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From Bare to Birch

Large-Scale Ecosystem Restoration in Iceland

Mount Hekla © Berglind Orradottir

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Introduction

The manager of the Hekluskógar restoration project, Hrönn Guðmundsdóttir, was driving to the vast woodland restoration area in Southern Iceland. On the way she had a good view to Mount Hekla that glistened under the clouds of an early March 2018 morning glow. On a day like that, the approximately 4-hour hike to reach the summit of this 1491 m volcano to glimpse the view from the top was tempting. It certainly was hard to believe that what now stood peacefully in the distance, majestic and calm, has caused fear and unease for the local population in this region.

Located in the highly active South Iceland seismic volcanic zone, Mt. Hekla's approximately 23 eruptions since the settlement of Iceland in 874 AD[1] have influenced both the ecosystem and the people living in the area. Today, only remnants of the lush vegetation that was common at the time of settlement persist in the area. However, the destruction of the ecosystem was not caused by the volcanic eruptions alone, as woodlands thrived in the area before the arrival of humans to the island[2] and some of Mt. Hekla's biggest and most destructive eruptions occurred before historic times in Iceland[3].

At the time of human settlement, over 1100 years ago, about one-fourth of Iceland is estimated to have been covered by native birch (*Betula pubescens*) woodlands[2,4,5]. Extensive wood cutting, burning of woodlands and grazing, followed by a cooling climate in the Middle Ages and volcanism, caused extensive land degradation[5,6,7] and made Iceland one of the most deforested countries in Europe as of 2018[2]. Nowadays, the total area of birch woodlands in Iceland is estimated to be 150 600 hectares, or 1.5% of the land area[2]. The vast majority of the original woodland cover has therefore been lost (Appendix A).

On arrival to one of the areas of the Hekluskógar project, Guðmundsdóttir paused for a moment to observe the landscape. She was standing by a "woodland cluster". Planting these woodland islands has been the main restoration strategy of the project, because these clusters serve as seed sources for further natural colonization of the area[8].

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This case is based on field research. It was written to provide material for class discussion and for the MOOC Business Model Innovation for Sustainable Landscape Restoration rather than to illustrate either effective or ineffective handling of a management situation.

The small island with birch saplings and willow shrubs looked good after the winter. Frost heaving of the saplings and signs of sandblasting or frost damage on the plants, a common stress for small plants that can cause high mortality, seemed minimal at this site. This was promising, as the woodland clusters are very important for the success of the whole restoration project.

The planning of the Hekluskógar (meaning "Hekla woodlands") project was initiated in 2005 with the aim of increasing the resilience of the ecosystem to tephra fall from eruptions. Restoring the natural vegetation, that is, the native birch and willow woodlands and shrublands around Mt. Hekla, would reduce the risk of damage from redistribution of tephra[9,10]. Other goals of the project were to restore ecosystem function and biodiversity, sequester carbon and improve future land use options[10].

Having served as a project manager of the Hekluskógar project for about a year, Guðmundsdóttir admired the work that had been done so far to restore the land that surrounds Mt. Hekla. Yet she was cautiously optimistic about what the future would hold for the many landowners, farmers, volunteers, tourism entrepreneurs, scientists, and government workers that had worked so diligently in the area. The potential of what a successful ecosystem restoration could do for each of these stakeholders was one that envisioned plentiful future opportunities. Guðmundsdóttir reflected on the positivity and joy that she got from her job, but would it always be this way? What would the land look like in thirty years? And then, what kind of future initiatives could the restoration support among these different groups? Joint efforts and collaboration would be necessary to ensure that the use of the land would be coordinated in the future and the land itself would be cared for. She silently pondered this responsibility as she started another workday.

Perhaps the biggest question that dwelled in the back of her mind was what would happen to the land and to the many years of work if the volcano were to erupt in the near future? The answer would likely not be known until such an event happened, but continuing to strengthen the resilience of the land remained the only solution.

Mount Hekla and Surrounding Ecosystems

Mount Hekla's History

Mount Hekla is one of Iceland's most famous volcanoes. It has been called the "Gateway to Hell" because of its lava flows and towering lava fountains. Hekla's eruptions were said to have looked like the Earth had opened up and hell was exposed—an accurate description, given the damage that took place. Indeed, major losses of livestock and mass death of lake fish have been reported after Hekla eruptions before the 20th century[11,12,13].

Hekla can eject millions of tons of tephra[1,14], an unconsolidated material that consists of clastic rock particles, fragments and other airborne volcanic materials. Tephra eventually forms deposits on the ground, covering anything in its path, forming thicker layers closer to the site of the eruption[14,15]. The tephra spewed from Hekla has covered much of the area of Iceland over the centuries (Appendix B).

On deforested land, erosion processes by wind and water can redistribute tephra, especially where vegetation is sparse or short. These processes can reduce the thickness of the tephra layers in some areas while accumulating elsewhere, leading to burying of vegetation in new areas, damage to vegetation, and further erosion[15].

Ecosystems in the Hekla Area

The lowlands surrounding Mt. Hekla are estimated to have been mostly covered with birch woodlands, the dominating ecosystem of the lowlands at the time of settlement[2,7]. Downy birch, *Betula pubescens,* is the only native tree in Iceland that forms forests, and as a native species it is adapted to the conditions in Iceland. In addition to the birch, the shrubby willows *Salix phylicifolia* and *S. lanata* play a major role in many Icelandic ecosystems. Three other woody species are found within the birch woodlands, Rowan (*Sorbus aucuparia*), Juniper (*Juniperus communis*), and the most rare, Aspen (*Populus tremula*). The willows and Juniper form a shrub layer in the birch woodlands, while the Rowan is commonly scattered and sparse in the birch woodlands.

The birch woodlands were an important resource for the settlers. They provided wood for buildings and were an important source for firewood and charcoal making. Woodlands were also burned and cleared for fields and used for grazing[6]. The extensive and unsustainable human use of the woodlands, together with a cooling climate in the Middle Ages and the frequent volcanism, led to their decline, and in the late nineteenth century most of the woodlands in the area were gone[7,16].

Birch forests can capture tephra, and in their shelter, leftover ash from volcanic eruptions is not blown around and settles more quickly. With the deterioration of the woodlands, the resilience of the land to tephra deposition following eruptions was reduced. Shorter vegetation is not as effective in capturing tephra, and the root systems of weakened vegetation do not provide as much cohesion to the soil. This is particularly important for the soils of this area[15] because these volcanic soils, called Andosols, are not very cohesive and are easily blown or washed away once the vegetation is gone[17].

Evidence of the ecosystem destruction can be found in detailed farm registers from the early eighteenth century, which often mention vegetation damage caused by sand drift and soil erosion[18]. Other historical records of vegetation loss, soil erosion and sandstorms in the eighteenth and nineteenth centuries testify the extensive degradation[16]. For instance, a particularly devastating sandstorm took place in the Hekluskógar area in the spring of 1882. During three weeks, the storm blew away soils and weakened the already sparse vegetation. This big storm caused the loss of thousands of sheep and horses and left farms deserted. Streams dried up and disappeared in the storm; the lake Reyðarvatn became full of sand and the trout from the lake lay scattered in the sand after the storm. As the land was already in critical condition, this storm was the tipping point that erased thousands of hectares of vegetation and soil[16,19].

Clearly, the extensive land degradation not only affected terrestrial but also

freshwater ecosystems. Iceland is known for its impressive waterfalls, crystal clear water and powerful glacial rivers, and the Hekluskógar area is no exception. Several rivers run through the area and host salmon and trout, like the Þjórsá River, Fossá River, Rangá River and Sandá River, making them popular among tourists for recreational fly-fishing. But some of the waterholes and smaller streams disappeared during the period of most severe degradation, making it necessary to move the farmhouses, as the farmers had lost their water resource[16]. It is also likely that the extensive erosion caused higher sediment loads and turbidity of the river water, changing conditions for the aquatic organisms and destroying their habitats. It is well known that poor land conditions can modify both physical and ecological conditions of water bodies in the same catchment[20].

At the initiation of the Hekluskógar project the condition of the land was surveyed and mapped. The area outlined for the project was approximately 90 000 hectares. About 70% of the area was classified as having limited vegetation cover, and half of that land had very active erosion[9,9] (**Exhibit 1**). However, it is important to note that not all the land surrounding Mt. Hekla was highly degraded. About 30% of the land was still well vegetated, including remnants of the old ecosystem and land that had been revegetated in last century[9,9] (**Exhibit 2**). The remnants of birch woodlands found in the vicinity of Hekla have survived not only the management in the last centuries but also thick deposits of tephra during past eruptions. This is clear proof that land with woody vegetation is effective in capturing and preventing redistribution of ash by wind.

Characteristics of the Degraded Areas and Degradation Processes

Despite the restoration efforts, most of the Hekluskógar project area is still today characterized by extensive degradation of vegetation and soil loss. Where vegetation is scarce the surface is mainly rough lava partly filled with sand and pumice, and sand and gravel surfaces. These surfaces are unstable, as wind and water easily move the loose surface material[10, 21]. In addition, frost churning of the soil in winter detaches soil particles on the surface, contributing to the lack of surface stability in the area[22] and negatively influencing plant establishment.

New sediment is brought to the area along water channels[21] and from recurring volcanic eruptions, not only from Mt. Hekla but also from other volcanoes in the vicinity[10]. As an example, just 50 km away from Mt. Hekla is Eyjafjallajökull, a volcano that made the headlines worldwide in 2010 after it sent massive plumes of volcanic ash into the air. These ash clouds were detected over ~7 million km^2 and grounded flights in Europe and the North Atlantic for several days[23]. Luckily the wind direction during that eruption caused little ash fall directly in Hekluskógar, but still the volcanic materials from this eruption contributed a source of sediment to the area.

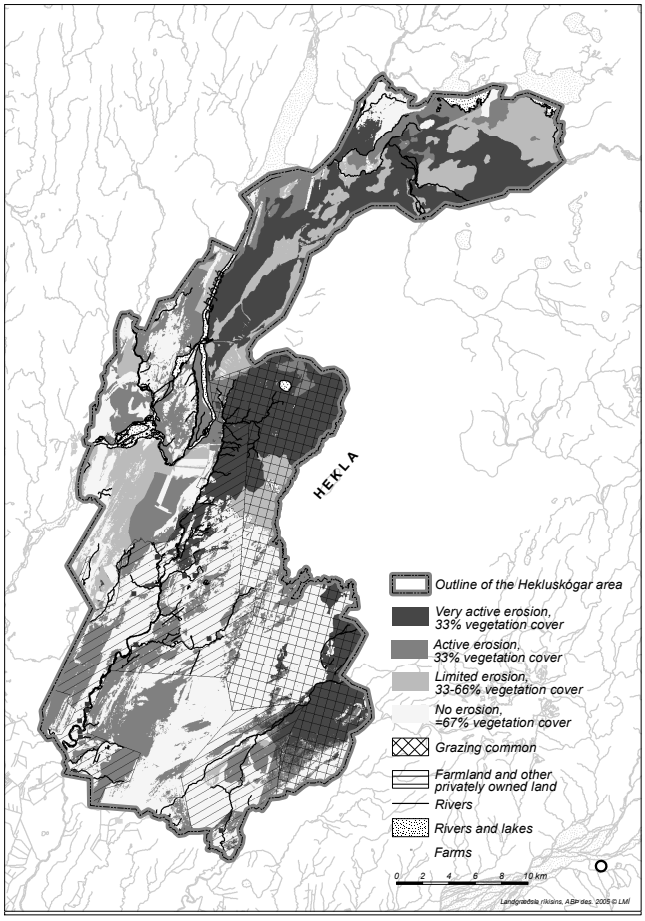
Despite the humid climate in the south of Iceland (mean annual precipitation is around 1000 mm[24]), wind erosion is considerable due to the abundance of loose surface material[21] and the frequent high-speed winds[24] that are amplified by the barren landscape. The loose surface materials of volcanic origin (glass and pumice) are light, so even larger particles can be transported at low wind speed, resulting in

more particle movement than is often observed in arid and semiarid areas where the loose material is denser and heavier[21]. Wind erosion is prevalent in summer but also occurs in winter when the surface is free of snow, which is quite common in the mild winters of Iceland[24]. Water erosion is most common in spring and during thaw events in winter when precipitation and thaw water cannot enter the frozen ground[25,26].

The soils of the eroded areas have lost most of their finer materials, their organic matter and clays, which are important for the water and nutrient cycles of the ecosystem. These soils are thus not able to hold much water or nutrients and have lost their fertility. The ecosystem is thus leaky and has lost its previous production potential and its ability to resist disturbances. Furthermore, during these degradative processes biodiversity is lost, both above- and below ground. Conditions are harsh for plant survival and establishment in those degraded areas (Exhibit 2). The predominant processes in the system are geophysical, which override the biotic processes that prevail in healthy ecosystems.

Exhibit 1:

Erosion and vegetation cover in the Hekluskógar area. An initial survey of the area by the Soil Conservation Service of Iceland delimited the areas with various severity of soil erosion and different vegetation cover. The Hekluskógar area includes common grazing areas and privately owned lands.



Source:
Aradóttir ÁL (2007) Restoration of birch and willow woodland on eroded areas. Pages 67–64. In: Halldórsson G, Oddsdóttir ES, Eggertson O (eds) Effects of afforestation on ecosystems, landscape and rural development – Proceedings of the AFFORNORD conference, Reykholt, Iceland, June 18-22, 2005. Norden, Reykjavík.

Exhibit 2: The degraded areas surrounding Mt Hekla (the snow-covered mountain in the centre) used to be covered by lush birch forests.

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The Hekluskógar Project

Origin and Organization

The idea of the Hekluskógar restoration project was born in the early 2000s and was first pitched by the Soil Conservation Service of Iceland (SCSI) in 2003-2005. The idea was based on promising results of a small scale tree planting project by SCSI, the Land Reclamation Forest project, the Icelandic Forest Service (IFS) and local Forestry Associations in barren and eroded areas near Hekla. The main goal of the Hekluskógar project is to reduce the potential damage from volcanic ash from future eruptions in Mt. Hekla and other volcanoes by restoring the native birch woodlands on vast areas around Hekla[10]. The idea was based on the effectiveness of woodlands and shrublands in capturing and preventing redistribution of ash by wind, as they have higher surface roughness than sparsely vegetated land or land dominated by low vegetation. Restoration and maintenance of birch woodlands and willow shrublands is therefore expected to increase the ecosystems' resilience to future ash deposits.

A collaboration committee of stakeholders that were interested in seeing the project come to life was formed in April 2005. It included representatives of three governmental entities, SCSI, IFS and the South Iceland Regional Afforestation Project, as well as representatives of local farmers and three NGOs: the Soil Conservation Fund, and the Forestry Associations of Rangárvallasýsla and Árnessýsla[10]. The collaboration committee oversaw the activities of a few working groups that dealt with the planning, promotion and funding of the project. The

working groups submitted a report to the government in autumn 2005[10] and were able to secure initial funding for the project to move forward.

SCSI facilitated the creation of the collaboration committee and emphasized the importance of including representatives from the diverse stakeholder groups. For SCSI it was obvious that the large area of the project, with diverse ownership and land uses, required the involvement of multiple and diverse stakeholders. Furthermore, involving people and entities with local knowledge on tree planting in the area would benefit the project through good practices and local involvement. This would increase the project's viability and its potential success. SCSI also realized the importance of using participatory approaches in this large and ambitious project[27].

In May 2007 the government signed a contract with SCSI and IFS to fund the project for the following ten years. When the baseline governmental funding was secured, Hekluskógar became an independent governmental project[28] hosted by SCSI and IFS. A project manager runs the daily activities, while the collaboration committee's role changed to being mainly advisory. The responsibility of planning the area remains within the local authorities. As of 2010, an executive board is formally responsible for the project[27] (**Exhibit 3**). After the contract expired in 2017, a new agreement was signed for another five years to guarantee the project's continuation into 2021. At the same time, two representatives were added to the collaboration committee: one from the Ministry for the Environment and Natural Resources and one from the municipalities in the area.

Exhibit 3: Hekluskógar project organization and committee compositions since 2007

Collaboration Committee	*Representatives of the following organizations:* Farmers / landowners of the Hekluskógar area Agricultural University of Iceland (**AUI**) Soil Conservation Service of Iceland (**SCSI**) Icelandic Forest Service (**IFS**) Regional Afforestation Project South Iceland* Soil Conservation Fund Forestry Association of Rangárvallasýsla Forestry Association of Árnessýsla Ministry for the Environment and Natural Resources Municipalities in the area	2007 - 2017
Executive Board	Representative of the Soil Conservation Service of Iceland (**SCSI**) Representative of the Icelandic Forest Service (**IFS**)	2010 - 2017
Project Manager	Hired by a project board$ in the beginning, but from 2010 by the Executive Board.	

Source: Based on Berglund et al. 2013 and personal communication with Hreinn Óskarsson, Hekluskógar Project Manager from 2007-2017.
** Since 2016 a part of IFS and not a separate entity.*
$ Included representatives from the Ministry of Agriculture, SCSI and IFS

Strategies and Methods

The area outlined for the project was over 90 000 hectares, roughly 1% of the area of Iceland. Yet in the initial stages, restoration was only planned for about 60 000 hectares, due to conflicting interests with other land uses, like sheep grazing. The areas with the worst erosion (**Exhibit 1**) were the ones prioritized for the restoration efforts. In 2017 the total area was enlarged to the south, to 100 000 hectares when a new agreement on the project was signed.

A cost-effective way of undertaking restoration of such a vast area is to create "islands" of native vegetation and rely on natural regeneration to aid in the process of recovery[8,9]. Native birch and willows, species that are early colonizers in Iceland[29] were initially used to create these clusters, but for several years now the planting of willow has stopped, and the focus is entirely on propagating the birch[8]. Birch and willow seeds are mainly dispersed by wind, so their colonization is strongly directional based on the prevailing winds[30]. Thus, tree "islands" in certain locations can be used as seed sources for the surrounding areas[8]. The strategy of planting in islands, instead of planting in the whole area, greatly reduces the financial cost and instead, makes use of natural processes to better stimulate the regeneration of the land (**Exhibit 4**).

Exhibit 4: A birch tree "island" in the Hekluskógar area; the main restoration strategy of the project. The snow-capped mountain in the back is Mt Hekla.

© Isabel C Barrio

The chance of natural regeneration is greatest in stable and open areas, while it is most challenging on unstable bare ground. Therefore, while planting clusters was the common strategy, slightly different restoration methods were used depending on how severely affected by erosion an area was (**Exhibit 5**). For the areas in worst condition with the most unstable surfaces, revegetation treatments, mostly by

seeding of grasses and distribution of mineral fertilizer, are necessary to stabilize the soil surface and create suitable conditions for seedling establishment[8]. For instance, stabilization of the land characterized by drifting sand and very active erosion usually requires the seeding of lyme grass (*Leymus arenarius)*, a native grass particularly adapted to unstable sandy surfaces[9,31]. In recent years, organic kjötmjöl (meat meal) mulch has also been used for revegetation in a small portion of the area, but its application is bound by stringent regulations, as it is produced from slaughterhouse waste.

Exhibit 5: Proposed measures for restoration based on erosion class and vegetation cover

Erosion class	Vegetation cover	Estimated area (ha)	Revegetation measures	Reforestation measures
Very active erosion	≤33%	15 000	~50% seeded with Leymus arenarius; all the area seeded with fertilizer 3-4 times	Planting of islands with birch, willows and native legumes 8-10 years after revegetation
Some erosion	≤33%	19 000	~75% seeded with Poa and Festuca, fertilized 3 times	Planting of islands with birch, willows and native legumes 2-3 years after revegetation
Limited erosion	34-66%	11 500	~70% fertilized 3 times	Planting of islands with birch, willows and native legumes
No erosion	≥67%	17 000	No revegetation needed	Planting of islands with birch and/or willows

Source: Aradottir, A.L. (2007). Restoration of birch and willow woodland on eroded areas. In: Halldórsson G., Oddsdottir, E.S. and Eggertson, O. (eds) Effects of afforestation on ecosystems, landscape and rural development – Proceedings of the AFFORNORD conference, Reykholt, Iceland, June 18-22, 2005. Norden, Reykjavík. p. 67-64.

Financing

Since the initiation of the project the main source of funding has come from the Government of Iceland, while roughly 20% of funding has been generated from private companies.

Initially, the Government guaranteed project funding between 2007-2017, but the contract suffered considerable fluctuations throughout the years. The initial promise of 50 million ISK per year was not followed through, and in some years the project received less than half of that amount. These fluctuations continued with the contract renewal in 2017. In 2017 the project received extra funding that allowed for buying more plants, but the budget was reduced again in 2018 and a similar amount is expected for 2019. These fluctuations in the core funding by the Government have created large uncertainties in the management of the project. However,

Guðmundsdóttir anticipates that the project will get more funding from the state in the next years in connection with the state's efforts in carbon sequestration with land reclamation and afforestation. The limited funding in the past years has meant that the project manager position has been a part-time position, around 30% for most of the project time.

Several associations, private companies, government agencies or companies have supported the project and even taken care of a plot of land in the Hekluskógar area and paid for the restoration of the land. To name an example, the National Power Company of Iceland (NPCI), which made an agreement with the Hekluskógar project to cover half of the costs of distributing the fertilizer kjötmjöl, which added up to a few million ISK per year. The NPCI contribution to the project was mostly due to their interest in restoring the land and ensuring robust vegetation cover around the roads, power lines and transformers that they had in the area, as well as a compensation measure for the environmental impact of their operations.

Funding of such a large-scale restoration project requires a long-term approach and commitments, and patient financing. The project is thus very ambitious but at the same time will bring many and diverse benefits to the environment and local community. The initial plans in 2005[10] assumed 30 years of implementation for the project. However, the level of funding from the Government has never been at the level anticipated in 2005. Therefore, as of 2018, the plan was that the implementation of the project would take 40-60 years, but this depends on the level of funding. The restoration process, however, will continue for decades after the completion of the implementation phase, through ecological succession and colonization of birch, willow and other native species by natural regeneration.

Stakeholders

Stakeholders in such a large-scale and long-term restoration project are of course many and diverse. It is obvious, for example, by looking at the land ownership of the area. Approximately half of the Hekluskógar area is owned by municipalities and private people, and the other half by the Icelandic government and managed by SCSI and IFS. The project's diverse effect on ecological conditions of the area also brings to the table the national Government, environmental organizations, scientists and other stakeholders, including the local community.

Public Bodies

SCSI and IFS were both working on land reclamation and restoration in the Hekluskógar area before the project started. These two government agencies have their roots in a forestry and soil conservation act, which was passed in Iceland in 1907. SCSI's main goals are to reduce soil erosion, restore degraded land and promote sustainable land use[32]. The mandate of IFS is to protect and expand the remaining native forests and woodlands, and grow new forests[33].

Other governmental bodies involved in the project are the Agricultural University of Iceland (AUI) and the Regional Afforestation Project in South Iceland, which was merged with IFS in 2016. AUI provides education in restoration and forestry and does

research in those fields, while the Regional Afforestation Project worked on promoting the growth of multi-use forests and shelter belts in the South of Iceland for securing regional development and strengthening livelihoods in the area.

National and Local Governments

The extensive land degradation in the area has rendered the society much more vulnerable to natural disasters like volcanic eruptions and floods. The potential of costly damage is therefore high, but it can be lowered by increasing the resilience of the ecosystem to disasters. The restoration activities are thus likely to help preventing disasters in the long run and ease their damage.

A healthier environment for the local community as well as increased land use options are likely to attract more inhabitants and create more revenue – increasing tax income for governments.

Private Residents

The Hekluskógar project generated a lot of interest from the homeowners and people living in the area around Mt. Hekla. Locals who had not known much about reforestation, and some who were owners of summer cottages in areas with harsh winds, were offered counseling and education and became invested in planting birch seedlings. As part of the project, local residents received free seedlings to plant on their lots, while they only had to provide their own fertilizer, fences and planting tools. After this initial planting had sparked their interest, local residents contributed annually by planting seedlings and became enthusiastic about the restoration efforts.

Part of the reason for the high interest in the project was aesthetic: more vegetation around the properties. But the overarching driver for the participation by local residents was environmental. Strong winds often consumed the area around the volcano with accompanying sandstorms and bad air quality, and it was precisely the local residents who wanted to create more shelter from these harsh storms. Thus, these residents and other landowners have become an integral part of the work.

Farmers

The south of Iceland is one of the country's main agricultural production areas. Farms in the Hekla area are family-owned and run, as is the case for most farms in Iceland. Many of the farms in the Hekluskógar area were abandoned because of the severity of land degradation. Among the farmers remaining in the area, the project had been positively received for the most part. Some of the farmers were already involved in restoration projects on their farmland in cooperation with SCSI and have beautiful examples of birch colonization in grazing land – where the grazing is moderate and regulated. For the Hekluskógar project, some of the farmers involved were engaged as contractors and were paid for their help in planting. Farmers who have livestock can use their own land for grazing, but the grazing rights in the commons within the project area (**Exhibit 1**) have not been used since around 1960 because of the bad condition of the land. While this land is legally still grazing land, local sheep farmers would not experience a benefit from the reforestation for several decades, and for some, the future utilization of the land was a struggle to

envision today.

Since the early days, farmers' opinions have always been represented in the collaboration committee of the Hekluskógar project, respecting the opinions of those farmers who did not wish to participate in the project. This was indeed the case of one of the younger farmers who objected to the project; his land bordering the planting area was therefore not included in the delineation of the project area. This farmer believed that traditional sheep farming and reforestation simply did not fit together, so money could be better spent on other projects. It was difficult for him to see the point in restoring the land and not being able to use it for several decades, especially when part of being a farmer is to be able to use the land.

Tourism Enterprises

Tourism is, along with agriculture, a main profession in the area and has grown rapidly in the last decade. The Hekluskógar area holds great potential for tourism, through outdoor activities like hiking, horseback riding and recreational fishing. An example of a family-run tourism business is Hotel Leirubakki. Leirubakki used to be a prosperous farm in the old days, and still today breeds horses. The hotel opened in 1980 and receives thousands of visitors each year[34]. Leirubakki is also home to the Hekla Center, an exhibition that showcases the influence of the volcano and its impact on the people and surrounding areas throughout history. The Hekla Center also serves as an active tourist information center, and provides educational materials for school groups and visitors. In addition, the Hekla Center encourages cooperation with scientists working in the Hekluskógar project.

Recreational fishing is another popular tourist attraction in the area. Amid the lava fields north of the volcano runs the top class salmon and trout river, Fossá. Many tour operators offer fishing excursions in the area.

The National Power Company of Iceland

As part of its social responsibility and sustainability practices, NPCI tries to mitigate the effects that its operations in the area have on the environment and communities. Its contribution to the Hekluskógar project is one of those mitigation methods. Many of NCPI's operations have directly affected the vegetation in the area, e.g. damming rivers to build reservoirs for hydropower plants, so NPCI has taken part in many on-site restoration projects. These projects have included the planting of trees and the distribution of meat meal (kjötmjöl) fertilizer.

The nationwide impact of carbon sequestration is also a major cause for the involvement of NPCI in the Hekluskógar project, as it contributes greatly to NPCI's carbon sequestration plan. NPCI had a negative carbon footprint of approximately 53 000 tonnes in 2017, with a sequestration of only 30 000 tonnes in the same year. Thus, the NPCI relies on Hekluskógar to help reach its carbon-neutral emissions goal by 2030.

Non-Governmental Organizations and Volunteers

This stakeholder group consists of NGOs, volunteers and student groups who have

been eagerly involved in the restoration project. Community participation is recognized as an important component in building awareness for the project. Especially for such a long-term, large-scale project in which progress happens slowly, it has been important to focus on activities targeted at building awareness.

Every spring and autumn the Hekluskógar project manager organizes numerous planting events where volunteer groups come together, contribute with their work, and learn about the project. Many school groups as well as motorcycle-, sports- and choir clubs have participated in these activities and some have made this an annual event in their club activities. Thousands of volunteers have participated in such events. This contributes significantly to the interest in and awareness of the project and strengthens community participation overall.

SCSI and the leading environmental NGO in Iceland, Landvernd, have also been working with schools in the Hekluskógar area by creating teaching materials, holding classes on restoration and doing small hands-on experiments. Landvernd started a project in 2017 where student groups and volunteers could come and learn about the planting work for one day in a designated area, with plants and tools provided. This element of using education to create awareness is expected to contribute further to the interest of youth in getting involved and to strengthen community participation overall. Everyone involved so far has been incredibly keen to participate, and Guðmundsdóttir considers it a huge win-win for the project.

The two regional Forestry Associations of the districts Árnessýsla and Rangárvallasýsla are non-governmental organizations (NGOs), established in 1940 and 1943. Their members are people who want to protect and grow forests in their districts. They have been planting trees in parts of the Hekluskógar area since before its initiation, and their valuable local knowledge on tree planting in the area has served the project well from the beginning.

Opportunities and Obstacles

National Park and Tourism

With the optimism and success of the project so far, the different groups have started to picture what the future project area would look like and to imagine what they would like to see the land being used for in several decades' time. Some hope to see a more vivid and lively landscape with a booming, renewed ecosystem that would continue to stimulate the tourism, through for example horseback riding, fishing and hiking. Guðmundsdóttir herself hopes that a healthier ecosystem will lead to an increase in wildlife and, eventually, that hunting would become a viable new opportunity in the area.

An idea could be to establish a national park in the area, focusing on the volcanic activity, geology, human land use history and the restored native ecosystem, which would attract both tourists and locals, and surface new opportunities - more local hotels to accommodate the increase in guests, smaller, specialized tourism companies and a broader base of tourism activities. A visitor centre[35] already exists at

the SCSI headquarters in Gunnarsholt, which displays the degradation and restoration history in the area; this centre could already be an important focal point integrated in the national park.

The NGO Landvernd started an innovative project in 2017, *Care in Iceland*, where tourists, study groups from abroad and Icelanders alike can come and learn about the ecology, history and development of land degradation in Iceland as well as land restoration process and methods. In the one-day tour, participants are assigned an area and provided with plants and tools used to carry out restoration work under professional guidance[36]. This informs the visitors of local environmental challenges and gives them an opportunity to be a part of the solution through unique volunteering experiences. Such educational tourism is an example of initiatives that can be created in the area (**Exhibit 6**).

Exhibit 6: There are many opportunities to educate and spark interest in the value of nature and the benefits we get from restoration projects. No matter how the world turns, we see the Hekluskógar project as a viable and necessary project.

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Carbon Sequestration

Successful ecosystem restoration contributes to carbon sequestration. Restoring the native vegetation has great potential to restore carbon in soils that have lost their carbon due to severe degradation. This is particularly true in Iceland, as Andosols can hold large amounts of carbon[17]. In the years 2007-2009 a local car dealership company Hekla hf, signed a contract with Hekluskógar on offsetting their carbon footprint by planting in the Hekluskógar project area. After the economic collapse in 2008 the interest in CO2 sequestration decreased, but has been increasing again in the past years. At this stage in the project, further carbon sequestration initiatives

have been discussed and private companies have become increasingly interested. However, a new carbon sequestration project to bring in revenue has not yet been launched. Such financing potentials may however be increasing due to the heightened urgency of addressing climate change and international agreements like the Paris Agreement. As an example, Festa, the Icelandic Center for Corporate Social Responsibility, has been working on raising awareness among businesses on those issues. Festa strives to promote corporate social responsibility and its awareness raising initiative is hoped to bring companies on board to participate in a carbon sequestering initiative. Effective carbon sequestration has the potential to offset 5-15% of global fossil fuel emissions[37]. Evidently, this opportunity has already generated interest among stakeholders in Hekluskógar and is a potential opportunity to harness and reap economic rewards. As one professor from AUI noted, "The question was not if it was happening, but if the different parties would take advantage of carbon sequestration and create business opportunities out of it."

The model chosen by Hekluskógar specifically focuses on planting native species, in compliance with several international conventions and agreements, including the Convention on Biological Diversity (CBD)[38], the United Nations Convention to Combat Desertification (UNCCD)[39] and the recent United Nations Sustainable Development Goals[40] (SDGs). The Aichi Biodiversity Targets of CBD[41] specifically address the importance of reducing pressure on biodiversity such as loss of natural habitats and preventing the introduction and establishment of alien species. Within the Hekluskógar project, carbon sequestration initiatives will follow those international agreements.

Conclusion

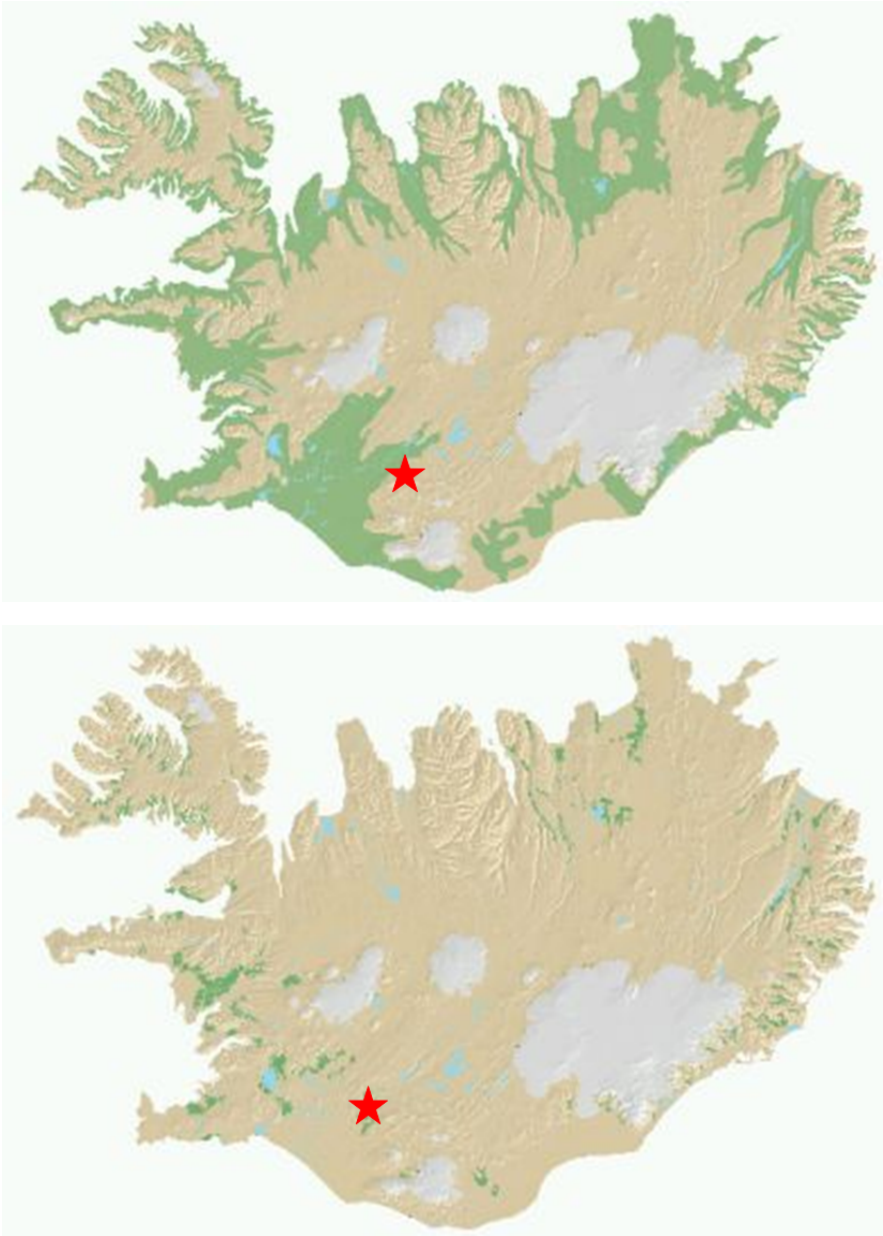
As mid-day approached, Guðmundsdóttir surveyed the land and walked over to an island of newly planted seedlings. She embraces these quiet moments in the winter off-season, with only the sounds of nature cutting through the silence. As spring was approaching, so were the busy months of April, May and June. Most of the work at this time of year involves planning and prepping the orders for the deliveries of fertilizer and plants, and getting everything moving for the upcoming season. The winter months were generally slower, with less pressing work, but Guðmundsdóttir took the time to recharge and –with increasingly greater interest in the project – plan ahead for the year.

On her way back to the office in Selfoss, she noticed in the rear view mirror the dark clouds of a coming storm pushing their way closer. The question returned: What would happen if Hekla erupted soon?

One thing was certain: there were no certainties. Even though planting a few hundred thousands of trees a year seemed like a lot, it was only a drop in the bucket. She could only hope that if an eruption did happen, the work that had been done would be enough.

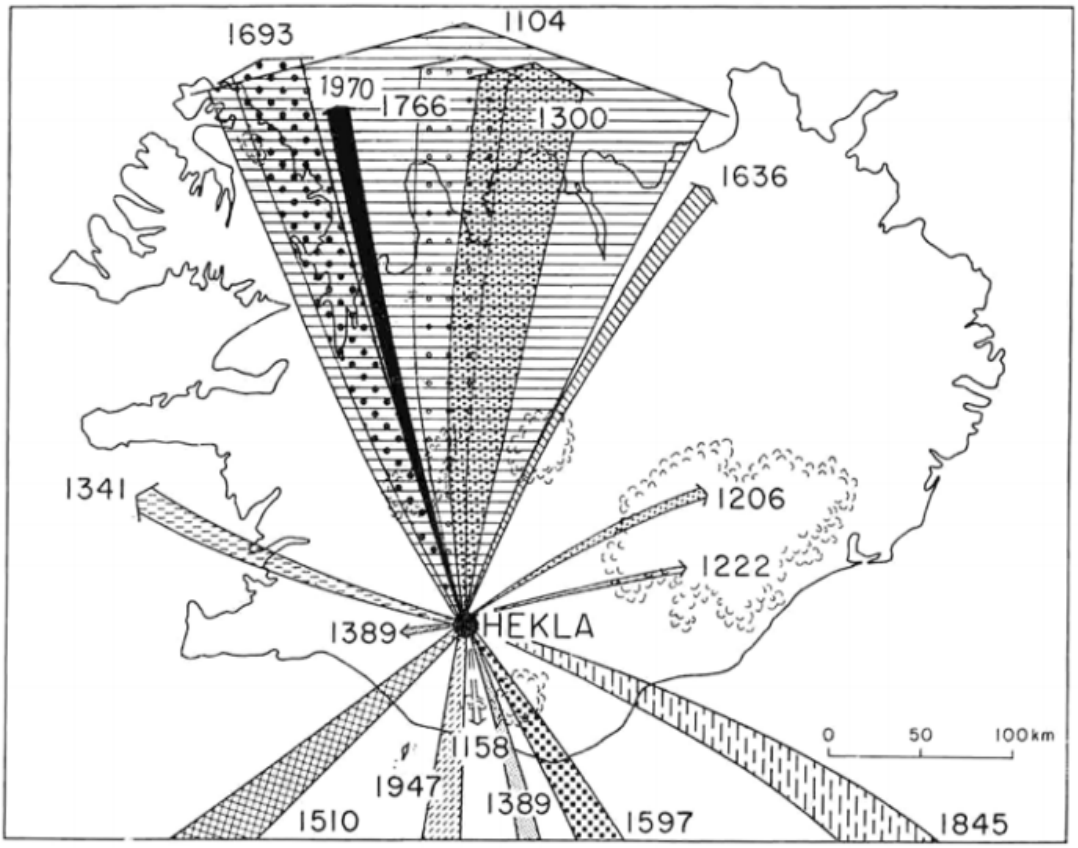
With the abundance of ideas, potential, excitement and growing interest on the kind of benefits Hekluskógar could create, conversations need to start happening between stakeholders in the preparation, planning, marketing and funding of these future initiatives. Naturally, there is hesitation to start planning too early – a lot of uncertainty and time stands between now and what the land could look like in the next two to three decades. Still, it remains important for her to align the interests of all groups involved, so that they can all reap the benefits of a reforested and booming land in approximately 50 years' time. But how can she balance all the societal, environmental and economic requirements of such a large-scale undertaking? Moreover, how can she engage all the stakeholders and even mobilize new ones to contribute to the project? And will it be possible to guarantee a stable, long-term budget so that the project can be carried out as planned? … There are still many questions to be answered.

Appendix A: Distribution of native birch forests from the time of Iceland's settlement in the 9th century (top) to the distribution of native birch in 2005 (bottom) showing Mount Hekla (red star).



Source: Kjartansson BK, Eggertsson Ó (2005, 13 January) Er til einhver skógur frá landnámsöld á Íslandi? (Does some forest from the period of settlement still exist?) Vísindavefurinn. https://www.visindavefur.is/svar.php?id=4712 (in Icelandic)

Appendix B: Map showing the multiple directions of tephra distribution during the initial phase of each of Hekla's 15 eruptions throughout history. The width of each arrow is an approximate indication of the relative size of the tephra layers' volume.



Source: Thorarinsson S, Sigvaldason GE (1972) The Hekla Eruption of 1970. Bulletin of Volcanology 36:269–288

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