ECOLOGICAL SUCCESSION AFTER RECLAMATION TREATMENTS ON AN ERODED AREA IN ICELAND

ARADOTTIR, Asa L. [1] *– ORRADOTTIR, Berglind* [1] *– ARNALDS, Olafur* [1] *– SVAVARSDOTTIR, Kristin* [2]

[1] Faculty of Environmental Sciences, Agricultural University of Iceland, Keldnaholt, IS-112 Reykjavik, Iceland, e-mail: asa@lbhi.is
[2] Soil Conservation Service, Iceland

Abstract: The effects of different reclamation methods on successional trajectories and ecosystem function were studied in a large-scale experiment with 40 one ha plots (10 treatments, replicated four times) on a barren eroded area in South-Iceland. Results showed rapid initial changes in vegetation cover and OC in the uppermost layer of the soil. Adding fertilizer, with or without seeding grasses, had most impact on measured ecosystem properties, formation of biological crust and colonization of native species.

Keywords: 9040 Nordic subalpine/subarctic forests with *Betula pubescens*, 4080 Sub-Arctic Salix spp. scrub, driving pressure soil erosion, reclamation of eroded areas, reintroduction of key species.

Introduction

Effective restoration strategies overcome thresholds that limit ecosystem development. Restoring land with minimum interventions or inputs is especially important where degraded areas are extensive and/or resources for restoration are limited. Over 40% of Iceland is characterized by moderately to severely eroded land, which is prone to intensive cryoturbation and erosion and limited ecosystem functioning (Arnalds and Kimble 2001). Various methods have been used for reclamation of eroded land in Iceland, but their success varies (Gretarsdottir et al. 2004). Better understanding of the effects of different reclamation treatments on succession and ecosystem functions can improve the design and management of restoration projects. This paper summarizes results from the initial years of a large-scale, long-term experiment on the effects of different reclamation treatments on ecosystem properties and functions.

Materials and methods

The experiment was established on a barren area with active soil erosion in South-Iceland (63°49'N, 20°13'W). January and July temperatures are about -2°C and 11°C, respectively, and annual precipitation 1260 mm (averages for 1971-2000, www.vedur.is). The experiment consists of 40 one ha experimental plots, set up in a randomized block design with four replicates (Figure 1). The

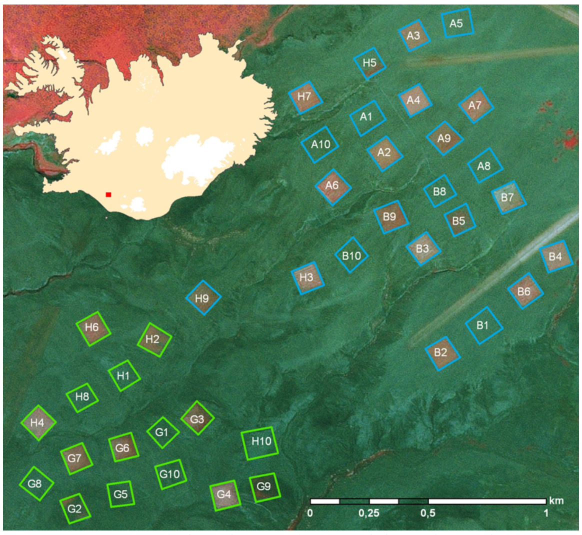

Figure 1. An infrared SPOT image of the Geitasandur experiment, showing individual plots labeled by replicate (A, B, G or H) and treatments (1-10, see text for explanations). (SHB/AUI, 2008).

ten treatments are designed to meet a broad range of restoration goals and represent different intensity of inputs:

1: Control (untreated, eroded land);
2: Fertilized;
3: Seeded with grasses (*Poa pratensis* and *Festuca rubra*) and fertilized;
4: Seeded with *Leymus arenarius* and fertilized;
5: Seeded with lupine (*Lupinus nootkatensis*);
6: Seeded with grasses (*P. pratensis*, *F. rubra* and *Lolium multiflora,* different varieties than treatment nr. 3) and planted with clusters of birch and willows (*Betula pubescens*, *Salix phylicifolia* and *S. lanata*);
7: Seeded with grasses (same as nr. 3), planted with clusters of birch and willows;
8: Planted clusters of native legumes, birch and willows;
9: Seeded with grasses (same as nr. 3), whole plot planted with birch and spruce (*B. pubescens* and *Picea sitchensis*);
10: Seeded with lupine, whole plot planted with birch and spruce.

The seeding was completed prior to the 2000 growing season. Plots were fertilized at the time of seeding, and again in 2001, 2003 and 2005 with approximately 50 kg ha^{-1} N and 27 kg P_2O_5 ha^{-1} each time. Trees and shrubs were planted in 2001-2003. Various biotic and soil properties have been monitored in the study plots, including vegetation cover and composition, seedling colonization, soil and surface fauna, soil properties and hydrology. Here we present results on vegetation cover, selected soil properties and plant colonization. Vegetation cover was determined in 30 permanent 0.25 m^2 quadrats in all plots in 2002 and 2006 and in a subset of the treatments in other years. Soil samples were collected in the fall of 2007 at 0-5 and 5-10 cm depths: three samples (10 cores per sample) in each 1 ha plot. Total soil organic carbon (OC) and nitrogen (N) was quantified by dry combustion and soil pH was determined in water. Colonization of *Agrostis* sp., *Rumex acetosella* and *Thymus praecox* was studied in treatments 1 and 3. In August 2005 the current year seedlings were recorded in 10 quadrats in each plot. In July 2006, their survival was assessed and new seedlings recorded. Colonization of birch and willows in treatments 6-8 was recorded along transects laid over each of the planted clusters of those species. The effects of treatments on vegetation and soil parameters were tested with ANOVA. Effects of treatments, species and sward type on seedling survival were tested with logistic regression. SAS (ver. 9.1) was used for statistical analysis.

Results and discussion

Total vegetation cover (including vascular plants, mosses, lichens and biological soil crust) averaged around 5% in the control plots over the study period, while there was a steady increase in total cover for the first three years in all fertilized treatments (2,3,4,6,7,9) (Figure 2). In same treatments, biological soil crust (BSCs) had formed 6-17% cover in 2006, but none in control plots or plots with legumes (treatments 5, 8 and 10). Plots with planted clusters of native legumes, birch and willows had consistently low vegetation cover, due to limited survival and growth of the legumes. The effect of treatments on species density (in 0.25 m^2 quadrats and 100 m^2 subplots) was highly significant ($p<0.001$) and showed a similar pattern, with the fewest species in the control plots, followed by treatments 8, 10 and 5, but significantly greater number of

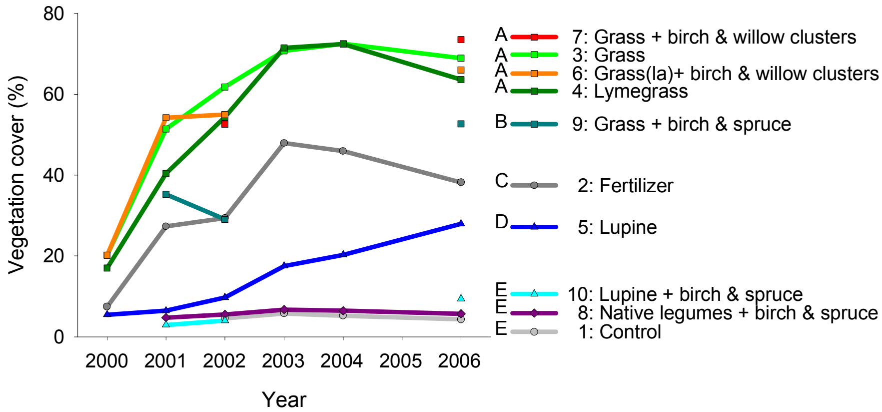

Figure 2. Total vegetative cover in the experimental plots. Treatments labelled with different letters were significantly different in 2006 (Tukeys HSD, α=0.05).

species in all fertilized treatments. Some of the species that have colonized the fertilized plots are important in native heath or woodland communities, e.g., *Empetrum nigrum*, *Salix lanata* and *Trisetum spicatum*. These results agree with chronosequence studies of older (20-45 yrs) reclamation sites where simple reclamation treatments helped overcome thresholds to vegetation succession (Gretarsdottir et al. 2005). There was a strong positive correlation between number of vascular plant species in 1 ha plots (not counting seeded or planted species) and average cover of BSCs ($r=0.81$, $p<0.001$). Our results strongly support earlier evidence (e.g., Elmarsdottir et al. 2003) that BSCs are important for early stages of succession by providing safe sites for establishment of vascular plant seedlings on eroded areas.

Soil OC content was significantly lower in control plots than in all treatments except for treatments 8 and 10 at 0-5 cm depth, and also treatment 2 (fertilizer) at 5-10 cm depth (Figure 3). Soil pH differed between treatments ($p<0,001$) at both soil depths and was significantly higher in the control than in all treatments. The increase in OC is relatively rapid and is important for restoring ecosystem functions such as water retention and nutrient cycling. There was a significant correlation between total vegetation cover and soil factors at 0-5 cm (Pearson r equals 0.78, 0.72, 0.71 and -0.76 for OC, %N, C:N ratio and pH, respectively, $p<0.001$ in all cases). No significant relationships were found between vegetation cover and soil factors at 5-10 cm ($p>0.05$). This indicates that the primary producers mainly affect soil development in the uppermost layers during early succession.

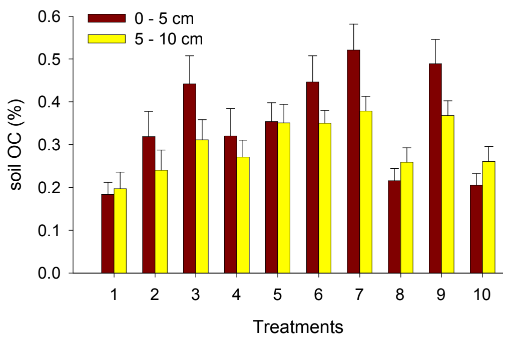

Figure 3. OC content in 0-5 cm and 5-10 cm of soils by treatments (mean and SE). See text for description of treatments.

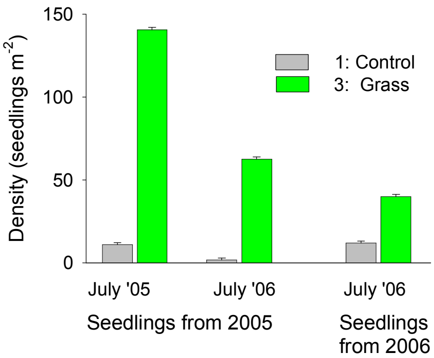

Figure 4. Combined density of *Agrostis* sp., *Rumex acetosella* and *Thymus praecox* seedlings in treatments 1 and 3 in 2005 and 2006 (mean and SE).

Density of new seedlings was an order of magnitude higher in plots seeded with grasses than in control plots in 2005 (Figure 4). Seedling survival was significantly affected by treatment, species and sward type ($p<0.001$). This demonstrates facilitative effects of revegetation on establishment of native species. Colonization of birch and willow seedlings around planted clusters (treatments 6-8) had not started in 2005. In 2006, a low density of seedlings was found near the planted clusters in treatments 6 and 7, corresponding to 0.4 and 0.6 seedlings m^{-2}, but no seedlings were found in treatment 8. Although some seed production was observed in birch and willow plants within the planted clusters in 2004, 2005 and 2006, seed rain was probably still limited. In treatment 8, which had very low vegetative cover and hardly any BSCs, birch and willow colonization may have been further hampered by unfavourable surface conditions for seedling establishment.

Conclusions

Our results demonstrate clearly that simple revegetation treatments can trigger natural succession and development of ecosystem services. Within the time-frame of this study, treatments involving fertilization - with or without seeding of grasses - were the most effective in restoring vegetative cover, species diversity and OC. Vegetation cover developed more slowly in treatments seeded with lupine and planted with clusters of native legumes. The large scale of the Geitasandur experiment provides a unique opportunity to study some of the fundamental processes involved in ecosystem development on severely degraded areas. Improved understanding of the effects of different reclamation methods on successional trajectories will aid in restoration of Iceland's extensive eroded areas.

Acknowledgements

We thank colleagues at the Soil Conservation Service, Agricultural University of Iceland and others that have contributed to this research. The establishment of the Geitasandur experiment and this research was supported by grants from the Icelandic Research Fund (Rannsóknasjóður).

References

Arnalds, O. & Kimble, J. (2001). Andisols of deserts in Iceland. Soil Science Society of America Journal 65, 1778-1786.

Elmarsdottir, A., Aradottir, A.L. & Trlica, M.J. (2003). Microsite availability and establishment of native species on degraded and reclaimed sites. Journal of Applied Ecology 40, 815-823.

Gretarsdottir, J., Aradottir, A.L., Vandvik, V., Heegaard, E. & Birks, H.J.B., 2004. Long-term effects of reclamation treatments on plant succession in Iceland. Restoration Ecology 12, 268-278.