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Effects of slash and stump harvesting after final felling on stand and site productivity in Scots pine and Norway spruce ☆

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ABSTRACT

As a response to the increased market for biomass for energy in Sweden logging residues such as slash and stumps, previously left in the forest at stemwood harvest, have been targeted as a resource. Negative effects on site and stand productivity have been suggested as unwanted effects of this increased harvest intensity. Slash with its high nutrient content has the potential to impact forest production on nutrient limited northern forest sites. Stumps, with a lower nutrient content, may therefore be more favourable from a production point of view and the additional soil disturbance caused by the harvest may counteract the nutrient loss as a result of stimulated mineralization and reduced competition from the ground vegetation. Seedling survival is another critical factor that could be affected with potential effect on future stand productivity. Here stand and site productivity data from four long-term field experiments planted with, Scots pine (2 sites) and Norway spruce (2 sites) seedlings following (i) conventional stemwood harvest (S), (ii) stem and stump harvest (SS), and (iii) stem, stump, and slash harvest (SSS) is analysed and presented.

The statistical analyses based on data from all sites did not reveal any general treatment effects on seedling survival, standing volume (after 24–27 years), basal area growth (between the last two revisions), upper quartile mean height (25% highest trees) after 10 years or top height (after 24–27 years).

Analyses at the species level revealed a significant main treatment effect on top height for the spruce sites, with lower top height following SSS (11.6 m) as compared to S (12.9 m). No main treatment effect was detected for the pine sites.

Analyses at the site level gave significant but inconsistent results for the least productive site in both pine and spruce, suggesting site and possibly also species-specific responses. Response variables affected by treatments at the pine site were survival rate after 15 years (S < SS), standing volume after 24 years (S < SS and SSS), and upper quartile mean height after 10 years (S < SS and SSS). Response variables affected at the spruce site were standing volume after 27 years (SSS < S and SS), upper quartile mean height after 10 years (SSS < S and SS), and top height after 27 years (SSS < S and SS). Thus, responses on increased harvest intensity were from a forest production perspective positive in pine, whereas the spruce responded negatively – primarily on slash harvest. From a forest production perspective these results suggest that pine forests should be targeted before spruce forests and that stumps should be targeted before slash in spruce forests.

1. Introduction

Together with some other countries with large forest resources and lack of domestic fossil energy resources Sweden has launched policies to promote the development of renewable energy sources including bioenergy (Björheden, 2006). This development has been further accelerated by the Renewable Energy Directive (2009/28/EC), which sets targets for the proportion of renewable energy for EU member states. Initially emerging bioenergy markets target secondary industrial residues and tertiary end-of-life residues, both from domestic sources and as import, since they are already piled up and therefore relatively cheap. With this resource exhausted, primary residues like logging residues following stemwood harvest for conventional forest products are targeted (Egnell and Björheden, 2013). This includes branches and tops (slash), small-diameter trees, other trees with no other market, and stumps. This has raised concerns about the sustainability in these more intense harvesting practices. For slash, with its high nutrient content, concerns about long-term site and stand productivity has been an important issue reviewed by Thiffault et al. (2011). Site

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and stand productivity is an issue also for stump harvest as suggested in a review by Walmsley and Godbold (2010). But there are other maybe more important issues linked to stump harvest such as climate mitigation benefits (Vanhala et al., 2013) and loss of coarse woody debris, an important habitat/substrate for many saproxylic species (Hjältén et al., 2010).

A number of studies have shown that when slash is harvested in addition to stemwood the amount of harvested biomass increases moderately, whereas the increase in harvested plant nutrients increases substantially (e.g. Achat et al., 2015; Mälkönen, 1976; Palviainen and Finér, 2012). In Swedish forests within the boreal and northern temperate zone, particularly N limits forest growth on mineral soils (Tamm, 1991), whereas P and K are critical on peat soils (Moilanen et al., 2002). Slash harvest including leaves and needles often double or triple the export of these three nutrients. Furthermore, if slash is left on site it may have a mulching effect (Emmett et al., 1991b), stimulating mineralisation of nutrients and keeping competing vegetation away. Therefore decreased site and stand productivity could be expected as a result of slash harvest. Published data support that conclusion (Achat et al., 2015; Egnell and Leijon, 1999), although there does not seem to be a general effect over all sites and tree species as suggested by Thiffault et al. (2011).

Additional biomass harvested with stumps is roughly in the order of that in slash, but due to the relatively low nitrogen content in stump and coarse root biomass (Hellsten et al., 2013) the nitrogen export does not increase as much. Relatively high potential losses of P and K have been reported after stump harvesting (Uri et al., 2015). Furthermore, the soil disturbance caused by stump harvest has been suggested to increase nutrient mineralisation and will reduce the amount of competing vegetation. Indeed increased N concentrations and lower C:N ratios in the soil have been reported from stump-harvested sites as well as larger areas of exposed mineral soil (Kataja-aho et al., 2012b; Tarvainen et al., 2015). Stumps as an available carbon source following harvest have been shown to immobilize N as decomposers exploit the resource. Palviainen et al. (2010) showed higher N content in pine and spruce stumps as compared to the levels at harvest as long as 40 years after harvest. This N may be readily available for the next forest generation if the stumps are harvested. Together these are post stump harvest conditions that could favour seedling establishment, recruitment of natural regeneration and growth. This suggests that stump harvest may effect site and stand productivity in a positive or neutral direction rather than the opposite – at least in the short to medium term. There are only few studies published where site and/or stand productivity following stump harvest are reported. Karlsson and Tamminen (2013) reported a higher standing volume on stump-harvested plots planted with Scots pine (*Pinus sylvestris* L.) seedlings in Finland 30 years after harvest as compared to the control plots. No significant difference was reported for plots planted with Norway spruce (*Picea abies* (L.) Karst.) seedlings at the same site, although the standing volume was slightly higher on stump-harvested plots. Positive, but not significant, short term (3 years) height growth responses following stump harvest have also been reported for planted Norway spruce seedlings from another experiment in Finland (Kataja-aho et al., 2012a). Significantly higher biomass production for planted spruce including natural regeneration during the first 4 years following stump and slash harvest was reported for two out of three areas (north and south) in boreal Finland by Tarvainen et al. (2015). In central Finland biomass production was reduced. Most studies on stump harvest have focused on root rot control where Vasaitis et al. (2008) in a review concluded that volume growth increased as a response to stump removal.

Both the review on slash harvest (Thiffault et al., 2011) and the one on stump harvest (Walmsley and Godbold, 2010) highlight the importance of more long-term experiments to verify whether there are any long-term negative impacts of slash and stump harvest and if there are differences in response between sites and/or tree species. Here data on site and stand productivity following slash and/or stump harvest from four long-term field experiments established in the early 1980s are analysed. The four experiments are located from northern to southern Sweden, giving a variation in site conditions. Two of the experiments were planted with Norway spruce and two with Scots pine. This design allows for analyses of general treatment effects over all four experiments, as well as for site and species-specific effects. In the analyses effects on stand productivity were analysed through data on seedling survival, total volume production, and basal area growth. Early height growth data for the tallest trees and top height at the last revision were used as approximations for analyses on site productivity effects. Based on the experiences from previously published research there was no expectation on general treatment effects over all sites, but possibly at the site and/or species level.

2. Material and methods

2.1. Study sites

Data presented here are based on four long-term field experiments established in the early 1980s after clear-cutting of mature coniferous stands. The field experiments are located along a gradient from northern through central to southern Sweden (Fig. 1). This creates a natural climate and fertility gradient and a gradient in anthropogenic nitrogen deposition with 12–15 kg N ha^{-1} yr^{-1} in southern Sweden to 1–2 kg in northern Sweden. All four sites were

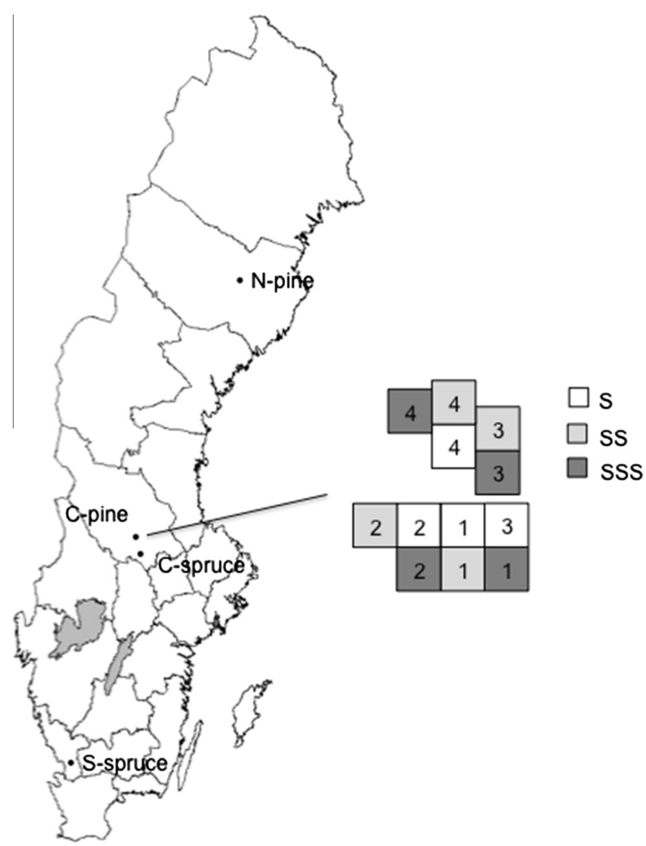

Fig. 1. Map over Sweden showing the locations of the four experimental sites and the randomized block design for one of the sites (C-pine) with block numbers 1–4 and the three biomass harvest intensities applied, S – Stemwood harvest, SS – Stem and stump harvest, SSS – Stem, stump and slash harvest.