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WOODLAND RESTORATION BY NATURAL REGENERATION AND PLANTATION (ASSISTED REGENERATION) IN ICELAND

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ABSTRACT

In a given area different ecological restoration methods can be used depending on the extent and duration of past disturbances, cultural practices that shaped the landscape and present opportunities and constraints. The objective of this study was to evaluate the spreading of birch (*Betula pubescens*) in areas with natural and assisted regeneration. The study was done at two sites in southern Iceland. Aerial photographs from 1987 and 2008 were used to map birch cover change in Gunnlaugsskogur (natural regeneration) and aerial photographs from 2008 to quantify the existing birch cover in the Bolholt (plantation) using ArcGIS10. Two age classes were used at both sites. Within each age class permanent plots of 10x20 m size with three replications were used to measure the basal diameter and height of the tallest and average tree to see if there were significant differences in the two sites. There was no significant difference in height and basal diameter due to the regeneration methods. However, height and diameter of birch trees at both sites was significantly affected by age. There was an overall increment of birch cover detected in aerial photographs of Gunnlaugsskogur over the 21 years. The areal increment was, however, higher in the higher diameter classes (4.7 ha) and there was a decrease in area coverage of the lower cover class (25-50% canopy cover). The recruitment of birch plants was directional with most recruitment in the north and north-western part of the site. In Bolholt, since the first plant was planted in 1990, 23 ha of the planted area had more than 75% canopy cover of birch and a total of 60 ha had greater than 25% canopy cover. The cost of birch establishment in Bolholt per hectare was around 122,000 Icelandic kronas (ISK) whereas it was negligible for Gunnlaugsskogur.

Key words: Ecological restoration, plantation, natural regeneration, aerial photographs, Arcmap

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1. INTRODUCTION

1.1 Background

Land degradation has become a central point of concern for the world's environmental scientists and nations. Poverty, natural resource depletion and climate change are among the current environmental problems. Alarming population growth, natural hazards, deforestation, the nature of landscape, unsustainable land management and overgrazing are among the main causes of land degradation worldwide (FAO, 1994).

In earlier times Ethiopia was one of the green areas in the world and forests covered 40% of the Ethiopian land a century ago (Bishaw, 2001). Population increase resulted in the need for additional arable land, and the need for wood for fuel, fodder and construction material resulted in a reduction in forest cover to less than 3% within a century (Bishaw, 2001). The highlands of Ethiopia are the areas where agriculture was started in the early human settlement of the country (Wagayehu, 2003). These are areas where most of the population is living and they have a steep topography.

Continuous mismanagement in addition to the nature of the land and rainfall pattern of the country have led to severe soil erosion and loss of soil fertility. This has affected the productivity the land. A large portion of forest in the highlands has been cleared off for fuel wood, agricultural land, grazing land and construction materials (Zenebe, Kooten & Soest, 2006). Furthermore, animal dung and crop residues are collected for energy sources, contributing to the loss of organic material from the croplands, challenging the productivity of the land by affecting moisture availability, leaching of nutrients and surface run off (Zenebe et al., 2006).

Similar to Ethiopia, Iceland was once rich with vegetation. At the time of human settlement, 1100 years ago, 50 to 60% of its land mass was covered by vegetation and 25 to 30% was covered by birch (*Betula pubescens*) woodlands (Eysteinsson, 2009). Removal of wood products for heating and charcoal production, burning of the woodlands and extensive sheep grazing have led to severe soil conditions, deforestation and in some cases widespread soil erosion (Fridriksson, 1976). The settlers started cutting and burning forests and shrubs to create extra agricultural fields and grazing lands (Eysteinsson, 2009). After continued cutting, sheep grazing prohibited regeneration of the birch woodlands; therefore, the forested area continued to dwindle over time (Eysteinsson, 2009). Iceland has lost 95% of its birch woodlands. Today, birch woodlands cover only 1% of the country (Ministry of the Environment & Icelandic Institute of Natural History, 2001), and the barren desert areas cover around 40,000 km^2 (Aradottir & Arnalds, 2001). The early cutting of woodlands and overgrazing (primarily by sheep) throughout the centuries are the main causes for this huge loss of forests (Ministry of the Environment & Icelandic Institute of Natural History, 2001). One of the reasons for the profound effects of grazing on deforestation and ecosystem degradation was that the vegetation of Iceland developed in the absence of grazing animals, which made it vulnerable to grazing when livestock was introduced. With continued grazing and natural process such as volcanic eruptions, glaciation and water and wind erosion, which are prevalent in unvegetated areas, the Icelandic vegetation communities have been unable to close the gaps between them (Runolfsson, 1987; Arnalds, 1987).

Natural regeneration by area enclosures, where degraded lands are protected from cultivation and grazing, is a widely used restoration method in Ethiopia (Mengistu, Teketay, Hulten &

Yemshawd, 2005). Research on the use of enclosures includes studies on their role in recovery of woody vegetation (Mengistu et al., 2005), seed bank status and natural regeneration of woody species (Tenkir, 2006), actual and potential contribution of enclosures to enhance biodiversity of woody species (Birhane, Teketay, and Barklund, 2006), and area closure as a strategy for land management (Tsetargachew, 2008). On the other hand there is little or no research available regarding plantation or assisted regeneration and their role in land restoration. It seems that this sector is not recognized as important for land restoration as the natural regeneration in Ethiopia. In Iceland, on the other hand, both area enclosures and direct planting are used in forest restoration and afforestation. Spreading of mineral fertilizer with or without seeding of grass species is used to stabilize degraded lands and facilitate the establishment of seedlings planted for land reclamation (Aradottir & Eysteinsson, 2005). Planting has been a common method for birch establishment since early in the 20th century when organized planting was started to protect loss of birch woodlands. This planting activity was focused on the native birch and this species was planted abundantly between 1935 and 1951 (Aradottir & Eysteinsson, 2005). Birch, which is the only native tree species that forms forests in Iceland, is also restored by other methods such as direct seeding and natural expansion (Aradottir & Eysteinsson, 2005). But still there is need to monitor the expansion of birch woodland by both restoration methods**.**

1.1 Objectives and research questions

The aim of this study was to evaluate the spreading nature of birch in natural and assisted regeneration.

This paper addresses the following questions

1. Are there differences in the height and diameter of woody species in birch stands established by natural regeneration and plantation?
2. Can the spread of birch woodlands by natural regeneration be assessed with RS and GIS?
3. What are the main costs of natural regeneration versus plantation?

2. LITERATURE REVIEW

2.1 Ecological Restoration

Ecological restoration is a young discipline. It will have a major role in reversing and mitigating the damage and unwanted changes made on the earth system by mankind, such as loss of biodiversity, food, water and energy security and global climate change (Harris & Diggelen, 2005).

There are various definitions for ecological restoration given by different scholars.
Ecological restoration is the process of assisting a degraded ecosystem to recover from damage and losses caused by human activities (Society for Ecological Restoration International Science & Policy Working Group, 2004; Ober & Trusty, 2009). Ecological restoration is a process that recovers and improves the functionality of ecosystems within landscapes consisting of lands in agricultural production as well as designated nature reserves (Aronson, Clewell, Blignaut, & Milton, 2006). Restoration work requires a re-establishment of plant communities and attempts to restore ecosystems to their historic trajectories that are destroyed by human induced disturbance (Society for Ecological Restoration International Science & Policy Working Group, 2004).

Ecological restoration projects may aim at the restoration of degraded landscapes for different reasons that include enhancing habitat for wildlife, to increase biodiversity, to restore ecosystem services, to increase natural beauty, or simply to take personal enjoyment in recreating the natural conditions that occurred historically (Ober &Trusty, 2009).

2.1.1 Ecological restoration methods

In a given area different ecological restoration methods can be used depending on the extent and duration of past disturbances, cultural practices that shaped the landscape and present opportunities and constraints (Society for Ecological Restoration International Science & Policy Working Group, 2004). According to Whisenant (1999) areas that have more or less fully functional ecosystems may need management changes to redirect the ecology to a desired species or combination of species so as to achieve the desired restoration goals. On the other hand, areas that are highly degraded and therefore have crossed the threshold may need some physical and chemical modifications so as to create better environment for colonizers and restore the needed ecological functions (Whisenant 1999).

Natural regeneration

Natural regeneration is an option for ecological restoration that often relies on old trees existing or left in the area or small planted stands that can serve as a seed source to initiate seedling establishment (Duryea, 2000; Aradottir & Eysteinsson, 2005). Natural regeneration is one of the best options for rehabilitating degraded hill slopes, especially in areas where favourable environmental conditions such as those of temperature and rainfall prevail (Tekele, 2001). Area enclosures are a typical example of restoration methods where an area is given enough time and protection from agricultural activities and grazing to allow natural vegetation could start to regenerate (Mengistu et al., 2005). Ecosystem degradations vary in scale and extent and often may have multiple and prolonged sources and the historical constituents might be substantially lost. The development of these degraded ecosystems is sometimes blocked altogether and restoration by natural process (natural regeneration) appears to be delayed indefinitely (Parrotta, Turnbull, & Jones 1997; Society for Ecological Restoration International Science & Policy Working Group, 2004). Severely degraded areas need a new approach of restoration methods where modifications of physical and biological entities are possible. Research has shown that tree plantations can usually enhance forest successions (Parrotta et al., 1997).

Assisted regeneration

Plantation forests (revegetation or afforestation) which are planted for the purposes of land restoration are good examples of human intervention for land reclamation or restoration. Plantation forests are defined as stands of trees created by the regular placement of seeds or seedlings. Restoration may need a deliberate reintroduction of indigenous species and elimination or control of invasive exotic species (Society for Ecological Restoration International Science & Policy Working Group, 2004). Exotic plant species can be introduced accidentally or purposefully to an area. Among the ecological draw backs of using exotic species is that they can destroy natural pasture, displace native trees, and reduce grazing potential of rangelands if they become invasive (Admasu, 2008). In recent years an increasing emphasis has been on using a native species in reclamation and rehabilitation world recently a great concern has been given to using native species for their advantages over the exotic species in restoring desirable ecological function to an area with minimal ecological drawbacks (Sorley, 1999). Ecological restoration using native plant species is now among the most widely used techniques (Harrington 1999). The difficulty with indigenous species is, however, that their silvicultural practices are often not well known (Sorley, 1999).

Plants can be introduced into a desired site through different methods. Direct seeding which can be done by broadcast sowing or by sowing with drills and planting an entire plant or parts of a plant are among the well-known and practiced techniques (Whisenant, 1999). Planting entire plants (seedlings) or plant parts (stolons, rhizomes, bulbs, etc.) is more reliable in a harsh environment, but it is more expensive (Whisenant, 1999).

The effectiveness of assisted regeneration depends on both abiotic and biotic interaction within the site. When birch plants are introduced or reintroduced to a site by plantation a number of factors can be detrimental on the establishment of the seedling, such as the availability of soil nutrients, competition from other plant species, the presence or absence of insect that feed on the plant, selection of planting spot, the effect of frost heaving and proper planting techniques (Aradottir & Arnalds, 2001).

Plantation can successfully establish forest stands but it is a labour intensive and costly strategy to use in extensive areas. For such wide target areas establishment of patches of plant groups at a distance from each other and allowing the gap between them to be filled by natural expansion from these patches can reduce the time compared to natural expansion alone and the high cost needed for plantation alone (see Fig. 1) (Aradottir & Eysteinsson, 2005).

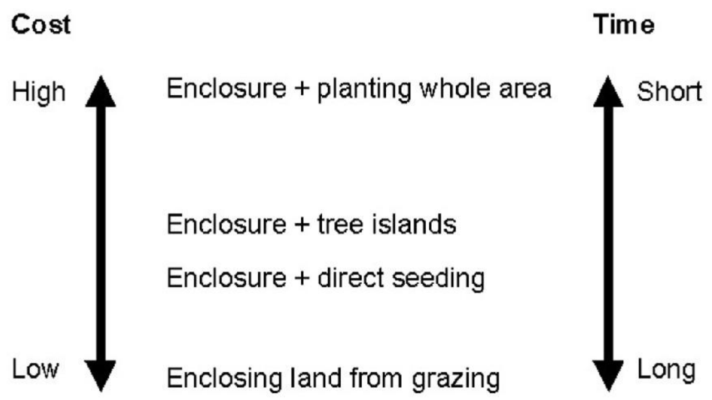

Fig. 1. *The cost and time relationship with restoration strategies (from Aradottir & Eysteinsson, 2005.)*

2.2 Gender and land restoration

Nowadays, it is well recognized that effective conservation and regeneration of forests is dependent on rural communities scattered across the globe. However, rural communities vary with regard to many factors such as socioeconomic inequalities and differences, and their relationship to the forest on which they depend is characterized by complex interests that can vary by gender and class (Agarwal, 2009). Landowners and those who do not own land, as well as men and women, differ in nature and the extent of their dependency on the forests and their products. Rural women are mostly interested in none timber forest products, fire wood and fodder, whereas men are mainly interested in the timber products (Agarwal, 2009). Restoration projects should be planned taking the political, cultural, technical, historical, aesthetical and societal demands into consideration so as to make their results sustainable in the long term. Without full participation of the society (group of societies), tree planting and re-introduction of species will not succeed on a long term basis (Harris & Diggelen, 2005).

Land degradation, even though it affects everyone, has an especially great impact on women. Deforestation and soil erosion depletes energy sources (fuel wood) and fodder for livestock. It is often the responsibility of the woman and the children to fetch water, collect fuel wood and follow after the cattle. Therefore, as the resource are depleted the distance women and children need to travel will be increased and the time children can spend in school will be reduced or eliminated. The effect land degradation has on women and children is among the justification for restoration, reclamation, and sustainable use of degraded land. With increasing population and the need for more land for producing food to sustain life, tackling land degradation by protecting soil erosion and revegetating already degraded areas and managing sustainably what is left is necessary.

3. METHODOLOGY

3.1 Area description

3.1.1 Location

Iceland is an active volcanic island located on the Atlantic ridge, in the middle of the Atlantic Ocean 63°–66° N, 13°–24° W. The total land area is 103 000 km^2.

This study was done in areas which are included in the Kolbjörk (Carb Birch) project which is a research project focusing on a comprehensive study of ecosystem changes, carbon sequestration and carbon flux in reclaimed mountain birch areas (Halldórsson et al., 2009). The project addresses changes in understory vegetation, carbon stocks and fluxes, productivity of plant biomass, colonization of mycorrhizal fungi and soil development in a chronosequence through tree plots dating back 60 years with comparison to nearby natural old growth forests (Halldórsson et al., 2009).

The research sites for the Carb Birch project are located in a severely degraded area close to the active volcano Hekla in south Iceland (Fig. 2). The land has been badly eroded and affected by volcanic ejecta from Hekla and other nearby volcanic systems. The volcanic tephra has coved vegetation and caused destabilization of surfaces by both killing vegetation directly and by subsequent erosion due to aeolian movement of tephra cutting and covering the above-ground biomass. There are five study sites in the Carb Birch project; three restored birch woodlands, Gunnlaugsskogur (1), Bolholt (2) and Stori Klofi (3), all established on formerly eroded land, and two old natural birch woodlands, Hraunteigur (4) and Búrfellsskogur (5) (Halldórsson et al., 2009) (see Fig. 2).

For this study, two sites of the Carb Birch project, Gunnlaugsskogur and Bolholt were used, as they fulfil the criteria for achieving the objective of this study and were easily accessible.

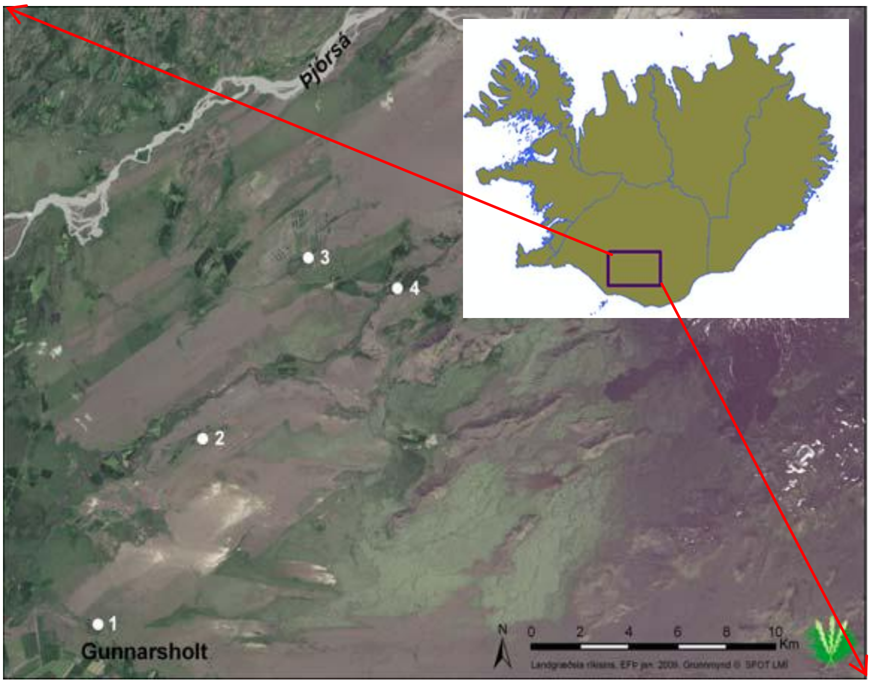

Fig. 2. *Kolbjork study areas (Halldórsson et al., 2009), study area 1 (Gunnlaugsskogur) and 2 (Bolholt) are used in the current study.*

Gunnlaugsskogur is located approximately 1 km north of the farm Gunnarsholt, Rangarvallasysla, south Iceland at 63°52’N and 20°12’ W. The altitude ranges between 100 to 110 m.s.l. (Aradottir, 2007). The site was enclosed and protected from grazing in 1926 and the surface of the eroded land had been stabilized by sowing and an aerial spreading of mineral fertilizers. In 1939 birch was seeded in a patch of land approximately 100m^2. An additional plot of 50 m^2 was seeded in 1945 (Magnusson & Magnusson, 1989, as cited in Aradottir, 1991) (see fig. 3). Furthermore, in 1945, several small stands of birch were established on a nearby lava field by transplanting birch seedlings established after the direct seeding in 1939 (Aradottir & Arnalds, 2001). After the birch trees started producing seed (age 10-20 years) the birch started spreading from seeded and planted stands (Aradottir, 1991; Aradottir & Arnalds, 2001). Between 1973 and 1980, the lava field was revegetated by seeding of grasses and fertilization (Aradottir, 1991).

Being part of the birch wood restoration and erosion protection, Bolholt plantation was established in 1990. The actual area planted was 317 ha. The area is not composed only of birch trees but also has other woody species like *Pinus contorta*, *P. sylvestis* , *Larix sibirica*, *Salix phylicifolia* and *S. lananta* and forbs like *Lupinus nootkatensis.* These species, however, cover an insignificant part of the area compared to the area coverage of *Betula pubescens*. A maximum effort was exerted to discriminate the other species in the area. The area covered by these species was considered and classified in the lower class of the canopy cover used in this study (<25%).

3.1.2 Climate

The climate of the Iceland is strongly influenced by the Gulf Stream. This results in a cold temperate to sub-arctic climate with frequent freeze-thaw cycles. The precipitation varies from place to place. The lowland areas receive precipitation of between 600 and 1500 mm per year. Winter thawing is common, especially in the southern part (Arnalds, 2005). The mean annual temperature and precipitation for the period 1961-1990 in both study areas was 3.7 °C and 1219 mm, respectively (Data from the Icelandic Meteorological Office, 2011).

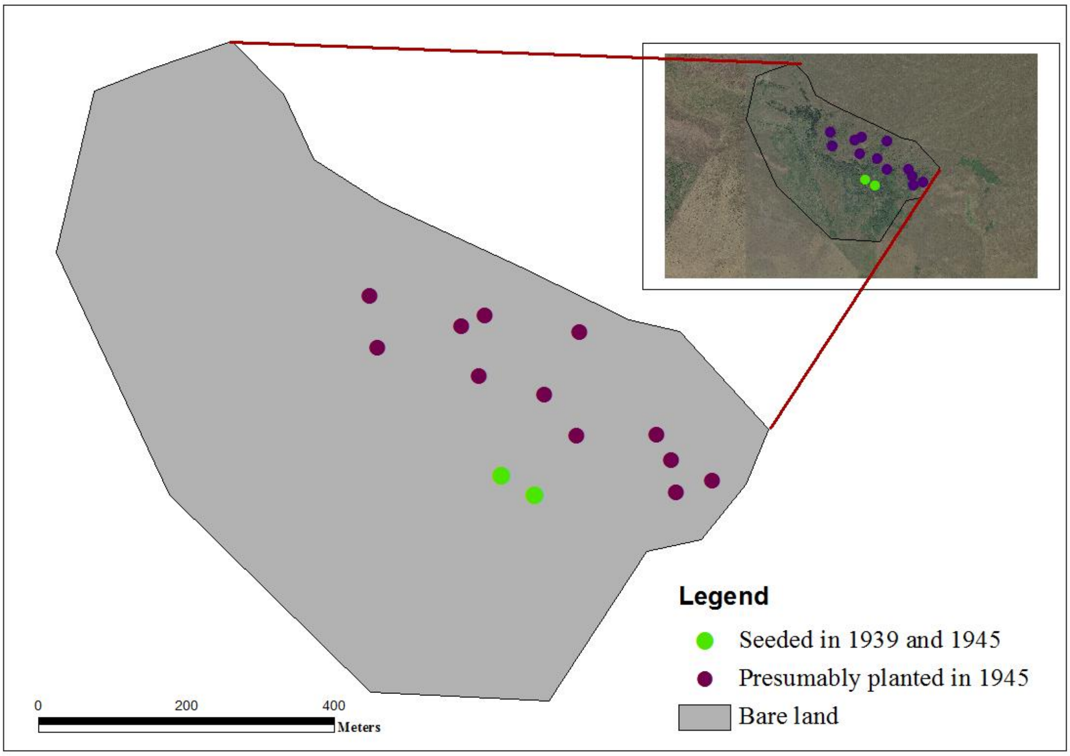

Fig. 3. *The originally seeded and planted sites in Gunnlaugsskogur, south Iceland.*

3.1.3 Soil

Soils on undisturbed areas in Iceland are mainly Andosols, which originate from volcanic parent material (Arnalds, 2004). The soil in deserts is mainly Vitrisol, constituted of coarse grained tephra, volcanic glass and some clay minerals and organic matter (Arnalds, 2004). The formation of soils is highly influenced by the deposition of eolian materials that come from unstable deserts and tephra from volcanic eruptions (Arnalds, 2005). Andosols are vulnerable to erosion as they have weak cohesion and are characterized by poor clay crystalline and considerable organic matter (Arnalds, 2005). The soils in the study sites are Andosols resulting from volcanic eruptions.

3.2 Data collection

Aerial photographs of the study area were obtained from the National Land Survey of Iceland (taken on 8, August 1987) and from Loftmyndir (taken on 12 August, 2008). Both photographs were in true colours. The photographs were used to compare the distribution of woodland over 21 year period. The 1987 photograph was at the scale of 1:25000 and the 2008 photograph at the scale of 1:20000. Field survey and measurements were done to validate the cover classification made by using aerial photographs and to collect data on the population structure of birch and compare growth of planted versus self-regenerated birch trees.

3.2.1 Classification of birch woodland cover

All woodland seen on the aerial photographs was classified into four classes, using the Braun-Blanquet scale by omitting the lowest two classes. This classification relates to the coverage of the tree canopy of the area. The classes were as follows (Ganderton & Cooker, 2005):
a) Woodland with more than 75% areal coverage. In aerial photographs this appears as dense woodland with only few visible clearings.
b) Woodland with 50-75% areal coverage. In aerial photographs this appears as relatively dense woodland with visible clearings.
c) Woodland with 25-50% areal coverage. In aerial photographs this appears as scattered woodland with visible clearings.
d) Woodland with less than 25% areal coverage. In aerial photographs no continuous woodland cover can be discerned, only scattered scrubs/trees.

3.2.2 Field survey

The field survey was done to verify classification of woodland done by inspection of aerial photographs and record changes in distribution since the most recent photograph was taken. This was done by walking through the study area, stopping at selected study spots and taking notes on the condition of the woodland in the neighbourhood. The woodland distribution was simultaneously drawn onto the aerial photographs.

3.2.3 Characteristics of the birch stands

Data on population structure of the birch stands were collected in the study plots from the Carb Birch project representing chronosequences of birch woodlands that were established by natural regeneration from old seeded stands or by planting.

Within the woodland already established plots of 10x20 m in size were used. There were three replicates in each habitat. Two age categories in both Bolholt and Gunnlaugsskogur were used: young open stands of estimated age 10-20 years and dense medium age stands with estimated age 20-30 years. A count of annual rings revealed that the actual age was not in all cases the same as expected (Olafur Eggertsson, pers. comm.). Thus, there were four plots in each category in Gunnlaugsskogur and three in Bolholt. Within the three replicates the tallest and average tree were systematically selected and height and basal diameter were measured. The basal diameter measurement was taken at 30 cm above ground. The sample number was limited because of the time constraint. The age class and the age of plots derived from annual ring analysis for Gunnlaugsskogur and Bolholt are summarized in Table 1.

3.3 Data processing

The aerial photographs produced by ArcGis (ESRI, 2010) were used. The data were processed in the IS 1993 (a local co-ordinate system for Iceland) co-ordinate system and photographs were run through this before processing the photographs. Older aerial photographs (1987) were georeferenced and corrected, using the IS 50 standard (www.lmi.is). The newer photographs came from the aerial photograph database owned by Loftmyndir ehf and had, therefore, already been corrected.

Statistical analysis was done with SAS version 9.2 (SAS Institute Inc., Cary, NC, USA, 2002-2010). A two way ANOVA was used to compare the population characteristics (basal diameter and height) of birch woodland in restoration areas facilitated by natural regeneration

(Gunnlaugsskogur) and assisted regeneration (Bolholt). The two way ANOVA was run for the tallest and average trees measured in the two sites. This analysis was done by taking only the age classes that were common to both sites. This was to see if there was a significant difference in growth development of the birch wood in these different treatments and age classes. The restoration methods (site) and age of stands (age classes) were used as independent variables (driving factors) and the basal diameters and heights of the sample trees were used as responses for the two way ANOVA analysis.

Table 1. *Age of plots sampled within the age classes in Gunnlaugsskogur and Bolholt (annual ring counts were provided by Ólafur Eggertsson).*

Category (years)	**Gunnlaugsskogur**		**Bolholt**	
	Plot number	**Annual rings**	**Plot number**	**Annual rings**
Young open stand (10-20)	KG 20-1	12	KB 20-1	11
	KG 20-2	20	KB 20-2	12
	KG 20-3	15	KB 20-3	12
	KG 30-2	13	-	-
Dense medium age (20-30)	KG 30-1	22	KB 30-1	19
	KG 30-3	23	KB 30-2	18
	KG 45-1	26	KB 30-3	18
	KG 45-2	22	-	-

4. RESULTS

4.1 Birch spread through time and forest development by natural regeneration

According to the image from 1987, 2 ha of Gunnlaugsskogur were occupied by birch trees that formed good canopy cover (>75 %) and 6.7 ha had a canopy cover of 25-50%. The canopy covers of birch decreased with distance from the sites where birch was originally established. The small scattered patches of birch stands that formed 50-75% canopy cover (see Fig. 4) probably represented small stands that were transplanted in 1945 from the seedling established from the seeded sites. They covered almost 0.7 ha in 1987. In the remaining portion of the study area there were some individual birch trees scattered here and there but generally around 37 ha (79%) of the area had few or no birch trees forming less than 25% canopy cover.

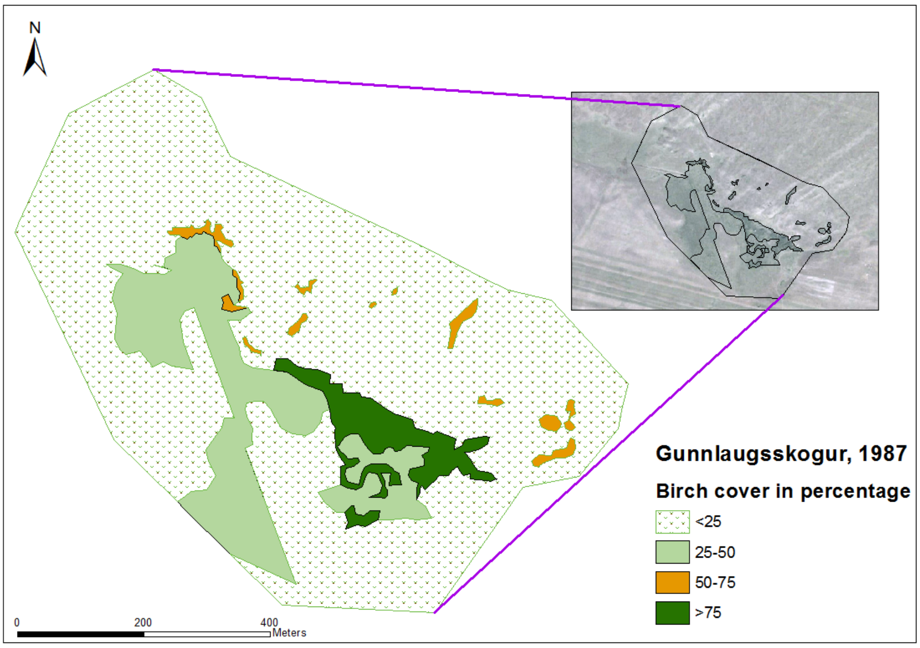

Fig. 4. *Canopy cover of birch in Gunnlaugsskogur in 1987, based on aerial photograph (see upper right).*

4.1.1 Birch cover in Gunnlaugsskogur in 2008

According to the aerial photograph from 2008 of the total area, 47.8 ha, or about 14%, were covered by a very dense canopy cover of birch (> 75%). Most of this very dense birch cover was concentrated at the centre of the study area with some new patches of dense birch canopy further away from the centre (Fig. 5). Still, a large part of the study area (32.7 ha) had less than 25% canopy of birch.

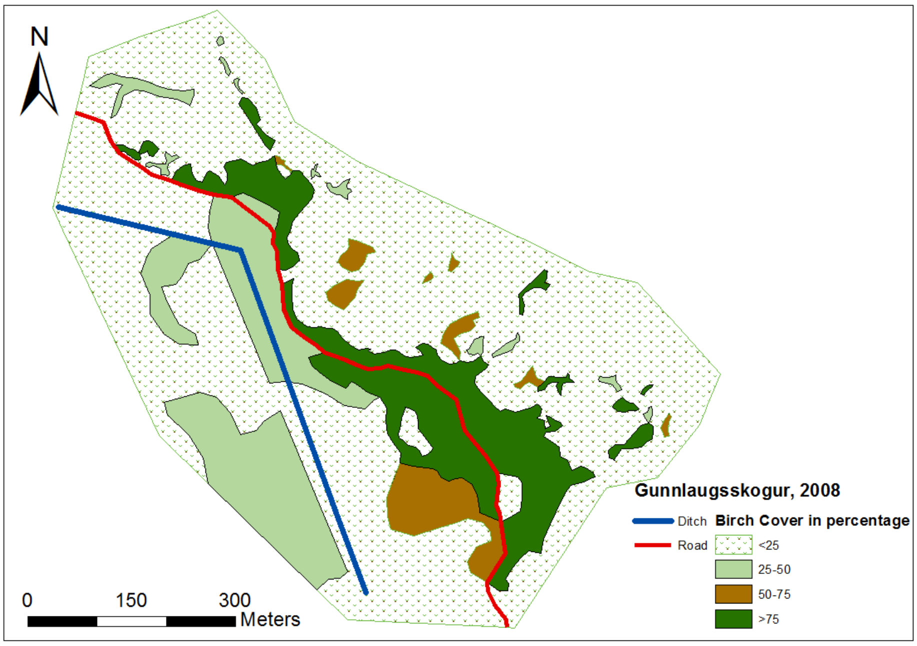

Fig. 5. *Canopy cover in percentage of Gunnlaugsskogur in 2008 based on aerial photograph.*

4.1.2 Birch cover change between 1987 and 2008 in Gunnlaugsskogur

The total area with identifiable birch trees in the 1987 aerial photograph was 46.8 ha but this was increased to 47.8 ha in 2008. Overall birch cover in the study area increased over this period (Table 2). In 1987 only 2 ha were covered by a very dense birch forest (75% cover) but this increased to 6.7 ha in 2008. However, there was a 0.7 ha decrement in birch with 25-50% canopy cover. Simultaneously, the area with scattered birches (<25% canopy cover) had shrunk.

Table 2. *The changes in birch cover between 1987 and 2008 in Gunnlaugsskogur.*

Canopy cover in%	**Gunnlaugsskogur**			**Bolholt**
	Area in ha			
	1987	**2008**	**Change**	**2008**
Total area	46.6	47.8	+1.2	254
<25	36.4	32.7	-3.7	193
25-50	7.4	6.7	-0.7	22
50-75	0.7	2.5	+1.8	15.3
>75	2	6.7	+ 4.7	23

4.2 Birch spread and forest development by assisted regeneration (plantation) within 1990-2008

The approximate area of the Bolholt study area in which birch cover was identifiable was around 254 ha (Table 2) In 2008, 19 years after the first birch trees were planted at Bolholt, 60.3 ha of land within the study area had a >25% canopy cover of birch. Of this, almost 23 ha in the middle of the forest stand running from south-west to north-east had >75% canopy cover (Fig. 6). The south- west part of the area had overall a higher birch cover than the rest of the area.

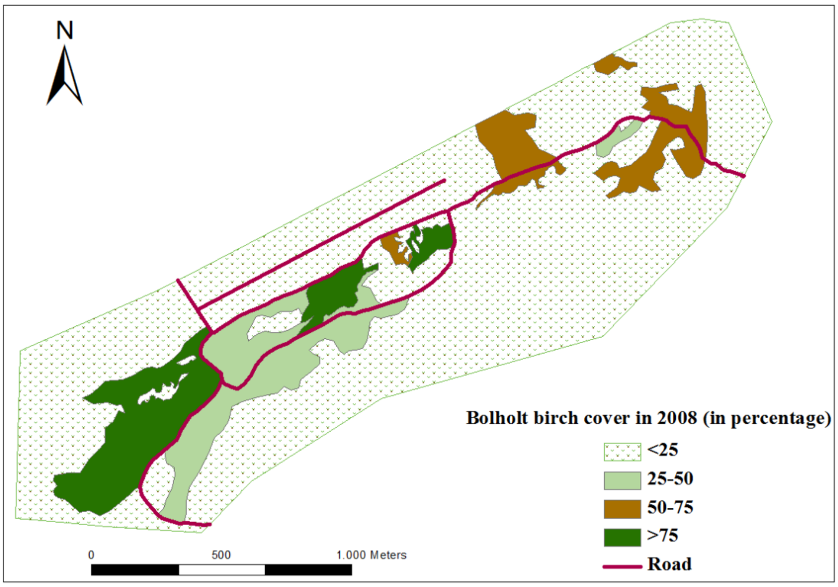

Fig. 6. *Map showing the cover of birch in the Bolholt plantation area based on aerial photograph from 2008.*

4.3 The characteristics of birch stands

Birch trees in the plantation in Bolholt were relatively taller and thicker than their counterparts in the natural generation at Gunnlaugsskogur (Table 3). Both diameter and height also increased with age. There was no significant difference in either basal diameter or height or the average tree between the two sites representing natural regeneration versus assisted regeneration (Table 4). However, there was a significant difference in height between the age classes of the average trees. For the tallest trees, there was no significant difference in either height or basal diameter due to the restoration methods but there was a significant difference in height and basal diameter due to age differences (see Table 4).

Table 3. *Average height and basal diameter across the age classes in Gunnlaugsskogur and Bolholt.*

Age, years	Gunnlaugsskogur (N=4)				Bolholt (N=3)			
	Basal diameter, cm		Height, m		Basal diameter, cm		Height, m	
	Tall	Average	Tall	Average	Tall	Average	Tall	Average
10-20	3.4	3.4	2.1	1.6	4.4	3.2	3	2
20-30	9	2.2	4.2	2.6	10.4	6.2	5.2	3.2

Table 4. *Two way ANOVA results for the tallest and average trees*

Measurements	Factors	Degree of freedom	F value		P value	
			Tallest tree	Average tree	Tallest tree	Average tree
Height	Site	1	2.7	2.9	0.1345	0.1153
	Age	1	30.5	10.8	0.0003	0.0082
Basal diameter	Site	1	0.7	0.02	0.4356	0.9044
	Age	1	20.3	1.2	0.0011	0.2988

In both study areas, there was a strong significant correlation between the basal diameter and height of trees. As the height increased the basal diameter also increased. But the correlation was relatively stronger in the naturally regenerated ($r=0.77$) than the plantation site ($r=0.67$).

4.4 The cost of establishment

The cost of birch establishment for both the natural regeneration and plantation was estimated using variables such as price per seedling (30 Icelandic kronas, ISK), planting cost per plant (30 ISK), and assuming a spacing of 2x2 m which results in 2500 plants per ha. The cost of fertilizer and fertilizing was not included as it was the same for both sites. The rough estimation of cost of establishment per ha was almost 122,000 ISK. In Bolholt the planted area was 317 ha and the total establishment cost was around 39 million ISK whereas it was negligible for Gunnlaugsskogur.

5. DISCUSSION

Since birch was introduced in Gunnlaugsskogur in 1939 and 1945 by seeding two small plots and planting several small plots birch cover has changed profoundly. Between 1987 and 2008, the area with >25% canopy cover of birch increased from 10.1 ha to 15.8 ha. The recruitment of birch varied; however, within the area as larger areas were colonized north and north-west of the first stand than the other directions. Even though seed dispersal decreases as distance increases; seedling establishment patterns can be highly directional (Aradottir, Robertson & Moore, 1997).

There was better birch colonization in the northern part of the study area than the southern part. Grazing may have destroyed seedlings that established outside the fence line. Grazing may play a crucial role in recruiting seedlings in areas where there is a dense ground cover of other palatable species by opening areas and giving safe sites to the seed to germinate. But continued grazing will then result in a decline in the number of surviving young plants as they will also be a target for the grazing animals (Martin and Osvaldo, 1990). Viable seeds of birch need open space for establishment (Aradottir, 1991). However, in the southern part of the study, most of the area is occupied by a wetland which may have dense ground cover and hence limited the availability of safe sites for birch seedling establishment.

There were considerable number of seedlings recruited at a distance from the main seed sources but it was not possible to see any seedling under the forest canopy. This might be due to multiple reasons but the density of the safe site seems also to be crucial here. The number of safe sites probably increased with increased distance from the centre of the seed source as the effect of shadow and competition from a crowded undergrowth declines with distance. Martin and Osvaldo (1990) found that safe site density, among other factors, played an important role in plant recruitment as the age of the stand was increased.

The increase in area with 50-75% and greater than 75% birch canopy cover in Gunnlaugsskogur between 1987 and 2008 showed clearly that there had been good birch recruitment and expansion of birch accompanied with growth of individual trees in height, diameter and canopy over time. In this study, there was no significant difference found between height and basal diameter at the different restoration sites. The only difference was among the height and basal diameter of plants in different age classes. This is similar to the findings from Jordan & Farnsworth (1982), and Janas & Brand (1988) that the productivity (biomass) of plants in plantation and natural regeneration was reasonably similar after a certain number of years (12) even though there was a difference during the early stages of establishment. Thus, ten years might have been enough to balance the differences in growth parameters between the two sites. There was a direct relationship between basal diameter and height in both the natural regeneration site and the plantation site. However, there was a relatively higher correlation between the two parameters for natural regeneration than for plantation. This can be accounted for by the faster growth of trees during the early ages of stand establishment in the plantation site. This may have led to a faster growth in height than in basal diameter at Bolholt.

At Bolholt there was continuous planting activity and a total of 317 ha were planted. However, the area on which birch cover was identifiable in the aerial photograph was 254 ha. This can be explained either by the fact that some amount of area was covered by very young plants or there had been considerable mortality of birch in some part of the area. Similarly, in Gunnlaugsskogur there were considerable number of birch seedlings outside the actual plots, which explains the continuous natural expansion of birch, and the colonization was better some meters away from the dense birch stand. However, at Bolholt no seedlings that had dispersed from the mature stand were observed. This might be because of the continuous plantation activity in the area. Therefore, there might have been seed dispersal in the site but the seeds had landed on sites that were already occupied by young birch plants from planting and they failed to establish due to competition.

6. CONCLUSION

The results of this study indicate that natural regeneration is an efficient and cost effective way of land restoration in areas where availability of safe sites is not a limiting factor. In areas where degradation is severe, the response from natural regeneration or area enclosures might be delayed or might not be responding at all. In such conditions, assisted regeneration (planting or seeding) can be used to effectively restore the land. Previous research has shown that revegetation by grasses and fertilization modifies the biological crust. However; continuous planting, as at Bolholt, may not be an efficient approach to land restoration as it is not cost effective and does not utilize or maximize the use of natural expansion. Instead, forming a group of plants in strategic areas for seed dispersal by planting, as was done in Gunnlaugsskogur, is the better strategy to minimize the cost and maximise the use of natural expansion. In areas where there is a threat of sand and volcanic ash deposition by wind, plantation is preferable to natural regeneration as these conditions demand fast growth in height. This helps the seedlings to resist the effect of wind- deposited sand and volcanic ash. In such difficult conditions, stabilizing the moving sand and volcanic ash by using adaptive grasses and fertilizing them until they are well established and halting the movement of sand and volcanic ash is crucial before attempts are made to restore the native vegetation of an area. This creates better conditions such as increased availability of safe sites for the establishment of the vegetation intended to be restored.

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