(Im)mobile Vikings? Environmental stress, adaptation, and the decision not to leave Iceland

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ABSTRACT Several thousand settlers from Norway and the British Isles started migrating to the North Atlantic in the late ninth century. The inhospitable environment of their main settlement earned it the name Ísland, "the land of ice". This rapid colonization swiftly showed its ecologically destructive impact: deforestation resulted in soil erosion, while overgrazing and depletion of fish populations triggered famines and conflicts over agricultural land and natural resources. This article aims to survey the anthropogenic impact on the basis of palaeoecological proxies obtained from pollen, tephra, and stable isotopes and to complement them with written accounts from the North such as the Icelandic sagas, annals, and law codes. Furthermore, the article investigates how medieval Icelanders adapted to environmental and socioeconomic challenges such as overexploitation of the land and natural hazards like volcanic eruptions or earthquakes. This article discusses the central question: Why did medieval Icelanders not continue their migration to more hospitable lands like the British Isles or the North American Vinland? In other words, what immobilised the intrepid Vikings?

KEY WORDS migration – mobility – climate change – Iceland – Vikings – environmental stress – adaptation

DAMM, C. (2025): (Im)mobile Vikings? Environmental stress, adaptation, and the decision not to leave Iceland. Geografie, 130, 3, 251–269.
https://doi.org/10.37040/geografie.2025.015
Received April 2025, accepted August 2025.

1. Introduction

Iceland lies between 63°–67° N and 14°–23° W, warmed by the North Atlantic Current; c. 11% is glaciated, while only c. 1% is arable. Despite those constraints, Iceland became a Norse settlement during the late ninth century which stands as a crucial migration event in medieval history, proving human societies' ability to adapt and the severe environmental effects of establishing settlements in vulnerable ecosystems. Existing research on Norse colonisation of Iceland has primarily focused on two central themes: the ecological impacts of settlement and the sociopolitical drivers of migration. Landmark studies by McGovern et al. (1988), Dugmore et al. (2012), Vésteinsson et al. (2014) and Streeter et al. (2015) have provided fundamental insights into how early Norse settlement led to rapid deforestation, dramatic soil erosion, and enduring transformations in Iceland's landscapes and ecosystems. Their interdisciplinary approaches, combining archaeological, palaeoecological, and historical evidence, have demonstrated how the importation of agricultural strategies, suited to different environmental contexts, resulted in long-term degradation of local flora and soils, sometimes with catastrophic outcomes for later generations.

At the same time, archaeological investigations by Ashby (2015), Raffield, Price, Collard (2017), and Barrett (2008), as well as palaeoenvironmental reconstructions by Erlendsson et al. (2012), Eddudóttir, Erlendsson, Gísladóttir (2015), and Bates et al. (2022) have highlighted the complex interplay of political consolidation, demographic pressures, and environmental opportunities that underpinned Norse migration to the North Atlantic. These studies also debate prevailing hypotheses, whether environmental degradation was the principal catalyst of social and economic change, or whether Icelandic settlers developed adaptive strategies and legal frameworks (such as those revealed in the *Grágás* ["Grey Goose"] law codes) to mitigate ecological decline and manage resource conflicts.

Recent developments in the field increasingly employ high-resolution palaeoecological proxies (pollen, tephra layers, stable isotopes) and integrate them with written sources like sagas and law codes, enabling researchers to disentangle the impacts of climate versus those of human activity and trace the emergence of social hierarchies and coping mechanisms.

This study departs from previous research by systematically integrating palaeoecological data with documentary accounts to explore how medieval Icelanders perceived and addressed the cascading effects of environmental and socio-economic challenges. In doing so, this research addresses persistent gaps concerning the resilience of Norse societies to ecological stress, thereby advancing our understanding of medieval environmental management and its legacies in (sub)arctic societies.

Research on climate-related human mobility underscores that adverse environmental change can generate large-scale movements, but also acknowledges that

migration outcomes depend on social, economic, and political context (McLeman 2014; Kaczan, Orgill-Meyer 2020). Iceland's settlement (c. 870–930 CE) and the population's subsequent immobility during periods of ecological stress provide a deep-time case study that complicates linear "climate-push" narratives. Integrating insights from migration scholarship, this article reassesses the Icelandic Norse settlement and long-term land use in Iceland to address three questions:

1. How did initial settlement transform Iceland's landscapes and ecosystems?
2. What cultural and institutional responses emerged to manage ensuing environmental challenges?
3. Why did most Icelanders remain *in situ* when analogous Norse colonies, notably Greenland, were abandoned?

Situating Iceland within a North-Atlantic comparative framework clarifies how similar stresses yielded divergent mobility outcomes and highlights the role of governance, violence, and identity in shaping "immobility as adaptation".

2. Data and methods

By integrating palaeoecological proxies, tephrochronology, archaeological evidence, and historical textual analysis (see Table 1), this research seeks to provide a comprehensive understanding of human-environment interactions in medieval Iceland and extract lessons relevant to contemporary environmental challenges. The study combines pre-existing palaeoecological results (pollen, stable isotope analysis, tephrochronology using volcanic ash layers), archaeological evidence (including turf-built structures and zooarchaeological material), and the historical analysis of medieval texts such as Icelandic sagas. These prose narratives, mainly written during the 13th and 14th centuries, detail numerous environmental conditions. For example, the medieval texts *Landnámabók* and *Egils saga* present information about woodland clearance and land claims which matches the palaeoecological evidence showing deforestation. Furthermore, the sagas document multiple famines that usually resulted from severe winters and volcanic eruptions. Through these stories that originated predominantly in the clerical milieu of Iceland or among the chieftain elite like in the case of the most famous saga author, Snorri Sturluson (1179–1241 CE), we can understand how medieval Icelanders perceived and reacted to environmental challenges. However, the saga accounts call for a critical evaluation as historical sources with their writing time commonly surpassing the so-called "Viking Age" (c. 750–1050 CE) by two or more centuries. Yet, some saga accounts detail specific resource conflicts which include disputes about grazing rights as well as woodland use, and fishing grounds. Growing

Table 1 – Overview of sources and evidence for Icelandic settlement and environmental history

Type	Evidence	Chronology and context
Written accounts	Icelandic sagas (*Landnámabók*, *Egils saga*): settlement motives, land claims, conflict	Settlement period (c. 870–930), sagas compiled 12th–13th c.
	Medieval law codes (*Grágás*), annals: resource management, legal adaptation	Laws twelfth–thirteenth c., annals from medieval period
	External descriptions (Adam of Bremen's *Gesta Hammaburgensis*)	Late eleventh century
	Place names (e.g., Akurey, Bygggarðar): evidence for cultivation/agriculture	From settlement period onward
	Written accounts of volcanic disasters, famines, communal labour practices (*réttir*), and adaptation	Medieval and early modern periods
Archaeology	Settlement pattern evidence: rapid colonisation, identification of settlers as wealthy free farmers	9th–10th centuries (settlement period)
	Material culture: farm buildings (architecture adapted to environment), animal husbandry evidence	Viking Age and medieval period
	Zooarchaeological remains: livestock keeping, changing practices, connection with political power	Viking Age and medieval period
Natural-scientific proxies	Palaeoecological proxies: pollen, stable isotopes, tephra for environmental reconstruction	Entire human occupation (post-870), tephra-layers deliver high precision
	Tephrochronology: volcanic ash layers for dating landscape and social changes	Whole period (870 to present, highlights medieval eruptions)
	Modern climate and environmental data (Icelandic Met Office): land fertility, glacier cover	Recent, for comparative context
	Proxy studies for volcanic eruptions (Laki fissure 1783–84, Hekla, Katla, Öræfajökull)	Medieval and early modern eruptions

population numbers led, in turn, to increased resource competition which became more severe since environmental degradation reduced landscape productivity. Further sources from the "archives of society" (Pfister 2018) include law codes (*Grágás*) as well as annals and external accounts from Central Europe (e.g., Adam of Bremen's *Gesta Hamma*burgensis).

Referenced dating methods include Bayesian Highest Probability Density analysis (830–881) and Greenlandic ice core correlations (e.g., the Landnám Tephra Layer now dated to 877±1 CE). The implementation of this data set thus allows for:

1. Multi-proxy palaeoecological synthesis to reconstruct land-cover change;
2. Critical textual analysis to extract perceptions of resource stress;
3. Comparative typology contrasting four Norse colonies on 12 variables (environmental productivity, political structure, external trade, conflict intensity, etc.);
4. Interpretive dialogue with contemporary climate-migration theory to assess relevance.

3. Results and discussion

3.1. Environmental impacts of settlement and its challenges

The Norse settlement of Iceland during the late ninth century stands as a crucial migration event in medieval history. Escaping political turmoil and land scarcity in Norway and the British Isles, these migrants established a lasting society in an environmentally challenging landscape. Their story demonstrates both the adaptive capacity of human societies and the profound environmental consequences of human settlement on fragile ecosystems (see Vésteinsson et al. 2014, Streeter et al. 2015, Dugmore et al. 2007), while the migration of Norse populations to Iceland was driven by a complex interplay of political, social, and demographic factors (Barrett 2008; Ashby 2015; Raffield, Price, Collard 2017). The consolidation of political power in Norway under Harald Fairhair (c. 850–932 CE) created tensions that prompted chieftains and their followers to seek new territories where they could maintain their independence and traditional power structures. This political catalyst for migration is vividly described in the Icelandic *Egils saga*, composed in the thirteenth century:

"In each province, King Harald took over all the estates and all the land, habited or uninhabited, and even the sea and the lakes. All the farmers were made his tenants, and everyone who worked the forests and dried salt, or hunted on land or at sea, was made to pay tribute to him. Many people fled the country to escape this tyranny and settled various uninhabited parts of many places [...]. And at this time, Iceland was discovered" (*Egils saga*, Einarsson 2003).

Medieval Icelandic sources like *Egils saga* and *Landnámabók* ("Book of Settlements") mention frequently that some individuals left Norway for Iceland due to King Harald Fairhair's oppressive rule (*fyrir ofríki Haralds konungs hárfagra*, Benediktsson 1986). The scarcity of land in Norway and parts of the British Isles provided further motivation for migration, as population growth placed pressure on available resources. This outward expansion can be seen as a continuation of Viking-Age exploratory patterns, with Iceland representing one of the most significant permanent settlement ventures beyond Scandinavia. Archaeological evidence suggests that most settlers were wealthy free farmers (*bóndi* in Old Icelandic), motivated by the prospect of new agricultural lands (Karlsson 2000). The twelfth-century *Landnámabók* lists about 400 settlers by name, primarily Norwegians, but also includes inhabitants from Scandinavian colonies in the British Isles, as well as Irish people, frequently captured slaves who could often become free men and establish their own farms in the new land.

Contrary to its name, Iceland experiences a milder climate than one might anticipate from its northern latitude. This is due to the influence of the Gulf Stream, which not only warms its climate but also brings with it a rich marine ecosystem.

Without this moderating effect, Iceland's climate would likely be too harsh for permanent human habitation. Approximately 11.6% of its landmass is covered with glaciers, with only 1.2% of the land (mainly the coastal areas) being fertile enough to allow agriculture (data retrieved from the Icelandic Met Office, Clunies Ross 2010). The environmental state of Iceland during pre-Norse settlement times becomes accessible through analysis of palaeoecological data. The traditional image of Iceland as a barren wasteland proves incorrect since scientific evidence shows that birch forests once covered between 25–40% of the island before the arrival of the first permanent settlers. The birch woodland ecosystem started its development process following the last glaciation period when birch woodlands emerged at Lake Kagaðarhóll in Northwest Iceland before the previously recorded time period (Bates et al. 2022). During the early Holocene period, the climate warmed up which led to woodland expansion but this growth was interrupted by cold periods. Northwest Iceland's pollen and plant macrofossil evidence shows that woodland expansion paused during a cooling period spanning according to radiocarbon calibrating to the timespan from 8700 to 8200 cal. yr BP with cold spring and summer temperatures making plant reproduction difficult (Eddudóttir, Erlendsson, Gísladóttir 2015). The Icelandic ecosystem shows how vulnerable it remains to climate fluctuations even when human activities had not yet become significant.

The possibility of pre-Viking settlement adds an important dimension to our understanding of Iceland's human history and raises questions about potential cultural exchanges or knowledge transfer regarding environmental management. However, it was undoubtedly the Norse settlement that initiated large-scale environmental transformation of the landscape. Archaeological evidence indicates that the colonisation of Iceland occurred rapidly, with most of the habitable areas claimed within sixty years of initial settlement around 870 CE, as documented in the twelfth-century *Landnámabók*. This source, though compiled several centuries after the events it describes, provides our most comprehensive account of the settlement process and details the claims of early settlers and their distribution across the landscape.

Archaeological models provide a fairly precise chronology of the migration process, suggesting that the settlement of the coastal areas of Iceland preceded a phase of inland expansion that was driven by the competition for space and the population's need to sustain access to forest resources (Vésteinsson 1998, Erlendsson et al. 2018). Material evidence left by the first settlers is consistently unearthed above a distinct layer of volcanic ash, known as the Landnám Tephra Layer (LTL). This tephra isochrone has been dated to the year 877±1 CE based on Greenlandic ice cores (Zielinski et al. 1997, Schmid et al. 2017). The deposition of the LTL thus occurred just before any significant human activity left archaeological traces across the island. The same ice cores reveal another tephra layer, related to

the eruptions of the Icelandic volcanoes Eldgjá (dated to 939) and Veiðivötn (V-Sv, dated to 938±6), which covers the earliest evidence of human settlements. This helps to narrow down the period of settlement to the years 877–938/939, which coincides with the information from *Landnámabók* that Iceland was completely settled "in a flood" within two generations (Schmid et al. 2021).

Tephrochronology – the dating of volcanic ash layers – has provided exceptional chronological precision for environmental records in Iceland. Research utilising 15 precisely dated tephra layers spanning the entire 1,200-year period of human settlement has yielded 2,625 horizons of known age within 200 stratigraphic sections, creating a high-resolution spatial and temporal record of landscape change (Streeter, Dugmore, Vésteinsson 2012). This technique allows to correlate environmental changes across different sites and to precisely date shifts in erosion rates, vegetation, and land use. What kind of environment did the first settlers then encounter? Historical and palaeoecological records indicate that Iceland's pre-*Landnám* vegetation must have been considerably different from what we observe today. Upon their arrival, Scandinavian settlers encountered vast woodlands of downy birch that covered at least a quarter of the island (Arnalds 2015). The woods offered shelter, and the soil was fertile in areas where the settlers had practised their slash-and-burn agriculture. As a result, the conditions for cultivating cereal crops were more favourable than they are today. Place names like Akurey (Cornfield Island) and Bygggarðar (Barley Field) attest as well to arable farming. Coastal populations of sea mammals, including walruses, were part of this picture, as well as green pastures capable of sustaining imported livestock.

During the Viking Age, the economy of the newcomers was based on animal husbandry and complemented by limited barley cultivation as well as the extensive use of wild species (McGovern, Perdikaris, Tinsley, 2001; Simpson et al. 2002; Dugmore et al. 2005). Zooarchaeological material suggests that pastoralism served as the primary source of wealth and influence, with a clear connection between cattle ownership, favourable grazing grounds, and political power – as evidenced both by archaeological findings and written records (Vésteinsson 1998). The importance of livestock is already attested in the story of one of the first Norwegian explorers, the farmer Flóki Vilgerðarson, who attempted to settle in Iceland around the year 865: "Flóki and his crew sailed west across Breiðafjörður and made land at Vatnsfjörður in Barðaströnd. At that time the fjord was teeming with fish, and they got so caught up with the fishing they forgot to make hay, so their livestock starved to death the following winter" (translation after Pálsson, Edwards 2007).

After this failure, Flóki left the land discouraged and gave it the name *Ísland*. But, only nine years later, another Norwegian magnate, Ingólfr Arnarson, left for Iceland because of a land dispute. His migration coincided with the slow onset of the Medieval Climate anomaly in the North that gradually transformed "the land of ice" into an attractive settlement area suitable for agriculture and animal

husbandry. The early medieval expansion of Scandinavians to Iceland, but also to the Faroe Islands and Greenland, is thus deeply tied to such environmental factors as the retreat of the polar ice cap, which allowed ice-free navigation, and the northward shift of fish populations. Despite benefiting from the favourable conditions of the Medieval Climate anomaly, Iceland posed numerous challenges for its settlers. All areas above 500 metres asl remained covered by massive glaciers beneath which could lurk the threat of lava, as in 1104 CE when a lava flow engulfed two dozen farmsteads west of Hekla (Þórarinsson 1967, Dugmore et al. 2007, Damm 2025).

As settlement progressed, the Norse colonists established distinctive social and political structures adapted to their new environment. By 930 CE, they had formed the Alþing, a national assembly that represented one of medieval Europe's earliest parliamentary institutions. This development reflected both the Norse cultural background of the settlers and their adaptation to Iceland's unique geographical and social conditions. The commonwealth period (930–1262) saw the development of a society characterised by dispersed farmsteads, regional assemblies (þing), and a complex system of chieftainships (*goðorð*) that mediated social relationships and resource access (Vésteinsson 2007). These emergent social structures would prove crucial in managing the environmental challenges that soon became apparent as the cumulative impact of settlement transformed Iceland's fragile ecosystem. The Icelandic commonwealth developed without a king or centralised executive authority, relying instead on communal decision-making and a complex legal system to resolve disputes, including those related to land use and resource access. Taking part in the political system required meeting specific criteria. According to the Icelandic laws called *Grágás* that were codified in the early twelfth century, a farmer needed to pledge allegiance to a particular chieftain, pay a þing tax, own a debt-free cow for each dependent, and possess a debt-free horse or ox along with all essential farming tools (McGovern et al. 1988). Supporting a nuclear family of 3–5 members meant owning at least 4–5 cattle or assets of similar value. These prerequisites indirectly capped the number of fully autonomous farmers who could establish themselves in a given area and potentially prevented high population densities (McGovern et al. 1988).

Quite apart from volcanic eruptions and other natural hazards like earthquakes and landslides, the anthropogenic factor also swiftly showed its destructive impact on the vulnerable Icelandic ecology. It is estimated that 90% of the birch woodlands and 40% of the soils present at the time of settlement have vanished today, and 73% of the contemporary land surface are affected by soil erosion (Arnalds 1987). As the vegetation cover diminished, the vulnerable Icelandic andosols (a volcanic soil type) became exposed to wind and water erosion, which lead already during or shortly after the initial settlement period, the so-called *Landnám*, to widespread soil loss. However, landscape instability and soil erosion

started even prior to the Viking-Age settlement, and was not only triggered by the arrival of the first settlers (Geirsdóttir et al. 2009). The most immediate and visible environmental impact of Norse settlement was widespread deforestation. Settlers cleared woodland for multiple purposes: to create fields and pastures, to obtain construction materials, and to produce charcoal for ironworking. Pollen records from across Iceland show a consistent pattern of declining birch percentages following settlement, with corresponding increases in grass pollen indicating conversion to pastureland (Erlendsson 2012). This deforestation had profound cascading effects on Iceland's ecosystems. The removal of woodland eliminated the protective cover that had previously stabilised soils, particularly on slopes and in areas with volcanic soils susceptible to erosion. Wind erosion increased substantially, as evidenced by tephra studies showing heightened sediment accumulation rates in post-settlement deposits. The loss of woodland habitat also affected biodiversity, altering the composition of plant and animal communities (Hiles et al. 2021). Deforestation appears to have accelerated over time as population increased and the demand for timber and agricultural land grew. By the early modern period, woodland covered only a small fraction of its pre-settlement extent, creating serious resource challenges for Icelandic society as timber became increasingly scarce.

3.2. Cultural responses and (in situ) adaptations

It is undisputable that the grazing pressure of the livestock was the main reason for soil deterioration (Buckland 2000). An examination of the 8th to 11th-centuries archaeofauna showed that the settlers imported a mix of domesticated animals to their new colonies. These included cattle, pigs, goats, sheep, horses, dogs, and cats, with the same standardised mix being introduced to every newly colonised island (McGovern, Perdikaris, Tinsley 2001). This effort to establish an agricultural system in an ecosystem that is unsuitable for such practices led, for example, to a brief attempt at pig farming in Greenland during the eleventh century. In Iceland, a similar attempt was given up broadly at the same time (McGovern 1985; Ólafsson et al. 2005). Radiocarbon dating of animal bones indicates that Icelanders started to shift their farming strategies in the eleventh century and relied mainly on sheep and cattle. These new species could better utilise the available pastures, that were already affected by soil erosion, and endure the harsh winters. They also proved to be economically more viable than pigs since they provided not only meat but also milk, and wool. Furthermore, calf skins were indispensable to produce the extensive medieval text corpus Iceland is known for.

Landnámabók reports that Geirmundr heljarskinn, a Norwegian chieftain, "was the noblest born of all the original settlers of Iceland. [...] He and Kjallakr

quarrelled over the land between Mount Klofningar and Fábeinsár River, and they fought at the cornfield north of Klofningar where they both wanted to grow corn" (translation after Pálsson, Edwards 2007).

Ch. 42 of *Landnámabók* relates how the settler "Sturla had a son called Bjarni, who quarrelled with Hrólfr the Younger and his sons over [Kalmans]tunga lítla. Then Bjarni promised to become a Christian, and afterwards Hvítá [= White River] changed its course and made a new channel where it flows now, so Bjarni gained possession of Tunga lítla down to Grindr and Sölmundarhöfði" (translation after Pálsson, Edwards 2007).

As it appears from these notices, quarrels over territory were common and often triggered by the limited amount of arable land. The settlers, many of whom were chieftains like the Norwegian Geirmundr, often competed for the most fertile and geographically most valuable plots. *Landnámabók* refers to numerous instances of these violent conflicts, as is demonstrated by the following episode: "There was a man called Þormóður inn rami [= the Strong]. He killed Gyrðr, uncle of Skjálrg of Jaðarr [= Jæren in Norway], and for that reason he had to get out of Norway, so he went to Iceland. [...] He took possession of the entire fjord, [...] and made his home at Siglunes. He quarrelled with Óláfr bekk over the Hvanndalir valley and killed sixteen men before they were reconciled on the terms that each was to have the valleys every other summer" (translation after Pálsson, Edwards 2007).

Annals and other documentary sources record numerous environmental disasters affecting medieval Iceland. Major volcanic eruptions together with severe winters that killed livestock and disease outbreaks which harmed both humans and animals made up these events. Such events often triggered food shortages and social stress, testing the resilience of Icelandic communities. We also have insights from the continent on Icelandic environmental and climatic limitations. One of the earliest views from the outside comes from the late 11th-century *Gesta Hammaburgensis* of Adam of Bremen. In his fourth book, Adam notes that "this island is so very large that it has on it many peoples, who make a living only by raising cattle and who clothe themselves with their pelts [presumably the Icelandic homespun cloth *vaðmál*]. No crops are grown there; the supply of wood is very meagre. On this account the people dwell in underground caves, glad to have roof and food and bed in common with their cattle. Passing their lives thus in holy simplicity, because they seek nothing more than what nature affords [...]" (*Gesta Hammaburgensis*, transl. after Tschan 1959, 2002).

Medieval Icelanders considered it necessary to channel these conflicts over land and resources by administrative and legal measures. Iceland's medieval law codes, particularly *Grágás*, contain numerous provisions related to resource management. These include regulations concerning grazing rights, woodland harvest, and marine resource use (Amorosi et al. 1996). The detailed attention given to these matters in legal texts reflects their social importance and suggests conscious

efforts to manage resources sustainably in the face of growing pressure. Laws regarding farm boundaries, common grazing areas, and seasonal resource use reveal a complex understanding of landscape processes and ecological limitations. Regulations on the number of livestock permitted on common grazing lands, for example, show awareness of the dangers of overgrazing. Similarly, restrictions on woodland cutting demonstrate concern about timber depletion. The creation and enforcement of these regulations through the þing system – Iceland's assemblies at local, regional, and national levels – provided mechanisms for addressing resource conflicts and adapting management practices to changing environmental conditions. The law codes thus represent institutional responses to environmental challenges, though their effectiveness in practice varied considerably. Eventually, Icelanders developed numerous social and institutional adaptations to manage environmental challenges. The commonwealth-era system of governance, with its elaborate legal framework and assembly system of the þing, provided mechanisms for resolving resource conflicts and establishing sustainable management practices. The division of the landscape into private farms, common grazing areas, and wilderness zones created a nested system of property rights that helped regulate resource access.

Communal labour arrangements facilitated resource harvesting and risk management. Practices such as *réttir* (the autumn sheep round-up) combined practical resource management with social reinforcement of community bonds (Aldred 2006). These cooperative labour systems were especially important for activities requiring substantial workforce mobilisation, such as hay harvesting, which needed to be completed within narrow weather windows. As resources became more constrained, social stratification intensified, with wealthy landowners gaining greater control over productive lands. This concentration of resources created both challenges and opportunities for environmental management, potentially allowing more coordinated decision-making but also sometimes leading to exploitation of marginal lands by those with fewer options.

Adaptation strategies to Iceland's challenging environment included specialised building techniques using turf, stone, and limited timber resources. Homes and outbuildings were designed to provide maximum insulation with minimal wood use, adapting Norse architectural traditions to local material constraints caused by deforestation. Agricultural innovations included careful management of home fields (*tún*) fertilised with manure to maintain productivity for hay production (Friðriksson, Vésteinsson 2003; Adderly, Simpson, Vésteinsson 2008). The development of irrigation systems in some regions demonstrated efforts to enhance productivity in the face of marginal growing conditions. Farmers also adapted livestock management practices, developing specialised breeding strategies for sheep and horses suited to Iceland's harsh conditions (McGovern, Perdikaris, Tinsley 2001). Diversification of subsistence activities provided resilience against

environmental fluctuations, with most farmsteads combining livestock raising with fishing, egg collecting, hunting of birds and seals, and gathering of wild plants. This mixed subsistence strategy allowed for flexible responses to changing resource availability and environmental conditions.

The development of specialised environmental knowledge was crucial to adaptation. Settlers and their descendants accumulated detailed understanding of local conditions, including indicators of weather changes, patterns of resource availability, and techniques for maximising productivity in a marginal environment. This knowledge was transmitted intergenerationally through both practical experience and formal mechanisms such as legal codes and sagas. Such a process of "landscape learning" is evidenced in the strategic placement of farms to balance access to diverse resources. Early settlers selected locations with access to a variety of ecological zones, often positioning farmsteads at the boundary between lowland and highland areas to facilitate resource diversification (Dugmore et al. 2009). As understanding of the landscape deepened, settlement patterns and land use strategies evolved to accommodate local environmental conditions and constraints. Traditional ecological knowledge encompassed understanding of sustainable harvest rates, appropriate timing for resource use, and recognition of environmental feedback signals indicating resource stress. While this knowledge did not prevent all instances of resource degradation, it provided a framework for adapting practices in response to environmental changes and hazards that will be discussed in the following.

The Mid-Atlantic Ridge position of Iceland leads to recurring volcanic activity. The medieval period saw major volcanic eruptions at Hekla (1104, 1158, 1300), Katla (1262, 1357) and Öræfajökull (1362) which produced major effects on local and regional areas. The exact dates of these eruptions and others have been determined through tephrochronological research which enables the study of the interconnectedness between environmental and social changes (Thordarson, Larsen 2007; Dugmore, Vésteinsson 2012; Hartman et al. 2017; McCreesh 2018; Nordvig 2021; Damm 2025). Documentary sources record temporary abandonment of farms in areas severely affected by eruptions, demonstrating how volcanic activity could force population displacement and land use changes. Studies around the Laki fissures in southern Iceland document the impacts of the 1783–1784 eruption, showing vegetation changes following ash deposition that were likely compounded by changes in grazing practices as farmers temporarily removed livestock to protect them from fluorosis (Thordarson, Self 2003; Kleemann 2023; Morison et al. 2024). Written sources often emphasise the role of contingent events – specific eruptions, unusually cold winters, or disease outbreaks – in causing hardship. However, palaeoecological evidence suggests that many of these acute crises occurred against a background of gradual environmental degradation that had already reduced the resilience of both ecosystems and social systems to short-term stressors.

Recovery from eruptions often required community support and resource redistribution. The þing system provided mechanisms for adjusting tax obligations for affected farms and organising assistance. The church also played a role in disaster response, with monasteries and wealthy church farms sometimes providing resources to affected communities, a practice that demonstrated accumulated knowledge about volcanic hazards and appropriate mitigation strategies.

3.3. Development of cultural resilience

Cultural adaptations to environmental stress included the development of social norms and narratives that fostered resilience. Saga literature often valorised perseverance through hardship, potentially reinforcing cultural traits conducive to survival in a challenging environment (McCreesh 2018). Religious practices provided psychological coping mechanisms and frameworks for interpreting environmental disasters (e.g. public vow contracts, the so-called *Heitbréf*, see Damm 2025), whereas social cohesion facilitated collective responses to environmental challenges. The extended family household structure common in medieval Iceland created multi-generational units capable of managing diverse tasks and sharing labour. This social organisation enhanced adaptive capacity by distributing risk and facilitating knowledge transmission across generations. Such practices indicate incorporation of environmental risk into cultural landscapes and worldviews, potentially normalising hazards as part of everyday life rather than exceptional catastrophes.

3.4. Factors for (im)mobility

Despite environmental challenges, Icelanders had substantial incentives to remain rather than migrate further. Considerable investments in infrastructure, including farm buildings, field systems, and irrigation works, represented sunk costs that would be lost through emigration. The development of specialised fishing stations, boats, and processing facilities similarly anchored communities to particular locations despite environmental degradation in the surrounding landscape. The medieval farm represented not just a physical place but accumulated generations of labour investment in land improvement. Home fields (*tún*) had been carefully fertilised and managed to maximise productivity, while field boundaries, drainage systems, and outbuildings represented significant capital investments. The prospect of abandoning these improvements and starting a new elsewhere may have presented substantial economic disincentives to further migration. Infrastructure development extended beyond individual farms to include

community investments such as assembly sites, harbours, and churches. These shared investments reinforced community attachment to place and created collective incentives for adapting to environmental challenges rather than abandoning settlements.

By the end of the settlement period, Icelanders had developed distinctive cultural identities and social networks that provided powerful reasons to remain despite environmental hardships. Family connections, inheritance systems, and local knowledge all bound people to particular landscapes even as those landscapes degraded. The development of a distinctive Icelandic identity, expressed through language, law, and above all literature, created cultural attachments to the island's unique geography that transcended environmental challenges. The complex web of social obligations and relationships documented in the sagas created systems of mutual support that may likewise have enhanced resilience against environmental stress. These relationships were place-specific, embodied in particular farms, districts, and assembly locations. Migration would have required not just physical relocation but reconstruction of these essential social networks. Cultural practices evolved specifically in relation to Iceland's environment, creating specialised knowledge systems adapted to local conditions. This environmental knowledge that was accumulated over generations, would possibly have proven to be only of limited value in other regions than Iceland which may have created additional disincentives to migration despite environmental challenges.

The commonwealth period (930–1262 CE) provided not only a unique political system but also considerable local autonomy and self-governance for medieval Icelanders. This political independence, though it eventually gave way to Norwegian and later Danish rule, shaped a distinctive society that valued its separation from continental power structures. The prospect of migrating to areas under more direct royal control may have seemed unattractive in spite of environmental hardships at home. The development of Iceland's legal tradition, with its emphasis on procedural justice and community participation, created a political culture adapted to local conditions. This distinctive political identity, alongside literary achievements such as the sagas, fostered national pride that strengthened attachment to Iceland despite its environmental and societal challenges.The latter were most significantly expressed in the so-called "Age of the Sturlungs" (*Sturlungaöld*) with Icelandic chieftains and family clans competing for influence and political power in a feud-ritten society (Byock 2023). Even after the end of the commonwealth in 1262–1264, when Iceland subdued to Norwegian royal authority, considerable local autonomy remained. This political arrangement allowed Icelanders to maintain their distinctive cultural practices and identity while profiting from some benefits of external connections, such as more regular trade (Karlsson 2000). This balance of autonomy and connection may have reduced incentives for further migration.

4. Conclusion

Medieval Iceland serves as an exceptional example to study how human societies adapted to environmental difficulties through permanent settlement and persistence. The swift population expansion led to immediate environmental alterations which included deforestation and livestock introduction that reshaped Iceland's terrain during the first few centuries of settlement. The modifications made to the environment by Icelandic society led to persistent difficulties which deteriorated due to volcanic eruptions and climate oscillations. Yet despite these challenges, medieval Icelanders developed sophisticated strategies for environmental management and adaptation. These included institutional innovations for resource governance, diversified subsistence strategies, specialised environmental knowledge, and cultural practices fostering resilience. The persistence of Icelandic society through periods of significant environmental stress demonstrates the potential for human adaptation even in marginal environments, however, in the conflict-ridden society of high medieval Iceland not exclusively successfully. Strategies of mitigation and adaptation such as the introduction of alternative livestock and legal regulations attest to the willingness and ability to establish a long-lasting Scandinavian community in the North Atlantic until the present day that is aware of the errors of the past and driven to mitigate current challenges, such as land degradation, by reforestation. The Icelandic case offers valuable insights for understanding human-environment relations in marginal environments, and demonstrates both the potential for human societies to adapt to challenging conditions as well as the consequences of exceeding environmental thresholds. As contemporary societies face accelerating environmental change, the medieval Icelandic experience provides both cautionary lessons about the consequences of environmental degradation and examples of human adaptive capacity.

Eventually, Iceland demonstrates that severe ecological stress need not precipitate exodus. Immobility can be an active adaptive strategy when anchored by:

1. Material investments that are non-fungible elsewhere.
2. Institutions enabling flexible resource reallocation yet preserving identity.
3. Cultural narratives legitimising persistence.

Modern policymakers should therefore avoid deterministic claims of inevitable "climate refugees" and instead analyse how governance, social capital, and attachment shape decisions to stay or move (McLeman 2014; Kaczan, Orgill-Meyer 2020). Understanding such dynamics is vital for designing interventions that support both migration and dignified immobility in a warming world.

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ACKNOWLEDGEMENTS

This article was supported by the National Science Centre Poland (2022/47/P/HS3/01044).

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