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A review of Nordic trials studying effects of biomass harvest intensity on subsequent forest production ☆

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ABSTRACT

In the Nordic countries, emerging markets for renewable energy have resulted in increased harvest intensity, i.e., branches, tops, and stumps are now also harvested. This increased harvest intensity changes site conditions in a way that may impact future forest production. In this review published results are compiled from long-term field experiments in the Nordic countries. The objectives are to identify general patterns or inconsistences, to identify possible causes, and to discuss the practical implications of the results. I summarize 16 publications where short to medium-term forest production data were presented from 72 experimental sites. Data on growth of the subsequent stand following slash harvest in final felling indicate a moderate negative growth effect in Norway spruce, whereas growth in Scots pine appears unaffected, as compared to stem-only harvested control plots. Spruce data also showed a trend suggesting that poorer sites are more sensitive. Stump harvest in final felling did not have a negative effect on growth – rather the opposite – particularly on poor Scots pine sites. Trends in the data suggest that the positive growth effect in pine is stronger on poorer sites at higher latitudes. Slash harvest in thinnings resulted in more consistent growth reductions in the residual stand in both pine and spruce. There was a weak trend suggesting that poorer spruce sites are more susceptible. Seedling survival rates or stem numbers following slash and stump harvest were either unaffected or positively affected by the treatments – particularly by stump harvest. Trends in data suggest a stronger positive effect on more fertile sites. High relative survival or stem numbers coincided with high relative growth. Thus, survival rates or stem number may partly explain the lack of consistency in growth responses in field experiments. Management of natural regeneration in the experiments is discussed as potentially critical. Both short- and medium-term growth responses have been reported in individual studies. It is therefore recommended that a final evaluation should be based on longer-term data. The recommended next step is to combine all available data into a formal meta-analysis.

1. Introduction

The European Union has set high targets for the proportion of renewable energy sources (Renewable Energy Directive, 2009/28/EC), which have created a market for biomass energy in Europe. These targets were driven mostly by climate change concerns. However, the shift towards renewable energy had already started in the Nordic countries after the oil crises in the 1970s, driven at that time by security of supply and employment concerns. In Finland and Sweden, where most of the biomass originates from forests, policies to support a development towards more renewables have been crucial for the development (Ericsson et al., 2004). Initially this resulted in better use of industrial residues, not the least as process energy in the industry itself. Thereafter the growth has been on the power and heat market, where biomass-based combined heat and power plants connected to district heating networks have increased the market for biomass further. As a result of this market growth the demand side became bigger than what could be supplied by industrial residues, therefore primary residues available following forest harvest operations were targeted. This includes logging residues such as slash, small-diameter trees, non-industrial wood due to damages or species, and stumps.

The idea of using logging residues raised questions within the scientific community already in the 1970s. The prime questions at that time were potential impact of increased harvest intensity on site and thereby stand productivity, and whether long-term site and stand productivity could be maintained. This was particularly the case for harvest of the nutrient rich slash, where a moderate

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increase in biomass removal coincides with a substantial increase in nutrient loss from the site (Mälkönen, 1976; Nykvist and Rosén, 1985). Therefore a number of long-term field experiments were established already in the 1970s, and new ones have been added over time. These experiments have now, from a long-rotation forestry perspective, generated short- to medium-term data (with long-term here referring to one rotation period or more). Published results from some of these experiments were used in a review by Thiffault et al. (2011), where it was concluded that: "*There are no consistent, unequivocal and universal effects of forest biomass harvesting on soil productivity. However, climate and microclimate, mineral soil texture and organic C content, the capacity of the soil to provide base cations and phosphorus, and tree species autecology appear to be critical determinants of site sensitivity to biomass harvesting*". Published data from some of the experiments were also included as a part of the global data set used in a meta-analysis by Achat et al. (2015), with results suggesting a tree growth reduction by 3–7% in the short- to medium-term when slash was harvested in final felling.

Most studies on slash harvest analyse productivity effects by analysing the growth of the subsequent stand or in the case of thinnings, growth of the residual stand. Since stand productivity is a function of site productivity + silvicultural practices + genetics + random events such as frost, browsing, pests, storm and snow events, it is difficult to sort out effects on site productivity based on these kind of data. Furthermore, management of the experiments over time could be important for the outcome. E.g. if an increased harvest intensity stimulates natural regeneration it will be important how that regeneration is managed over time. If it is included in growth estimates they may fall out high, but if only growth of planted seedlings is included in the analyses, management of the natural regeneration becomes critical. If the natural regeneration was removed late it may have hampered establishment and growth of the planted seedlings. Overall there is much more than just the direct impact of additional nutrient withdrawal that may have an impact on growth of the subsequent crop. This adds to possible reasons why Thiffault et al. (2011) failed to find an unequivocal and universal response pattern in their review. Another could be that there is no such unambiguous treatment response, but rather site- or species-specific responses. For slash harvest in thinnings there is less to consider when analysing the data, but important factors are thinnings strength and standing stock after thinning. Both are valid covariates in an analysis of growth effects following slash harvest in thinnings. This could also change over time due to self thinning, e.g. through snow, wind, pest- and disease-caused mortality, that may not be linked directly to the treatments, but will have an impact on stand production and the interpretation of the results.

This review is based on stand productivity response data following slash and stump harvest in final felling and slash harvest in thinnings from long-term field experiments in the Nordic countries published in the peer-reviewed literature. In addition, some more information on site characteristics and metadata has been gathered through professional networks. Metadata are used in the discussion on possible explanations for altering treatment effects in the experiments. The aim has been to identify response patterns. In the absence of such patterns possible site and species-specific responses or response differences due to experimental design, management, and random events are discussed. The results are compared and discussed together with published results from similar studies from other countries. Finally, the results are discussed in relation to practical forest operations with suggested practical implications. The review focuses on forest production and does not consider other possible effects of increased harvest intensity on other ecosystem services and biodiversity or possible trade-offs between them.

2. Material and methods

The figures presented in this review are based on data from long-term field experiments in the Nordic countries published in the peer-reviewed literature. Data includes short- to medium-term data (5–34 years) on seedling survival and growth of the subsequent stand following slash and/or stump harvest in final felling and growth of the residual stand following slash harvest in thinnings. In all experiments but one, stem-only harvest is used as a reference. The exception is Karlsson and Tamminen (2013), where stump, slash, and stem harvested plots were compared with slash and stem harvested plots. In total 16 studies were found presenting data from 72 experimental sites. Data from one site includes stand growth in the residual stand following slash harvest in two thinnings (Helmisaari et al., 2011) and for the subsequent stand following slash harvest in final felling (Tamminen and Saarsalmi, 2013). Slash is harvested on all sites, whereas stump harvest is restricted to 13 sites. Presented growth data varied between studies including volume (most studies), basal area (Egnell, 2011; Egnell and Leijon, 1999), and carbon in tree biomass (Jurevics et al. 2016). In general each treatment from an experimental site is only presented once in the figures. In the case where data have been collected multiple times only the most recent data have been used in the figures with some exceptions. Data from the 22 experimental sites with slash harvest in thinnings in Helmisaari et al. (2011) are presented twice in the figures since the publication reports growth data between year 0–10 and between year 11–20. The latter follows a second thinning (10 years after the first thinning) with slash harvest on 11 out of the 22 sites. Studies reporting data for both the planted tree species and the planted tree species together with natural regeneration are also represented twice in the presented figures (Karlsson and Tamminen, 2013; Tamminen and Saarsalmi, 2013; Wall and Hytonen, 2011). In those where data are presented twice in a figure this is indicated with a dashed arrow connecting the two data points. The individual experiments are described briefly in Table 1.

To facilitate the graphical presentation, reported responses in the studies were normalized by dividing treatment response values with the corresponding value for stem-only harvested control plots (with the exception of the stump harvest study by Karlsson and Tamminen (2013), where slash was harvested also on control plots). Thus, control plots have a normalized value of 1 in all experiments represented by the dashed horizontal line in the presented figures. These values were then plotted over common site characteristics presented in the studies, e.g., site index and latitude. These plots together with metadata from the experiments were used as a basis for a discussion on consistencies and inconsistencies in the results and possible reasons for this. As an objective support to that discussion Spearmans rank-order correlation coefficient was calculated for the plot variables by means of Minitab 17 (2010). No further statistical analyses of the data set have been performed.

3. Results and discussion

3.1. Slash harvest in final felling

Slash harvest effect data in final felling was collected from 10 different publications covering 31 long-term experiments in Finland and Sweden. From some experiments presented data includes data with and without natural regeneration (Tamminen and Saarsalmi, 2013; Wall and Hytonen, 2011), thus, the same treatment on a site is in some cases represented by more than one data point. Furthermore, presented data following slash harvest also includes a treatment where both slash and stumps were harvested (Egnell, 2016; Jurevics et al., 2016).