Forest Ecology and Management 257 (2009) 1104–1111

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Full length article

Whole tree harvesting can reduce second rotation forest productivity

J.D. Walmsley [a,*], D.L. Jones [a], B. Reynolds [b], M.H. Price [a], J.R. Healey [a]

[a] School of the Environment and Natural Resources, College of Natural Sciences, Bangor University, Bangor, Gwynedd LL57 2UW, UK
[b] Centre for Ecology & Hydrology, Bangor, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd LL57 2UW, UK

ARTICLE INFO

Article history:
Received 18 June 2008
Received in revised form 4 November 2008
Accepted 15 November 2008

Keywords:
Biomass energy
Sitka spruce
Soil quality
Aspect
Productivity
Forest residue harvesting
Plantation
Sustainable forestry
Great Britain

ABSTRACT

The practice of harvesting forest residues is rapidly increasing due to rising demand for renewable energy. However, major concerns have been raised about the sustainability of this practice and its net impact on productivity, in particular through negative effects on the growth of subsequent tree crops. We measured height, diameter at breast height (DBH) and tree spacing density on 23-year-old second rotation stands of Sitka spruce (*Picea sitchensis*), following whole tree harvesting (WTH—of all above ground biomass, by cable crane) or conventional stem-only harvesting (CH) of the first rotation crop. Overall, WTH reduced tree DBH by 10.3% ($p = 0.017$), with weaker evidence that it may have reduced height (by 8.2%, $p = 0.164$) and stand basal area (by 15.3%, $p = 0.101$). However, treatment effects differed greatly between individual blocks and, analysed separately by block, significant differences (WTH plot trees smaller than CH plot trees) were most notable in the two more exposed south-facing blocks (where, in both cases, $p < 0.01$ for height and $p < 0.05$ for basal area). Variation in productivity between the experimental plots cannot simply be attributed to preharvesting site environment – no correlation was found between first rotation and second rotation productivity – nor was treatment effect explained by differences in tree spacing density. Treatment effects can be attributed to the removal of three to four times larger quantities of N, P and K in the tree biomass by WTH than by CH of the first rotation crop, combined with greater competition with tree natural regeneration and other vegetation in WTH plots during the early stages of the second rotation. Soil moisture was higher in WTH plots but there was no evidence that WTH increased soil acidity or aluminium mobility nor that it decreased soil organic matter. The results also highlight the complexities of predicting the effect of harvesting treatment on future productivity, even within single-age, single-species forests. The study demonstrates the risk that WTH can reduce second rotation productivity of conifer forests in acidic upland sites, and that this practice will only be sustainable with appropriate interventions to overcome shortage of nutrients and high levels of vegetation competition.

1. Introduction

A decrease in carbon emissions is an essential national and international goal to meet commitments on climate change mitigation. The efficient use of wood biomass as a renewable energy resource is viewed as an important replacement for non-renewable and imported energy resources (UNECE and FAO, 2005; Stupak et al., 2007). Increased utilisation of domestic, renewable resources of biomass has also been identified as an opportunity for many European countries to increase their energy security (McKay, 2006; Stupak et al., 2007). Significant impacts on roundwood and wood residue markets are expected as the energy sector becomes a major consumer of wood biomass. There has already been a rapid increase in the production of energy from harvested forest residues (small diameter tree stems, branchwood and foliage). For example, the production of wood chips from forest residues increased 22-fold in Finland between 1995 (49,000 m^3 $year^{-1}$) and 2003 (1.11 million m^3 $year^{-1}$), with a production target of 5 million m^3 $year^{-1}$ by 2010 (Hakkila, 2005, 2006). Similarly in Sweden, energy production from forest residues increased fivefold between 2002 and 2005 (Ling, 2005).

Commercial harvesting of forest residues is typically carried out directly after the harvesting of large tree stems for timber. The combined operation is termed whole tree harvesting (WTH) as opposed to the conventional harvesting (CH) of timber where the residues are left in situ in the forest. Increased mechanisation of harvesting has enabled the efficient removal of whole trees from forests, as well as the baling of forest residues for ease of storage and transport. A wide range of positive and negative implications of WTH for forest production and environmental impacts have been reported; the most notable being the potential for long-term depletion of soil nutrients (Nykvist and Rosen, 1985; Federer et al.,

* Corresponding author. Tel.: +44 1248 383703; fax: +44 1248 354997.
E-mail address: j.walmsley@univ.bangor.ac.uk (J.D. Walmsley).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2008.11.015

1989; Olsson et al., 1996; Reynolds and Stevens, 1998) to reduce long-term forest productivity (Morris and Miller, 1994; Merino et al., 2005). WTH has also been associated with increased competition from colonising vegetation, whereas retained residues have been found to suppress weed establishment (Stevens and Hornung, 1990; Fahey et al., 1991; Proe and Dutch, 1994).

On sites with high levels of N deposition, where critical loads for N are already exceeded and on relatively fertile soils, removal of forest residues may offer both environmental (e.g. reduction in nitrate losses and acidification of streams and lakes) and economic (e.g. production of biomass fuel, reduction in re-stocking costs) benefits (Swedish National Board of Forestry, 2002). On other sites, however, particularly on acidic nutrient-poor soils, complete residue removal may increase acidification and reduce stocks of scarce mineral nutrients (e.g. K, Ca, P) that limit forest productivity (Nykvist and Rosen, 1985; Federer et al., 1989; Olsson et al., 1996; Sverdrup and Rosen, 1998). After 9–10 years of second rotation, Sitka spruce growth (tree biomass and mean tree height) was significantly lower following WTH than CH at Kielder Forest, northern England (Proe and Dutch, 1994). This was attributed to the initial loss of shelter and weed suppression due to the removal of forest residues followed by reduced nutrient availability.

At the Beddgelert Forest site used in the present study and described in Section 2.1, WTH increased the removal in harvest of N by 234%, K by 279%, Ca by 85% and P by 254% compared with CH (Fahey et al., 1991). Nutrient budget calculations for a complete crop rotation showed that P and Ca losses in harvested material are likely to result in their long-term depletion and that these effects will be significantly greater with WTH (Stevens et al., 1995). Whilst the likelihood of P and K deficiencies were higher following WTH than CH at Beddgelert Forest, the levels of leaching of nitrate, K and, to a lesser extent, Ca and P, were lower (Emmett et al., 1991; Fahey et al., 1991; Stevens et al., 1995). The lower levels of leaching following WTH compared with CH arise because the source of the leached nutrients (i.e. residues) is removed, coupled with considerably greater cover, biomass and nutrient content of the regrowing herbaceous and shrub vegetation following WTH, whereas forest residues left by CH effectively suppress plant growth (Stevens and Hornung, 1990; Fahey et al., 1991). However, this reduction in leaching is less important for longer-term site nutrient status than is the greater removal of nutrients in the residues harvested in WTH (Fahey et al., 1991; Stevens et al., 1995).

There is an urgent need for further research to examine whether these reported negative effects of WTH on nutrient stocks and early productivity in conifer plantations persist into later stages of the second rotation. Our aim was to determine if WTH of a conifer forest on an acidic upland site does reduce longer-term productivity of the second rotation tree crop and damage soil properties.

2. Methods

2.1. Site description

An experiment was established at Beddgelert Forest, North Wales (53°01′13″N, 4°06′49″W), in 1982 to test the effects of whole tree harvesting (WTH) and conventional harvesting (CH) on soil and stream water chemistry, establishment of the second rotation and long-term site nutrition (Stevens and Hornung, 1990; Stevens et al., 1995). The forest was a first rotation plantation of Sitka spruce (*P. sitchensis* (Bong.) Carr.). The experimental plots were 320–350 m in altitude in a formerly glaciated valley with acid predominantly ferric stagnopodzols, formed primarily from base-poor Ordovician slates, shales or mudstone (Stevens et al., 1995). The site has a temperate maritime climate with mean soil temperature at 30 cm depth of 8 °C and mean annual rainfall of 2800 mm (Reynolds et al., 2004). Detailed descriptions of soils, geology and climate are provided by Stevens and Hornung (1988).

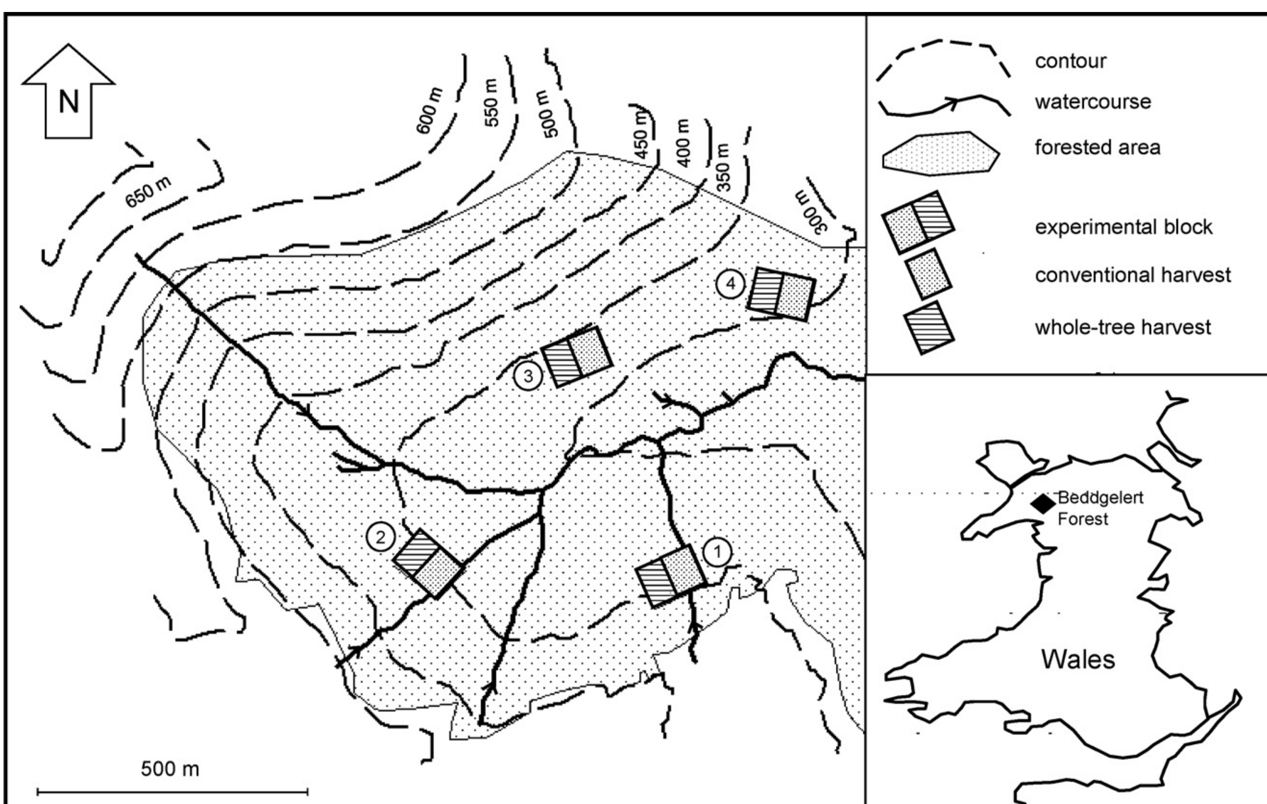

Fig. 1. Arrangement of experimental blocks at Beddgelert Forest.