Medium-rotation production of downy birch biomass on cutaway peatlands in Finland

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Abstract
In Finland approximately 2,500 hectares of cutaway peatlands are annually released from peat harvesting for after-use. We studied growing of dense, native downy birch stands with medium rotation management (MRM) on former peat production areas. The establishment, biomass production and harvesting, as well as coppicing of downy birch were studied in several field experiments, and the economic feasibility of biomass production was evaluated based on bare land value. After wood ash fertilisation, high amounts of downy birch seedlings were obtained by natural regeneration or broadcast seeding. The mean leafless above-ground biomass production of naturally afforested 10–27-year-old stands was 3–4 t ha^{-1} a^{-1}. Clear-cutting of dense stands with the whole-tree method was efficient. Following clear-cutting, birches sprouted well, and their initial development surpassed that of seed-originated birches. Our results showed that production of downy birch energy biomass with medium rotation (> 20 years) on cutaway peatlands can be profitable without subvention.

Keywords: cutaway peatland, afforestation, *Betula pubescens*, wood ash, economics

Introduction

The European Union's aim to reduce greenhouse gas (GHG) emissions by 80–95% by 2050 relative to emissions in 1990 is among the headline targets of the European climate policy. To meet the targets for reducing greenhouse gas emissions, Finland has focused on substituting fossil fuels with wood-based fuels. For instance, the annual consumption of forest chips in energy generation is to be raised from 8.0 million m^3 (2015) to 13.5 million m^3 (ca. 25 TWh) by 2020. Currently, wood biomass used in energy generation is harvested for the most part as a by-product of industrial roundwood procurement (e.g. small-diameter thinning wood, logging residues).

Fuel peat accounts for 4% of the total energy consumption in Finland, and the peat-production area accounts for 60,000 ha. Annually, about 2,500 ha of peat-harvesting areas are released for after-use. It has been estimated that about 44,000 ha cutaway peatlands have to be shifted into another form of land-use by 2020. The large nitrogen store in the residual peat layer is an advantage from the biomass production point of view, but the low concentrations of potassium and phosphorus usually necessitate improvement of soil nutrient status (Aro et al. 1997). Wood ash containing phosphorus, potassium and micronutrients could be an ideal fertiliser for cutaway peatlands (Hytönen 2016).

The production of bioenergy on cutaway peatlands could be continued through growing of various energy crops, which would also sequester carbon. The concept of short-rotation forestry (SRF) includes the establishment of dense stands of fast-growing tree species and the application of intensive and highly mechanised cultivation practices and repeated harvesting with short cutting cycles, followed by stand regeneration via sprouts or suckers. SRF management practices have been studied widely all over the world. Most research effort has been put on growing willows with rotations of 3–5 years. These plantations are mostly established on limed and fertilized agricultural soils, planted with cuttings and harvested with dedicated machinery. Due to high harvesting cost of small-sized trees and some other practical limitations, interest in extending rotations and the utilisation of deciduous forest tree species has arisen. Such medium-length rotation management (MRM) could be applied in particular for producing lignocellulosic biomass with alders (Hytönen and Saarsalmi 2015, Rytter and Rytter 2016), hybrid aspen (Tullus et al. 2012), and hybrid poplars (Johansson and Karacic 2011).

In central and northern Finland, MRM of native downy birch (*Betula pubescens* Ehrh.), a primary successional tree species colonising open areas and thriving also on peatlands, would be based on low stand establishment cost, clear-cutting with the whole-tree method at an early stage, and coppice regeneration. However, a significantly longer rotation length is required than in the case of willows (Hytönen and Aro 2012, Jylhä et al. 2015). Even though downy birch stems are larger than those of willows, the harvesters designed for cutting industrial roundwood are still inefficient or too costly in downy birch thickets. On the other hand, insufficient cutting capacity and uneven space distribution of trees limit the use of modified agricultural harvesters developed for willow SRF plantations.

Aims of the study

We studied the feasibility of medium-rotation management of downy birch on cutaway peatlands based on several studies (Fig. 1), including:

- establishment methods of downy birch stands
- biomass production of naturally afforested birch stands
- sprouting and coppice regeneration
- profitability of biomass production based bare land value for empirical case stands treated with a hypothetical management chain
- productivity of harvesting (whole-tree cutting and forwarding)

We also estimated the biomass production potential with downy birch on cutaway peatlands and some marginal lands in Finland.

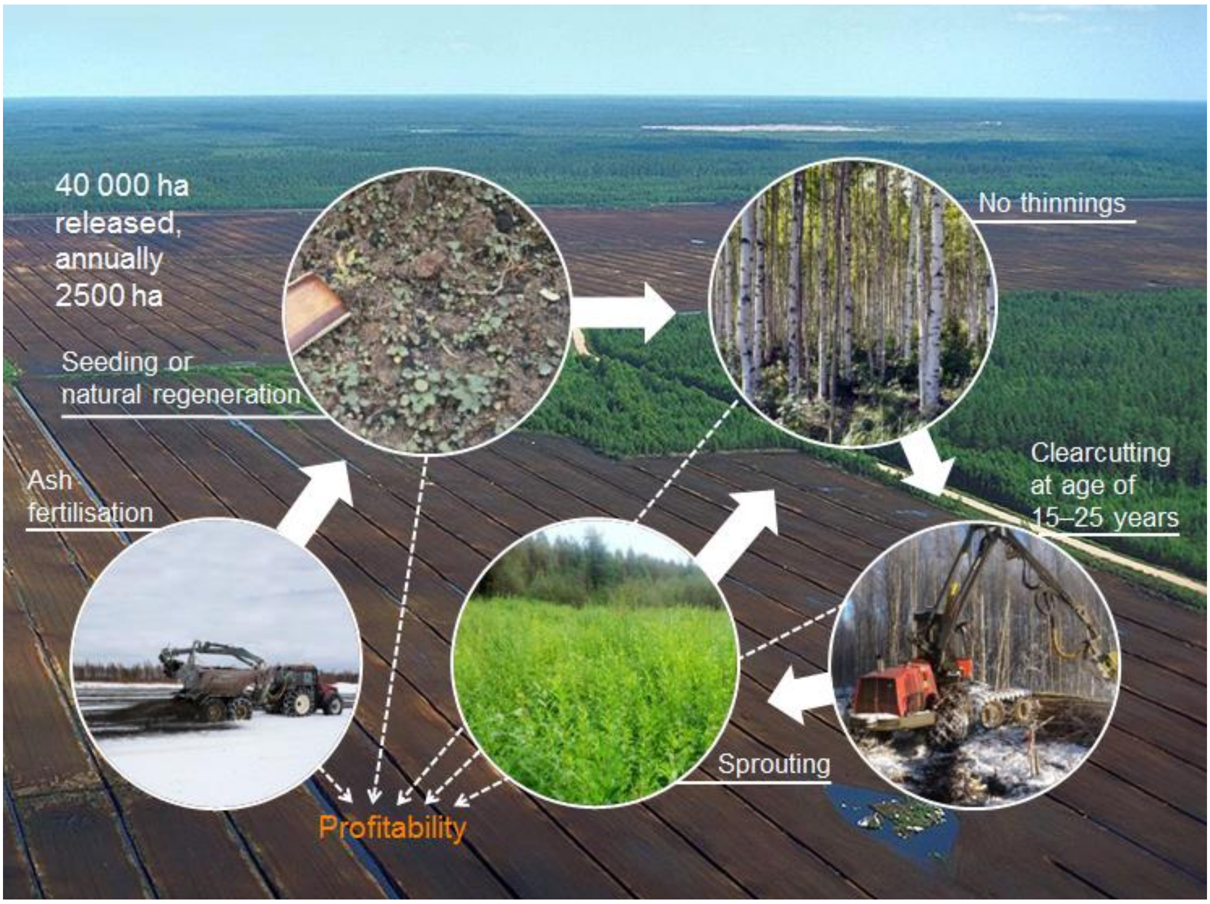

Figure 1. Framework or the case studies.

Material and methods

The experiments included in WoodBio were established in cooperation with a peat production company (Vapo Oyj). The WoodBio project enabled the measurement of experiments after the joint project. The studies on harvesting techniques and profitability were completed earlier. However, they were included in this report in order to give a holistic view of the feasibility of the MRM production of downy birch.

Stand establishment

The study was carried out on Piipsanneva cutaway peatland in Haapavesi, northern Finland (64°06'N, 25°36'E). Peat production had ceased on the experimental site of 15.3 ha in 2010. The former peat production strips were first levelled with normal peat production machinery (excluding control plots), followed by ditching, and mounding or ash-fertilization. Mounding was done by an excavator in August 2011, and the tops of created mounds were composed of mineral soil. Ash-fertilization was done on 23rd of March 2012 (Fig. 2). The granulated wood ash (3.3 t ha^{-1} dry matter) spread contained P 29 kg ha^{-1}, K 114 kg ha^{-1}, Ca 441 kg ha^{-1} and Mg 56 kg ha^{-1}. Peat depth measured from 20–92 points on each treatment was on average 21 cm.

The soil amelioration treatments were assigned on main plots (each 3.8–4.0 ha). They were:

1) control (untreated),
2) ash-fertilization,
3) mounding,
4) mounding, levelling and ash-fertilization,
5) mounding and ash-fertilization.

In May 2012, downy birch seeds (and 6 other tree species, Fig. 2) were sown (hybrid aspen and Siberian larch planted) with three replications onto each main plot as a split-plot study.

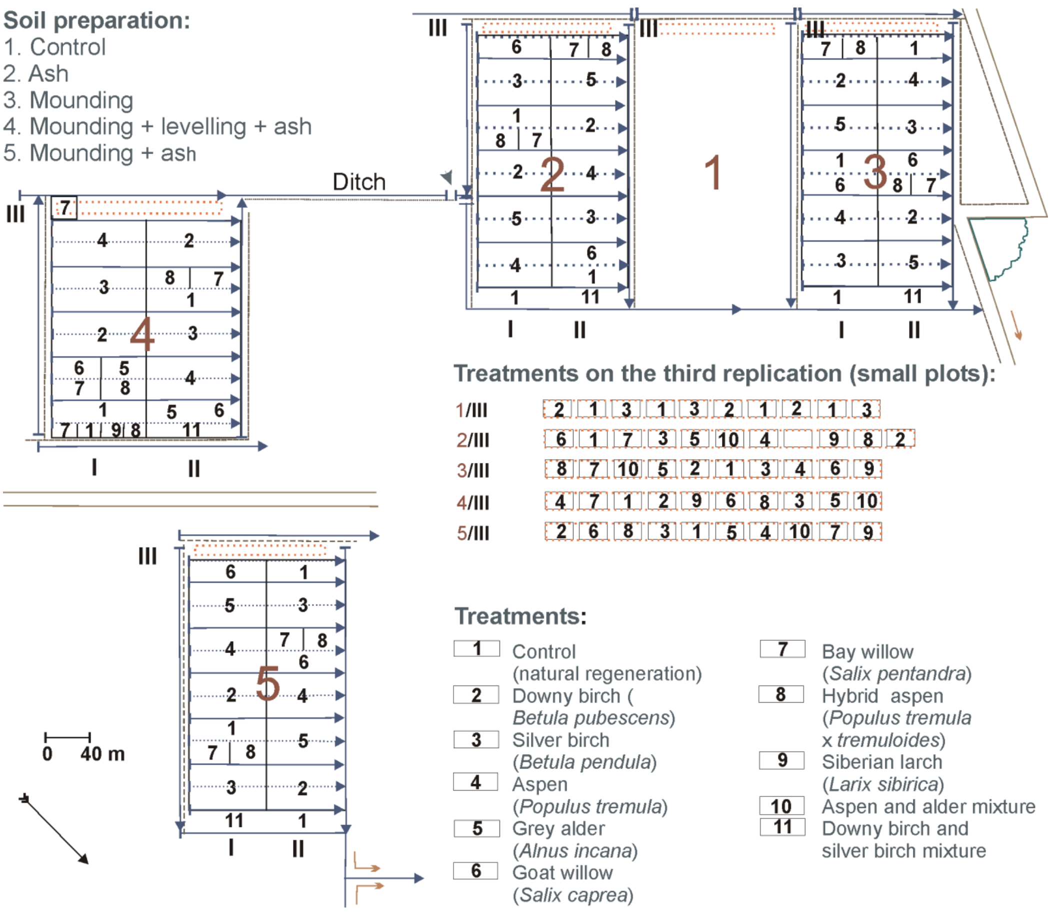

Figure 2. Experimental design at Piipsanneva, Haapavesi.

For the measurement of establishment success a network of circular sample plots with a radius of 1 m was located on each plot (in all 377 plots). The number of seedlings on each sample plot was inventoried at the end of 1st, 2nd, 3rd and 5th growing seasons. In the final inventory also the height of the seedlings was measured and sample sprouts for biomass models were taken.

Biomass production

We identified 26 naturally regenerated 10–30-year-old downy birch thickets on cutaway peatlands in northern (Liminka, Hirvineva; 64°48'N, 25°24'E) and central Finland (Kihniö, Aitoneva; 62º12'N,23º18'E). These sites are among the oldest peat production areas in Finland. In each stand, 2–12 circular sample plots of 50 or 100 m^2, depending on stand density, were established. Breast height diameter (DBH) was measured from all trees greater than 10–30 mm, depending on stand density. Height was measured from every 5^{th}–10^{th} tree. Biomass of the birches was calculated with the equations presented by Repola (2008).

Sprouting of downy birch

The sprouting potential of natural downy birch thickets on cutaway peatlands was studied after clear-cutting of six stands located at Hirvineva, Liminka. Permanent sample plots were established in the clear-cut 10–26 years old downy birch stands. The biomasses of the mother stands were measured prior to clear-cutting taken place in spring 2011. After clearcutting trees and braches were forwarded to roadside. Diameter and height of the stumps were measured. The number and height of sprouts were recorded annually up to 2016. Furthermore, altogether 78 downy birch sample trees were taken for constructing biomass equations.

Profitability of biomass production

The profitability of biomass production was evaluated by calculating the bare land values (BLV) for six case stands measured in Liminka (Hirvineva). The stand-establishment costs in the economic analysis included the cost of natural or broadcast seeding, wood-ash fertilisation or mounding, harvesting with the whole-tree method, chipping, chip transport, and overheads. In the calculations, rotation periods of 14–26 years were assumed, and a price of 21 € MWh^{-1} for the fuel chips was used (see Jylhä et al. 2015). Because time consumption models for whole-tree harvesting of young downy birch stands were not available, models designed for other conditions were used as explained in Jylhä et al. (2015).

Productivity of harvesting

The studies were performed in a former peat production area in Liminka (Hirvineva). In all, 17 rectangular time study plots with an average area of 794 m^2 were established in seven naturally afforested downy birch-dominated stands with an age of 14–29 years. A six-wheeled Valmet 911.3 harvester was used for clear-cutting with the whole-tree method. The bogie tires were fitted with tracks and the rear tires with chains. A Cranab crane with a reach of 11m was equipped with the Bracke C16.b accumulating biomass felling head. The forwarder was a modified Ponsse Buffalo S16. Cutting and forwarding were recorded with a digital video camera. The videos were analysed by continuous timing method with a Microsoft Excel-based application.

Results and discussion

Establishment

Downy birch thickets can be established naturally or by broadcast seeding, if the soil is fertilised or nutrients from the of mineral sub-soil are made available to the trees by means of soil preparation, or the residual peat layer is not too thick (see Fig. 3 and 4). In particular, ash fertilisation of unprepared soil proved to be an efficient way to increase seedling density fast, already during the first growing season (Fig 3 and 4; Reinikainen et al. 2012, see also Huotari et al. 2008). Ash increased the number of seedlings also in the mounding treatment. After five years the broadcast seeding increased the number of seedlings in all treatments except in unprepared control. However, after five years the number of seedlings was quite high in all treatments. The lowest number of seedlings was found on mounded area left for natural regeneration (65 000 seedlings ha^{-1}) and highest number in mounded and ash fertilized area following broadcast seeding (145 000 seedlings ha^{-1}). Even though the number of birch seedlings was quite high after five growing seasons also in the control plots it is unlikely that they will grow well in the future due to low phosphorus and potassium stores in the peat.


Figure 3. Ash fertilisation combined with natural afforestation or broadcast seeding (left) on cutaway peatland at Haapavesi resulted in dense downy birch stands. The birches on the right are five years old, and their density is 112800 seedlings ha^{-1}. (Photos: Jyrki Hytönen and Jorma Issakainen).

After five growing seasons the highest birch biomass was obtained when broadcast seeding was applied on area where wood ash had been spread (Figure 4). In this treatment the biomass was manifold compared to other treatments. This was due to faster initial germination of downy birch seeds following broadcast seeding and increased growth of the seedlings. Despite the high number of birch seedlings in e.g. mounding and ash fertilization treatment they were still much smaller than those found in treatment were ash was applied on unprepared soil. The use of ash a fertiliser also reduces waste accumulation at landfills.

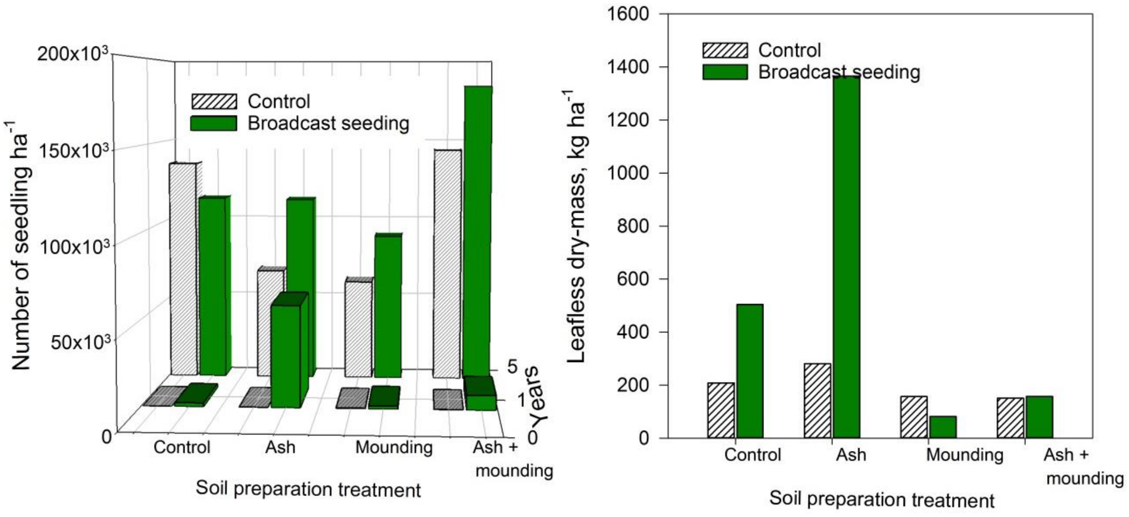

Figure 4. The effect of broadcast seeding (control vs. broadcast seeding) and ash and soil preparation treatments on the number of downy birch seedlings after first and fifth growing seasons (left) and on the leafless above-ground biomass after fifth growing season (right). Results from experiment located at Haapavesi (Piipsanneva), see Figure 2 for experimental design.

Biomass production of downy birch stands

The mean annual leafless above-ground biomass production of naturally regenerated 10–30-year-old downy birch stands was 3–4 t/ha (see Fig. 5), yielding in a total biomass of 17–115 t ha^{-1}. The initial fertilisation treatments of inventoried stands are mainly unknown.

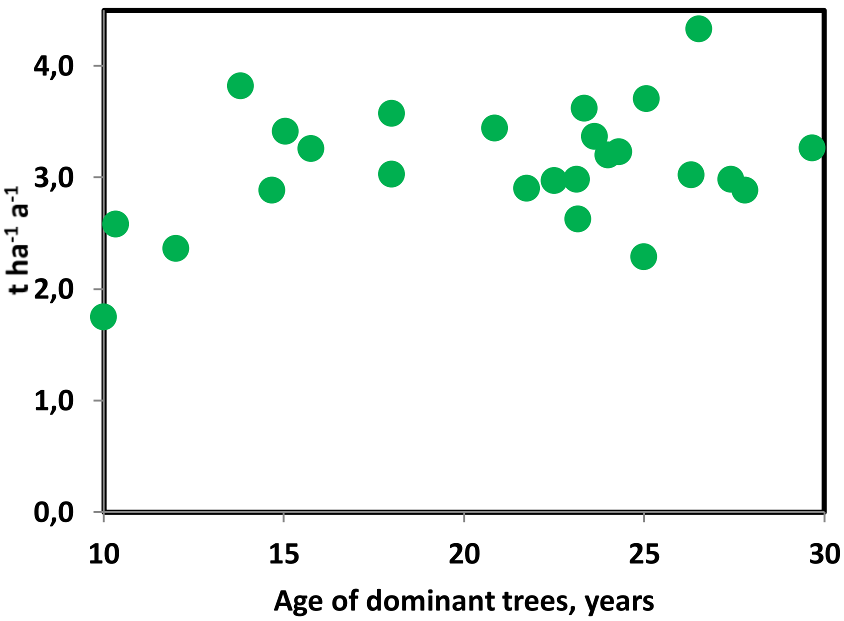

Figure 5. The mean annual leafless above-ground biomass production of dense downy birch stands on the cutaway peatlands located in northern and central Finland.

Sprouting

The density of birches in the mother stands before clearcutting varied from 129,000 trees ha^{-1} of the 10-year-old stand to 10,600 trees ha^{-1} of the 22-year-old stand (Fig. 6). The stem number of the second tree generation was manifold in the first year, and it was dependent on the age of the mother stand. The stands clear-cut at the age of 10–24 years coppiced well (Fig. 8, Hytönen 2015). Due to smaller stand density of the older mother stands the density of sprouts remained lowest also after coppicing. After the first growing season the number of stems was highest in the stand clear-cut at the age of 10 years (669,500 ha^{-1}) and lowest in the 24-year-old stand (47,200 ha^{-1}).

The biomass production of the coppice stands depended on stand density during the first 6 years. The stands clear-cut at the youngest ages produced more biomass than the stands clear-cut at higher ages. After five growing seasons the amount of above-ground leafless biomass was 8.4–19.6 t ha^{-1}, depending on the density and the age of the mother stand (Fig 8). The mean annual increment during the first 6 years varied from 3.3 t ha^{-1} of the youngest stand to 1 t ha^{-1} a^{-1} of the oldest stand.

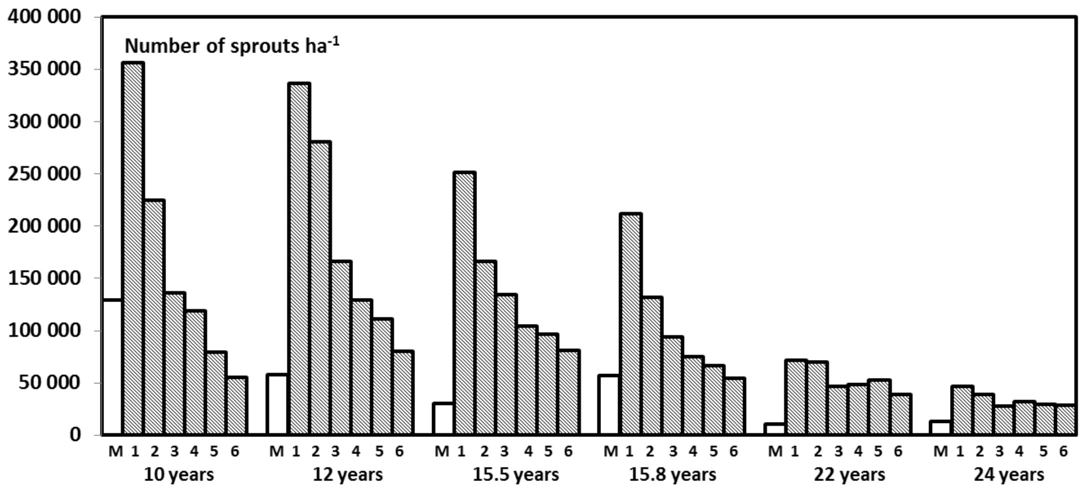

Figure 6. Stand densities (trees ha^{-1}) in the mother stands (M) before clearcutting and the number of sprouts 1–6 years from clearcutting.

Figure 7. A 15-year-old birch stand with a leafless above-ground biomass of 56 t DM ha^{-1} and a stand density of 30,200 trees ha^{-1} prior to clear-cut (left). After six growing seasons (right), the coppice stand biomass was 16 t DM ha^{-1} and stand density was 61,700 trees ha^{-1}. (Photos: Jorma Issakainen).

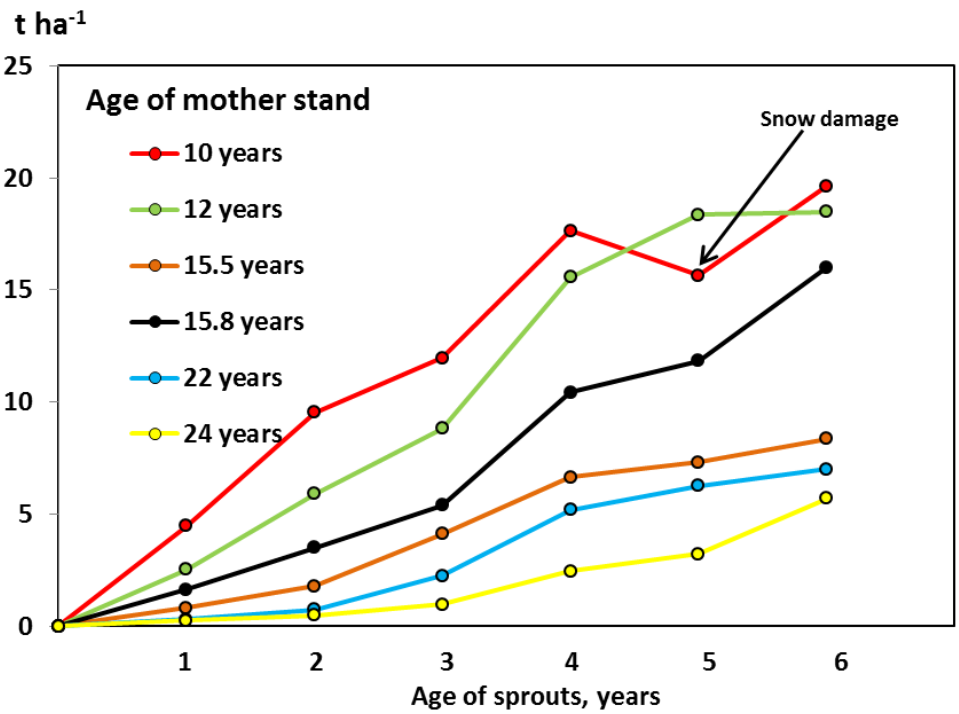

Figure 8. Leafless above-ground biomass of coppiced downy birch stands 1–6 years after clear-cutting of mother stands of varying age.

Profitability of biomass production

Sales revenues from fuel chips covered the costs of harvesting, chipping, and chip transportation without subvention in five cases out of the case stands (Fig. 9A) (Jylhä et al. 2015). In the youngest 15-year-old stand the sales revenues did not cover the production costs. Biomass production resulted in positive bare land value in five cases, with an interest rate of three per cent, for example (see Fig. 9B). With equal biomass production, the assumed one-year shortening of rotation with broadcast seeding did not offset the increase in stand-establishment costs.

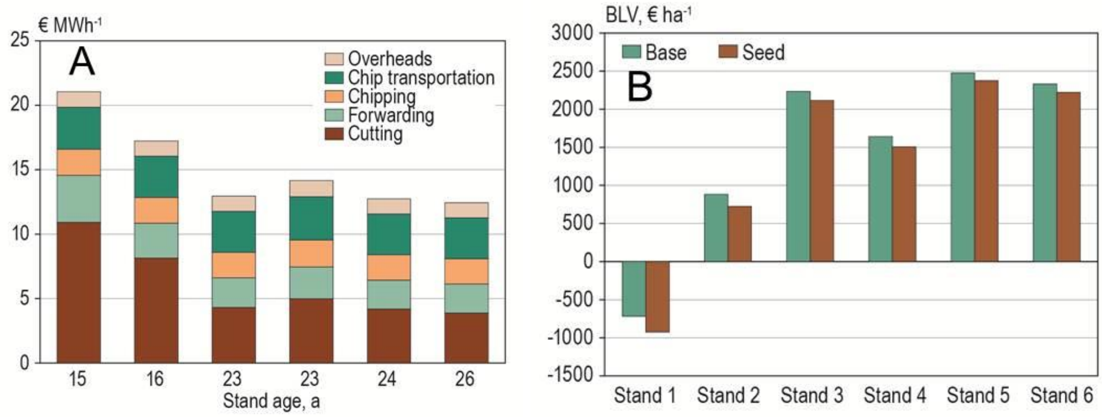

Figure 9. Production costs of fuel chips (A, in € MWh^{-1}) and bare land value, BLV, (B, in € ha^{-1}) at an interest rate of three per cent for the study stands at two intensity levels ('Base' = natural regeneration, 'Seed' = broadcast seeding of birch).

Productivity of harvesting

Productivity of clear-cutting was 3–11 tons (DM) per effective hour (E_0-h), and it was highly dependent on stand characteristics (Fig 6). At a distance of 300 m, for example, the productivity of forwarding was 6.7–10.4 t E_0-h^{-1}. The study indicates that energy biomass can be harvested from young downy birch thickets efficiently by clear-cutting with appropriate machinery. The felling head studied enables efficient harvesting of energy biomass from dense, small-diameter stands. Observed cutting productivity was about one third greater than expected in the profitability calculations above (Jylhä et al. 2015). Also forwarding productivity exceeded the values used in the profitability calculations.

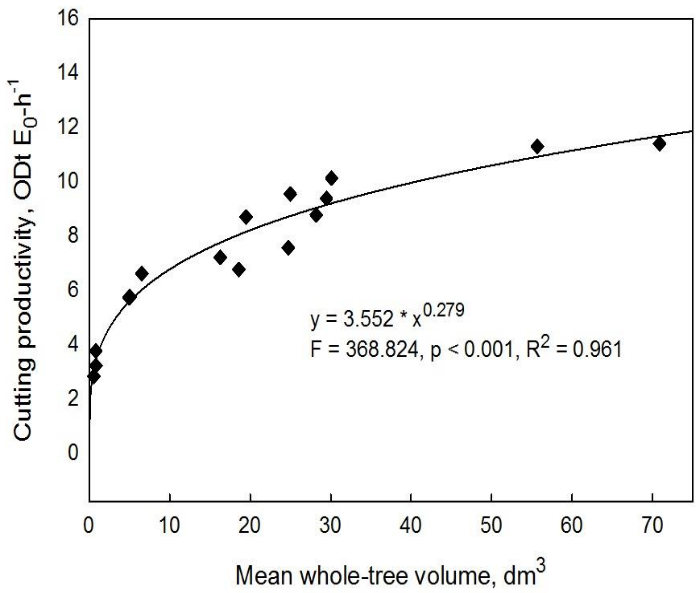

Figure 6. Productivity of harvester work in whole-tree cutting of dense downy birch stands in Liminka (Hirvineva) as a function of mean whole-tree volume cut.

Conclusions

Dense downy birch stands can be successfully established in ash-fertilised areas both by broadcast seeding and by natural regeneration. Broadcast seeding increased the number of seedlings especially when ash fertilisation is used. Wood ash fertilization on unprepared peat proved to be the best treatment in terms of biomass production. Since currently only a shallow layer of residual peat is left after peat harvesting, birch roots can later penetrate the subsoil to take up mineral nutrients. Thus refertilisation is likely not needed, even after stand regeneration by coppicing.

An annual biomass production of over 3 t ha^{-1} can be achieved with downy birch established in former peat-production areas even in northern Finland.

Our study also indicates that energy biomass can be harvested from young downy birch thickets in a cost-efficient way by clear-cutting with the whole-tree method. Adopting clear-cutting of young downy birch stands for energy biomass in the form of whole trees may increase significantly the profitability of wood production compared to traditional stand management based on selective thinnings and longer rotations.

Young birches sprout and grow well. The biomass production of sprout-originated birches on cutaway peatlands can be further increased by PK or ash fertilisation (Hytönen & Aro 2012). However, birch sprouts are vulnerable to browsing by moose and hares, which could reduce biomass production.

Cutaway peatlands show potential for profitable production of downy birch biomass without subsidies at the prevailing price level of forest chips in Finland. Only minor inputs are required in comparison to other energy crops (e.g. willow or reed canary grass). Rotation period (i.e. stand age at the clear-cut) affected considerably the profitability of biomass production. In the case of the shortest rotation, sales revenues did not cover the direct costs of forest-chip production. Profitability was sensitive to harvesting cost, which greatly depends on tree volume and biomass removal. It is likely that the optimal rotation exceeds 20 years. In a nutshell, the good financial performance of downy birch is basically due to modest establishment and harvesting costs and the relatively short rotation period. Applying the productivity models constructed for whole-tree clearcutting of downy birch would have reduced the production costs of fuel chips in the case stands by 7–19%., which would have further improved profitability of the MRM concept. Downy birch stands located in peatland forests have shown only a slight thinning response (Niemistö 2013). Consequently, coppice production of downy birch is a flexible form of wood production, as decisions about the timing and method of harvesting can be made based on the market situation and price relations of pulpwood and energy biomass.

The peat industry releases annually 2,500 hectares of cut-away peatlands. Assuming that 2,000 hectares of this would be annually harnessed for birch cultivation with a mean biomass production of 3.5 t $ha^{-1}a^{-1}$, after 20 years 140,000 t (ca. 300,000 m^3) of biomass could be annually harvested from these sites. MRM of downy birch could be applied also for forest road sides. Growing downy birch on a 5 m wide stretch on 20% of the Finnish forest road sides (25 000 ha) would yield an annual biomass production of 87,500 t (ca. 187,500 m^3). Peat-based agricultural soils are responsible for 14% of the total GHG emissions of Finland. Allocating 50% of agricultural peatlands (260,000 ha) to carbon sequestration by growing downy birch with MRM system would result in an annual biomass production of 560,000 t (ca. 1,200,000 m^3). Also in some peatlands forests biomass production could be intensified by applying MRM of downy birch.

Further perspectives

Based on the first case studies, the MRM concept applied to downy birch on cutaway peatlands shows great potential for profitable biomass production. However, there are some uncertainties associated with the profitability calculations. The growth of sprout originated stands compared to mother stands is not known. Also research on the effects of repetitive coppice regeneration on biomass production (in comparison with seed-originated stands) is needed. Studies on the energy balance of the management chains would contribute to life cycle analysis of the MRM concept. Furthermore, research into the potential of carbon sequestration with downy birch is of great importance as cutaway peatlands still emit considerable amounts of CO_2 (Mäkiranta et al. 2007, Silvan & Hytönen 2016). In Finland birch-dominated stands on drained peatlands amount to 572 000 ha (Kojola et al. 2015). It might be possible to increase biomass production in these sites by utilizing MRM with high stand densities and coppicing.

Besides birch, also other coppicing tree species are interesting alternatives for intensive biomass production. These include alders, aspen, hybrid aspen and in the southern parts of Finland also hybrid poplars.

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