Short Communication

Regeneration after clear-felling and selection-felling in an Icelandic birch forest

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INTRODUCTION

Extensive literature exists on birch silviculture in North America and Europe (Perala & Alm 1990, Hynynen et al. 2010). Birches are managed by both coppicing and seedling-based regeneration with good success. High light levels are considered essential for vigorous growth and therefore clear-felling or seed-tree silvicultural systems are recommended rather than selection systems (Perala & Alm 1990). Similar to most other birches, native downy birch in Iceland (*Betula pubescens* Ehrh. ssp. *czerepanovii* [N. I. Orlova] Hämet-Ahti) is light-demanding and regenerates readily from stump sprouts. Regeneration from seed is most successful on partially vegetated land but less so within woodlands (Aradóttir & Eysteinsson 2005).

Traditional tree harvesting in Iceland, where all trees in a given area were removed (Blöndal & Gunnarsson 1999), is accurately described as clear-felling. Regeneration often failed due to livestock grazing and fodder harvesting, eventually resulting in the nearly complete deforestation of Iceland (Bjarnason 1942). During the early 20th century, the Iceland Forest Service promoted single-tree selection instead of clear-felling, the goal being to prevent forest clearing. Harvesting of birch generally ceased during the 1940s, but a few natural birch forests have been managed for wood production by single-tree selection for over a century (Blöndal & Gunnarsson 1999). Recently, mechanised harvesting has resulted in slightly heavier felling, more accurately described as group selection.

Selection-based silviculture works in the management of Icelandic birch woods, the managed forests having improved in height and straightness with no regeneration failure (Blöndal & Gunnarsson 1999). However, saplings surrounded by taller trees tend to be slender. Slow diameter growth lengthens the rotation period and possibly also increases the likelihood of various types of damage. These perceived negative outcomes awakened questions as to the possibility of improving early diameter growth by regeneration after clear-felling.

Despite the long experience with birch regeneration after selection-felling in Iceland, it has never been properly documented and never compared to other silvicultural systems such as clear-felling. This paper compares regeneration and growth of *Betula pubescens* ten years after selection-felling and clear-felling in a forest in north Iceland.

MATERIAL AND METHODS

An experiment to study regeneration after clear-felling was set up in Thordarstadaskogur National Forest, North Iceland (65°39´12.75´´ N, 17°50´21.36´´ W, 200 m elevation a.s.l.). A good description of the forest exists from 1945, indicating a history of clear-felling and livestock grazing (Sæmundsen 1945), both of which have been excluded since then and replaced by selection-based silviculture. The experimental area had not been harvested since before 1945.

In the autumn of 2000, a 0.5 ha (50 x 100 m) rectangular plot was clear-felled, an adjacent plot of the same size was selection-felled according to the currently practiced method (group selection), and a third adjacent area was left uncut. All trees in the clear-felled area were felled regardless of size, including any stump sprouts already regenerating (advance regeneration). Large trees were delimbed and topped on site. In the selection-felled area, advance regeneration was not specifically removed although some smaller trees were felled to facilitate extraction. Felling was done using chain saws and logs extracted using a forwarder. Exposure of mineral soil was negligible.

In September 2010, six 50 m^2 circular, randomly located plots were measured within each treatment area, avoiding sites within 10 m (roughly the maximum tree height in the area) of treatment area edges. Height (H) of the tallest stump sprout on each stump, the height of each seedling/sapling (stems less than 5 cm in diameter at breast height (DBH), and not associated with a stump) and the DBH of all stems with DBH greater than 5 cm were measured.

Since advance regeneration stump sprouts were sometimes left in place in the selection-felled area but always removed in the clear-felled area, the above measurements did not accurately reflect growth after felling. In July 2011, randomly placed transects were walked across the clear-felled and selection-felled areas to measure stumps that only had sprouts younger than from the time of felling. Sprouts were counted on each stump and height and the diameters at 50 cm above the ground (D50) of the three tallest on each stump were measured. Stumps with advance regeneration sprouts (i.e. with two or more size classes) were excluded from these measurements based on uniformity of sprout size. The proportion of stumps with no sprouts (stump mortality) in the clear-felled area was also counted.

Analyses of variance (ANOVA) were carried out using Sigmaplot 12.0. (Systat Software Inc. 2010) on the number of seedlings and total stocking per hectare by treatment, the number of sprouts per stump, H, D50, H/D50 (slenderness), and the height of seedlings vs. stump sprouts in the clear-felled area.

RESULTS

Differences in total stocking (stems ha^{-1}) and the number of seedlings ha^{-1} between treatment areas were not significant ($p = 0.193$ and 0.502 respectively) (Table 1). The large confidence interval for seedlings (Table 1) in all three treatment areas indicates uneven distribution of seedling regeneration (large variation among plots). Young seedlings represented 11% of the regeneration in the clear-felled area, whereas seedlings of various ages but

Table 1. Descriptive statistics (mean ± 95% confidence interval) for the three treatment areas in 2010, 10 years after felling.

Parameter	Clear-felled area	Selection-felled area	Uncut area
Stump sprout clumps ha^{-1}	2933 ± 770	1867 ± 646	1400 ± 637
Seedlings ha^{-1} < 5 cm DBH	367 ± 449	567 ± 614	733 ± 589
Trees ha^{-1} > 5 cm DBH	0	800 ± 351	2203 ± 497
Total stocking (stems ha^{-1})	3300 ± 1026	3234 ± 1049	4336 ± 1396
Stump mortality ha^{-1}	630 (13.8%)	-	-

Table 2. Comparison (mean ± standard deviation) of stump sprout measurements between the clear-felled and selection-felled areas eleven years after felling. H3 = mean height of the three tallest sprouts per stump, D50 = mean diameter at 50 cm above ground of the three tallest sprouts per stump, H/D50 = the ratio of height to diameter of the three tallest sprouts per stump.

Parameter	Clear-felled area	Selection-felled area	Significance
Sprouts per stump	12.27 ± 8.08	13.87 ± 5.79	$p = 0.381$ (n.s.)
H3 cm	119 ± 30.9	173 ± 37.1	$p < 0.001$
D50 cm	0.82 ± 0.39	1.05 ± 0.37	$p < 0.001$
H/D50 (slenderness)	171.52 ± 68.32	179.59 ± 50.21	$P = 0.368$ (n.s.)

less than 5 cm in DBH represented 17% of the stocking in the other two areas.

In the clear-felled area, stump sprouts were significantly ($p < 0.001$) taller than seedlings, averaging 113.8 cm compared to 59.6 cm for seedlings.

Stump mortality in the clear-felled area averaged 13.8% and was roughly uniform across the area, ranging from 11.5% to 15.4%. Thus, 86% of stumps were regenerating with stump sprouts eleven years after felling.

The number of sprouts per stump did not differ significantly ($p = 0.381$) between the clear-felled and selection-felled areas (Table 2). Stump sprouts were on average 45% taller in the selection-felled area than in the clear-felled area and with a significantly greater D50 ($p < 0.001$ for both H and D50). Slenderness (H/D50) did not differ significantly between the two treatments ($p = 0.368$).

DISCUSSION

Regeneration in both the clear-felled and selection-felled areas was sufficient to regain a similar stocking level as in the uncut area. Seedling regeneration was sporadic and seedlings in the clear-felled area were much shorter than stump sprouts. Stump sprouts of *Betula pubescens* grow more rapidly than seedlings to begin with but are quicker to develop mature traits such as greater branchiness and slower apical growth and are thus eventually overtaken by seedlings (Kauppi et al. 1988). That was not yet the case at the trial site and the low number of seedlings makes it unlikely that seedling-origin trees will appreciably replace stump sprout-origin trees in the next generation.

Stump sprouts in the clear-felled area were expected to show greater diameter growth but not necessarily greater height growth than those in the selection-felled area due to the effects of light and wind levels (Messier & Puttonen 1995, Telewski & Pruyn 1998). Thus, greater growth in both height and diameter in the selection-felled area and the lack of a difference in slenderness between treatments (Table 2) require an explanation.

Since the selection felling was rather heavy, it seems likely that the difference in light levels between the two felling treatments was insufficient to affect growth significantly. These results were similar to the results of Johansson (1987) where relative light levels from 25 to 100% did not significantly affect growth of *Betula pubescens* stump sprouts.

Movement by wind can retard height growth in plants through the process of thigmomorphogenesis (Telewski & Pruyn 1998) and could explain the shorter stump sprouts in the clear-felled area. Other effects of shelter include protection from radiative cooling and less wind-chill, both of which could explain greater growth in the selection-felled area. Besides differences in shelter, the greater growth in the selection-felled area might be related to defoliation by insects. During heavy outbreaks of *Epinotia solandriana* L. in 2003-2005, more defoliation was noted on stump sprouts in the clear-felled area than in the selection-felled area (Skúlason 2006). Since *E. solandriana* eggs are laid on young shoots in the upper parts of trees (Moisten et al. 1980), overstory trees in the selection-felled area may have provided the stump sprouts there with some degree of protection from defoliation.

Clarification of these effects and perhaps others would require more research. But regardless of the explanation, the fact remains that the forest was regenerating much faster in the selection-felled area than in the clear-felled area, both because of the faster growth of stump sprouts and because of the advance regeneration left on the site. Additionally, greater height growth was not achieved by sacrificing diameter growth. Therefore, these results do not support recommending clear-felling over selection-felling in Icelandic birch forests when stump sprouts are expected to account for most of the regeneration.

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