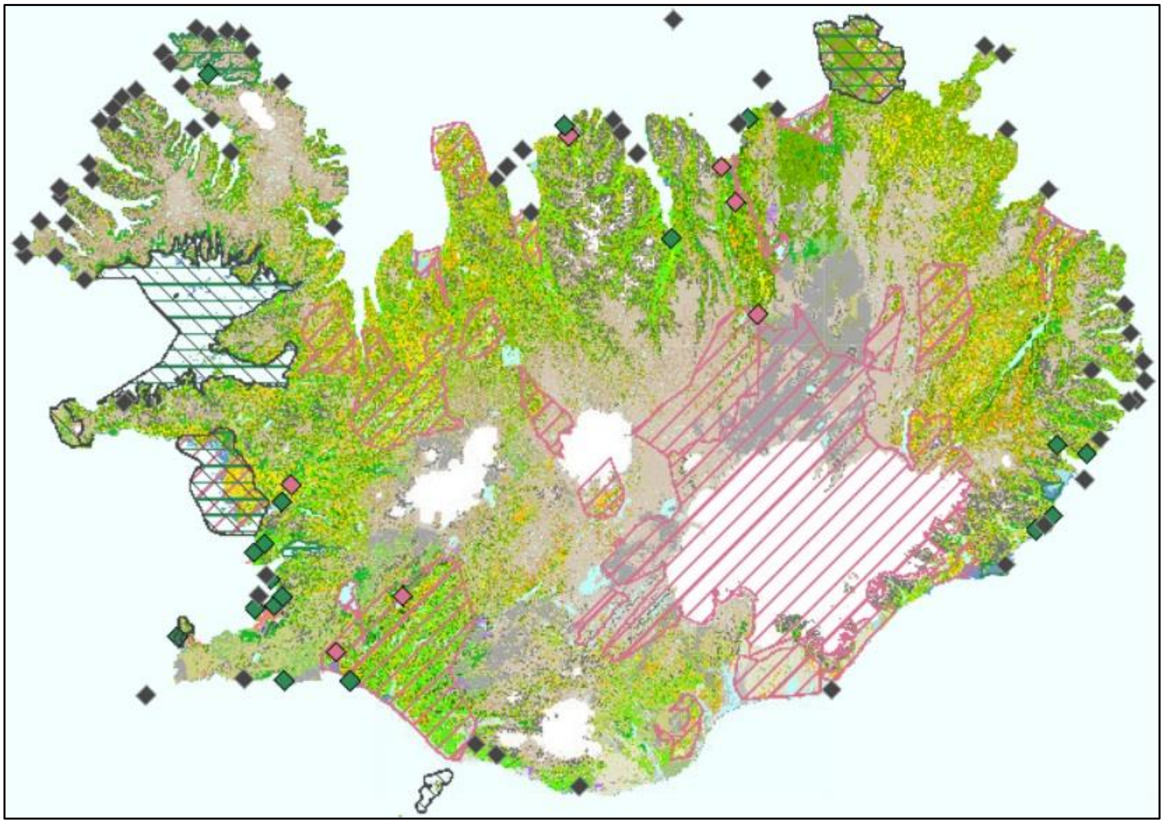

Figure 6. Vegetation coverage model, Vistgerðakórt (Náttúrufæðistofnun Íslands 2018).

The classifications for vegetation coverage within Vistgerðakórt are divided into seven main categories: *Mosi* (mossland), *Moléndi* (heathland), *Graslendi* (grassland), *Blómlendi* (flowering vegetation), *Kjarr- og skóglendi* (shrub and woodland), *Ræktað land* (farmland), and *Votlendi* (wetland) (Ottóson et al. 2016). Each of the seven main categories have been further subdivided into sub-categories consisting of: *Mosagróður* (moss vegetation), *Hélumosagróður* (snowfall vegetation), *Lyngmói* (dry heaths), *Fjalldrapamói* (dwarf brich), *Viðimói* (hilly), *Þursaskeggs- og sefmói* (thornbush), *Starmói* (dryland), *Fléttumói* (stripped vegetation), *Valllendi* (grassland), *Melgresi* (sand vegetation), *Sjávafitjar* (coastal vegetation), *Finnungur* (lowland vegetation), *Alaskalúpína* (lupine), *Birkikjarr- og skóglendi* (brich grove and woodland), *Gulvíðikjarr*

(shrub groves), *Garðlönd og tún* (gardens and fields), *Uppgrætt land* (farmland), *Skogræt* (forested), *Deiglendi* (damp lands), *Mýri* (swamp), *Flói* (bay), and *Vatnagróður* (wetland). Overall, vegetation assignments were decided based on the growth pattern and presence of surrounding vegetation in an area. If vegetation coverage is less than 10% in an area, then the land is classified as lacking vegetation, and subsequently sorted by land type (Ottóson et al. 2016).

The main categories of vegetation in Iceland under the Vistgerðakórt model vary by landscape depending on soil coverage, water proximity, and environmental or anthropogenic effects. *Mosi* (mossland) covers more than half of the country's total vegetation. If there is *more* than 50% of moss coverage in an area where there is additional vegetation, the classification assigned is "mosi". While there are areas that include an extensive amount of moss coverage, if the total is *less* than 50%, then this will not be noted within the vegetation classification. *Moléndi* (healthland) consists of a dry, low-lying, dense vegetation that often forms in hummocks across the landscape. Several berry variations grow in this type of vegetated area. *Graslendi* (grassland) characterizes areas covered in tall grasses. Often found in lowlands, this coverage can also be seen on sand and in areas close to water. *Blómlendi* (flowering vegetation) describes an area covered in flowering plants with little moss. Vegetation such as this is found is areas where the soil is very favorable to growth. *Kjarr- og skóglendi* (shrub and woodland) includes trees that grow in clusters or small groups; birch trees are the only tree native to Iceland in these areas. *Ræktað* (farmland) land encompasses any area that has been affected anthropogenically. These include areas cultivated for fodder, and forested areas

that have been repopulated due to human intervention. *Votlendi* (wetland) consists of areas that have water levels just above or below ground surface (Ottóson et al. 2016).

Application to Current Research

Accurately representing past landscape coverage can be difficult; for this research the contemporary vegetation coverage is utilized as an estimation of past vegetation. Using contemporary vegetation maps for a historical analysis can be problematic as the identified vegetation coverage has most likely changed over time. In Iceland, pollen data tells us that the original settlement landscape would have been wooded, with a forest cover that declined significantly during the settlement period, eventually returning to a relatively stable, albeit less tree-covered, vegetation (Hallsdóttir 1996). However, the modern vegetation coverage databases do not incorporate such extensive past woodlands. While past vegetation change cannot be accurately modeled, this research modelled the effects of past landscape change by looking at the SeAR, not changes in past vegetation cover, and therefore is less affected by specific vegetation changes.

Before beginning calculations for utilizable biomass, the Nytjaland vegetation layer was compared to the vegetation coverage for Vistgerðakórt to determine which vegetation model offered the best data. During this comparison, Vistgerðakórt was determined to have higher resolution, greater vegetative detail, and to better correspond with the actual vegetation on the landscape. Due to the greater quailty of Vistgerðakórt,

this vegetation layer was used for this research. In order to work with the newer vegetation database model in Búmodel, the vegetation layers from Vistgerðakórt had to be converted to match the eight grazeable vegetation communities in the simulation. The data was manipulated through application of ESRI ArcGIS Versions 10.5 and 10.6. First, the Vistgerðakórt data layer was clipped to Skagafjörður in ArcMap to eliminate the additional Icelandic landscape coverage.

To apply Búmodel calculations to past landscape management as closely as possible, the vegetation assignment needed to be indicative of past spatial distribution, while representing a variety of vegetative diversity. A partial solution to this issue involved the reclassification of modern cultivated homefields. During the process of preparing to work with the vegetation data for this research, all areas previously classified as cultivated land were converted to early modern homefield areas as defined by homefield maps (*túnakort*) areas from 1918. This was appropriate as homefield areas were relatively stable through the medieval to early modern period (Bolender 2006), and past research on farm production on Hegranes has shown that there is little change in the recorded homefield sizes between 1850 and 1901-1920 (Pálsson 2010). The túnakort layer was then reclassified to remove modern cultivated fields and replace these locations with past homefields and vegetation coverage. Past vegetation was estimated from aerial photography and neighboring values within Nytjaland and Vistgerðakórt.

Land cover values throughout Skagafjörður within this reclassified layer included: *Graslendi* (grassland), *Ríkt mólendi* (richly vegetated heath land), *Ræktað* (cultivated

land), *Rýrt mólendi* (poorly vegetated heath land), *Náttúrulegt birkilendi* (birch shrubland), *Ræktað skóglendi* (forestry), *Mosi* (moss land), *Hálfdeigja* (semi wetland), *Votlendi* (wetland), *Hálfgróið* (partially vegetated land), *Littgróið* (sparsely vegetated land), *Straum-og stöðuvötn* (lakes and rivers), *Jöklar og fannir* (glaciers), and *Ófokkað eyjar/sker* (uncategorized, islands and reefs). This layer was further simplified to fit Búmodel values as needed (Table 2). While this is problematic, as the process converts the Icelandic landscape to fit within the constraints of the environmental simulation model, the amount of work required to rebuild Búmodel based on the Vistgerðakort vegetation categories would have been too extensive for the current research.

Table 2. Vegetation Classifications Between Vistgerðakórt and Búmodel.

Vistgerðakórt	Búmodel Classifications
Aðrar landgerðir	Hayfield
Strandlendi	Grassland
Graslendi	Grassland
Mólendi	Grassland; Dwarf shrub heath; Moss heath
Melar- og sandlendi	Moss heath; Sparsely vegetated land
Eyrar	Moss heath; Sparsely vegetated land
Moslendi	Moss heath
Mýrlendi	Moss heath; Bog/Mire
Skriður og klettar	Sparsely vegetated land
Moldir	Sparsely vegetated land
Strandlendi	Sparsely vegetated land

Búmodel vegetation classifications consist of only eight grazeable categories, and as such many vegetation classifications have been combined: hayfield is equivalent to cultivated grassland; sparsely vegetated land to barren land; bog/mire contains both communities of wetland, bog and fen; and the riverine vegetation community was created to cover areas equivalent to halfbog, or mire margin. Riverine is not included in the

model for the current research due to lack of clarity in its application. Due to the number of years between Thomson's (2003) vegetation assignments and research conducted for this thesis, aerial photographs of Thomson's study locations were compared to Hegranes to see how the vegetation between the regions compared and whether assignments made sense. Given current restrictions and time limitations it would be difficult to discern any further land coverage interpretation without ground-truthing the entire study area. Observations from the 2017 fieldwork for the current research, and the inspection of aerial imagery, has determined that the vegetation classifications from the Vistgerðakórt conversion into Búmodel vegetation communities are acceptable for an initial investigation of the historical interaction between land and farm productivity.

Calculating Utilizable Biomass

Employing the tools within ArcMap, the vegetation layer compatible with Búmodel allowed for areas of utilizable biomass to be calculated for each farm. Two areas were used, one within the 350-meter catchment buffer around each known farmstead on Hegranes, and the 19th century farm property boundaries. There is no modern property boundary available for the farm Rein, located in southern Hegranes, or Ásgrímsstaðir, located just south of Helluland on the western side of Hegranes. The 350-meter buffer served as a catchment area for each farm, including variations in topography, vegetation, and soil coverage within a close vicinity to the farmstead. The calculated area of utilizable biomass can show the differences in carrying capacity at each farm. This was calculated for all types of vegetation coverage (with the exception of

riverine) represented in Búmodel: hayfield, grassy heath, dwarf shrub heath, moss heath, birch woodland, bog/mire, sparsely vegetated field, and ungrazeable. A comparison between calculations of available utilizable biomass allowed for a visualization of the variability of grazing pressures around each farm.

In order to calculate the utilizable biomass for each farm, a catchment analysis was performed (Figure 7). First, the total amount of land for each vegetation coverage classification was calculated within the 350-meter catchment buffer and 19th century modern property boundary. The resulting vegetation coverage totals were converted into available utilizable biomass to estimate the carrying capacity of the land. By comparing utilizable biomass amounts for the changing farmstead areas over the three study periods, the amount of utilizable biomass at each farm can be identified and examined in relation to changes in farmstead size. Further assessment of fluctuations in sediment accumulation rates in relation to available utilizable biomass could identify periods of erosion and how areas of soil movement affected subsequent vegetation coverage. In reviewing resource availability in relation to area for each farm, we can see whether the average utilizable biomass within a specified landscape around the farm potentially influences the productivity of a farm, and fluctuations in farmstead size.

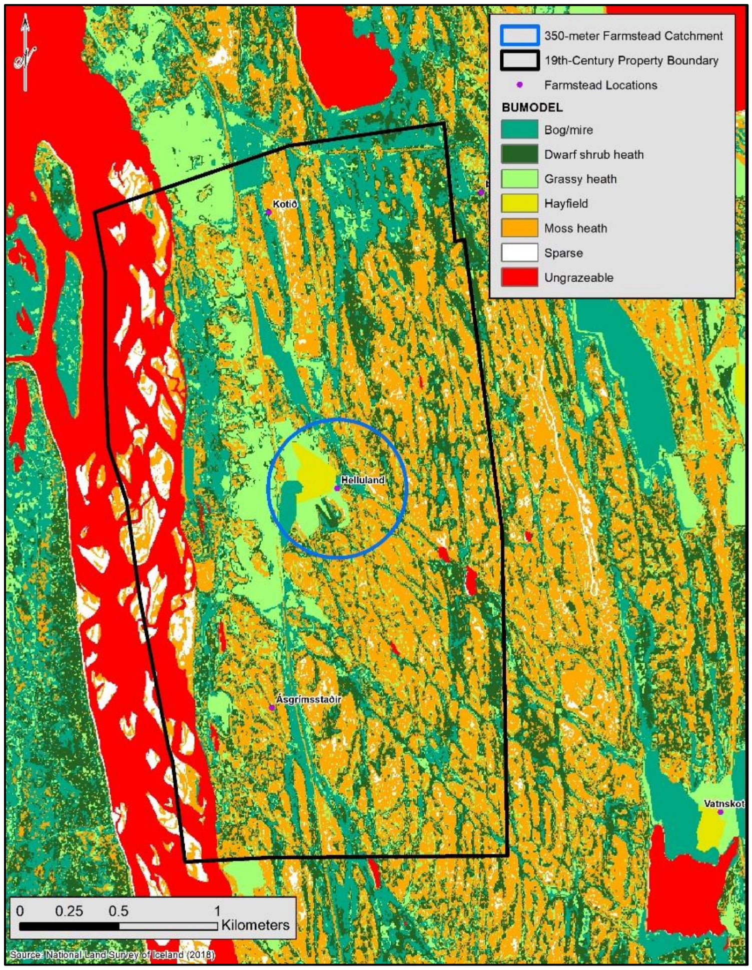

Figure 7. Búmodel vegetation categories as seen within the 19th century modern property boundary and 350-meter catchment buffer for Helluland.

To calculate the total area of each vegetation classification within the 350-meter catchment buffer and 19th century modern property boundary, the Spatial Analyst tabulate area tool in ArcMap was applied. This resulted in an attribute table with the area of each vegetation class within each boundary. Using the values from Búmodel for each land cover type, the total utilizable biomass for each farmstead catchment was calculated. To do this, a new field was added within the previously created attribute table for the farmsteads, and a calculation was scripted applying specific grazing values for each

vegetation classification. This resulted in the calculated amount of utilizable biomass for each type of vegetation. The grazing values came from the four climatic scenarios of herbage inputs in Búmodel: baseline, warm, cold, and extreme cold. These calculations were conducted four separate times for each climatic scenario using the values provided by month, and a total cumulative value for all 12 months. The grazing values for utilizable biomass in kilograms (kg)/hectare (h) (10,000m^2) for each vegetation community for the baseline climatic scenario in July, considered the most productive month of the year in Iceland, can be seen in Table 3 (italicized values are not present on Hegranes).

Table 3. Amount of Utilizable Biomass Per Vegetation Class in Búmodel.

Vegetation Class	Utilizable biomass (kg/h)
Hayfields	3080
Grasslands	3130
Dwarf Shrub Heath	1485
Moss Heath	140
Bog/Mire	1280
Riverine	*3800*
Grazed Birch Woodland	*2700*
Sparsely Vegetated Land	200

As the area values from the catchment sizes are in square meters and the utilizable biomass values are per hectare (10,000m^2), within each calculation the land class area had to be divided by 10,000 and multiplied by the utilizable biomass values above. The equation below is a model of the baseline climatic scenario utilizable biomass calculation for each farm. This equation was run for both the 350-meter catchment buffer and the 19th century modern property boundary buffer:

([HAYFIELD] /10000*3080) + ([GRASSY_HEATH] /10000*3130) +
([DWARF_SHRUB] /10000*1485) + ([MOSS_HEATH] /10000*140) +
([BOG_MIRE] /10000*1280) +
([SPARSE] /10000*200)

This calculation was applied for all four weather scenarios within Búmodel: baseline, warm, cold, and extreme cold. A utilizable biomass value was calculated for each month, January – December, with a total cumulative number calculated for all 12 months. With these calculated cumulative utilizable biomass amounts for each farm within both the 350-meter catchment buffer and modern 19th century boundary, a collective excel spreadsheet was created that contained all the utilizable biomass calculations, farmstead establishment dates, farmstead calculated size at Pre-1000, Pre-1104, Post-1104, between 1104-1300, Post-1300, and an average size over all the phases. Additionally, farm production variables of the Homefield Area Average, Homefield Fertility Average, Homefield Hay Average, Outfield Area Average, Outfield Hay Average, Total Cattle Average, and Total Sheep Average were included. This table allowed for an assessment of bivariate correlations between the provided utilizable biomass values and additional agricultural data to see just how much impact the land had on farm productivity and vice versa.

Farmstead Size

An estimation of farm settlement dates on Hegranes was completed using the tephra sequences found in cores during the previous SCASS field seasons (Bolender et al.

2016, 2017; Steinberg et al. 2016). Where complete tephra sequences were found, test units were opened to confirm the sequence and collect samples for radiocarbon dating. By revealing change in the depth and thickness of sediment layers, coring can assist in determining potential patterns of erosion across the Icelandic landscape.

For this research, farmstead areas were examined in relation to cores with presence of the H3, 1104, and/or 1300 tephra layers. Estimates of farmstead area on Hegranes were previously determined by SCASS through the coding of coring data for presence and absence of farmstead deposits within three phases: pre-1104, 1104-1300, and post-1300 (Bolender et al. 2016; Bolender et al 2017). Within each chronological period, cores were given a “yes”, “no”, or “maybe” based on the presence of cultural deposits between tephra layers. “Maybe” applied to cultural deposits that could not be bound to any specific period due to an absence of tephra. These coring assignments of “yes”, “no”, and “maybe” were then plotted in GIS and outlined for each phase. In general, “yes” deposits defined the basic shape of a farmstead. “Maybe” refined the initial “yes” formation, while “no” deposits were either ignored (when present surrounded by “yes” and “maybe”) or utilized to determine clearer extent of a boundary. Extent boundaries were placed equidistant between a “yes” and “no”; if a “maybe” was present between the two, then the boundary would pass through that point. GIS produced an estimated farmstead footprint and area calculation for each phase based on archaeological data. All farmstead sizes are reported rounded to the nearest $100m^2$ (Bolender et al. 2017).

Sediment Accumulation Rate and Erosion (SeAR/E)

Several avenues were taken to visualize SeAR/E when exploring the coring data and how this may relate to utilizable biomass and farm productivity. Previous research supports using tephra layers to measure soil accumulation rates and therefore potential areas of erosion (Dugmore and Buckland 1991; Dugmore et al. 2000; Streeter et al. 2012; Thórarinsson 1961). Accumulation rates are calculated by measuring the stratigraphic sections between identified tephra layers within testing locations (Dugmore and Buckland 1991). The thickness of tephra layers is removed from the measurements as these have little to do with soil movement. Instead, tephra thickness is a result of how much ash a volcanic eruption released, and the direction of wind at the time of the eruption.

There are difficulties in examining erosion rates through tephrochronology, as badly eroded areas lead to a lack of tephra layers and/or an incomplete sedimentological record. Additionally, accumulation rates can vary over location depending on their position relative to areas of erosion and exposure to natural influences; often sediment accumulation rates increase towards vegetated areas as the vegetation can capture the coarser particles preventing complete erosion of a slope (Dugmore and Buckland 1991). Calculations of SeAR have been used to model erosion on the landscape by examining the rate of thickening soils after A.D. 1104 and the availability of vegetation (Thórarinsson 1961). Visual increases in SeAR after the period when settlers arrived in Iceland show that anthropogenic actions did influence movements of soil (Streeter et al.

2012). These recorded measurements have indicated a contrast with SeAR prior to A.D. 870.

To better conduct analysis on coring data, cores were eliminated that did not have the specific tephras of H3, 1104, or 1300 present. The cores with tephra were clipped to the 350-meter catchment buffer areas to spatially examine the locations of tephra presence, the depth of tephra layers, and whether there is a visible pattern of tephra presence and/or absence in relation to the farmstead. As vertical stratigraphy has been used to calculate past SeAR, the depth of tephra layers provides a good indication of where erosion may have occurred (Dugmore and Buckland 1991). Running localized analyses of spatial autocorrelation on tephra presence within the cores (Anselin Moran's Local I [Cluster and Outlier Analysis] and Getis-Ord Gi [Hot Spot Analysis]) in ArcMap, revealed potential patterns of soil accumulation. Possible erosional events were visible in areas where a specific tephra layer was absent while another tephra layer/s were present. Additional visualization within ArcMap using a graduated color symbology for each tephra, revealed most of the greater soil depths near the farm mound and lesser depths in highland areas, with the exception of a few deeper areas of soil accumulation in recessed highland locations.

SeAR was calculated for the seven systematically cored farmsteads as well as the entirety of farms on Hegranes. This was done in two ways: through application of various spatial analyst tools in ArcMap, and a basic average calculation. To calculate the SeAR in ArcMap, boundaries of the farmsteads for each of the three periods, Pre-1104, 1104-

1300, and Post-1300, were merged together using the Merge tool, to create a polygon for the total farmsteads' area across time. Then, cores were excluded with cultural material to exclude anthropogenic farmstead deposits from the SeAR calculations. To exclude cores with cultural material from the data, the "erase point geoprocessing tool" was applied in ArcMap to first eliminate cores that fell within the total farmstead boundaries. The remaining cores that contained cultural material were further excluded by creating a "Query" for specific cores. The "Query" specified a search for cores where the depth of a selected tephra was greater than zero (SpecificTephra >0) and where any presence of culture within a core was equal to "no" (CultureAllTime = "No"). This selected only the cores that were desired for SeAR calculation and did not include cultural material. After selecting these desired cores for the SeAR calculation, the spatial analyst interpolation tool "Natural Neighbor" in ArcMap was applied for the depths of the necessary tephra layers (Depth_H3, Depth_1104, and Depth_1300) within each 350-meter catchment buffer. This action looked for spatial patterns of SeAR to be identified within the map.

The 3D analyst tool "Surface Volume" was then run on the "Natural Neighbor" interpolated surfaces to provide values for volume of depth of sediment accumulation within the 350-meter catchment buffer for each individual farm. This tool resulted in an attribute table which included values for the volume and total area of sediment accumulation between each tephra layer. By dividing the volume value by total area, the result was the average vertical depth of layers of sediment accumulation between tephra falls within the 350-meter catchment areas. A further division of this vertical depth by the calibrated BP dates of tephra accumulation provided an estimate of the yearly SeAR.

Tephra layers have both uncalibrated BP dates and calibrated BP dates. Uncalibrated BP dates are the initial ^{14}C radiocarbon dates. Calibrated BP dates are the recalibrations from the initial radiocarbon dates received for tephra layers (Streeter et al. 2015). Calibration is necessary to convert initial radiocarbon dating results from a value of “radiocarbon years” to known calendar years. As the atmospheric ^{14}C amount has not remained consistent over the years, calibration is employed to minimize discrepancies in historical dating. The basic average SeAR was calculated by adding together each depth of a specific tephra layer within the cores and dividing by the total number of cores in which this tephra layer was present. Dugmore et al. (1995) has provided further verification of the ^{14}C dating of tephra layers in Iceland.

CHAPTER 4: ANALYSIS

The following chapter provides a discussion of the three main variables that will be examined for this research: farmstead size, SeAR/E, and utilizable biomass. Interplay of these three variables is considered within a 350-meter catchment buffer, and the 19th century modern property boundary for Hegranes farms. Farmstead area is examined as a proxy for farm productivity and represents the changes in farmstead size during three periods of occupation: Pre-1104, 1104-1300, and Post-1300. These three periods reflect moments of anthropogenic change in Iceland, when the landscape would have been most affected by human occupation. SeAR/E is examined as a proxy for environmental change. Soil accumulation rates are calculated from the vertical stratigraphy of tephra layers within the coring data; moments of erosion are identified within periods of dramatic fluctuation in sediment accumulation. This variable examines soil movement within the local and regional landscape around farms on Hegranes. The amount of utilizable biomass (i.e. vegetation carrying capacity) within a farming landscape indicates how well that farm can support its livestock. Measurements of utilizable biomass are considered within four climatic scenarios: Baseline, Cold, Warm, and Extreme Cold. Collectively, these three variables allow us to estimate how well a landscape can support farming production activities and therefore farm sustainability. Methods employed to

break down the main variables for an in-depth analysis of farm productivity and sustainability are described below.

Farmstead Size

Icelandic farms consist of a core farmstead location, in addition to other turf structures, fields, and resources specific to each farm. The core of each farm includes domestic buildings, the kitchen, sleeping quarters, storage areas, and workshops. Surrounding these interior structures is the homefield, where sheep and cattle were housed. To the outside of this location were often wetlands, meadows, and pastures that included the outfields for grazing (Bolender 2006; Steinberg et al. 2016). Environmental and anthropogenic effects on the landscape, like climatic change or widespread cultivation, can indirectly impact farmstead size. These actions cause responses within the landscape, such as erosion and changes in vegetation, that can affect farm yield and productivity, thereby influencing farmstead size. However, it can be difficult to determine which effects cause the greatest impact on a change in farmstead area. A main component of this research is an examination of the transformation in farmstead size over time as a proxy for farm productivity. Studying abandoned and currently active farms on Hegranes allows for a comparison between changes in the surrounding environment and farmstead size. If a farmstead area changes over a specific period of time, or within a certain landscape, then we can determine whether this change in size is a result of an environmental consequence attributed to climate change or impacts resulting from

anthropogenic actions like land management choices. The change in farmstead size is considered during three periods of occupation: Pre-1104, 1104-1300, and Post-1300.

The change in farmstead size was considered through three calculations: farmstead area in each of the three periods (Pre-1104, 1104, and Post-1300); the change in absolute farmstead area (the maximum amount of change experienced) between each of the three periods; and the percentage change (the relative measure of growth or decline) in farmstead area between the three periods. An examination of the change in farmstead size in relation to the data for SeAR/E and utilizable biomass, identifies potential influences of environmental change on farmstead area within the three selected periods.

Changes in farmstead size for each of the three periods was identified by utilizing the information from the coring data in ArcMap. The stratigraphic and location information from the cores was analyzed within ArcGIS, and the boundaries of farmsteads for each of the three periods, determined and drawn in ArcMap. Areas of sedimentation or erosion were examined in relation to the changing boundaries of the farmstead, in an effort to identify any patterns within the soil movement. During visual analysis of the data, possible erosional events were identified through lack of specific tephra layers. Lack of tephra layers are indicative of either a local or regional erosional event, subsequently tied to soil accumulation within, or outside of, the farmstead's 350-meter local catchment buffer. This means that any areas of identified erosion resulted in an increase or decrease of soil within the most productive core area of a farm. Highland

areas that were situated within the 350-meter catchment buffer were difficult to interpret due to sparse vegetation, resulting in greater absence of soil.

Five of the seven selected farms: Ásgrimsstaðir, Helluland, Rein, Vatnskot, and Utanverðunes, distinctly fluctuate in size between the three study periods. These changes in size and area reflect the productivity of farms in the amount of livestock they can support and land intensification practices.

SeAR/E

Previous research involving SeAR/E in southern Iceland has looked at exploring rapid changes in the environment from anthropogenic and climatic influence (Streeter et al. 2012). One of the questions considered in this thesis, is whether the nature of such impacts can be assessed on a farm by farm basis. In looking at the data for the current research, the relationship between SeAR/E and farm productivity appears to be quite complex; there is no definitive pattern of soil accumulation directly impacting an increase or decrease in farmstead size. Contrary to the initial hypothesis, that high sediment accumulation rates should generally correlate with *increases* in farmstead size, the data does not reveal any predictive effect of SeAR on such changes. While local erosion would be assumed to impact farm productivity and subsequently *decrease* farmstead size, this predicted pattern was also not seen in the data. Examining SeAR/E as a proxy for environmental change, against farmstead area as a proxy for productivity, allows for a

consideration of the extent of environmental influence on farm productivity and farmland sustainability. This relationship is examined through the impact of changes in the environment in lowland areas, specifically from erosion, on individual farmstead size.

Stratigraphic information from the coring data was examined to determine the presence or absence of known tephra layers associated with the three study periods. The presence of tephra can be used to calculate patterns of sediment accumulation within a specific location (Dugmore and Buckland 1991; Streeter et al. 2012; Thórarinsson 1961). On Hegranes, these tephra layers are from the volcanic eruptions from H3, LNL, 1104, and 1300. SeAR was modelled for these tephra-defined periods by measuring the amount of soil above, below, and between each visible tephra layer within a core. Two processes were followed to create values for SeAR on Hegranes. First, the SeAR values for each core within the 350-meter catchment area were averaged to produce an average rate. While this method is highly sensitive to the density of coring and localized patterns of tephra preservation among farms, this provided a basic calculation of the approximate amount of sediment accumulation in each area. A second SeAR value was calculated for the same soil measurements within ArcMap, through application of spatial analyst tools.

To better visualize soil movement at each period, the SeAR was calculated within the 350-meter catchment areas for each of the seven systematically cored farms. Focusing within these 350-meter catchments gave a more structured view of the SeAR/E around the immediate farmstead landscapes. To calculate the SeAR for each period, a spatial analysis on the depth of sedimentation between the known tephra layers provided a depth

value for total sediment accumulation. The resulting sediment depth total was then divided by the calibrated date for each tephra to receive the rate of yearly soil accumulation. Cores with cultural material in any layer were excluded from the calculations. These were eliminated as presence of cultural material added depth between tephra layers, causing an inaccurate representation of SeAR within a specific coring location. Excluding cores with cultural material prevented inaccuracies of soil accumulation depictions both within the immediate farm area and external landscape. This coring data was incorporated into ArcMap to visualize potential patterns of SeAR throughout the three study periods. Areas with distinct fluctuations in SeAR between periods are most likely indicative of some sort of erosional activity. Within ArcMap, the coring data could be easily manipulated, allowing for a selection of specific cores to examine by tephra presence or core location. The resulting SeAR calculations for the soil depths between tephra layers were compared to the three farmstead area variables over the three study periods:

1. SeAR in relation to *farmstead area* at the beginning of each of the three periods: this revealed the amount of available soil relative to farmstead size for each of the three study periods.
2. SeAR in relation to the *absolute farmstead area* throughout an entire period: this revealed the maximum change a farmstead size could have experienced with a change in soil accumulation in the same period.
3. SeAR in relation to the *percentage farmstead area* for each of the three periods: this revealed the relative measure of growth or decline for

farmstead size from one period to the next in relation to the changing amount of soil.

SeAR within the 350-meter catchment area examines how the immediate landscape around a farmstead was affected by soil movement. This soil movement is a product of erosion, either local or regional, or a combination of the two. A change in sediment accumulation is often a result of upland erosion, whether through natural or anthropogenic effects (Dugmore and Buckland 1991). Soils travel downslope, impacting lowland areas through an increase or decrease in soil levels. Depending on how much soil accumulates within a farm, the affected farm responds through land intensification practices, fluctuation in farmstead size, relocation, or abandonment.

Utilizable Biomass

Utilizable biomass amounts reveal the potential carrying capacity of a specific landscape, which is the ability of vegetation within a landscape to sustain livestock. The calculated areas of utilizable biomass for this research are representative of the carrying capacity at each farm on Hegranes. Utilizable biomass was calculated within Búmodel for the 19th century property boundaries and 350-meter catchment areas. Examining the change in farmstead size over the three study periods shows whether the size of farmsteads is correlated with availability of utilizable biomass, or that another environmental or social factor is more important in establishing a farm area. While the

vegetation coverage model (Vistgerðakórt) used for this calculation is of the modern landscape, correlations with historical measures of farm productivity and farmstead size, suggest that it is a reasonable approximation of past land cover and grazing yields. The biomass calculations from Búmodel do correlate with measures of farmstead size, showing that available vegetation is a strong factor in determining the size (and resulting productivity) of farms for each study period.

For the calculations of vegetative utilizable biomass within the 350-meter buffer and 19th century property catchment areas, Búmodel provided input data for each type of main vegetation classified in Iceland during four different climatic scenarios: Baseline, Cold, Warm, and Extreme Cold. Additional values in the model included the number of livestock that could be supported on specific amounts of utilizable biomass offered by each type of vegetation. The calculated utilizable biomass data allowed for examination of the amount of utilizable biomass in relation to farmstead size and location, over time and climatic change.

The amount of utilizable biomass within each catchment area is indicative of the ability of a specific landscape to support the livestock necessary for farm productivity. Comparing the available utilizable biomass values for the four climatic scenarios, with changes in farmstead size over the three periods, can reveal whether a certain weather scenario correlates better with farm productivity or, that changes in the weather do not factor into changes in farm productivity. Differences in utilizable biomass values due to the amount of land available per farm potentially shows whether the size of the farmstead

is related to the amount of available utilizable biomass. Changes in farmstead size can then be examined to determine whether the amount of available utilizable biomass was able to continuously support the farms' productivity throughout the three study periods.

Correlations

Each of the values provided by the above data were cumulated and examined in a Statistical Package for the Social Sciences (SPSS) analysis program to explore relationships between the varying data. Bivariate correlations were run on the data values to provide insight as to how these values interacted in the past. Specific variables included in the correlations were: *SeAR*, change in SeAR (*Δ SeAR*), *Total Farm Area*, *Total Farmstead Area*, change in Farmstead Size (*Δ Farmstead Size*), *Utilizable Biomass Values*, and *Farm Production*. The *SeAR* included the basic soil accumulation values calculated around the three selected periods (H3, H3-1104, 1104, 1104-1300, 1300, and Post-1300). *Δ SeAR* includes two variables: the absolute change of SeAR (the maximum change) and the percentage change of SeAR (the relative measure of growth or decline) between the three periods. The *Total Farmstead Area* is the calculated area in m^2 of the shapefile for farmstead size. *Δ Farmstead Size* also includes two variables: the absolute change of the farmstead size and the percentage change in farmstead size, in comparison to the size in the previous period. *Utilizable Biomass Values* included total amounts from each climatic scenario for both the 350-meter catchment buffer and 19th century property boundary. Additional biomass values for each climatic scenario from the months of July and January provided a month-by-month examination of how well the vegetation inputs

from Búmodel accurately represented vegetation coverage of the landscape during changes in climate. According to Thomson (2003), July is the warmest and most productive month in Iceland, therefore January provided an appropriate counter comparison. *Farm Production* includes variables that are associated with farm production: homefield and outfield area averages; homefield and outfield hay fields; and livestock counts. The livestock counts include numbers from the late 19th century records and the early 18th century recorded in the Járðabók Árna Magnússonar (Magnússon and Vídalín 1930).

To thoroughly examine the farmstead survey data and develop an understanding of how the different variables related, the following correlations were run:

1. SeAR : Total Farm Area : Total Farmstead Area : Δ Farmstead Size
2. SeAR : Utilizable Biomass Baseline Values
3. Δ SeAR : Δ Farmstead Size
4. Δ SeAR : Total Farm Area : Total Farmstead Area
5. Total Farm Area : Total Farmstead Area : Δ Farmstead Size : Utilizable Biomass Baseline Values
6. Farm Production : Utilizable Biomass Baseline Values
7. Farm Production : Total Farm Area : Total Farmstead Area : Δ Farmstead Area : Absolute Farmstead Area

The results were inspected to see whether variables were statistically correlated and the strength of these relationships. Correlations between variables indicated which

aspects of the environment are most interrelated with farm productivity and sustainability. A correlation between *SeAR*, *Total Farmstead Area*, and *Δ Farmstead Size* looked specifically at farmstead size as a product of soil accumulation. This demonstrates whether the size of a farmstead was affected by the rates of sediment accumulation over time, or if the size of a farmstead affected the amount of sediment accumulation on the local landscape. The absolute and percentage farmstead sizes explored whether these relationships between SeAR and Total Farmstead Area could be predictive of the change in farmstead size and/or SeAR during a specific study period.

SeAR compared to the *Utilizable Biomass Baseline Values* examined the effect of SeAR on available utilizable biomass. A correlation here indicates that the SeAR directly affects the amount of utilizable biomass available during the three research periods. Past research has looked at the effect of SeAR/E on changes in vegetation (Dugmore and Buckland 1991; Thórarinsson 1961). Studies show that alterations in the vegetative landscape are significantly impacted by fluctuations in available soil, and that these impacts can be easily identified through destruction of vegetation coverage and heavily eroded areas (Dugmore and Buckland 1991).

Δ SeAR in comparison to *Δ Farmstead Size* looks at the probability of a change in sediment accumulation relating to a change in farmstead size. In other words, does the amount of sediment accumulation over a specific period indicate the percent change of a farmstead from one period to another. A correlation between *Δ SeAR* and *Total Farmstead Area* would indicate that the total change in farmstead area can be

approximated by the probability of a change in SeAR. Previous studies have explored how SeAR can reveal information about environmental shifts in the landscape (Streeter et al. 2012; Streeter and Dugmore 2013). Transitions in SeAR have identified patterns of erosion and subsequent land surface transformation. A relationship between SeAR and Δ Farmstead Size or Total Farmstead Area would instead focus on the cause/result of soil accumulation and anthropogenic shifts on the landscape.

The *Total Farmstead Area* in relation to *Δ Farmstead Size* and *Utilizable Biomass Baseline Values* looks at how farmstead size is affected by the amount of available utilizable biomass. If either farmstead variable is related to the utilizable biomass, then the amount of utilizable biomass could be a determining factor in the size of a farmstead, as utilizable biomass amounts can only support a fixed number of livestock. Alternatively, a relationship here could mean that farmstead size is relative to practices of land intensification, and as farming land practices increase, so too does the amount of available utilizable biomass.

Farm Production compared to *Utilizable Biomass Baseline Values* examines how the variables associated with farm production are potentially affected by the available vegetative biomass within a local and regional setting. Vegetation layers have a specific carrying capacity and as such the land surrounding a farmstead can only support a certain amount of livestock. This relationship between livestock and utilizable biomass has been previously studied in Iceland using the Búmodel environmental simulation model (Thomson 2003; Thomson et al. 2005; Thomson and Simpson 2006, 2007). Focusing on

grazing pressures in relation to vegetation carrying capacity, these studies found that early divisions of the landscape between settlements impacted later livestock/vegetation interaction. Additional considerations like grazing and livestock management scenarios and climate also affected vegetation coverage. The Hegranes landscape was divided during the settlement period; this partitioning of the land could lead to certain areas of the region better supporting vegetation and therefore higher numbers of livestock.

Farm Production variables in relation to *Total Farmstead Area*, *Δ Farmstead Area*, and *Absolute Farmstead Area* considers how the farm production variables influence, or are indicative of, changes in the farmstead area over time. If the production variables (homefield and outfield areas and hay yield in addition to livestock counts) do correlate with farmstead area variables, then resulting hay yields and livestock counts determines farmstead size. Alternatively, the amount of productivity influences the changes in farmstead area over time. Should the different variables for farmstead area correlate with each other, then initial sizes of farmsteads can predict future patterns of farmstead change in area, both in percentage of change over time and general size becoming smaller or larger. If there are no relationships between any of the variables, then farm production is not a key factor in changing farmstead sizes, nor can changes in farmstead size be predicted by visible patterns of farmstead change.

CHAPTER 5: RESULTS

The goal of this research is to understand how fluctuations in farmstead size may have been affected by the changing landscape through identification of correlations between variation in farmstead size over time and SeAR/E. Differing rates of soil accumulation and varied vegetation cover can be a result of anthropogenic and climatic influence (Erlendsson et al. 2009; Streeter et al. 2012; Thórarinsson 1961). By exploring the relationship between environmental impacts and landscape transformation, this will assist in determining the potential effect of SeAR/E on settlement patterning and landscape cultivation. Practices of landscape management, like grazing strategies, are additionally affected by environmental change, subsequently impacting farm productivity. Correlations between the environmental (SeAR/E, utilizable biomass amounts) and anthropogenic variables (farmstead size, farm production activities) identify which elements are most interrelated and provide the greatest indication of a change in farmstead size or abandonment.

To examine a potential relationship, the SeAR/E and vegetation coverage variables were compared to two categories of farm values: farmstead areas and farm catchments. These were further divided to include five sub-variables: farmstead area pre-1104, farmstead area 1104-1300, farmstead area post-1300, a 350-meter catchment buffer

around the central farmstead, and the 19th century property boundary for the farm. Within the 350-meter catchment buffer and the 19th century property boundary, calculations were performed to estimate the amount of available utilizable biomass during four climatic scenarios (Baseline, Cold, Warm, and Extreme Cold), and the sediment accumulation rate within the six periods of study (H3, H3-1104, 1104, 1104-1300, 1300, and Post-1300).

Datasets for the total utilizable biomass amounts within the catchment areas are further sub-divided by two variables: *Large farms* and *All farms*. *Large farms* include the farms on Hegranes that were established first, as the landscape would have been divided differently during initial settlement with access to a larger amount of land and greater amount of resources during this early division. *All farms* consist of all the farms, large and small, on Hegranes. This represents the current division of the landscape. Sediment accumulation rates surrounding the LNL tephra layer were not reflected in the correlations as the coring data used for this research had a limited representation of LNL across the selected farms. Farmstead area values, amounts of utilizable biomass, and measurements of SeAR were compared to farm production variables for the late 19th century including total cattle average, total sheep average, homefield area average, homefield fertility average, homefield hay average, outfield area average, and outfield hay average.

The calculations for farmstead size and SeAR are expanded to include values for the absolute (maximum) and percent (relative growth or decline) measurements of

change between periods. Measuring between periods includes values from *H3-1104 to Post-1104*, *1104-1300 to Post-1300*, *Pre-1104 to 1104-1300*, and from *1104-1300 to Post-1300*. Absolute change is the maximum amount of change experienced within a certain period. Percentage change is the relative measure of growth or decline of a farmstead or SeAR from one period to another. These calculations were added to explore how these relate to measurements of farmstead area and SeAR at each period, and whether the measurement of area or soil accumulation is predictive of fluctuations in the data. Correlations showed a complex relationship between variables when examining changes in farm productivity, utilizable biomass, and SeAR. These relationships are further expanded upon below.

Relationships Across Hegranes

<u>Utilizable Biomass</u>

Vegetation coverage within a farm translates to utilizable biomass, which is the carrying capacity of the land to support livestock. For this research, the available utilizable biomass has been calculated for four climatic scenarios (Baseline, Warm, Cold, and Extreme Cold) and compared to the variables for the farmstead size, farm production activities, and SeAR. Utilizable biomass values for all four climatic scenarios within the 19th century boundary correlate with the farm production activities. These activities include the total cattle average (baseline climate scenario: $r = .884$), the total sheep average (baseline climate scenario: $r = .908$), homefield and outfield hay yield (baseline

climate scenario: r = .896; r = .775), and homefield and outfield sizes (baseline climate scenario: r = .915; r = .917) (Table 4). This means that the utilizable biomass input values used in Búmodel are an appropriate proxy for the vegetation that was present during the 19th century in Iceland. The identification of a relationship indicates that the vegetation model applied to this research, is useful in interpreting the past landscape of the study area.

There is no correlation between the total utilizable biomass within the 350-meter catchment buffer and farm production activities. This could indicate that the immediate landscape was not as important as the entirety of available land within the larger farm property boundaries, or that the homefield is the only area that matters within the immediate vicinity of the farmstead. Alternatively, this could mean that our retrogression of the expanded 20th century homefield areas to vegetation coverage at the time of settlement was not a proper estimate. However, there is a more significant correlation between the initial pre-1104 settlement area of a farmstead and the amount of utilizable biomass calculated within the 350-meter catchment buffer with all four climatic scenarios (baseline climate scenario: r = .474) than the utilizable biomass calculated for the 19th century property boundary (baseline climate scenario: r = .437) (Table 5). As both catchment areas are significantly correlated, this supports the finding that the current vegetation layer used to calculate the utilizable biomass in Búmodel, is a similar representation of the localized vegetation coverage available on Hegranes during the settlement period up to 1104, or that the relative productivity of the environments is similar. While the vegetation was most likely different during settlement, it was

Table 4. Sample of Correlations Between Farm Production and Utilizable Biomass Variables.

		Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Homefield Area Average	Homefield Fertility Average	Homefield Hay Average	Outfield Area Average	Outfield Hay Average	Total Cattle Average	Total Sheep Average
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	1	0.146	-0.033	.751**	.915**	0.256	.896**	.917**	.775**	.884**	.908**
	Sig. (2-tailed)		0.617	0.911	0.002	0.000	0.376	0.000	0.000	0.001	0.000	0.000
	N	14	14	14	14	14	14	14	10	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	0.146	1	0.023	-0.040	0.346	0.278	0.384	0.379	0.451	0.399	0.380
	Sig. (2-tailed)	0.617		0.909	0.880	0.206	0.316	0.157	0.251	0.092	0.141	0.162
	N	14	27	27	17	15	15	15	11	15	15	15
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson Correlation	-0.033	0.023	1	0.214	-0.240	0.063	-0.199	-0.075	0.045	0.118	0.060
	Sig. (2-tailed)	0.911	0.909		0.394	0.370	0.817	0.459	0.816	0.868	0.663	0.825
	N	14	27	34	18	16	16	16	12	16	16	16
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson Correlation	.751**	-0.040	0.214	1	.648**	-0.116	.600*	.611*	0.396	0.364	.553*
	Sig. (2-tailed)	0.002	0.880	0.394		0.007	0.670	0.014	0.035	0.129	0.166	0.026
	N	14	17	18	18	16	16	16	12	16	16	16
Homefield Area Average	Pearson Correlation	.915**	0.346	-0.240	.648**	1	0.085	.951**	.873**	.615*	.551*	.692**
	Sig. (2-tailed)	0.000	0.206	0.370	0.007		0.754	0.000	0.000	0.011	0.027	0.003
	N	14	15	16	16	16	16	16	12	16	16	16
Homefield Fertility Average	Pearson Correlation	0.256	0.278	0.063	-0.116	0.085	1	0.359	0.466	.615*	.674**	.596*
	Sig. (2-tailed)	0.376	0.316	0.817	0.670	0.754		0.172	0.126	0.011	0.004	0.015
	N	14	15	16	16	16	16	16	12	16	16	16
Homefield Hay Average	Pearson Correlation	.896**	0.384	-0.199	.600*	.951**	0.359	1	.929**	.785**	.740**	.848**
	Sig. (2-tailed)	0.000	0.157	0.459	0.014	0.000	0.172		0.000	0.000	0.001	0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Outfield Area Average	Pearson Correlation	.917**	0.379	-0.075	.611*	.873**	0.466	.929**	1	.841**	.766**	.867**
	Sig. (2-tailed)	0.000	0.251	0.816	0.035	0.000	0.126	0.000		0.001	0.004	0.000
	N	10	11	12	12	12	12	12	12	12	12	12
Outfield Hay Average	Pearson Correlation	.775**	0.451	0.045	0.396	.615*	.615*	.785**	.841**	1	.958**	.955**
	Sig. (2-tailed)	0.001	0.092	0.868	0.129	0.011	0.011	0.000	0.001		0.000	0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Total Cattle Average	Pearson Correlation	.884**	0.399	0.118	0.364	.551*	.674**	.740**	.766**	.958**	1	.960**
	Sig. (2-tailed)	0.000	0.141	0.663	0.166	0.027	0.004	0.001	0.004	0.000		0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Total Sheep Average	Pearson Correlation	.908**	0.380	0.060	.553*	.692**	.596*	.848**	.867**	.955**	.960**	1
	Sig. (2-tailed)	0.000	0.162	0.825	0.026	0.003	0.015	0.000	0.000	0.000	0.000	
	N	14	15	16	16	16	16	16	12	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5. Sample of Correlations Between Farmstead Area and Utilizable Biomass Variables.

		Farmstead Area Pre-1104	Farmstead Area 1104-1300	Farmstead Area Post-1300	19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms
Farmstead Area Pre-1104	Pearson Correlation	1	.878**	.825**	0.281	0.437	.474*	0.056	0.040
	Sig. (2-tailed)		0.000	0.000	0.353	0.135	0.017	0.767	0.887
	N	32	18	16	13	13	25	30	15
Farmstead Area 1104-1300	Pearson Correlation	.878**	1	.943**	0.455	0.394	0.251	-0.082	0.033
	Sig. (2-tailed)	0.000		0.000	0.118	0.183	0.315	0.745	0.907
	N	18	18	16	13	13	18	18	15
Farmstead Area Post-1300	Pearson Correlation	.825**	.943**	1	.563*	0.549	0.385	-0.136	0.151
	Sig. (2-tailed)	0.000	0.000		0.045	0.052	0.140	0.616	0.592
	N	16	16	17	13	13	16	16	15
19th Century Property Boundary	Pearson Correlation	0.281	0.455	.563*	1	.874**	-0.153	0.012	.754**
	Sig. (2-tailed)	0.353	0.118	0.045		0.000	0.601	0.968	0.002
	N	13	13	13	14	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	0.437	0.394	0.549	.874**	1	0.146	-0.033	.751**
	Sig. (2-tailed)	0.135	0.183	0.052	0.000		0.617	0.911	0.002
	N	13	13	13	14	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.474*	0.251	0.385	-0.153	0.146	1	0.023	-0.040
	Sig. (2-tailed)	0.017	0.315	0.140	0.601	0.617		0.909	0.880
	N	25	18	16	14	14	27	27	17
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson Correlation	0.056	-0.082	-0.136	0.012	-0.033	0.023	1	0.214
	Sig. (2-tailed)	0.767	0.745	0.616	0.968	0.911	0.909		0.394
	N	30	18	16	14	14	27	34	18
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson Correlation	0.040	0.033	0.151	.754**	.751**	-0.040	0.214	1
	Sig. (2-tailed)	0.887	0.907	0.592	0.002	0.002	0.880	0.394	
	N	15	15	15	14	14	17	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

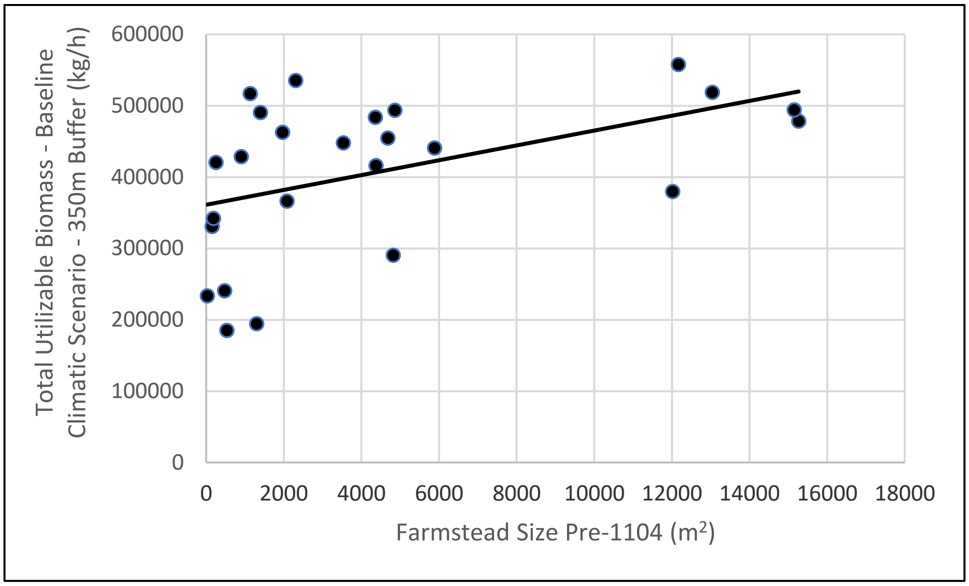

Figure 8. Correlation between the initial farmstead settlement size and available utilizable biomass within a local setting.

comparable to the current vegetation today in terms of the relative amount of biomass it provided to each farm. The landscape within the 350-meter catchment buffer, in terms of the utilizable biomass calculated for the Baseline climate scenario, appears to be more indicative of the size of the initial farmstead area pre-1104 (Figure 8). While there is noticeable variability in small farmstead sizes compared to the amount of available utilizable biomass, higher biomass amounts appear to be a better predictor of large farmstead sizes within the 350m catchment buffer. This means that the biomass available within the immediate vicinity determined the initial settlement size of a farmstead, particularly the larger farms. This is similar to a relationship identified between farmstead area pre-1104 and farm production activities, which shows that the immediate landscape appears to be more important to early farm productivity. In this instance, the initial settlement location and size appears to best predict productivity. This relationship is explored further in the discussion about *Farm Production Activities*.

The 19th century property boundary area shares a significant correlation with the total utilizable biomass for the baseline climatic scenario for the 19th century property boundary (r = .874) and the total utilizable biomass for the baseline climate scenario for *just farms* (r = .754). These relationships suggest that the size of the property affects the amount of available utilizable biomass. The more land available, the greater the utilizable biomass and therefore ability to support livestock and farm production activities.

While the available utilizable biomass for the 19th century property boundary correlates with all of the farm production variables, the 19th century property boundary area shares a significant correlation with all farm production variables except for the homefield fertility average and the outfield area average. This suggests that intensification matters more than the size of a property, as the amount of utilizable biomass is better correlated with all farm production variables than the amount of available land. The relationship between the 19th century property boundary area and farm production variables is elaborated upon in the section on *Farm Production Activities*.

The total utilizable biomass for the Baseline climate scenario for only the *large farms* on Hegranes correlates with homefield activities (homefield area: r = .648; homefield hay average: r = .600), the outfield area average (r = .661), and the total sheep average (r = .553). As the total utilizable biomass for the Baseline climate scenario value for *all farms* (which includes the smaller farms) does not correlate with any farm production activities, this suggests that utilizable biomass values are a better indicator of

landscape productivity around the larger, main farms on Hegranes. However, these calculations do not include the previous divisions of land for the forbýli (Catlin et al. 2016, 2017) which could have impacted the results of the data.

When considering utilizable biomass values for the most productive (July) and least productive (January) months, some surprising relationships are seen. Utilizable biomass values for the Cold and Extreme Cold climate scenarios in July, within the 350-meter catchment buffer, correlate with most farm production activities, however, the same does not apply to the two warmer scenarios. While this correlation could be a result of a random statistical correlation, this relationship suggests that during the colder years, the available land closest to the farmstead becomes a more valuable and necessary resource than in warmer years. If there were colder summers that did not allow for regular amounts of grazing, the dependency on nearby fodder in the colder winter would have increased. Values for utilizable biomass within the 350-meter catchment buffer for January, however, do not correlate with any variables for all four climatic scenarios. This indicates that within the entire landscape, either the immediate land is less useful, or in the coldest, least productive month, the landscape is not utilized, and farms are most likely depending on stored winter fodder.

Research conducted by Amanda Thomson (2003) addressed winter grazing areas as a major component of farm productivity. For Thomson's (2003) study, she assumed that the same pastures were used for grazing year-round; cattle remained indoors while sheep continued to graze and supplement with fodder when necessary. Results from

Thomson's (2003) analysis showed that a reduction in livestock counts assisted in preventing overstressing the landscape and allowed for continued winter grazing. The results from this thesis suggest that winter grazing is not a large factor in impacting livestock numbers; however, depending on the homefield and outfield hay yields, winter grazing may have been more sustainable than storing fodder to last throughout the cold season. Winter grazing is definitely an important aspect of the productivity of the farms. However, unlike Thomson's (2003) analysis which identified winter grazing and fodder needs as key elements in determining livestock counts, this study seems to indicate that livestock levels may not have been based on an expectation of winter grazing.

Though farmers use winter grazing to ensure their hay reserves, given the varied climate and hay yield, winter fodder may have been too unreliable to determine livestock counts. With an inability to consistently regulate how much hay a field would produce for later fodder storage, ensuring that grazing options would be available year-round provided stability for farmers and their livestock. Another possibility that Thomson (2003) discusses includes alternative winter foddering strategies like the utilization of seaweed and shrubbery for fodder in addition to hay. If such supplementary feeding were occurring in Iceland, then this could be a reason that winter grazing was not a determining factor for livestock counts, as there were abundant resources that could be used to sustain livestock throughout the colder months. Thomson (2003) also indicates that the thresholds for each vegetation community in Búmodel may not represent the full impact of grazing in the winter and spring months, therefore storage of winter fodder may not have been as vital as her initial results suggest.

Like the average utilizable biomass values for the 19th century property boundary, the utilizable biomass values for all four climatic scenarios for the 19th century property boundary, in both July and January, correlate with the farm production activities, except for the homefield fertility. This could indicate that homefield fertility is not tied to the vegetation within the larger boundary but is more dependent on the immediate, localized landscape. These relationships with the amounts of utilizable biomass reinforce the potential of the Búmodel values to represent available utilizable biomass during the 19th century, and to relate to actual farming practices. This means that the predictive model works and can be used to answer questions about vegetation and grazing management. The inputs can be altered to represent different study areas and the results will provide an accurate representation of the landscape.

These correlations revealed that the amount of utilizable biomass available within the local 350-meter catchment buffer is more important than the available utilizable biomass on a regional level. In general, the local landscape serves as an important predictor of farmstead size and productivity (see Figure 8). It is this local area surrounding the farmstead that determined the initial settlement size and location and provides key areas for fodder. The utilizable biomass on a regional level most likely supported broader grazing activities and supplemented the local biomass but was not a determining factor in farm settlement.

Farm Variables

Variables for the farms have been divided into *farmstead size* and *farm catchments*. These have been distinguished to better understand measures of farm productivity. *Farmstead Size* variables include: farmstead area pre-1104, farmstead area 1104-1300, farmstead area post-1300, absolute farmstead area pre-1104, absolute farmstead area 1104-1300, absolute farmstead area post-1300, percent farmstead area pre-1104, percent farmstead area 1104-1300, and percent farmstead area post-1300. These farmstead size variables serve as a material and diachronic proxy for farm productivity (Steinberg et al. 2016). *Farmstead Catchment* variables include: a 350-meter catchment buffer around the central farmstead, the 19th century property boundary for the farm, a catchment area created around all of the large farms on Hegranes, and a catchment area that is divided between all of the farms on Hegranes, large and small. The latter two catchment areas serve as a synchronic, but direct, measure of farm productivity.

Correlations with the 350-meter catchment buffer and 19th century modern property boundary examine how variables interact on a local, and more regional, setting around the central farmstead location. *Farmstead area* variables show the measured size of the farmstead for the three study periods. A relationship with these variables would suggest that a change in farmstead area indicates a possible change in the environment. If no change in the environment is evident, then there must be an alternative set of factors that is impacting farm productivity. The *absolute farmstead area* is representative of the maximum amount of *change* that the farmstead *size* experienced between the study

periods. Correlations with absolute farmstead area would mean that the environmental variables are directly impacting the total amount of change a farmstead encounters between periods, either by affecting farm production activities, or changing the amount of available land. If there is no correlation with the environmental variables, then the maximum change is related to an increase or decrease in productivity and/or household size over the course of a period. The *percent change in farmstead area* is the relative measure of growth or decline of a farmstead size between the three study periods. Similar to a correlation with farmstead area, a correlation with the percent farmstead area is indicative of something in the environment changing in a way that can predict the amount of change a farmstead will experience between periods. An absence of environmental correlations most likely indicates that there is another reason for this widespread change in farmstead size; perhaps a social aspect is affecting the fluctuation in settlement size across the region of Hegranes.

Farm variables for all three study periods do not correlate with the utilizable biomass value calculated for the 19th century property boundary within the Baseline climatic scenario. However, utilizable biomass values for the 19th century property boundary within the remaining three climatic scenarios (warm, cold, and extreme cold) do correlate with two farm variables: farmstead area 1104-1300 and farmstead area Post-1300. This relationship between the utilizable biomass values for the 19th century property boundary and farmstead area 1104-1300 and farmstead area Post-1300 suggests that there is a more specific interplay between available biomass and farmstead size. As farmstead size is a proxy for productivity, this means that as the farmstead changes in

area, production activities are also affected. As utilizable biomass values fluctuate, the ability to support livestock and maintain productivity values decreases/increases. Assuming that the amount of available utilizable biomass is related to a change in farmstead size, if farmstead sizes remain similar during these periods, then this relationship is indicative of a relatively stable environment.

Changes in farmstead area over time do not correlate with the utilizable biomass values within the 350-meter catchment buffer for all four climatic scenarios. This could suggest that the available biomass amount within the local area immediately surrounding the farmstead does not affect changes in farm productivity and sustainability. The initial farmstead area pre-1104 does correlate with increases in farmstead area throughout the three periods. These observations suggest that while the amount of utilizable biomass does affect the initial farmstead area, it is this original farmstead area that determines future increases or decreases in total farmstead area, and not the amount of available utilizable biomass. Instead, there must be an alternative environmental or anthropogenic factor that is impacting changes in farmstead size over the study periods.

The relationship between the pre-1104 farmstead size and utilizable biomass within the 350-meter catchment buffer ($r = .474$) shares a stronger correlation than what is seen with the 19th century property boundaries ($r = .437$), where biomass does not share as significant a correlation with pre-1104 farmstead size but is statistically significant when compared to later farmstead sizes (Figure 9). Although a similar correlation to the 350-meter catchment buffer, the amount of utilizable biomass within

the 19th century property boundaries is a less effective predictor of large farmstead size, given the broader range of data points. This greater variability of utilizable biomass within the 19th century property boundaries may indicate that while the local amount of utilizable biomass was important in the selection of initial settlement locations and farmstead sizes, over time as farm productivity changed, so did the amount of necessary utilizable biomass. This resulted in a relationship between a greater catchment area of available resources and farmstead size as reflected in the correlations between the larger 19th century property boundary and farmstead areas between 1104-1300 and Post-1300.

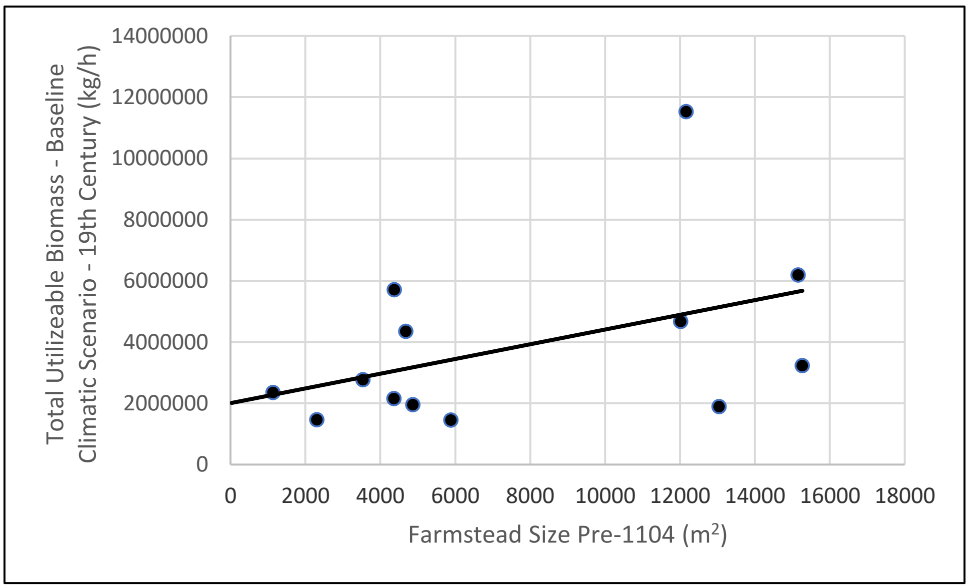

Figure 9. Lack of correlation between the initial farmstead settlement size and the available utilizable biomass within the 19th century property boundary.

These findings reveal that the initial farmstead size is the most important indicator of future changes in farmstead size, not the amount of available utilizable biomass. While the amount of utilizable biomass within a local setting (350-meter catchment buffer) is

important in determining the initial size of a farmstead, it is the amount of utilizable biomass available within the larger regional landscape (19th century property boundary) that impacts later fluctuations in farmstead size and productivity.

Farm Production Activities

The Farm Production variables include: total cattle average, total sheep average, homefield area average, homefield fertility average, homefield hay average, outfield area average, and outfield hay average. The total cattle average and total sheep average are from the 1883-1900 averages from the records of the farmer's society. The livestock values consisted of counts of the domestic stock recorded at individual Hegranes farms. Correlations with the livestock values provide a test of how the environment (SeAR and available utilizable biomass) and changes in farmstead size affect the ability of a farm to support the average number of livestock on Hegranes. The homefield and outfield area averages have been calculated from past measurements of homefield and outfield sizes at each Hegranes farm. Correlations with SeAR/E and/or utilizable biomass would indicate that field size is a direct response to SeAR/E and/or available vegetation. A relationship with these environmental variables shows that these field locations are somehow impacted by changes in the environment. A correlation with farm variables would indicate that fluctuations in farmstead size are indicative of changes in homefield and outfield average sizes. If the homefield and outfield area averages correlate with all the variables, then both environmental and anthropogenic actions have an effect on changes in field sizes over the study periods.

The homefield fertility average is calculated as the yield of grass per unit of homefield area and represents the relative productivity of each homefield. A relationship between SeAR and/or utilizable biomass values with this variable would indicate that environmental effects from changing soil accumulation or vegetation coverage is tied to the productivity of the soils. If there is no correlation with the environmental variables, but a relationship with farm variables, then the change in farm area is affected by the productivity of the soils, resulting in an increase or decrease in farmstead area. This would support the use of farmstead area as a proxy for productivity within this research. Homefield and outfield hay averages are the average amount of hay yield within these two field locations on Hegranes farms. Like the homefield fertility average, correlations between the environmental variables and the homefield and outfield hay averages suggest that hay yield is affected by changes in the environment, either from soil movement or variations in vegetation coverage over time. If the homefield and outfield hay averages correlate with the farm variables, then the average hay yield affects the resulting farmstead area.

Farmstead area pre-1104 shares its strongest correlation with farm production activities. Where other environmental and anthropogenic variables share a more statistically significant correlation with both the total cattle *and* total sheep averages, farmstead area pre-1104 *only* shares a significant correlation with the total cattle average ($r = .579$) (Figure 10). This relationship suggests that the initial farmstead size best represents farm productivity. However, there is an extreme outlier at Ás, where the farm maintained over 300 sheep, three times the amount of the next largest sheep count. This

outlier may be negatively affecting the significance of the correlation by skewing the trendline away from the rest of the sheep count dataset. Alternatively, this comparison between a pre-1104 farmstead area and livestock count from the 19th century could mean nothing; while this relationship may indicate that the number of cows (or relative number of cows) is closely tied to farmstead size over the long-term, any relationship between these variables is highly speculative given the temporal offset between the two.

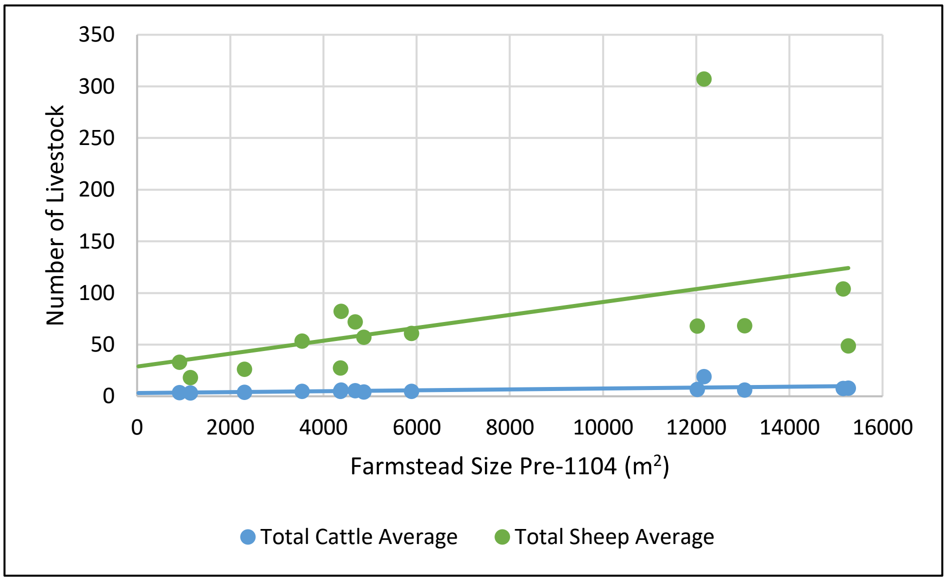

Figure 10. Correlations between the number of livestock recorded at each farm on Hegranes and initial farmstead size pre-1104.

The total cattle average count comes from the 1883-1900 averages recorded by the farmer's society on Hegranes. While the farmstead size is pre-1104 and the livestock counts are from the 19th century, despite this temporal separation, this relationship is still statistically significant. The dataset used to calculate utilizable biomass amounts is also from a modern vegetation layer that has been used to represent vegetation coverage at the time of initial settlement. During this research, this coverage has proven to be a

reasonable representation of the relative amount of available biomass at the settlement period. As the relative productivity has not changed drastically since that time, this means that the available biomass in the 19th century was most likely similar to that at the time of settlement. Therefore, we can assume that the amount of livestock supported on the landscape in the 19th century would be similar to the amount of livestock that could have been sustained by the landscape pre-1104.

Four other variables share a statistically significant correlation with *only* the total cattle average. These include: Farmstead area post-1300 (r = .561); the average SeAR for H3 within the 350-meter catchment buffer (r = .822); and the Baseline (r = .547) and Warm (r = .542) utilizable biomass for July within the 350-meter catchment buffer. When initially established, farmstead size was probably most dependent on farm productivity closer to the farm for survival. Cattle were generally a local grazer around the immediate farmstead area, whereas sheep affected the landscape regionally. This localized grazing pattern could indicate greater hay field and/or more productive soils immediately surrounding the central farmstead. The correlation may have only reflected cattle and not sheep, as sheep were potentially grazed further away or upland from the farmstead, therefore not affecting nearby farmstead landscape and activities.

Farmstead area post-1300 shares a statistically significant correlation *only* with the total cattle average (r = .561) and homefield production activities (r = .537) and *not* outfield variables. Again, this potentially shows that homefield activities were dependent on farmstead size, as the availability of land further away fluctuated with the effects of

sheep grazing. Homefield activities include cattle grazing, hay yield, and the management of the home field area (Adderley et al. 2008). Hay yield can be tied to shifts in soil productivity, the amount of available land, and changes in the climate. The farmstead size post-1300 is potentially well-situated, as by this period the farm has identified how best to manage homefield activities and maximum production value of the land. There is no statistically significant correlation between production activities and the farmstead area between 1104 to 1300.

There are several other variables that correlate with *both* the total cattle and total sheep averages. These include all climate scenario calculations for the 19th century utilizable biomass, all climate scenarios for utilizable biomass in January and July within the 19th century property boundary, the Cold and Extreme Cold utilizable biomass for January and July within the 350-meter catchment buffer, the 19th century property boundary, all of the variables for the homefield and outfield, and the average SeAR from H3-1104 within the 350-meter catchment. Only one variable correlates with *only* the total sheep average: the total utilizable biomass for the Baseline climatic scenario for the large farms ($r = .553$). This correlation most likely indicates that the amount of total sheep who were grazed far from the central farmstead was determined by the initial boundaries between farms on Hegranes. These larger areas of land were likely to have a greater amount of available utilizable biomass and therefore support the average number of grazing sheep.

In examining the relationship between the amount of available land per farmstead and productivity, the 19th century property boundary area strongly correlates with both total cattle (r = .677) and sheep (r = .720) averages, as well as homefield production activities (r = .695) and the outfield hay average (r = .539). This suggests that this larger property boundary determined the amount of productivity and sustainability of a farm. While the productivity of the general 19th century property boundary appears to determine the basic productive level of the farm, the homefield served to provide additional winter fodder to sustain the herd size determined by the broader farm property. If the productivity of the homefield changes, then the overall farm productivity might be affected as the homefield often yields the greatest amount of utilizable biomass and supports a majority of the farm production activities. This relationship is supported by the significant correlation between the 19th century property boundary area and the total utilizable biomass for the baseline climatic scenario for the 19th century property boundary (r = .874). A larger property boundary indicated greater utilizable biomass and therefore better ability to support livestock and an increased productivity.

The correlations between farmstead area pre-1104 with farm production activities is stronger than the relationship between farmstead area post-1300 with the same variables. This could indicate that the pre-1104 farmstead size was closely tied to the productivity of the farm, but as time continued this relationship started to break down. As the farmstead area changed over time, production activities were no longer closely related to the size of the farmstead, causing the elimination of a relationship between the

variables. 19th century farm production activities continue to correlate with the total farmstead area in all three periods of Pre-1104, 1104-1300, and Post-1300.

Looking at the productivity of farms in relation to the movement of soils, farm production variables share the strongest relationship with SeAR between H3 and 1104 within the 350-meter catchment buffer, apart from the homefield fertility average and outfield hay average. This means that the amount of soil accumulation early on may have affected where homefields/outfields were placed, and the initial livestock amount. While such a relationship is not visible for each of the seven study farms (see *SEAR/E by Farm*), this potential field placement is supported by the correlation between the average SeAR for H3 and the outfield area average and the total cattle average. This relationship indicates that the amount of livestock that were grazed close to the farmstead, in addition to outfield production activities, were influenced by the amount of localized soil. The average (r = .830) and natural neighbor (r = .812) values for the 1300 SeAR within the 350-meter catchment buffer correlate with the homefield fertility average – these are the only variables to do so. As relationships with the homefield fertility average are limited, this data does not reveal significant information.

These results indicate the initial size of the farmstead established the productivity of a farm within the local landscape (350-meter catchment buffer). These production activities were additionally affected by aspects of the environment within this local setting, like SeAR. As farmsteads changed in size over the three study periods, farm production became more dependent on available resources within the broader landscape

(19th century property boundary), rather than the changing size of the farmstead and availability of the local resources.

Sediment Accumulation Rate

Soil accumulation can vary depending on environmental and anthropogenic factors. By examining SeAR against vegetation coverage and farmstead size, this section explores how SeAR impacts farm productivity through grazing availability within the local and regional landscapes. If SeAR is consistent across Hegranes and affects farm productivity, then farms situated in locations with high SeAR will have lasting or permanent impacts on productivity. If the SeAR is not consistent over time, then environmentally driven effects on productivity may be visible as SeAR changes from farm to farm over the three study periods. The SeAR from farm to farm on Hegranes appears to be relatively consistent in fluctuations between the three study periods. However, not all tephra layers were present within each coring location. This led to a discrepancy in producing calculations for, and a pattern of, SeAR across Hegranes as some study locations included the presence of more tephra layers than others. For example, while it would have been useful to see the SeAR before and after the settlement period, due to the limited amount of values provided for the LNL tephra layer within the collected coring data, this was not possible. As such, the SeAR surrounding this layer was unable to be properly analyzed with respect to the other variables. To explore SeAR prior to settlement, this study uses the H3 to 1104 tephra grouping. This is beneficial in that it allows for an examination of the landscape prior to, and including, the first round

of extensive settlement up to 1104. However, this is also problematic as it prevents this research from separating and analyzing the pre-1104 SeAR immediately before and after the settlement. The SeARs discussed below have all been calculated for the 350-meter catchment buffer.

SeAR has a strong positive correlation that is statistically significant with utilizable biomass amounts between the average SeAR between the H3 and 1104 tephra layers and the utilizable biomass for the Baseline climate scenario for the 19th century property boundary (r = .963) (Table 6; Figure 11). This correlation between the utilizable biomass values and 19th century property boundary suggests that in the early settlement period the SeAR within the 350-meter catchment buffer was indicative of the amount of utilizable biomass within the surrounding area. Presumably, a higher SeAR would increase vegetation yields, thereby producing greater amounts of biomass. For this research, the 350-meter catchment buffer is considered indicative of local SeAR in general. As there is not a farm-wide measure of SeAR, the 350-meter catchment buffer serves to provide this farm measure in addition to a similar measurement that correlates with the amount of utilizable biomass within the same catchment buffer. The vegetation within the immediate vicinity of the farm is thought to be representative of the type of vegetation and utilizable biomass seen within the larger property boundary. This is further supported by a relationship between the total utilizable biomass value for just the *large farms* on Hegranes and the average SeAR between H3 and 1104 (r = .765). This correlation with only *large farms* and not *all farms* could indicate that further divisions in

Table 6. Sample of Correlations Between Sediment Accumulation Rate (SeAR) and Utilizable Biomass Variables.

		Average SeAR - 1104 - 350-meter Catchment Buffer	Average SeAR - H3-1104 - 350-meter Catchment Buffer	Average SeAR - LNL-1104 - 350-meter Catchment Buffer	Average SeAR - 1104-1300 - 350-meter Catchment Buffer	Average SeAR - 1300 - 350-meter Catchment Buffer	Average SeAR - H3 - 350-meter Catchment Buffer	Average SeAR - LNL - 350-meter Catchment Buffer	Average SeAR - H3-LNL - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms
Average SeAR - 1104 - 350-meter Catchment Buffer	Pearson Correlation	1	0.109	.b	0.007	0.113	0.496	0.392	-0.074	0.495	-0.362	0.690	0.013
	Sig. (2-tailed)		0.816		0.988	0.809	0.257	0.744	0.953	0.397	0.425	0.086	0.977
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - H3-1104 - 350-meter Catchment Buffer	Pearson Correlation	0.109	1	.b	0.139	0.715	.904**	0.904	0.607	.963**	0.384	-0.045	.765*
	Sig. (2-tailed)	0.816			0.767	0.071	0.005	0.281	0.585	0.009	0.395	0.923	0.045
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - LNL-1104 - 350-meter Catchment Buffer	Pearson Correlation	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b
	Sig. (2-tailed)												
	N	1	1	1	1	1	1	1	1	1	1	1	1
Average SeAR - 1104-1300 - 350-meter Catchment Buffer	Pearson Correlation	0.007	0.139	.b	1	-0.441	0.225	-0.745	-0.968	0.372	-0.416	0.225	0.212
	Sig. (2-tailed)	0.988	0.767			0.322	0.628	0.465	0.162	0.538	0.354	0.627	0.649
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - 1300 - 350-meter Catchment Buffer	Pearson Correlation	0.113	0.715	.b	-0.441	1	0.563	0.874	1.000*	.888*	.771*	-0.316	0.599
	Sig. (2-tailed)	0.809	0.071		0.322		0.188	0.323	0.020	0.044	0.042	0.490	0.155
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - H3 - 350-meter Catchment Buffer	Pearson Correlation	0.496	.904**	.b	0.225	0.563	1	0.593	0.157	.942*	0.074	0.333	0.681
	Sig. (2-tailed)	0.257	0.005		0.628	0.188		0.596	0.899	0.017	0.875	0.466	0.092
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - LNL - 350-meter Catchment Buffer	Pearson Correlation	0.392	0.904	.b	-0.745	0.874	0.593	1	0.888	1.000**	0.169	0.369	0.900
	Sig. (2-tailed)	0.744	0.281		0.465	0.323	0.596		0.304		0.892	0.760	0.287
	N	3	3	1	3	3	3	3	3	2	3	3	3
Average SeAR - H3-LNL - 350-meter Catchment Buffer	Pearson Correlation	-0.074	0.607	.b	-0.968	1.000*	0.157	0.888	1	1.000**	0.603	-0.099	0.600
	Sig. (2-tailed)	0.953	0.585		0.162	0.020	0.899	0.304			0.588	0.937	0.590
	N	3	3	1	3	3	3	3	3	2	3	3	3
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	0.495	.963**	.b	0.372	.888*	.942*	1.000**	1.000**	1	0.146	-0.033	.751**
	Sig. (2-tailed)	0.397	0.009		0.538	0.044	0.017				0.617	0.911	0.002
	N	5	5	1	5	5	5	2	2	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	-0.362	0.384	.b	-0.416	.771*	0.074	0.169	0.603	0.146	1	0.023	-0.040
	Sig. (2-tailed)	0.425	0.395		0.354	0.042	0.875	0.892	0.588	0.617		0.909	0.880
	N	7	7	1	7	7	7	3	3	14	27	27	17
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson Correlation	0.690	-0.045	.b	0.225	-0.316	0.333	0.369	-0.099	-0.033	0.023	1	0.214
	Sig. (2-tailed)	0.086	0.923		0.627	0.490	0.466	0.760	0.937	0.911	0.909		0.394
	N	7	7	1	7	7	7	3	3	14	27	34	18
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson Correlation	0.013	.765*	.b	0.212	0.599	0.681	0.900	0.600	.751**	-0.040	0.214	1
	Sig. (2-tailed)	0.977	0.045		0.649	0.155	0.092	0.287	0.590	0.002	0.880	0.394	
	N	7	7	1	7	7	7	3	3	14	17	18	18

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

b. Cannot be computed because at least one of the variables is constant.

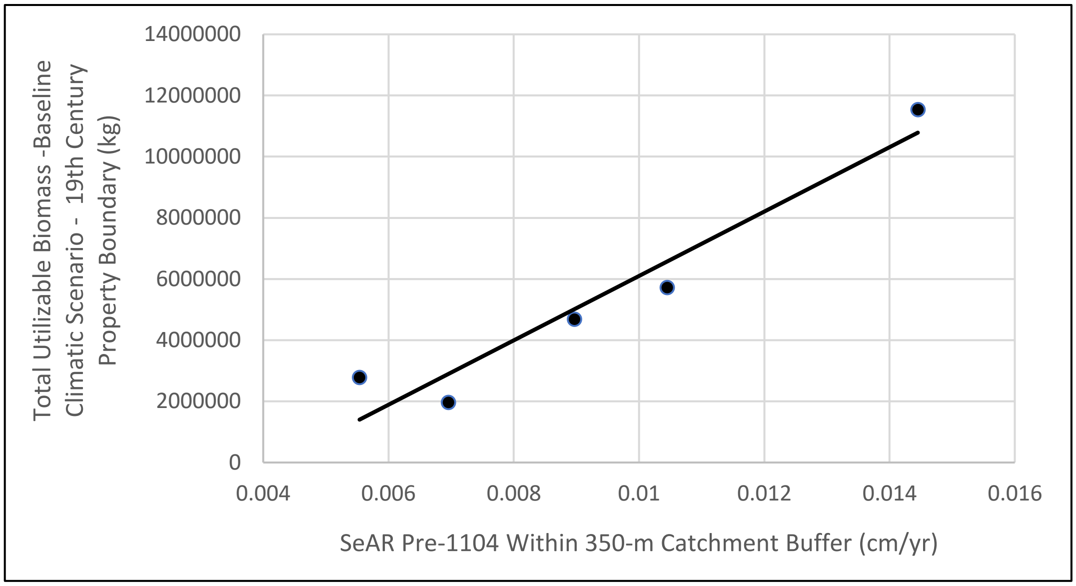

Figure 11. Correlations between the available utilizable biomass during the baseline climatic scenario within the 19th century property boundary and the calculated SeAR between H3 and 1104 within the 350-m catchment buffer.

the landscape on Hegranes resulted in an inability of the available utilizable biomass to support small farm resource needs.

The average SeAR for 1300 correlates with the total utilizable biomass for the Baseline climate scenario value within the 350-meter catchment buffer (r = .771). This relationship reveals that in the period following the final establishment of new farms, utilizable biomass is affected by the SeAR in a localized area. While SeAR between the 1104 and 1300 tephra layers was correlated with the 19th century utilizable biomass amounts for the Cold, Warm, and Extreme Cold climate scenarios, this correlation is not representative of a relationship over the whole of Hegranes. As stated above, not all tephra layers were present within the coring locations. This discrepancy between tephra presence means that applying generalized patterns of SeAR to the entirety of Hegranes

does not necessarily provide an accurate depiction of the past. The relationship between SeAR for 1104 to 1300 and the utilizable biomass values for the 19th century property boundary is only relevant for those farms where these tephra layers were present. Therefore, this correlation does not definitively depict the story of SeAR and utilizable biomass at surrounding farms.

Looking at SeAR in relation to the changing farmstead size over the three study periods explores the impact of soil accumulation on farm productivity. In general, SeAR does not add further insight into the development of farmstead area change over time. There were few correlations between SeAR and farmstead areas. The average SeAR between 1104 and 1300 correlates with the farmstead percent area change pre-1104 and 1104-1300 ($r = -.825$). This suggests that as soil amount within the immediate farmstead landscape increased or decreased, farmstead size was affected/influenced. As the farmstead size changed, so too did farm productivity. The natural neighbor calculation for SeAR at 1104 correlated with farmstead area pre-1104 ($r = .771$). This supports the prior relationship between the average SeAR 1104-1300 and the farmstead percent area change pre-1104 and 1104-1300, as this second correlation indicates that SeAR during 1104 in the immediate surrounding landscape contributes to the initial farmstead area. The area for the 19th century property boundary correlates with the values for the average SeAR between H3 and 1104 ($r = .945$), and the average SeAR for H3 ($r = .993$). As these values represent the initial settlement period, this could mean that the smaller 350-meter catchment buffer landscape is directly related to the overall size of the farm property. Early SeAR within the local catchment buffer seems to predict the amount of land within

the 19th century property boundary. High SeAR around the farmstead appears to be related to the establishment of larger farm properties.

These correlations suggest that SeAR and available utilizable biomass within a local setting (350-meter catchment buffer) around each farmstead is indicative of the amount of available utilizable biomass within the broader landscape (19th century property boundary) (see Figure 11). Locally, the SeAR/E impacts the amount of available utilizable biomass. While the SeAR within this local setting does not relate to later changes in farmstead size, the amount of soil during the settlement period most likely contributed to the initial farmstead area. Locations with greater levels of sediment accumulation are indicative of a larger initial farmstead size while areas with less soil predict a smaller farmstead area.

SeAR/E by Farm

During the settlement, one of the effects of highland erosion was soil accumulation in lowland areas. This current research reveals that patterns at individual farms may vary from the overall pattern of soil accumulation in Skagafjörður. Grétar Guðbergsson, an agricultural scientist in Iceland, conducted research on the SeAR for all lowland Skagafjörður (Guðbergsson 1975) (Figure 12). Recording SeAR along the central region of Skagafjörður on either side of the Héraðsvötn river basin, Guðbergsson found a general trend of sustained low-level soil accumulation up to the settlement. The SeAR increased by about 9x during the period between the settlement to 1104 and

maintained a slightly lower SeAR in the subsequent periods (Figure 13). It can be assumed that erosion in higher elevations in Skagafjörður lead to soil accumulation in lowland areas and their associated farms (Dugmore and Buckland 1991; Arnalds et al. 2001).

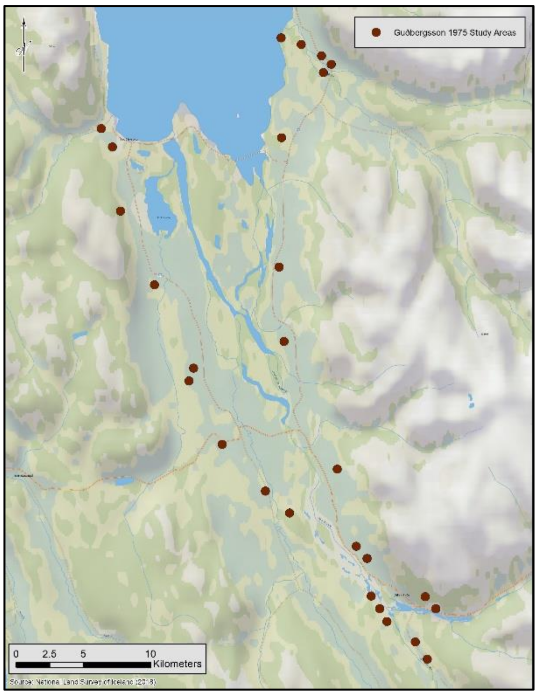

Figure 12. Locations of measurements of SeAR conducted in Skagafjörður (based on Guðbergsson 1975).

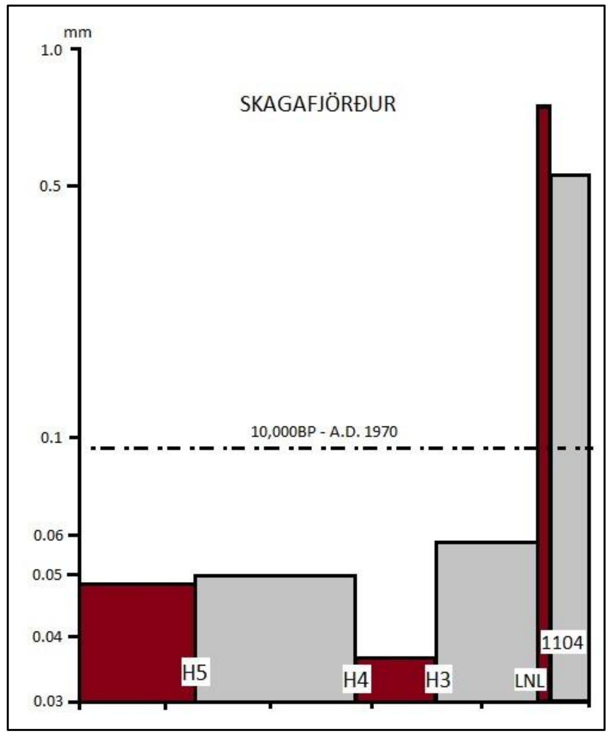

Figure 13. Sediment Accumulation Rate (SeAR) in mm/year for Skagafjörður (based on Guðbergsson 1975).

Patterns of lowland soil accumulation is evidenced in more recent local research conducted on Langholt, a region just to the west of Hegranes across the river (Catlin 2011). On Langholt, the SeAR appeared to be consistent until the Landnam period (LNL), when there is evidence of greater upland, continuous erosion. There is a roughly 90% spike between the LNL and 1104, which tapers slightly and maintains a consistent SeAR from 1104 to present. The pattern of SeAR seen on Langholt looks more like the

generalized background portrayed by Guðbergsson (1975) for Skagafjörður. On Hegranes, rather than following a broad pattern of SeAR for the entire region, the SeAR appears to vary on a farm by farm basis, with local accumulation events more common than regional movement of soils. Rather than a valley-wide movement of sediment from upland to lowland areas, the soil movement seems to be occurring within a more localized setting around farmsteads. This could be a result of a combination of regional and local movement of soils that contributes to the varying SeAR over the three study periods.

Regardless, this observation differs from the patterns seen throughout Langholt and Skagafjörður where the SeAR appears consistent during each of the three study periods throughout the general area (Guðbergsson 1975; Catlin 2011). While the average SeAR of all the farms on Hegranes appears to follow the pattern initially seen by Guðbergsson (1975) for Skagafjörður, when calculating the SeAR from the interpolated coring data, a spike was visible between 1104-1300. This could be a result of soil movement from anthropogenic or environmental effects on the landscape. Something happened that caused a greater transport of sediment to the farm locations amounting to a visible increase in the SeAR. For this research, a calculation of SeAR between LNL to 1104 was not possible due to the small amount of coring data collected with the LNL tephra present.

Similar to previous research, soil accumulation on Hegranes shows a visible spike following the settlement. Unlike the same previous research which shows the spike as a

general pattern throughout the region of Skagafjörður, this spike appears to only occur at some individual farms rather than broadly across Hegranes. Overall, the amount of increase in SeAR seems to vary by farm on Hegranes. In general, the average historic accumulation rates are greater than the prehistoric accumulation rates. In the Pre-1104 period, the least amount of soil accumulation occurs. Potentially this could be a result of averaging the SeAR from H3-1104 since we were unable to collect enough data to determine SeAR between LNL-1104. Alternatively, there could have been a small degree of soil movement prior to the settlement period as the landscape was not affected by extensive anthropogenic movement and cultivation until after 1104. Contrasting other studies of soil accumulation, in the calculations for this research the greatest influx of soil around the farmsteads is between 1104-1300 (Catlin 2011; Guðbergsson 1975). In the Post-1300 period soil accumulation appears to taper back out and accumulate at slightly lower rates.

It is unlikely that the increase between 1104-1300 is a result of general soil accumulation in Skagafjörður. It is more likely indicative of localized movement of soils. Considering soil movements at the seven extensively cored farms on Hegranes, the SeAR/E reveals evidence of varied intensification conducted at each farm. The relative size of the farms on Hegranes changes on a farm by farm basis, potentially due to their varied locations within the region (Figure 14): Helluland becomes gradually larger; Utanverðunes experiences a significant increase in size post-1300; Vatnskot becomes significantly large post-1300; Ásgrimmstaðir becomes smaller both in the 1104-1300 and post-1300 periods; and Ás, Keflavik, and Rein do not fluctuate dramatically in size.

Helluland

One of the most productive farms on Hegranes at the conclusion of the three study periods, Helluland appears to have a greater indication of localized erosion when compared to the other six study farms. Helluland becomes larger throughout the three periods of study, increasing in both area and productivity (Figure 15). This increase in localized SeAR seems to have led to an increase in farmstead size. Similar to the overall pattern in Hegranes, the SeAR increased between 1104 and 1300 at Helluland. However, this increase, seen in the 350-meter catchment buffer, was more defined at Helluland than within the 350-meter catchment buffer at the other study farms. This increase in SeAR was most obvious around the immediate farmstead area. This localized movement of soils within the 350-meter catchment buffer could indicate local erosional events outside of the homefield, possibly from grazing pressures in the higher elevations (Figure 16). The limited amount of soil and exposed rock within the highland areas at Helluland may be indicative of such soil movement. The representation of soil movement over the three study periods seen in Figure 15, appears to show a steady movement from the eastern/northeastern area of Helluland towards the southwest, increasing in overall depth by 1300.

The increased and steady SeAR could be a result of intensification of the landscape surrounding Helluland. Highland livestock grazing could have affected the soil movement from upper to lower Helluland, increasing soil depth within the homefield. This resulting soil accumulation within the homefield potentially increased the productivity of the land. By

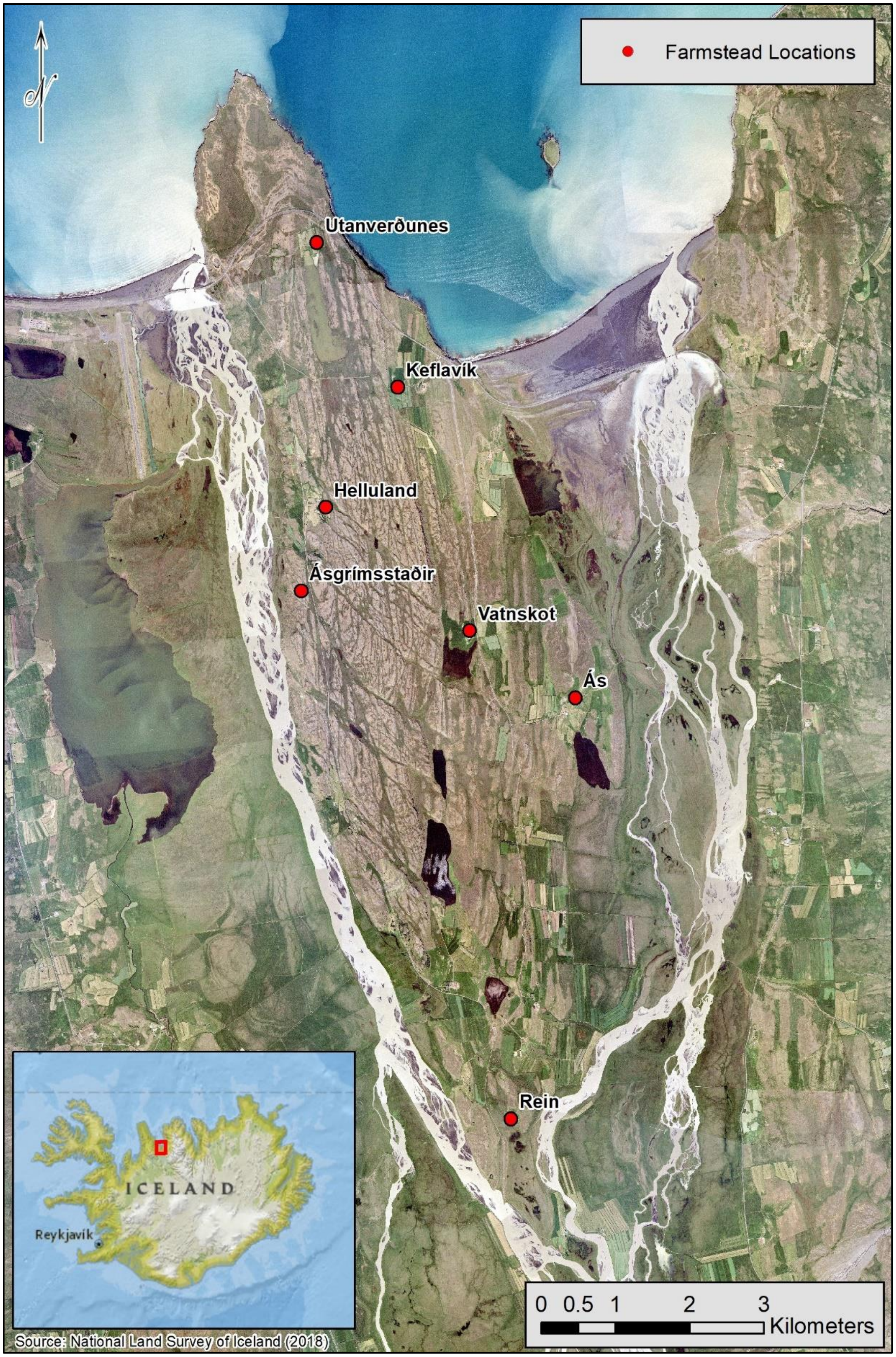

Figure 14. Location of the seven selected farms highlighted in this research.

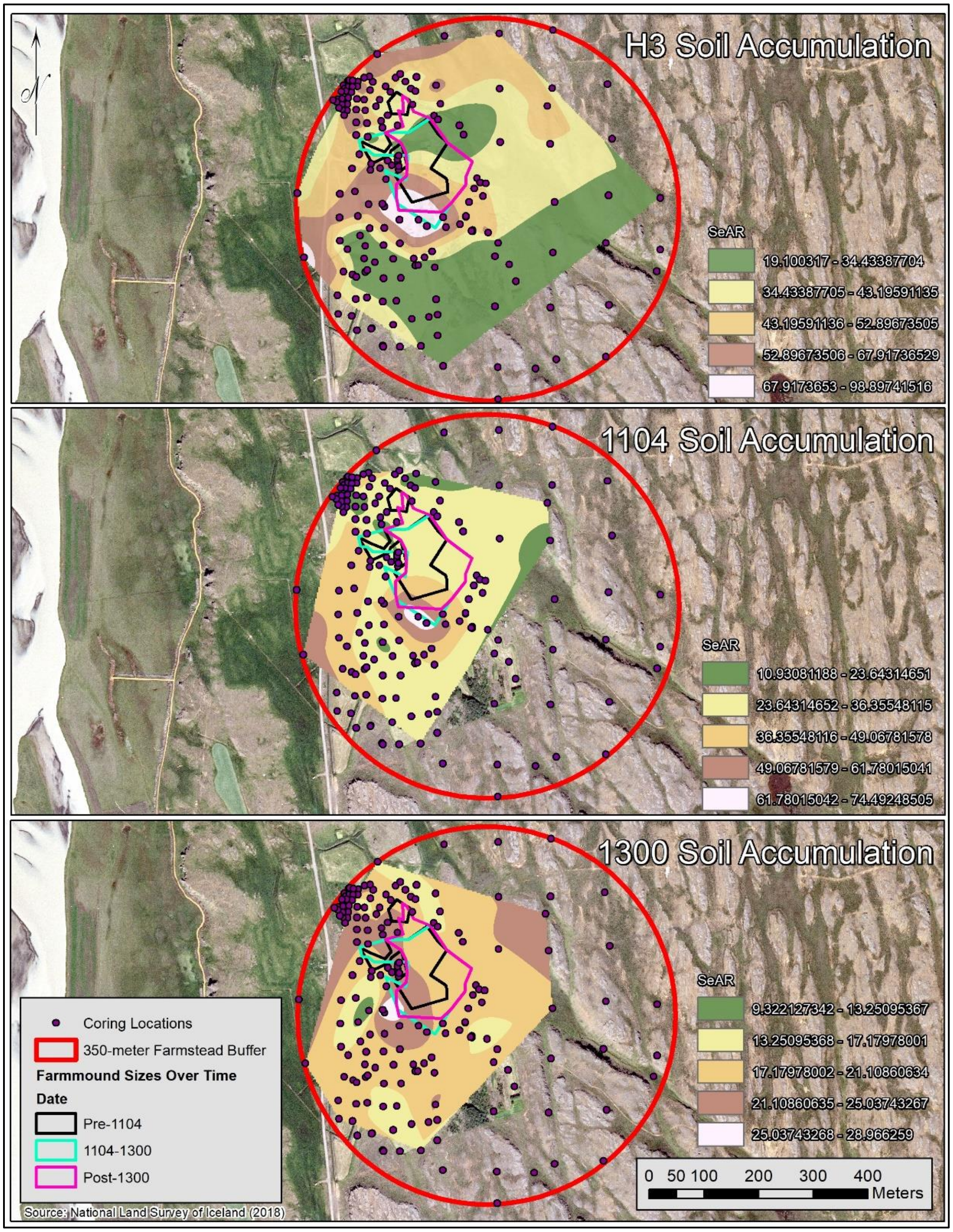

Figure 15. Movement of sediment accumulation over time at Helluland.

Figure 16. Southeastern side of Helluland, as seen during survey.

changing the productivity of the homefield, the overall productivity of the farm was affected. How and when farms react to the results of intensification on the environment depends on the local and regional landscapes. At Helluland, though practices of intensification (upland grazing and reworking of the homefield) appear to have been disruptive to the environment, the benefit Helluland received was greater than the negative environmental effects. In the case of Helluland, increased SeAR indicated greater productivity.

Keflavik

Keflavik and Ás also experience localized changes in SeAR. Keflavik, located in northeastern Hegranes, benefited from SeAR/E but does not appear to have had as great of an indication of heavy land intensification as seen at Helluland. Around settlement and 1104, the

SeAR indicates soil movement from the farmstead to lowland areas to the southeast (Figure 17). This could reveal evidence of homefield intensification practices which caused subsequent soil movement away from the central farmstead. Keflavik experienced greater localized soil movement around 1300. This could be a result of upland grazing, like Helluland, leading to subsequent erosion and an increased SeAR within the homefield. This can be seen within the 350-meter catchment buffer, as areas of exposed rock and shallow soils are present in the western portion of the buffer. Throughout the three study periods Keflavik actively maintained its relatively large farmstead size and is still active today. Given the stability of the farmstead size and surrounding landscape, the productivity of Keflavik has remained comparatively consistent during occupation (Figure 18).

Ás

Ás is located on the eastern side of Hegranes towards the center of the region. SeAR at Ás reveals some localized soil movement around the farmstead, but no extreme erosional or intensification events (Figure 19). Patterns of soil accumulation are contained to the southeastern area of the farmstead, again increasing across the farmstead by 1300. Given the topography of the farm (seen in the image below) upland pasture grazing could have led to an increase in soil movement towards the lowland area of the farm. Throughout the three study periods Ás maintained its fairly large farmstead area; Ás is still active today. The productivity of Ás remains relatively consistent allowing for the stability of its farmstead size and the surrounding landscape (Figure 20).

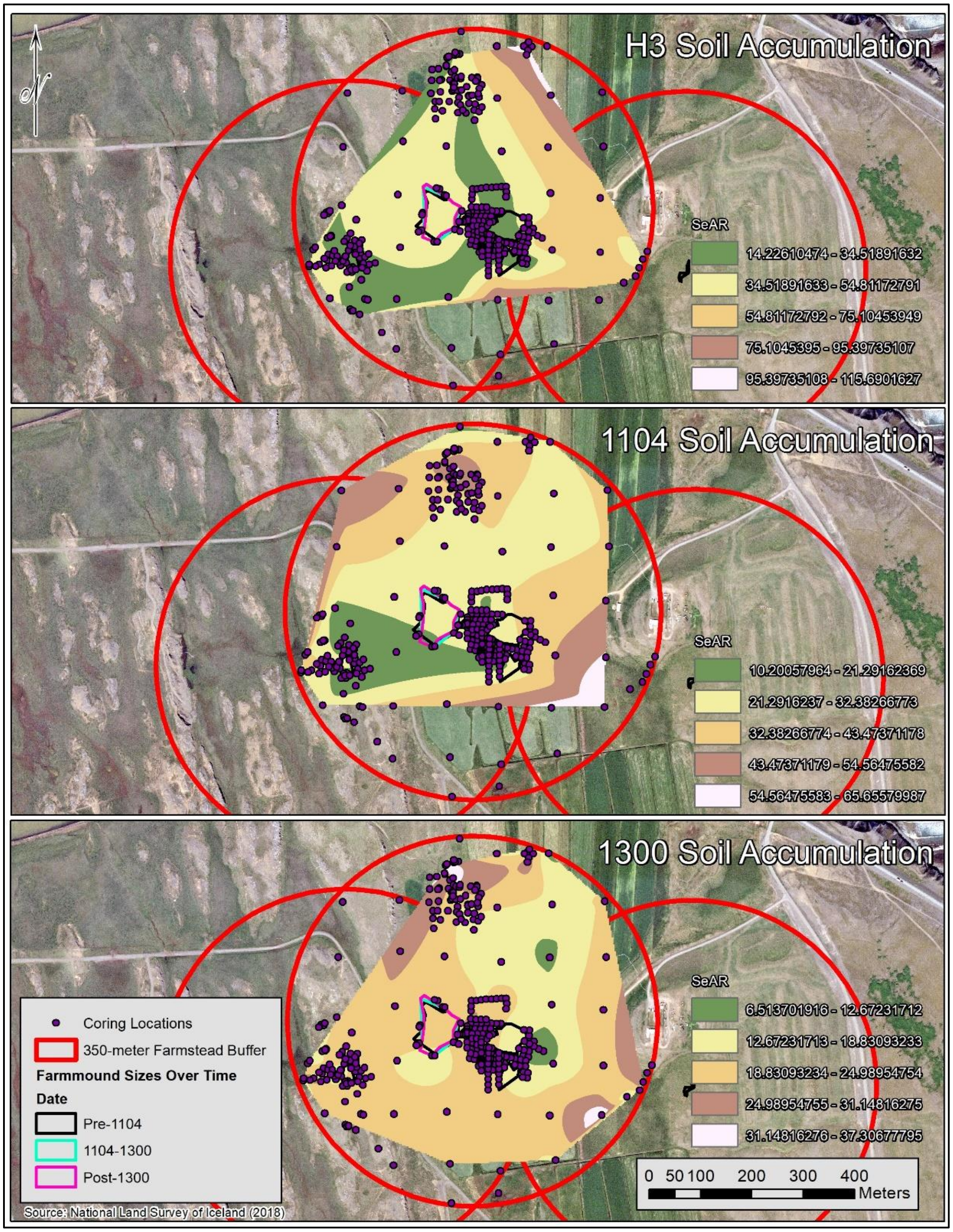

Figure 17. Movement of sediment accumulation over time at Keflavik.

Figure 18. Looking west towards the central farmstead of Keflavik, as seen during survey.

Vatnskot

Vatnskot, located in central Hegranes, began as a relatively small farmstead during initial settlement. Pre-1104, sediment accumulation was most noticeable to the northwest of the farmstead. During 1104, the SeAR was the greatest to the northeast of the farmstead; around 1300 soil movement was almost exclusively over the immediate farmstead (Figure 21). Fairly localized sediment accumulation in 1104 and 1300 may have contributed to an increase of double the original farmstead size by post-1300. This is a fairly dramatic fluctuation in size in comparison to the other six study farms. The pattern of SeAR seen at Vatnskot makes it difficult to interpret possible grazing pressures

Figure 19. Movement of sediment accumulation over time at Ás.

Figure 20. Looking south towards Ás, as seen during survey.

and erosional events. The direction of the SeAR pattern changes throughout all three study periods possibly indicating an instability of the soils within this area of Hegranes.

Pre-1104 identified a greater SeAR to the west of the farmstead; around 1104 greater SeAR was located north of the farmstead; and by 1300 the deepest sediment accumulation was recorded at the southern extent of the farmstead. The SeAR recorded within the farmstead is similar to the pattern of sediment accumulation that occurred at Helluland and Ásgrimsstaðir. For all three farms, by 1300, the greatest amount of soil accumulation was identified within the immediate farmstead. This could be a natural result of the farms being situated in lowland areas relative to their immediate surroundings, or, a result of intensive grazing pressures within the upland locations causing subsequent soil movement down towards the farmsteads. Like Helluland,

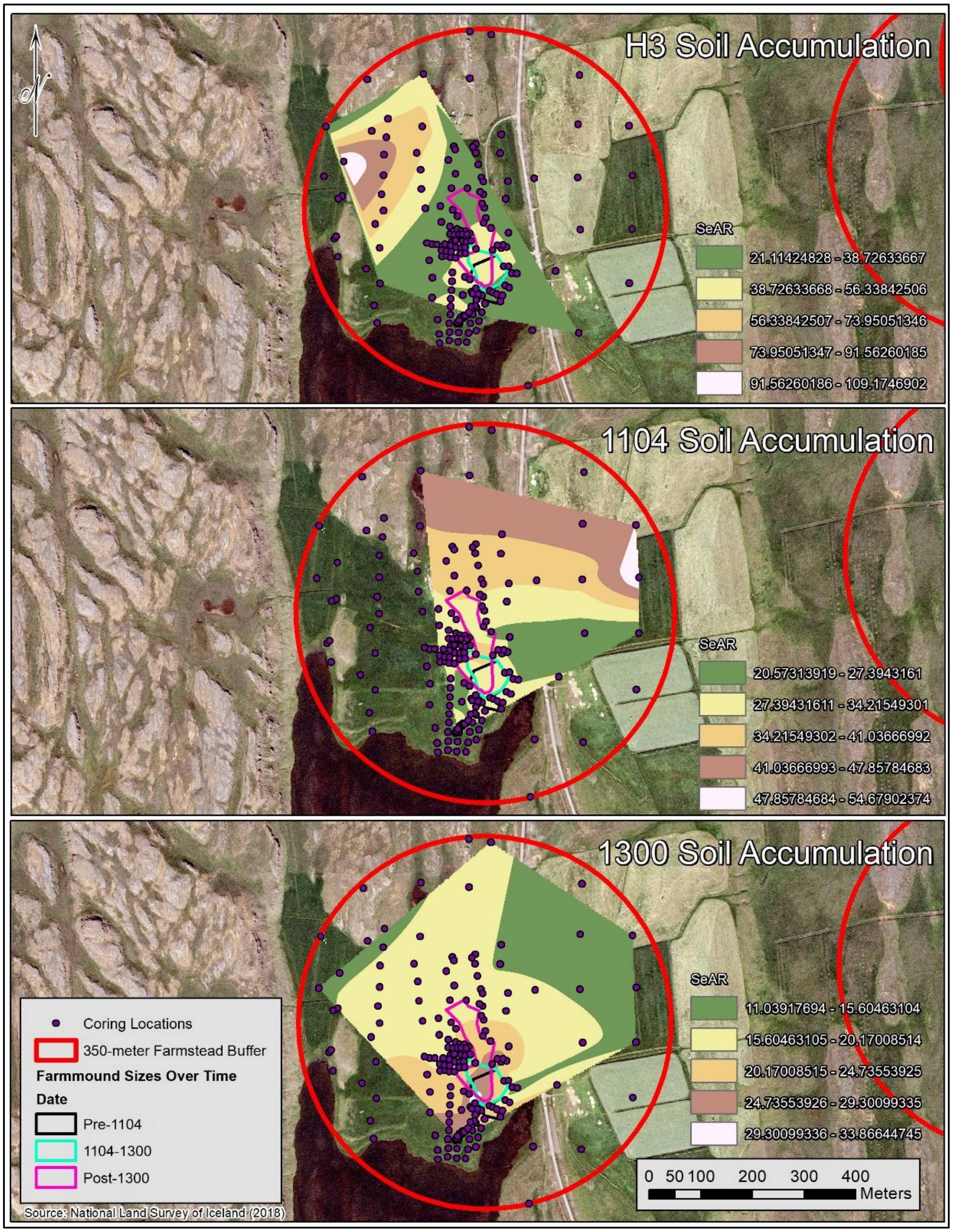

Figure 21. Movement of sediment accumulation over time at Vatnskot.

Figure 22. Landscape north of central Vatnskot, as seen during survey.

patterns of local SeAR/E appear to have encouraged farmstead growth and resulting productivity (Figure 22).

Utanverðunes

The northern-most farm on Hegranes, Utanverðunes appears to be subject to steady sediment accumulation east of the farmstead over the three study periods. This continued soil movement does not seem to have any great effect on the farm until after 1300 (Figure 23). Utanverðunes experienced a dramatic change in size post-1300 as its area tripled the original settlement size (Bolender et al. 2016). However, the relatively

minor fluctuations in SeAR are not indicative of why this might have happened. There are no sudden, dramatic changes in the SeAR throughout the local or regional landscape. This could indicate that Utanverðunes may not have been actively working the land and that the soil movement was a result of natural processes. Or, if practices of intensification were occurring, they did not largely impact the surrounding area in terms of soil movement. However, this increase in size post-1300 most likely indicates that the farm experienced some increase in productivity around this time as a result of environmental or social aspects, leading to the larger farmstead size. Utanverðunes is still an active farm on Hegranes (Figure 24).

Rein

While patterns of soil movement were identified at all seven study farms, not all farms benefitted from this local and/or regional sediment accumulation. The southern-most farm on Hegranes, Rein showed little to no evidence of sediment accumulation until 1300 (Figure 25). One of the smallest farms on Hegranes, Rein was established during the last phase of land division in the 11th century (Bolender et al. 2017). Rein experienced two major periods of occupation: the beginning of the settlement period through the late Middle Ages; and reoccupation around 1800 through the first half of the 20th century (Bolender et al. 2017; Pálsson 2010). In 1713, Rein is listed as an abandoned farm on the property of a larger farm, Egg (Magnússon and Vídalín 1930). In 1831, Rein is recorded as reoccupied, farmstead size over the three study periods,

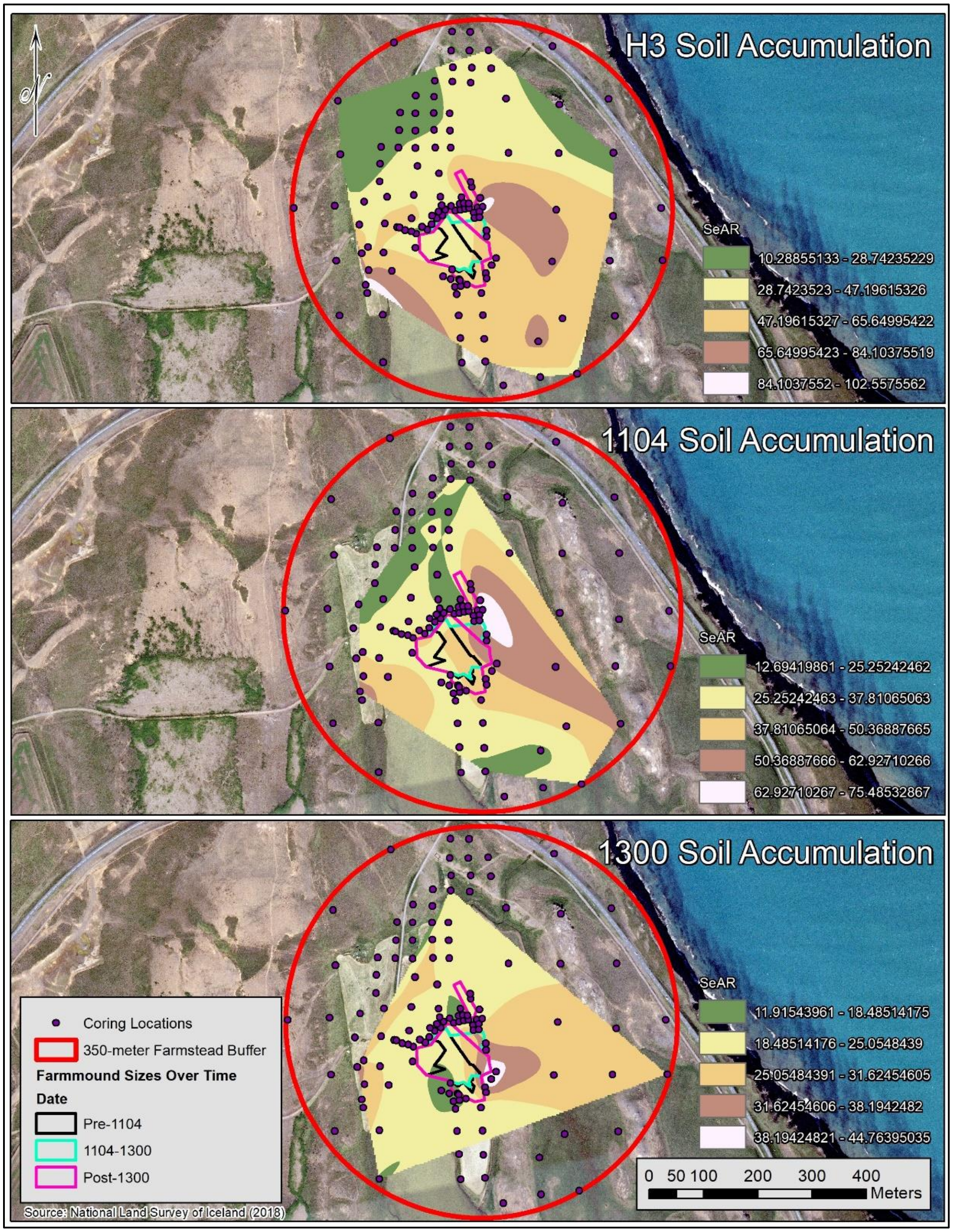

Figure 23. Movement of sediment accumulation over time at Utanverðunes.

Figure 24. Utanverðunes landscape, as seen during survey.

and continued to be occupied until 1931 with two short periods of abandonment from 1887-1889 and 1921-1923 (Pálsson 2010).

Previous fieldwork conducted at Rein indicated that some significant erosional event occurred between A.D. 1104 and 1300 during occupation (Bolender et al. 2017). Soil movement can be seen to the west of the farmstead pre-1104 and 1104-1300 (see Figure 25), possibly evidence of localized homefield intensification causing soils to move away from the farmstead. By 1300, the SeAR has increased at the farmstead location and east of the farmstead. This increase in sediment accumulation at the farm post-1300 could represent a final attempt at land intensification or confirms the natural erosional event predicted in previous research (Bolender et al. 2017). While Rein maintained its small the farm has since been abandoned (Figure 26). The potential erosional event identified in the

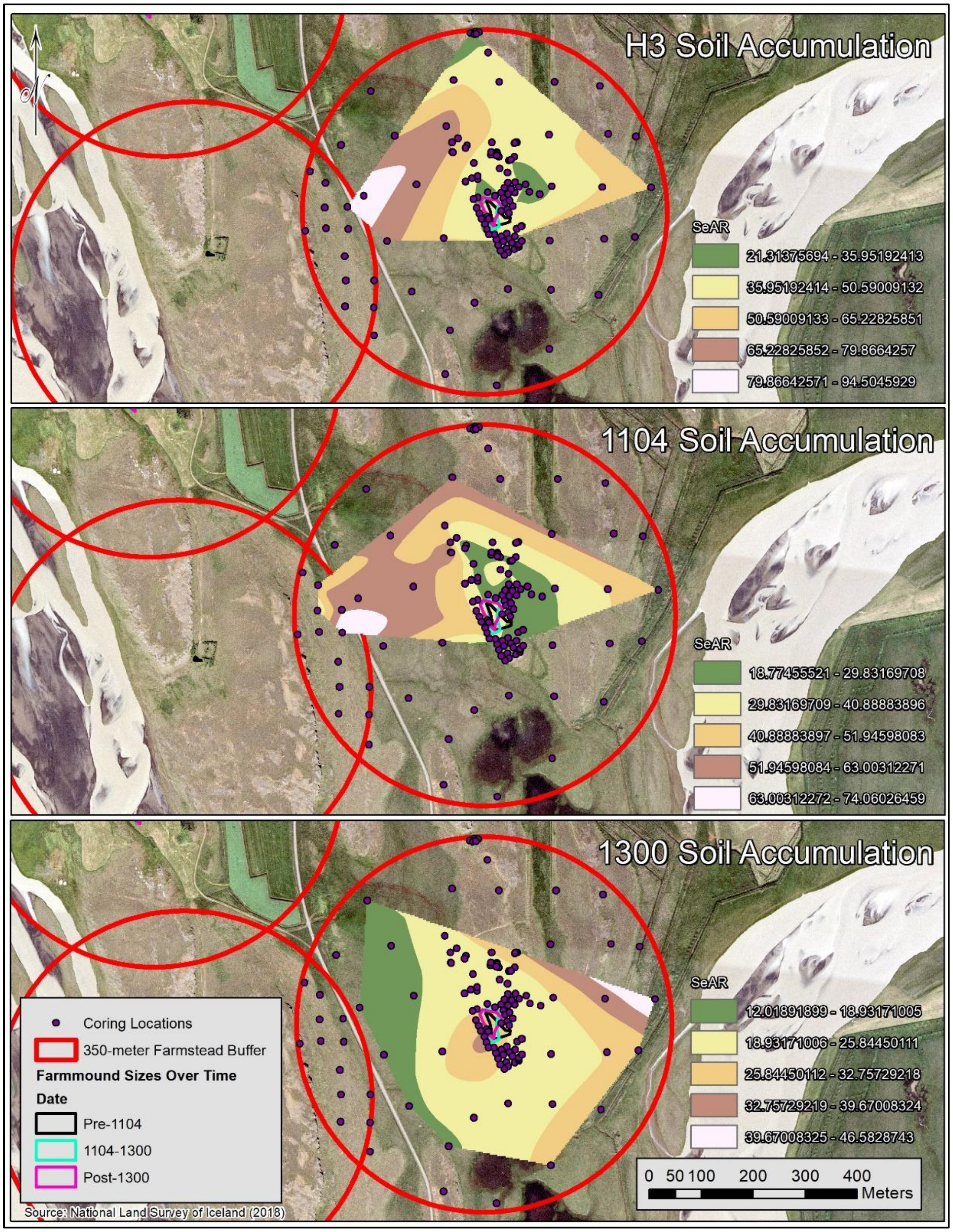

Figure 25. Movement of sediment accumulation over time at Rein.

Figure 26. Landscape across the Rein farmland during time of survey.

SeAR post-1300, and subsequent abandonment in the late Middle Ages, suggests that the abandonment of Rein may be a result of the sudden influx of soil. In the case of this smaller farm, a greater amount of soil indicated a decrease in farm productivity and sustainability.

Ásgrimsstaðir

Ásgrímsstaðir is located on the western boundary of Hegranes. Historically linked with Helluland, (as the two farms were sold together in A.D. 1388 and again in A.D. 1421 [Diplomatarium Islandicum, vol. 3:425, vol. 4:290-292]), Ásgrímsstaðir was noted in the Jarðabók as a long abandoned farm (Magnússon and Vídalín 1930); records

indicate that the farm appeared to have been abandoned by A.D. 1579 (Pálsson 2010). The SeAR at Ásgrímsstaðir shows an extensive amount of soil accumulation that progresses in an eastern movement towards the immediate farmstead from pre-1104 to 1300 (Figure 27). This most likely represents steady upland erosion, either from grazing pressures or natural processes.

Ásgrímsstaðir severely decreased in size to almost a third of its original pre-1104 area by post-1300. The area to the west of the farmstead, originally used for some sort of farming activity, was abandoned post-1104 (Bolender et al. 2017). This dramatic size recession could suggest that this decrease in size is a consequence of failed intensification that resulted in environmental degradation that was not offset in anyway. More likely, the increased SeAR suggests that the erosion was not a result of farm intensification, but rather a natural event from which the farm was unable to recover. Much like Rein, this sudden increase of soil led to a decrease in farm productivity and subsequent farm abandonment. This farm is currently abandoned; the existing structure on the property consists of the remains of an unfinished 20th century house (Figure 28).

Overall Effects of SeAR/E on Farms

Previous research on upland to lowland erosion indicated that farms that were subjected to this type of sediment accumulation experienced significantly limited resources and often were abandoned (Dugmore and Buckland 1991; Arnalds et al. 2001).

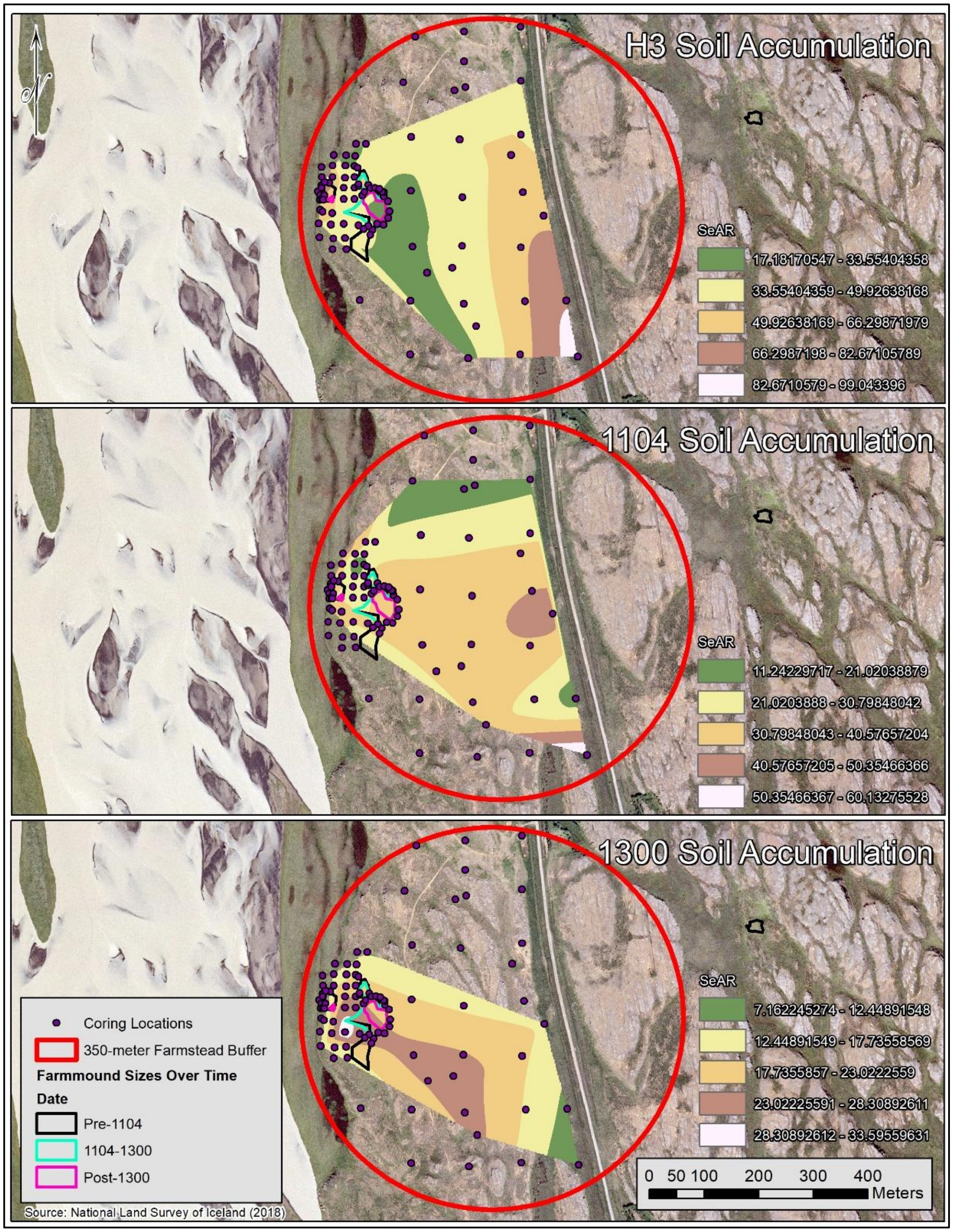

Figure 27. Movement of sediment accumulation over time at Ásgrimsstaðir.

Figure 28. The abandoned farm of Ásgrimsstaðir, as seen during survey.

As soil moved downslope, gradually or rapidly, vegetation within the area was negatively affected, subsequently impacting grazing livestock. While this pattern of erosion related abandonment was seen with Rein and Ásgrímsstaðir, the other five study farms were not negatively affected by an increase in SeAR.

Counter to the interpretation that localized erosion should negatively impact the productivity of farms, these findings indicate that most farms that saw localized disruption during this period increased in size and productivity at the same time. The dispersal of upland soils to lower farmsteads potentially increased these farms' productivity, showing that the amount of SeAR/E is more likely to be predictive of farm productivity. Per the results of this thesis research, low levels of disruption seem to be

associated with continuity in the farmsteads. When a dramatic increase in SeAR occurs, the resulting effects are more likely to be detrimental to a farm. These differences in the amount of SeAR and the resulting impact on each farm supports the importance of these findings; an increase in farm productivity is indicative of more local soil accumulation as a result of intensification, while upland erosion and accumulation often leads to farm abandonment.

CHAPTER 6: DISCUSSON AND CONCLUSION

This study was implemented to better understand how variations in farmstead size are influenced by changes in the surrounding environment on a local and regional level. Environmental cause and effect was examined through the vegetation cover on the landscape and the movement of soils. These aspects of the environment can fluctuate as a result of natural and/or anthropogenic actions on the landscape. Through an exploration of the relationship between such environmental impacts and landscape transformation, potential effects of SeAR/E on settlement patterning and cultivation can be identified.

In general, correlations with the SeAR suggest that the initial amount of soil within a settlement location pre-1104 was a determining factor in the early size and productivity of a farm. Soil depth pre-1104 was also indicative of the amount of available utilizable biomass within both the local and regional setting on Hegranes during this period. In the local 350-meter catchment buffer, the amount of available utilizable biomass correlated with the initial size of a farmstead and its homefield and served as an important predictor of initial farm productivity. The initial farmstead size was directly related to the early productivity of a farm, such as 19th century livestock amounts and hay yield. This initial farmstead size is the most important indicator of later changes in farmstead area. As farmsteads changed in size over time, farm productivity became less

predicted by the immediate landscape around the farmstead and more dependent on resources available within the broader landscape. The amount of utilizable biomass in a regional setting played a role in impacting these later changes in farmstead size and productivity but was likely not a determining factor of settlement for the larger farms. Homefield activities associated with each farm appear to be dependent on farmstead size rather than available resources located further from the farm. In general, measures of livestock appear to be a statistically significant predictor of farm productivity, however, extreme outliers need to be taken into consideration when analyzing datasets.

Farms on Hegranes seem to respond individually to environmental and anthropogenic pressures on the landscape throughout the study periods of Pre-1104, 1104-1300, and Post-1300. While the changing landscape did influence aspects of the farmstead, localized changes in SeAR/E appear to be tied to elements of the farm and intensification on farm land; intensification and its subsequent effect on soil movement varied from farm to farm. Past discussion concerning erosion and farm productivity indicated that rapid movement of soils led to farm abandonment and significant decrease of available resources (Adderley et al. 2008; Dugmore and Buckland 1991; Dugmore, Church et al. 2007; Dugmore, Keller et al. 2007; Streeter et al. 2012; Sveinbjarnardóttir et al. 1982). Erosion resulted in negative impacts on farmsteads and their surrounding environment. This pattern was identified at two of the seven study farms: Rein and Ásgrimsstaðir. An increase in SeAR at the farmstead of these two farms in 1300 led to abandonment of the farm shortly thereafter. When considering the overall study,

disruptions from erosion were expected to be associated with a decline in farmstead size and productivity; however, the data showed otherwise.

Greater indications of investment into the landscape, appear to have resulted in an increase in productivity; farms that actively worked to enrich the surrounding soils and landscape ultimately received greater yield from the land. For Helluland, Vatnskot, and Utanverðunes, SeAR over the three study periods resulted in an increase in farmstead size and productivity. For Ás and Keflavik, a relatively steady SeAR did not dramatically affect their farmstead areas, rather they maintained their productivity and sustainability from pre-1104 to 1300. At the local level, these impacts on the landscape can be interpreted in two ways: as either evidence of the effect of intensification practices on the land, or as a reaction to erosion, resulting in necessary intensification. While it is difficult to tell whether one is in response to the other, farmstead size is affected by the intensification of the land and soil accumulation. Regardless of the timing of intensification, these findings reveal evidence on a local level, of a complex relationship between SeAR/E and productivity. Though the current chronological resolution on this relationship is not very high, the late erosion might be suggestive of a specific moment of activity, directly impacting fluctuations in farmstead size and productivity, through the need for intensification of the landscape.

Examination of farmstead size and utilizable biomass indicates that environmental effects and subsequent productivity and sustainability is seen on a farm by farm basis rather than a general pattern that can be applied to the entirety of Hegranes. Previous

research on vegetation coverage examines utilizable biomass from a broad perspective in response to systems of grazing management (Thomson 2003; Thomson and Simpson 2006, 2007). Vegetation availability is shown to affect the productivity and abandonment of farms regionally, but the relationship with the local farmstead area is not extensively examined. This thesis explores the relationship from a more confined assessment; vegetation within a local area impacts fluctuations in farmstead size; however, this relationship is not always visible. Additional systematic testing of the remaining farms on Hegranes could further elaborate on this relationship between utilizable biomass and farmstead size, yielding greater evidence of tephra presence and subsequent knowledge of how SeAR may have affected farm productivity.

This research question focused on seven of the 14 principal farms on Hegranes. To enhance this study, the remaining seven farms should be similarly examined in addition to the several smaller fornbýli scattered across the landscape (Catlin et al. 2016, 2017). This would allow for a consideration of how these smaller subfarms and cottages were impacted by, and potentially affected, SeAR/E at the main farms. Presence of nearby fornbýli may have encouraged greater SeAR/E at the principal farms, affecting both farmstead size and abandonment seen today. Positive correlations between utilizable biomass calculations and multiple variables indicates that Búmodel does provide an accurate representation of the available utilizable biomass for the Icelandic landscape. Though correlations primarily occur during the initial settlement period, the continued relation during 19th century farm production activities suggest that the landscape vegetation in the research area did not change drastically throughout the three study

periods. The amount of available vegetation would have been shared between the principal farms and fornbyli; as such the boundaries used for this research may not accurately represent the existing utilizable biomass for each farm.

While this research successfully used Búmodel to calculate the utilizable biomass values on Hegranes, the vegetation classification is based only on grazeable vegetation rather than all present botanical varieties. Though this created a constant coverage that allowed for ease of calculations, it could be beneficial to utilize additional environmental diagnostic data, like pollen cores, to more precisely determine the landscape coverage and how this fluctuated over time (Thomson and Simpson 2006). Additional diagnostic data would make inputting the data into an environmental simulation model more complicated, however, it would provide a more robust landscape coverage, potentially affecting current calculations of land carrying capacity. Furthermore, a full month by month examination of available utilizable biomass could offer information regarding which months and climatic scenarios within the vegetation model are most correlated with various aspects of farm production. This could provide data for how particular climates affected vegetation coverage, and whether this in turn impacted SeAR/E. Despite these potential weaknesses, application of Búmodel was able to provide a good idea of the vegetation of northern Iceland and how this may have effected settlement location and development.

As with any research or historical modelling, potential inaccuracies in historical documentation must be considered as there could be biases in the number of livestock or people recorded on a tract of land. Thomson (2003) assessed historical records in her

development of Búmodel and included room for such errors in her estimates, but this does not ensure complete accuracy. Another issue to consider is over-interpretation of the results. Búmodel is an environmental simulation model, and its' results must be considered as part of an overall picture and not the entire story (Thomson and Simpson 2007).

Future Research

Comparative projects with other Scandinavian/Arctic locations could assist in determining the scale of effect, if any, SeAR/E and available utilizable biomass had on settlements over time. While the environmental simulation model used for this research was designed for Iceland, the values in Búmodel could be altered to fit other landscapes' historic vegetation coverage. Past applications of Búmodel in the Faroe Islands found that the livestock grazing pressures were not significant enough to contribute to erosion, and that the carrying capacity of available vegetation would not have been dramatically affected by any climatic changes (Thomson et al. 2005). On Hegranes, these conclusions were not possible as it was difficult to determine whether erosional events were a result of natural or anthropogenic actions. Though climatic scenarios in the study area were considered in relation to other human and environmental effects, the scale of climatic influence could not be established. Further examinations of vegetation coverage and soil movement across a variety of Arctic landscapes could support the theory that the amount of available vegetation within a given area impacts the productivity and sustainability of farms.

In considering the results of SeAR/E and utilizable biomass through the lens of historical ecology, these findings reveal that the environment does affect anthropogenic actions in a real way. Whether these actions are a direct result of an environmental affect, or the cause of other human interference, the two are intertwined. Past research has explored this connection in the North Atlantic, developing theories about how evolutions in nature and human response are entangled (Amorosi et al. 1997). Cultural change and modification of the landscape affected the available resources, subsequently impacting the natural environment and social interactions. In the Faroe Islands, researchers considered the effects of landscape intensification practices on the formation of soil types (Edwards et al. 2005). Through micromorphology, examination of soil profiles found that cultural modification to the landscape and soils contributed to the alleviation of soil wetness, potentially increasing the natural fertility and productivity of the soils. A similar research approach could be conducted on Hegranes, to see how the intensification practices on the landscape affected soils, and whether the resulting effect was the same across the region or seen in more local scenarios. An in-depth soil study could reveal how farm productivity and sustainability throughout Hegranes was affected by the type of intensification and available soils.

Determining how, and to what extent, the environment and anthropogenic actions are connected, helps researchers to understand the landscape of settlement and how this affected the productivity and sustainability of farms. This research showed that this methodology, as applied, cannot be used to portray an overarching description of a region, but serves to develop a story on a farm by farm basis. SeAR/E and utilizable

biomass contribute to the size and productivity of a farmstead, but this is in conjunction with social and political factors. To create an image of past settlement, environmental and anthropogenic factors are equally important. The landscape is affected by humans and nature alike, and as researchers, we cannot choose to focus on one without the other.

APPENDIX 1. CORRELATION TABLES

		Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Homefield Area Average	Homefield Fertility Average	Homefield Hay Average	Outfield Area Average	Outfield Hay Average	Total Cattle Average	Total Sheep Average
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson	1	0.146	-0.033	.751**	.915**	0.256	.896**	.917**	.775**	.884**	.908**
	Sig. (2-tailed)		0.617	0.911	0.002	0.000	0.376	0.000	0.000	0.001	0.000	0.000
	N	14	14	14	14	14	14	14	10	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson	0.146	1	0.023	-0.040	0.346	0.278	0.384	0.379	0.451	0.399	0.380
	Sig. (2-tailed)	0.617		0.909	0.880	0.206	0.316	0.157	0.251	0.092	0.141	0.162
	N	14	27	27	17	15	15	15	11	15	15	15
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson	-0.033	0.023	1	0.214	-0.240	0.063	-0.199	-0.075	0.045	0.118	0.060
	Sig. (2-tailed)	0.911	0.909		0.394	0.370	0.817	0.459	0.816	0.868	0.663	0.825
	N	14	27	34	18	16	16	16	12	16	16	16
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson	.751**	-0.040	0.214	1	.648**	-0.116	.600*	.611*	0.396	0.364	.553*
	Sig. (2-tailed)	0.002	0.880	0.394		0.007	0.670	0.014	0.035	0.129	0.166	0.026
	N	14	17	18	18	16	16	16	12	16	16	16
Homefield Area Average	Pearson	.915**	0.346	-0.240	.648**	1	0.085	.951**	.873**	.615*	.551*	.692**
	Sig. (2-tailed)	0.000	0.206	0.370	0.007		0.754	0.000	0.000	0.011	0.027	0.003
	N	14	15	16	16	16	16	16	12	16	16	16
Homefield Fertility Average	Pearson	0.256	0.278	0.063	-0.116	0.085	1	0.359	0.466	.615*	.674**	.596*
	Sig. (2-tailed)	0.376	0.316	0.817	0.670	0.754		0.172	0.126	0.011	0.004	0.015
	N	14	15	16	16	16	16	16	12	16	16	16
Homefield Hay Average	Pearson	.896**	0.384	-0.199	.600*	.951**	0.359	1	.929**	.785**	.740**	.848**
	Sig. (2-tailed)	0.000	0.157	0.459	0.014	0.000	0.172		0.000	0.000	0.001	0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Outfield Area Average	Pearson	.917**	0.379	-0.075	.611*	.873**	0.466	.929**	1	.841**	.766**	.867**
	Sig. (2-tailed)	0.000	0.251	0.816	0.035	0.000	0.126	0.000		0.001	0.004	0.000
	N	10	11	12	12	12	12	12	12	12	12	12
Outfield Hay Average	Pearson	.775**	0.451	0.045	0.396	.615*	.615*	.785**	.841**	1	.958**	.955**
	Sig. (2-tailed)	0.001	0.092	0.868	0.129	0.011	0.011	0.000	0.001		0.000	0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Total Cattle Average	Pearson	.884**	0.399	0.118	0.364	.551*	.674**	.740**	.766**	.958**	1	.960**
	Sig. (2-tailed)	0.000	0.141	0.663	0.166	0.027	0.004	0.001	0.004	0.000		0.000
	N	14	15	16	16	16	16	16	12	16	16	16
Total Sheep Average	Pearson	.908**	0.380	0.060	.553*	.692**	.596*	.848**	.867**	.955**	.960**	1
	Sig. (2-tailed)	0.000	0.162	0.825	0.026	0.003	0.015	0.000	0.000	0.000	0.000	
	N	14	15	16	16	16	16	16	12	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

		Farmstead Area Pre-1104	Farmstead Area 1104-1300	Farmstead Area Post-1300	19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms
Farmstead Area Pre-1104	Pearson Correlation	1	.878**	.825**	0.281	0.437	.474*	0.056	0.040
	Sig. (2-tailed)		0.000	0.000	0.353	0.135	0.017	0.767	0.887
	N	32	18	16	13	13	25	30	15
Farmstead Area 1104-1300	Pearson Correlation	.878**	1	.943**	0.455	0.394	0.251	-0.082	0.033
	Sig. (2-tailed)	0.000		0.000	0.118	0.183	0.315	0.745	0.907
	N	18	18	16	13	13	18	18	15
Farmstead Area Post-1300	Pearson Correlation	.825**	.943**	1	.563*	0.549	0.385	-0.136	0.151
	Sig. (2-tailed)	0.000	0.000		0.045	0.052	0.140	0.616	0.592
	N	16	16	17	13	13	16	16	15
19th Century Property Boundary	Pearson Correlation	0.281	0.455	.563*	1	.874**	-0.153	0.012	.754**
	Sig. (2-tailed)	0.353	0.118	0.045		0.000	0.601	0.968	0.002
	N	13	13	13	14	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	0.437	0.394	0.549	.874**	1	0.146	-0.033	.751**
	Sig. (2-tailed)	0.135	0.183	0.052	0.000		0.617	0.911	0.002
	N	13	13	13	14	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.474*	0.251	0.385	-0.153	0.146	1	0.023	-0.040
	Sig. (2-tailed)	0.017	0.315	0.140	0.601	0.617		0.909	0.880
	N	25	18	16	14	14	27	27	17
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson Correlation	0.056	-0.082	-0.136	0.012	-0.033	0.023	1	0.214
	Sig. (2-tailed)	0.767	0.745	0.616	0.968	0.911	0.909		0.394
	N	30	18	16	14	14	27	34	18
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson Correlation	0.040	0.033	0.151	.754**	.751**	-0.040	0.214	1
	Sig. (2-tailed)	0.887	0.907	0.592	0.002	0.002	0.880	0.394	
	N	15	15	15	14	14	17	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

		Average SeAR - 1104 - 350-meter Catchment Buffer	Average SeAR - H3-1104 - 350-meter Catchment Buffer	Average SeAR - LNL-1104 - 350-meter Catchment Buffer	Average SeAR - 1104-1300 - 350-meter Catchment Buffer	Average SeAR - 1300 - 350-meter Catchment Buffer	Average SeAR - H3 - 350-meter Catchment Buffer	Average SeAR - LNL - 350-meter Catchment Buffer	Average SeAR - H3-LNL - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms
Average SeAR - 1104 - 350-meter Catchment Buffer	Pearson	1	0.109	.b	0.007	0.113	0.496	0.392	-0.074	0.495	-0.362	0.690	0.013
	Sig. (2-tailed)		0.816		0.988	0.809	0.257	0.744	0.953	0.397	0.425	0.086	0.977
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - H3-1104 - 350-meter Catchment Buffer	Pearson	0.109	1	.b	0.139	0.715	.904**	0.904	0.607	.963**	0.384	-0.045	.765*
	Sig. (2-tailed)	0.816			0.767	0.071	0.005	0.281	0.585	0.009	0.395	0.923	0.045
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - LNL-1104 - 350-meter Catchment Buffer	Pearson	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b
	Sig. (2-tailed)												
	N	1	1	1	1	1	1	1	1	1	1	1	1
Average SeAR - 1104-1300 - 350-meter Catchment Buffer	Pearson	0.007	0.139	.b	1	-0.441	0.225	-0.745	-0.968	0.372	-0.416	0.225	0.212
	Sig. (2-tailed)	0.988	0.767			0.322	0.628	0.465	0.162	0.538	0.354	0.627	0.649
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - 1300 - 350-meter Catchment Buffer	Pearson	0.113	0.715	.b	-0.441	1	0.563	0.874	1.000*	.888*	.771*	-0.316	0.599
	Sig. (2-tailed)	0.809	0.071		0.322		0.188	0.323	0.020	0.044	0.042	0.490	0.155
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - H3 - 350-meter Catchment Buffer	Pearson	0.496	.904**	.b	0.225	0.563	1	0.593	0.157	.942*	0.074	0.333	0.681
	Sig. (2-tailed)	0.257	0.005		0.628	0.188		0.596	0.899	0.017	0.875	0.466	0.092
	N	7	7	1	7	7	7	3	3	5	7	7	7
Average SeAR - LNL - 350-meter Catchment Buffer	Pearson	0.392	0.904	.b	-0.745	0.874	0.593	1	0.888	1.000**	0.169	0.369	0.900
	Sig. (2-tailed)	0.744	0.281		0.465	0.323	0.596		0.304		0.892	0.760	0.287
	N	3	3	1	3	3	3	3	3	2	3	3	3
Average SeAR - H3-LNL - 350-meter Catchment Buffer	Pearson	-0.074	0.607	.b	-0.968	1.000*	0.157	0.888	1	1.000**	0.603	-0.099	0.600
	Sig. (2-tailed)	0.953	0.585		0.162	0.020	0.899	0.304			0.588	0.937	0.590
	N	3	3	1	3	3	3	3	3	2	3	3	3
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson	0.495	.963**	.b	0.372	.888*	.942*	1.000**	1.000**	1	0.146	-0.033	.751**
	Sig. (2-tailed)	0.397	0.009		0.538	0.044	0.017				0.617	0.911	0.002
	N	5	5	1	5	5	5	2	2	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson	-0.362	0.384	.b	-0.416	.771*	0.074	0.169	0.603	0.146	1	0.023	-0.040
	Sig. (2-tailed)	0.425	0.395		0.354	0.042	0.875	0.892	0.588	0.617		0.909	0.880
	N	7	7	1	7	7	7	3	3	14	27	27	17
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson	0.690	-0.045	.b	0.225	-0.316	0.333	0.369	-0.099	-0.033	0.023	1	0.214
	Sig. (2-tailed)	0.086	0.923		0.627	0.490	0.466	0.760	0.937	0.911	0.909		0.394
	N	7	7	1	7	7	7	3	3	14	27	34	18
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson	0.013	.765*	.b	0.212	0.599	0.681	0.900	0.600	.751**	-0.040	0.214	1
	Sig. (2-tailed)	0.977	0.045		0.649	0.155	0.092	0.287	0.590	0.002	0.880	0.394	
	N	7	7	1	7	7	7	3	3	14	17	18	18

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

b. Cannot be computed because at least one of the variables is constant.

		Homefield Area Average	Homefield Fertility Average	Homefield Hay Average	Outfield Area Average	Outfield Hay Average	Total Cattle Average	Total Sheep Average	Farmstead Area Pre-1104	Farmstead Area 1104-1300	Farmstead Area Post-1300	19th Century Property Boundary
Homefield Area Average	Pearson Correlation	1	0.085	.951**	.873**	.615*	.551*	.692**	.661*	0.527	.622*	.735**
	Sig. (2-tailed)		0.754	0.000	0.000	0.011	0.027	0.003	0.010	0.053	0.017	0.003
	N	16	16	16	12	16	16	16	14	14	14	14
Homefield Fertility Average	Pearson Correlation	0.085	1	0.359	0.466	.615*	.674**	.596*	0.042	-0.144	-0.163	0.070
	Sig. (2-tailed)	0.754		0.172	0.126	0.011	0.004	0.015	0.887	0.625	0.578	0.812
	N	16	16	16	12	16	16	16	14	14	14	14
Homefield Hay Average	Pearson Correlation	.951**	0.359	1	.929**	.785**	.740**	.848**	.596*	0.430	.537*	.695**
	Sig. (2-tailed)	0.000	0.172		0.000	0.000	0.001	0.000	0.024	0.125	0.048	0.006
	N	16	16	16	12	16	16	16	14	14	14	14
Outfield Area Average	Pearson Correlation	.873**	0.466	.929**	1	.841**	.766**	.867**	.622*	0.420	0.544	0.630
	Sig. (2-tailed)	0.000	0.126	0.000		0.001	0.004	0.000	0.041	0.199	0.083	0.051
	N	12	12	12	12	12	12	12	11	11	11	10
Outfield Hay Average	Pearson Correlation	.615*	.615*	.785**	.841**	1	.958**	.955**	.605*	0.375	0.492	.539*
	Sig. (2-tailed)	0.011	0.011	0.000	0.001		0.000	0.000	0.022	0.186	0.074	0.047
	N	16	16	16	12	16	16	16	14	14	14	14
Total Cattle Average	Pearson Correlation	.551*	.674**	.740**	.766**	.958**	1	.960**	.579*	0.416	.561*	.677**
	Sig. (2-tailed)	0.027	0.004	0.001	0.004	0.000		0.000	0.030	0.139	0.037	0.008
	N	16	16	16	12	16	16	16	14	14	14	14
Total Sheep Average	Pearson Correlation	.692**	.596*	.848**	.867**	.955**	.960**	1	0.457	0.316	0.447	.720**
	Sig. (2-tailed)	0.003	0.015	0.000	0.000	0.000	0.000		0.101	0.271	0.109	0.004
	N	16	16	16	12	16	16	16	14	14	14	14
Farmstead Area Pre-1104	Pearson Correlation	.661*	0.042	.596*	.622*	.605*	.579*	0.457	1	.878**	.825**	0.281
	Sig. (2-tailed)	0.010	0.887	0.024	0.041	0.022	0.030	0.101		0.000	0.000	0.353
	N	14	14	14	11	14	14	14	32	18	16	13
Farmstead Area 1104-1300	Pearson Correlation	0.527	-0.144	0.430	0.420	0.375	0.416	0.316	.878**	1	.943**	0.455
	Sig. (2-tailed)	0.053	0.625	0.125	0.199	0.186	0.139	0.271	0.000		0.000	0.118
	N	14	14	14	11	14	14	14	18	18	16	13
Farmstead Area Post-1300	Pearson Correlation	.622*	-0.163	.537*	0.544	0.492	.561*	0.447	.825**	.943**	1	.563*
	Sig. (2-tailed)	0.017	0.578	0.048	0.083	0.074	0.037	0.109	0.000	0.000		0.045
	N	14	14	14	11	14	14	14	16	16	17	13
19th Century Property Boundary	Pearson Correlation	.735**	0.070	.695**	0.630	.539*	.677**	.720**	0.281	0.455	.563*	1
	Sig. (2-tailed)	0.003	0.812	0.006	0.051	0.047	0.008	0.004	0.353	0.118	0.045	
	N	14	14	14	10	14	14	14	13	13	13	14

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
a. Cannot be computed because at least one of the variables is constant.

		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Pearson Correlation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Sig. (2-tailed)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Pearson Correlation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Sig. (2-tailed)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
c. Cannot be computed because at least one of the variables is constant.

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
c. Cannot be computed because at least one of the variables is constant.

		Absolute Change in ScAR 1104-1300 to Post 1300	Absolute Change in ScAR H3-1104 to Post 1104	Percent Change in ScAR 1104-1300 to Post 1300	Percent Change in ScAR H3-1104 to Post 1104	Farmstead Area Pre-1104	Farmstead Area 1104-1300	Farmstead Area Post-1300	Absolute Change in Farmstead Area Pre 1104 to 1104-1300	Percent Change in Farmstead Area Pre 1104 to 1104-1300	Percent Change in Farmstead Area 1104-1300 to Post 1300	Absolute Change in Farmstead Area 1104-1300 to Post 1300
Absolute Change in ScAR 1104-1300 to Post 1300	Pearson Correlatio	1	0.473	.936**	0.267	-0.020	0.035	0.257	0.087	0.542	0.424	0.629
	Sig. (2-tailed)		0.284	0.002	0.562	0.966	0.940	0.578	0.854	0.209	0.343	0.131
	N	7	7	7	7	7	7	7	7	7	7	7
Absolute Change in ScAR H3-1104 to Post 1104	Pearson Correlatio	0.473	1	0.510	0.290	0.427	0.542	0.548	0.445	0.451	-0.075	0.004
	Sig. (2-tailed)	0.284		0.242	0.528	0.339	0.208	0.203	0.318	0.310	0.873	0.993
	N	7	7	7	7	7	7	7	7	7	7	7
Percent Change in ScAR 1104-1300 to Post 1300	Pearson Correlatio	.936**	0.510	1	0.130	-0.007	-0.027	0.178	-0.039	0.431	0.244	0.581
	Sig. (2-tailed)	0.002	0.242		0.780	0.987	0.954	0.703	0.934	0.335	0.597	0.171
	N	7	7	7	7	7	7	7	7	7	7	7
Percent Change in ScAR H3-1104 to Post 1104	Pearson Correlatio	0.267	0.290	0.130	1	-0.471	-0.275	-0.154	0.080	0.296	0.436	0.349
	Sig. (2-tailed)	0.562	0.528	0.780		0.286	0.551	0.742	0.865	0.519	0.328	0.443
	N	7	7	7	7	7	7	7	7	7	7	7
Farmstead Area Pre-1104	Pearson Correlatio	-0.020	0.427	-0.007	-0.471	1	.878**	.825**	-0.022	-0.174	-0.058	-0.172
	Sig. (2-tailed)	0.966	0.339	0.987	0.286		0.000	0.000	0.931	0.490	0.820	0.494
	N	7	7	7	7	32	18	16	18	18	18	18
Farmstead Area 1104-1300	Pearson Correlatio	0.035	0.542	-0.027	-0.275	.878**	1	.943**	0.460	0.236	-0.049	-0.235
	Sig. (2-tailed)	0.940	0.208	0.954	0.551	0.000		0.000	0.055	0.345	0.846	0.348
	N	7	7	7	7	18	18	16	18	18	18	18
Farmstead Area Post-1300	Pearson Correlatio	0.257	0.548	0.178	-0.154	.825**	.943**	1	0.406	0.169	-0.028	-0.074
	Sig. (2-tailed)	0.578	0.203	0.703	0.742	0.000	0.000		0.118	0.531	0.918	0.786
	N	7	7	7	7	16	16	17	16	16	16	16
Absolute Change in Farmstead Area Pre 1104 to 1104-1300	Pearson Correlatio	0.087	0.445	-0.039	0.080	-0.022	0.460	0.406	1	.816**	0.004	-0.171
	Sig. (2-tailed)	0.854	0.318	0.934	0.865	0.931	0.055	0.118		0.000	0.988	0.497
	N	7	7	7	7	18	18	16	18	18	18	18
Percent Change in Farmstead Area Pre 1104 to 1104-1300	Pearson Correlatio	0.542	0.451	0.431	0.296	-0.174	0.236	0.169	.816**	1	0.065	-0.081
	Sig. (2-tailed)	0.209	0.310	0.335	0.519	0.490	0.345	0.531	0.000		0.799	0.748
	N	7	7	7	7	18	18	16	18	18	18	18
Percent Change in Farmstead Area 1104-1300 to Post 1300	Pearson Correlatio	0.424	-0.075	0.244	0.436	-0.058	-0.049	-0.028	0.004	0.065	1	.776**
	Sig. (2-tailed)	0.343	0.873	0.597	0.328	0.820	0.846	0.918	0.988	0.799		0.000
	N	7	7	7	7	18	18	16	18	18	18	18
Absolute Change in Farmstead Area 1104-1300 to Post 1300	Pearson Correlatio	0.629	0.004	0.581	0.349	-0.172	-0.235	-0.074	-0.171	-0.081	.776**	1
	Sig. (2-tailed)	0.131	0.993	0.171	0.443	0.494	0.348	0.786	0.497	0.748	0.000	
	N	7	7	7	7	18	18	16	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
c. Cannot be computed because at least one of the variables is constant.

		Farmstead Area Pre-1104	Farmstead Area 1104-1300	Farmstead Area Post-1300	Absolute Change in Farmstead Area Pre 1104 to 1104-1300	Percent Change in Farmstead Area Pre 1104 to 1104-1300	Percent Change in Farmstead Area 1104-1300 to Post 1300	Absolute Change in Farmstead Area 1104-1300 to Post 1300	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Baseline Climate Scenario - All Sites	Total Utilizable Biomass Baseline Climate Scenario - Just Farms
Farmstead Area Pre-1104	Pearson Correlatio	1	.878**	.825**	-0.022	-0.174	-0.058	-0.172	0.437	.474*	0.056	0.040
	Sig. (2-tailed)		0.000	0.000	0.931	0.490	0.820	0.494	0.135	0.017	0.767	0.887
	N	32	18	16	18	18	18	18	13	25	30	15
Farmstead Area 1104-1300	Pearson Correlatio	.878**	1	.943**	0.460	0.236	-0.049	-0.235	0.394	0.251	-0.082	0.033
	Sig. (2-tailed)	0.000		0.000	0.055	0.345	0.846	0.348	0.183	0.315	0.745	0.907
	N	18	18	16	18	18	18	18	13	18	18	15
Farmstead Area Post-1300	Pearson Correlatio	.825**	.943**	1	0.406	0.169	-0.028	-0.074	0.549	0.385	-0.136	0.151
	Sig. (2-tailed)	0.000	0.000		0.118	0.531	0.918	0.786	0.052	0.140	0.616	0.592
	N	16	16	17	16	16	16	16	13	16	16	15
Absolute Change in Farmstead Area Pre 1104 to 1104-1300	Pearson Correlatio	-0.022	0.460	0.406	1	.816**	0.004	-0.171	-0.028	-0.079	-0.009	-0.007
	Sig. (2-tailed)	0.931	0.055	0.118		0.000	0.988	0.497	0.926	0.756	0.973	0.982
	N	18	18	16	18	18	18	18	13	18	18	15
Percent Change in Farmstead Area Pre 1104 to 1104-1300	Pearson Correlatio	-0.174	0.236	0.169	.816**	1	0.065	-0.081	-0.033	0.114	0.037	-0.031
	Sig. (2-tailed)	0.490	0.345	0.531	0.000		0.799	0.748	0.914	0.651	0.884	0.912
	N	18	18	16	18	18	18	18	13	18	18	15
Percent Change in Farmstead Area 1104-1300 to Post 1300	Pearson Correlatio	-0.058	-0.049	-0.028	0.004	0.065	1	.776**	-0.131	0.388	0.266	0.122
	Sig. (2-tailed)	0.820	0.846	0.918	0.988	0.799		0.000	0.670	0.111	0.286	0.665
	N	18	18	16	18	18	18	18	13	18	18	15
Absolute Change in Farmstead Area 1104-1300 to Post 1300	Pearson Correlatio	-0.172	-0.235	-0.074	-0.171	-0.081	.776**	1	0.138	0.360	0.071	0.293
	Sig. (2-tailed)	0.494	0.348	0.786	0.497	0.748	0.000		0.653	0.143	0.780	0.290
	N	18	18	16	18	18	18	18	13	18	18	15
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlatio	0.437	0.394	0.549	-0.028	-0.033	-0.131	0.138	1	0.146	-0.033	.751**
	Sig. (2-tailed)	0.135	0.183	0.052	0.926	0.914	0.670	0.653		0.617	0.911	0.002
	N	13	13	13	13	13	13	13	14	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlatio	.474*	0.251	0.385	-0.079	0.114	0.388	0.360	0.146	1	0.023	-0.040
	Sig. (2-tailed)	0.017	0.315	0.140	0.756	0.651	0.111	0.143	0.617		0.909	0.880
	N	25	18	16	18	18	18	18	14	27	27	17
Total Utilizable Biomass Baseline Climate Scenario - All Sites	Pearson Correlatio	0.056	-0.082	-0.136	-0.009	0.037	0.266	0.071	-0.033	0.023	1	0.214
	Sig. (2-tailed)	0.767	0.745	0.616	0.973	0.884	0.286	0.780	0.911	0.909		0.394
	N	30	18	16	18	18	18	18	14	27	34	18
Total Utilizable Biomass Baseline Climate Scenario - Just Farms	Pearson Correlatio	0.040	0.033	0.151	-0.007	-0.031	0.122	0.293	.751**	-0.040	0.214	1
	Sig. (2-tailed)	0.887	0.907	0.592	0.982	0.912	0.665	0.290	0.002	0.880	0.394	
	N	15	15	15	15	15	15	15	14	17	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

		Total Utilizable Biomass Cold Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Cold Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Warm Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Warm Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Extreme Cold Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Extreme Cold Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Homefield Area Average	Homefield Fertility Average	Homefield Hay Average	Outfield Area Average	Outfield Hay Average	Total Cattle Average	Total Sheep Average
Total Utilizable Biomass Cold Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	1	.519	.900	.520	.997	.510	0.125	.999	0.329	0.279	0.364	0.379	0.452	0.374	0.362
	Sig. (2-tailed)		0.007	0.000	0.006	0.000	0.007	0.671	0.000	0.231	0.314	0.183	0.259	0.091	0.169	0.185
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Cold Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.519	1	.557	1.000	.499	1.000	.040	.550	.900	0.229	.000	.919	.049	.054	.045
	Sig. (2-tailed)	0.007		0.003	0.000	0.010	0.000	0.000	0.004	0.000	0.425	0.000	0.000	0.000	0.000	0.000
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Warm Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.900	.557	1	.559	.974	.555	0.295	.994	0.419	0.276	0.455	0.427	0.466	0.474	0.444
	Sig. (2-tailed)	0.000	0.003		0.003	0.000	0.003	0.419	0.000	0.126	0.319	0.000	0.190	0.000	0.074	0.097
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Warm Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.520	1.000	.559	1	.494	1.000	.045	.560	.900	0.247	.000	.910	.040	.052	.045
	Sig. (2-tailed)	0.006	0.000	0.003		0.010	0.000	0.000	0.004	0.000	0.490	0.000	0.000	0.000	0.000	0.000
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Extreme Cold Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.997	.499	.974	.494	1	.492	0.055	.992	0.262	0.266	0.292	0.315	0.410	0.299	0.295
	Sig. (2-tailed)	0.000	0.010	0.000	0.010		0.011	0.853	0.000	0.345	0.337	0.290	0.345	0.129	0.280	0.286
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Extreme Cold Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.510	1.000	.555	1.000	.492	1	.040	.557	.899	0.222	.006	.919	.049	.059	.044
	Sig. (2-tailed)	0.007	0.000	0.003	0.000	0.011		0.000	0.004	0.000	0.426	0.000	0.000	0.000	0.000	0.000
	N	26	26	26	26	26	26	14	25	15	15	15	11	15	15	15
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	0.125	.040	0.295	.045	0.055	.040	1	0.146	.915	0.256	.896	.917	.775	.004	.900
	Sig. (2-tailed)	0.671	0.000	0.419	0.000	0.853	0.000		0.617	0.000	0.376	0.000	0.000	0.001	0.000	0.000
	N	14	14	14	14	14	14	14	14	14	14	14	10	14	14	14
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.999	.550	.994	.560	.992	.557	0.146	1	0.346	0.270	0.304	0.379	0.451	0.399	0.300
	Sig. (2-tailed)	0.000	0.004	0.000	0.004	0.000	0.004	0.617		0.206	0.316	0.157	0.251	0.092	0.141	0.162
	N	25	25	25	25	25	25	14	27	15	15	15	11	15	15	15
Homefield Area Average	Pearson Correlation	0.329	.900	0.419	.900	0.262	.899	.915	0.346	1	0.005	.951	.879	.615	.551	.692
	Sig. (2-tailed)	0.231	0.000	0.126	0.000	0.345	0.000	0.000	0.206		0.754	0.000	0.000	0.011	0.027	0.003
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16
Homefield Fertility Average	Pearson Correlation	0.279	0.229	0.276	0.247	0.266	0.222	0.256	0.270	0.005	1	0.959	0.466	.615	.674	.596
	Sig. (2-tailed)	0.314	0.425	0.319	0.490	0.337	0.426	0.376	0.316	0.754		0.172	0.126	0.011	0.004	0.015
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16
Homefield Hay Average	Pearson Correlation	0.364	.000	0.455	.000	0.292	.006	.896	0.304	.951	0.959	1	.929	.785	.740	.840
	Sig. (2-tailed)	0.183	0.000	0.000	0.000	0.290	0.000	0.000	0.157	0.000	0.172		0.000	0.000	0.001	0.000
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16
Outfield Area Average	Pearson Correlation	0.379	.919	0.427	.910	0.315	.919	.917	0.379	.879	0.466	.929	1	.841	.766	.867
	Sig. (2-tailed)	0.259	0.000	0.190	0.000	0.345	0.000	0.000	0.251	0.000	0.126	0.000		0.001	0.004	0.000
	N	11	11	11	11	11	11	10	11	12	12	12	12	12	12	12
Outfield Hay Average	Pearson Correlation	0.452	.049	0.466	.040	0.410	.049	.775	0.451	.615	.615	.785	.841	1	.950	.955
	Sig. (2-tailed)	0.091	0.000	0.000	0.000	0.129	0.000	0.001	0.092	0.011	0.011	0.000	0.001		0.000	0.000
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16
Total Cattle Average	Pearson Correlation	0.374	.054	0.474	.052	0.299	.059	.004	0.399	.551	.674	.740	.766	.950	1	.960
	Sig. (2-tailed)	0.169	0.000	0.074	0.000	0.280	0.000	0.000	0.141	0.027	0.004	0.001	0.004	0.000		0.000
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16
Total Sheep Average	Pearson Correlation	0.362	.045	0.444	.045	0.295	.044	.900	0.300	.692	.596	.840	.867	.955	.960	1
	Sig. (2-tailed)	0.185	0.000	0.097	0.000	0.286	0.000	0.000	0.162	0.003	0.015	0.000	0.000	0.000	0.000	
	N	15	15	15	15	15	15	14	15	16	16	16	12	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

		Total Utilizable Biomass Cold Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Cold Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Warm Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Warm Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Extreme Cold Climate Scenario - 350-meter Catchment Buffer	Total Utilizable Biomass Extreme Cold Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Farmstead Area Pre-1804	Farmstead Area 1804-1900	Farmstead Area Post-1900	Absolute Change in Farmstead Area Pre 1804 to 1804-1900	Absolute Change in Farmstead Area 1804-1900 to Post 1900	Percent Change in Farmstead Area Pre 1804 to 1804-1900	Percent Change in Farmstead Area 1804-1900 to Post 1900
Total Utilizable Biomass Cold Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	1	.519	.900	.520	.997	.518	0.125	.999	.486	0.199	0.276	-0.247	0.200	-0.011	0.329
	Sig. (2-tailed)		0.007	0.000	0.006	0.000	0.007	0.671	0.000	0.016	0.444	0.310	0.402	0.262	0.967	0.198
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Cold Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.519	1	.557	1.000	.499	1.000	.940	.558	.725	.542	.572	-0.001	0.191	-0.120	0.207
	Sig. (2-tailed)	0.007		0.003	0.000	0.010	0.000	0.000	0.004	0.000	0.024	0.026	0.757	0.462	0.646	0.426
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Warm Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.900	.557	1	.559	.974	.555	0.295	.994	.404	0.217	0.300	-0.185	0.345	0.009	0.364
	Sig. (2-tailed)	0.000	0.003		0.003	0.000	0.003	0.419	0.000	0.047	0.402	0.265	0.476	0.175	0.973	0.151
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Warm Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.520	1.000	.559	1	.494	1.000	.945	.560	.726	.546	.574	-0.074	0.100	-0.117	0.205
	Sig. (2-tailed)	0.006	0.000	0.003		0.010	0.000	0.000	0.004	0.000	0.023	0.025	0.776	0.469	0.654	0.429
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Extreme Cold Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.997	.499	.974	.494	1	.492	0.055	.992	.401	0.186	0.250	-0.225	0.256	-0.017	0.300
	Sig. (2-tailed)	0.000	0.010	0.000	0.010		0.011	0.853	0.000	0.047	0.475	0.354	0.385	0.321	0.950	0.290
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Extreme Cold Climate Scenario - 19th Century Property Boundary	Pearson Correlation	.518	1.000	.555	1.000	.492	1	.940	.557	.724	.542	.579	-0.001	0.192	-0.120	0.200
	Sig. (2-tailed)	0.007	0.000	0.003	0.000	0.011		0.000	0.004	0.000	0.025	0.026	0.757	0.460	0.645	0.424
	N	26	26	26	26	26	26	14	25	24	17	15	17	17	17	17
Total Utilizable Biomass Baseline Climate Scenario - 19th Century Property Boundary	Pearson Correlation	0.125	.940	0.295	.945	0.055	.940	1	0.146	0.497	0.394	0.549	-0.020	0.190	-0.033	-0.191
	Sig. (2-tailed)	0.671	0.000	0.419	0.000	0.853	0.000		0.617	0.195	0.183	0.052	0.926	0.659	0.914	0.670
	N	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13
Total Utilizable Biomass Baseline Climate Scenario - 350-meter Catchment Buffer	Pearson Correlation	.999	.558	.994	.560	.992	.557	0.146	1	.474	0.251	0.385	-0.079	0.360	0.114	0.300
	Sig. (2-tailed)	0.000	0.004	0.000	0.004	0.000	0.004	0.617		0.017	0.315	0.140	0.756	0.149	0.651	0.111
	N	25	25	25	25	25	25	14	27	25	18	16	18	18	18	18
Farmstead Area Pre-1804	Pearson Correlation	.486	.725	.404	.726	.401	.724	0.497	.474	1	.870	.825	-0.022	-0.172	-0.174	-0.050
	Sig. (2-tailed)	0.016	0.000	0.047	0.000	0.047	0.000	0.195	0.017		0.000	0.000	0.931	0.494	0.490	0.020
	N	24	24	24	24	24	24	13	25	32	18	16	18	18	18	18
Farmstead Area 1804-1900	Pearson Correlation	0.199	.542	0.217	.546	0.186	.542	0.394	0.251	.870	1	.949	0.460	-0.295	0.296	-0.049
	Sig. (2-tailed)	0.444	0.024	0.402	0.023	0.475	0.025	0.183	0.315	0.000		0.000	0.055	0.940	0.945	0.046
	N	17	17	17	17	17	17	13	18	18	18	16	18	18	18	18
Farmstead Area Post-1900	Pearson Correlation	0.276	.572	0.300	.574	0.250	.579	0.549	0.385	.825	.949	1	0.406	-0.074	0.163	-0.020
	Sig. (2-tailed)	0.310	0.026	0.265	0.025	0.354	0.026	0.052	0.140	0.000	0.000		0.110	0.786	0.591	0.910
	N	15	15	15	15	15	15	13	16	16	16	17	16	16	16	16
Absolute Change in Farmstead Area Pre 1804 to 1804-1900	Pearson Correlation	-0.247	-0.001	-0.185	-0.074	-0.225	-0.001	-0.020	-0.079	-0.022	0.460	0.406	1	-0.171	.916	0.004
	Sig. (2-tailed)	0.402	0.757	0.476	0.776	0.385	0.757	0.926	0.756	0.931	0.055	0.110		0.497	0.000	0.900
	N	17	17	17	17	17	17	13	18	18	18	16	18	18	18	18
Absolute Change in Farmstead Area 1804-1900 to Post 1900	Pearson Correlation	0.200	0.191	0.345	0.100	0.256	0.192	0.190	0.360	-0.172	-0.295	-0.074	-0.171	1	-0.001	.776
	Sig. (2-tailed)	0.262	0.462	0.175	0.469	0.321	0.460	0.659	0.149	0.494	0.940	0.786	0.497		0.740	0.000
	N	17	17	17	17	17	17	13	18	18	18	16	18	18	18	18
Percent Change in Farmstead Area Pre 1804 to 1804-1900	Pearson Correlation	-0.011	-0.120	0.009	-0.117	-0.017	-0.120	-0.033	0.114	-0.174	0.296	0.163	.916	-0.001	1	0.065
	Sig. (2-tailed)	0.967	0.646	0.973	0.654	0.950	0.645	0.914	0.651	0.490	0.945	0.591	0.000	0.740		0.799
	N	17	17	17	17	17	17	13	18	18	18	16	18	18	18	18
Percent Change in Farmstead Area 1804-1900 to Post 1900	Pearson Correlation	0.329	0.207	0.364	0.205	0.300	0.200	-0.191	0.300	-0.050	-0.049	-0.020	0.004	.776	0.065	1
	Sig. (2-tailed)	0.198	0.426	0.151	0.429	0.290	0.424	0.670	0.111	0.020	0.046	0.910	0.900	0.000	0.799	
	N	17	17	17	17	17	17	13	18	18	18	16	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
a. Cannot be computed because at least one of the variables is constant.

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