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Short communications

Natural Regeneration of Lodgepole pine (*Pinus contorta*) in Steinadalur, SE-Iceland

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INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl.) is a coniferous tree species, native to the western parts of North America. It has been widely cultivated and is now found throughout the rest of America, in Europe and New Zealand (Simberloff et al. 2010). It has a wide ecological range and grows on various soil types, it is resistant to air pollution and spring frost and can adapt to different climatic conditions (Lotan & Critchfield 1990). Lodgepole pine produces viable seeds at an early age, commonly from 5 to 10 years in warmer climates and the percentage of germination is often high (Lotan & Critchfield 1990). The lodgepole pine is one of the most common tree species used in forestry in Iceland, with the first plantation taking place in 1940. The first seeds came from Smithers in British Colombia, north-western Canada (Bjarnason 1978) but the most common provenance of lodgepole pine used in Iceland is from Skagway in Alaska (Bragason 1995). The first self-regenerated plants in Iceland were recorded in Hallormsstaður before 1976, 20-25 years after the first planting took place there (Bjarnason 1978).

Lodgepole pine has been considered an invasive species in some parts of New Zealand, in Patagonia, Chile and in Argentina (e.g. Richardson et al. 1994, Nuñez et al. 2017). However, a recent study that took place in Sweden showed that the magnitude of the natural regeneration is limited at higher latitudes, and the species is not considered invasive in northern areas because its dispersal can be controlled (Jacobson & Hannerz 2020).

Steinadalur is located on the slopes of Mount Staðarfjall (928 m a.s.l.) in SE-Iceland (Figure 1). The average annual temperature in SE-Iceland is between 4,5 and 5 °C. In 1954, the planting of exotic tree species started at the foot of the mountain, 50 m a.s.l. and 4 km from the ocean. The plantation (0.4 ha) was originally fenced to exclude sheep grazing (Torfason 2007). In 1959, the first 300 3-year pine seedlings of Skagway provenance, coming from the Hallormsstaður nursery in East Iceland, were planted inside the fence. The planting continued until 1969 and the fence around the area had been extended at the end of planting, covering an area of 2.3 ha. In addition to lodgepole pine, also Sitka (*Picea sitchensis* (Bong) Carr.) and Norway (*Picea abies* (L.) Karst.) spruce were planted inside the fence (Torfason 2007). The first self-seeded pine plants outside the fenced area were found in 1985, 26 years after its first planting (Torfason 2007). The dominant tree outside the plantation is the native downy birch (*Betula pubescens* Ehrh.) which has recently

Figure 1. Photo taken from the slopes of Staðarfjall showing the old plantation and the dispersal of lodgepole pines towards southeast. Photo: Ólafur Eggertsson 27 July 2020.

spread throughout most of the area, most likely because of less sheep grazing (Figure 1). In this site, for some reason, the lodgepole pine has also had a more rapid natural regeneration and dispersal than has been observed around any other of the oldest plantations in Iceland. In 2010, Guðmundsdóttir (2012) estimated the size of the area with self-seeded lodgepole pine in Steinadalur and showed that the pines had spread from the original plantation of 2.3 ha to an area of 19.7 ha, with the most far-off seedling about 335 m from the original plantation.

The aims of this study were: 1) to quantify the distribution and density of the natural self-seeded regeneration of lodgepole pine in Steinadalur, and 2) to examine the changes that have taken place since last survey took place in 2010 (Guðmundsdóttir 2012). This paper is primarily based on the MSc thesis work of Delfina Andrea Castiglia (Castiglia 2020).

MATERIALS AND METHODS

The fieldwork took place during summer 2020. The area around the plantation was surveyed by systematically moving radially away from the plantation and the outermost limit of the natural lodgepole pine regeneration marked. Self-seeded lodgepole pines were also found further southeast, about 1.6 km away from the primary plantation, close to two cottages with lodgepole pines planted by them. The cottages were built in 1975 (www.skra.is). The same survey method was performed in that area. A high precision GPS (REACH RS2 Multi-band RTK GNSS) was used to record the location of the plants.

Moreover, a transect was placed southwest from the densest primary plantation, where the occurrence of self-seeded pines was most abundant in the area, towards an old growth downy birch forest. All trees were measured, collecting data on species, diameter and height, in a series of 200 m^2 circular plots separated by

20 m until no trees were found within the plots. A total of 11 permanent plots were placed, an iron bar was set in the middle of the plot and the position recorded with high precision GPS devices (REACH RS2 Multi-band RTK GNSS) for future surveying.

Microsoft Excel was used for processing the data collected in the field and Qgis software for producing explanatory maps e.g., using the "Distance matrix" tool of QGIS for calculating the average area increase of the regeneration.

RESULTS AND DISSCUSSION

Two distinct areas with self-seeded lodgepole pines were mapped in the study, a 66 ha area close to the primary plantation (site A) and a 33 ha area (site B) approx. 1.6 km south-east from it (Figure 2), with the total area being 99 ha where natural lodgepole pine regeneration was found. The average distance of plants from the primary plantation had increased from 270 m in 2010 to 500 m in 2020 (Figure 2). The annual rate of spread from the plantation during the period 1985-2010 was about 11 m and increased to 14 m considering the whole 1985-2020 period.

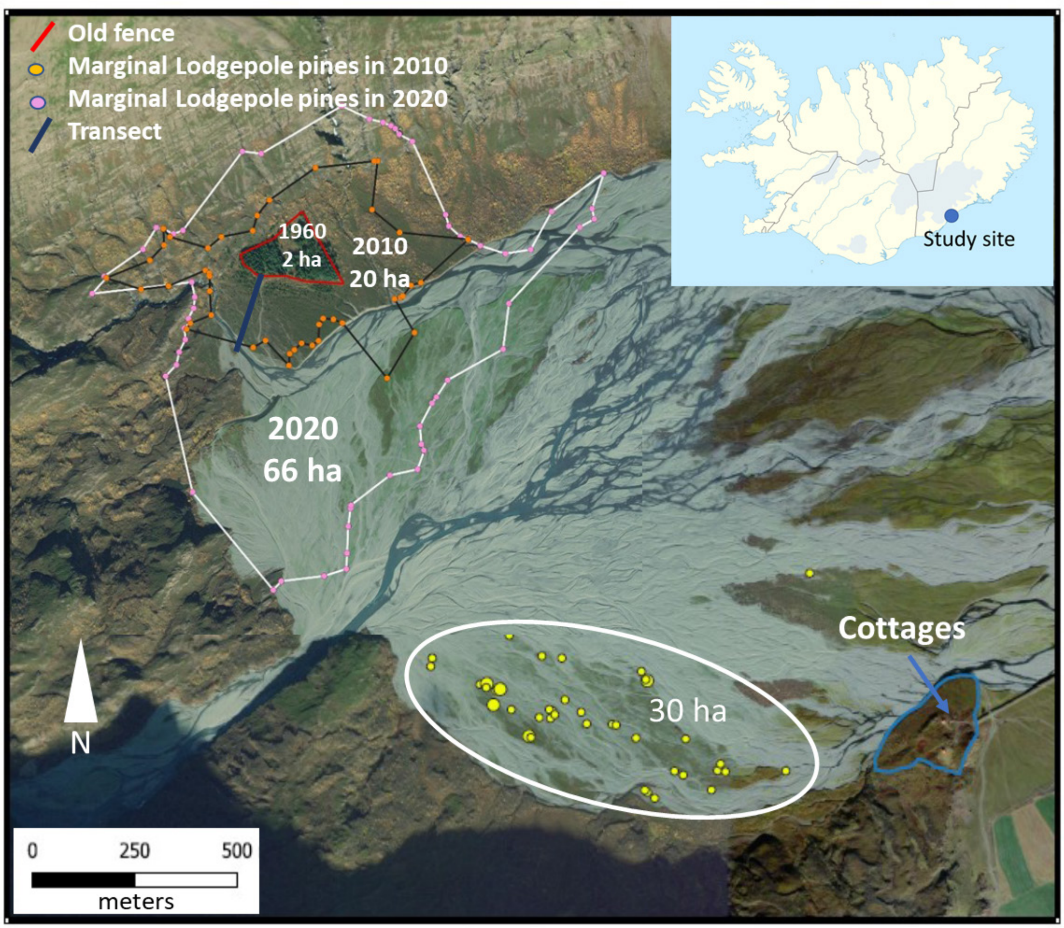

Figure 2. The location of the research site and an overview showing the distribution area of regenerated lodgepole pines in Steinadalur. The old plantation is defined by a red line (2 ha), the black line shows the boundaries of regeneration in 2010 (20 ha) and the white line the boundaries in 2020 (66 ha). The transect is shown as blue line. The red (site A) and blue (site B) lines specify the boundaries of areas where planted lodgepole pines can be found.

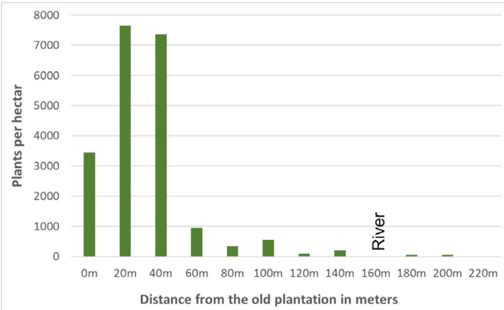

Figure 3. The number of natural lodgepole pine regeneration per hectare in relation to the distance from the plantation. The location of the transect can be seen in Figure 2.

Between 2010 and 2020, the rate was 23 m per year. The size of the distribution area was at least 66 ha in the summer 2020. If the regeneration in Steinadalur is split into two main portions, north and south respect to the old plantation, the average spread of the regeneration was 350 m and 610 m, respectively. The most far-off self-regenerated lodgepole pine in 2020 was about 760 m from the original plantation. In 2010 the most distant plant was about 335 m away (Guðmundsdóttir 2012).

The density of self-seeded pines was highest at 20-40 m from the plantation, with about 7500 plants per hectare, but decreased rapidly further away. At 200 meters the density was only 50 plants per hectare (Figure 3) and beyond this limit, the density was less than 50 plants per hectare. Consequently, we conclude that beyond 200 m from the primary plantation the density of self-seeded pines was less than 50 plants per ha. Within 60 m from the plantation, self-regenerated pines dominated, both in terms of density and size. However, as we moved further away the density of birch natural regeneration increased. The presence of self-seeded spruce in the plots was sporadic (Figure 4).

It cannot be excluded that the southernmost group of plants, located west of the cottages, were seedlings from the primary plantation, however they formed a discrete group well away from the main self-seeding area (Figure 2), therefore we consider it likely that they originated from the lodgepole pines planted next to the cottages. The average density of these pines was about 6 plants per ha.

As can be seen in Figures 1, 2 and 3, the pines distribution is rather anisotropic with most individuals growing on the poorly vegetated outwash plains, less on the hillside, and almost

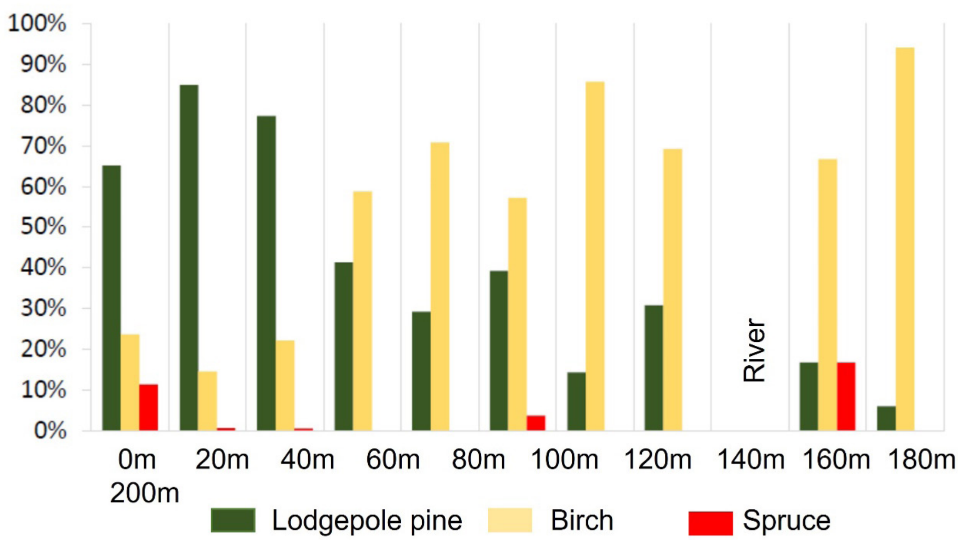

Figure 4. The frequency distribution of natural regeneration of the three most represented species in relation to the distance from the plantation. The location of the transect can be seen in Figure 2.

none where the vegetation cover is dense. No self-seeded pines were found inside the old growth birch stand.

In a study carried out in southern Chile on the dispersion of lodgepole pine, where the mean annual temperature was somewhat higher than in SE-Iceland (6-9 °C), the maximum density reached 5,319 trees per ha in the prairies where the farthest trees was recorded 310 m away from the seed source and 13,222 plants per ha in the comparatively less vegetated steppe where the furthest plant was 368 m away (Langdon et al. 2010). Comparing the results obtained in these two studies, three things stand out: i) the average regeneration success (seedling density) was much higher in the Chilean study, ii) the maximum distance of natural regeneration was higher in Steinadalur and iii) in both studies it is clear how the difference in the substrate and the presence of vegetation significantly affects seedling establishment. Regarding i), warmer climate resulting in more seed production can result in higher seedling density at the Chilean site. Regarding ii) higher wind speed a less vegetation cover might result in further spread of seeds at the Steinadalur site and regarding iii), the regeneration was much more successful in the gravel outwash plain south of the Steinadalur plantation than in the more dense herbaceous vegetation north of it. The dispersion capacity of lodgepole pine in Steinadalur was therefore in line with what has been found in other areas outside the natural range of the species (e.g. Nuñez et al. 2017). The maximum distance reached by dense regeneration (over 1000 plants/ha, Figure 3) was less than 60 m from the plantation, the absolute maximum distance of a single plant being 758 m, assuming that the southern-most group originated from the different sources, located at the cottages.

CONCLUSION

The dispersal of lodgepole pine regeneration in Steinadalur suggests that with time, in addition to an increase in the average density of plants, the expansion of pine will continue, especially on the poorly vegetated outwash plain. The purpose of this study was to describe the ongoing dynamics of natural pine regeneration, without going into the debate of its possible positive or negative consequences. It is important to study further the dispersal of self-seeded Lodgepole pines at other sites in Iceland to understand the dynamics and the impacts on native vegetation.

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