Helsinki 2010
ISSN 0039-5471
Suo 61(3–4): 59–76 — Research articles

The potential of birch afforestation as an after-use option for industrial cutaway peatlands

Koivun soveltuvuus suonpohjien metsittämisessä Irlannissa

Florence Renou-Wilson, Minna Pöllänen, Kenneth Byrne, David Wilson and Edward P. Farrell

F. Renou-Wilson, M. Pöllänen, K. Byrne, D. Wilson and E.P. Farrell, School of Biology and Environmental Science, Agriculture and Food Centre, University College Dublin, Belfield, Dublin 4. Tel: +353 17167725; Fax: +353 17161102; email: Florence.Renou@ucd.ie

In the next few decades, industrial peat extraction will cease gradually over more than 80,000 hectares of cutaway peatlands in Ireland and alternative land uses will change the landscape of these areas. This study showed that substantial natural regeneration of downy birch (*Betula pubescens*) can occur on abandoned as well as cutaway peatlands afforested with conifers. Natural seedling birch stands measured in this study had an estimated biomass production of between 3100 and 5800 kg dry matter ha^{-1} $year^{-1}$. This corresponded to an annual carbon stock increment estimated at between 1500 and 2900 kg C ha^{-1}. Direct sowing experiments conducted in this study were the first of their kind in Ireland and showed that sowing downy birch and fertilization with P and K could be a possible management option for the after-use of cutaway peatlands. Exposure was the main obstacle to successful germination and artificial shelter led to higher rates of germination and survival of birch seedlings after the first winter. It can be concluded that birch (naturally or artificially established) can be a feature of this future landscape, bringing many attributes: nurse species, biomass, increased woodland cover and biodiversity.

Keywords: Downy birch, biomass, cutaway peatlands, sowing, natural regeneration, fertilization, shelter

Introduction

Over the next few decades, industrial peat extraction will cease over an estimated 80000 hectares of cutaway peatlands in Ireland. While extensive research has been carried out to assess various after-use options for these areas (Renou et al. 2006), studies over the last number of years have concentrated on their possible use for forestry (Renou-Wilson et al. 2008b), as potential stores for atmospheric carbon (C) (Wilson & Farrell 2007, Wilson 2009, Wilson et al. 2009, Wilson et al. In review) and as new areas of wilderness (both wet and dry re-colonization/rehabilitation)

(Rowlands & Feehan 2000a, Higgins & Colleran 2006). So far, 16000 ha of peatlands have become cutaway and current after-uses include commercial forestry, natural mixed forests, semi-natural wetlands, grasslands and recreational amenities. Research has shown that land use options are constrained by a number of factors such as drainage, peat thickness and type, the nature of underlying soils and accessibility (Higgins & Colleran 2006, Renou-Wilson et al. 2008b). The biggest proportion (up to 30%) may be left to dryland recolonisation. After peat extraction has ceased, the residual peat is virtually free from seeds (Curran & MacNaeidhe 1984) and colonization may take several years due to microclimatic and substrate conditions of the cutaway (Salonen & Laaksonen 1994, Tuittila et al. 2000). In both 'plantation forestry' and 'dry colonisation' scenarios, it is likely that birch seedlings will colonize the sites naturally, initially in the more sheltered areas before it steadily spreads using previously generated trees to provide shelter for the new seedlings (Rowlands & Feehan 2000b, Renou-Wilson et al. 2008b).

Birch species are an important component of boreal and temperate forests throughout Northern Europe, Asia and America. Ireland has two native species of birch, silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.); the latter is also known as bog birch, being most common on cooler, wetter and poorer soils such as peatlands. From a botanical point of view, birch wood is the natural climax vegetation on many abandoned cutaway bogs (Feehan et al. 2008). Silver birch is generally associated with drier richer soils in sheltered areas (Horgan et al. 2003). Downy birch, in particular, has often been treated by foresters as a weed, under-valued, under-utilized and under-managed. This stigma comes from the fact that it is an opportunist colonizer of open landscape, its timber is of poor durability when untreated and it never reaches the larger, more financially attractive, size classes, often showing poor stem form. It usually goes into decline after reaching maturity (between 40 and 60 years). However, interest in birch is growing both in Ireland (Horgan et al. 2003) and in other countries (Hytönen & Aro 2004, Hytönen & Jylhä 2005, Johansson 2007, Repola 2008, Fay & Lavoie 2009). It has been recognized that, as a pioneer species, birch spreads naturally in open areas, especially in newly afforested areas (Watling 1984, Seaman 1994). Birch is also planted in mixtures with conifers to increase species diversity. Plantations that include native and broadleaved species are seen as being more valuable in terms of landscape, amenity, heritage and habitats. Due to its ability to regenerate profusely, areas can be naturally re-colonized with birch and thereby contribute to the increased national forest coverage. Birch grows relatively rapidly and can be used as a nurse species for more economically-attractive species (e.g. frost-sensitive species). The wood can then be used for pulpwood or chips. Planted or naturally regenerated birch stands can also be managed on a short-rotation basis for biomass production. The coppicing ability of birch means that after clear cutting, birch re-grow vigorous sprouts.

Birch woodlands could represent a welcome addition of considerable potential for the forester and also for the naturalist. Woodlands of natural native species in particular have widespread public appeal as well as being a new goal within the Forest Policy in Ireland under the Sustainable Forest Management guidelines. There are also likely to have popular support as a more 'natural' component of the countryside. While these new native woodlands may be of poor quality they are outstanding for their biodiversity (Rowlands & Feehan 2000b).

An exact figure for the total current area covered by birch woodland in Ireland is not available. In 1987, it was estimated that there were 5135 ha of birch (Keogh 1987) of which Coillte (State Forestry Board) owned just under 4000 ha (O'Leary et al. 2001). With only a few stands of natural birch woodlands scattered across Ireland, the full potential for birch and the appropriate management regimes for either artificially or naturally regenerated stands are yet to be fully determined. Efforts to fill this lacuna have been made with recent research on the growth potential of birch in Ireland (Nieuwenhuis & Barrett 2001, Nieuwenhuis & Barrett 2002). The authors observed that the maximum height increment occurred before the age of 20 years and the fastest growing trees achieved a height growth of >1m per year during this period. They found that a well-stocked unthinned stand of downy birch could achieve a standing volume of 200 m^3 ha^{-1} in 42 years (corresponding roughly to Yield Class 8 on peat (UK Classification System, Edwards & Christie 1981). The yield class varied from >4 on fen peat to 6 and 8 on two raised peat sites. However, the 33 sites investigated were selected for best possible stand quality and therefore may not have represented the general conditions that occur on cutaway peatlands. They also found that the majority of the stands surveyed had very poor stem form.

A selection and improvement programme was initiated in Ireland in 1998 to provide a source of improved birch planting stock for the Irish forestry industry as poor stem quality has prevented its commercial exploitation. Field trials (including one on a cutaway peatland) are on-going and populations have been selected (O'Dowd 2004, O'Connor 2006). More specifically, Renou et al. (2007) investigated the forestry potential of the two native birch species (*B. pendula* and B. *pubescens*) on industrial cutaway peatlands. Bare-root stock as well as container stock were tested using small and large seedlings. Results from several field trials demonstrated excellent survival and good growth potential. Silver birch was the superior species especially on well drained and shallow peat sites. It was concluded that larger seedlings/saplings performed better, regardless of birch species and that bare-root silver birch grew fastest with reasonable form (Renou et al. 2007).

Planting is the quickest way to establish birch but also the most expensive. Another option is direct sowing, which would be cheaper and could achieve land cover in reasonable timeframe. However several obstacles could be anticipated. Firstly, cutaway peatlands are characterized by their persistent exposure. While wind can be desirable from a colonization point of view (dissemination of pollen and seeds), it can have adverse effects at plant level (desiccation of young seedlings), and at soil level where erosion and crust-forming processes are common features due to the aerodynamically smooth surface of cutaway peatlands (Campbell et al. 2002). Secondly, cutaway peatlands located in the Irish Midlands are susceptible to late spring frost as well as having a tendency to surface drought in the spring (Renou-Wilson et al. 2008b). Sowing time is an important factor in the establishment of seedlings. In areas that do not suffer from winter frosts, but tend to be dry in early summer, autumn sowing may be advisable (McVean 1966). Alternatively, areas that are prone to frost but have a relatively high water carrying capacity may be more suitable for spring sowing (Anon. 2002). Seed treatment offers the possibility of extending the time of sowing. In natural conditions, germination of birch seeds are regulated by light but this can be overcome by subjecting the seed to a period of pre-chilling that removes the light requirement. Thirdly, fertilization with phosphorus (P) and later potassium (K) have been found to be critical to the growth of planted seedlings on cutaway peatlands (Renou-Wilson & Farrell 2007, Renou-Wilson et al. 2008a). While birch will readily establish wherever there is moderate soil phosphorus (P) status (Evans 1984), it is questionable whether P status in the remaining peat is sufficient for seedlings to establish and thrive.

The first objective of the present study was to explore existing naturally established birch stands on cutaway peatlands in the Irish Midlands: their composition (species), stocking, biomass production and quality. The second main objective was to investigate direct sowing of downy birch, testing different management options (seed treatment, sowing date, fertilizer application and shelter). Overall, this study aimed to present some recommendations of appropriate strategies of establishment of birch on industrial cutaway peatlands.

Material and methods

Geographical and environmental background

Eight areas were investigated during the course of this study (Table 1). These cutaway peatlands were all located in the Irish Midlands (c.60 m a.s.l.) in a basin-type landscape where precipitation averages 875 mm per annum with cool summers (July and August are the warmest months with an average of 14.5°C) and mild winters (January is the coldest month with an average of 4.1°C) (Collins & Cummins 1996).

Survey of existing natural birch stands

A field survey was carried out in summers 2003/2004 in order to investigate existing birch stands on cutaway peatlands. The material was collected from relatively dense stands of natural birch representing two types of natural regeneration on cutaway peatlands: (1) birch colonizing abandoned bare peat areas (n=58) and (2) birch colonizing afforested cutaways (n=63); the latter have been established in the late 1980s, mainly with Sitka spruce (*Picea sitchensis* (Bong.) Carr.), which, for the most part, had performed poorly. Based on past studies, local knowledge and personal experience, seven industrial cutaway peatlands located across the Irish Midlands were chosen (Table 1). At each site, 10 m × 10 m plots were laid out randomly. Within each plot the following variables were recorded: tree species, number of trees, number of stems, tree height and stem diameter (DBH > 7 cm). The year of cessation of peat extraction, presence of bottom, field or tree layer and competition as well as obvious damage (frost, animals, fungi) to the trees were also documented.

Laboratory analysis for species identification

Downy and silver birch often form mixed stands. Quite often the morphological characteristics shown by a tree can be an intermediate of both species making the identification in the field difficult. In order to accurately identify the birch species in question, a more reliable method is a laboratory analysis using a precipitation procedure developed by Lundgren et al. (1995). For this analysis, bark samples were collected from all of the trees in each plot apart from the smallest trees. These samples were brought back to the laboratory and analyzed by placing a sample of inner bark in a test tube containing a solution of 2,4-dinitrophenylhydrazine. Within two hours at room temperature the samples of silver birch form an orange precipitate whereas those of downy birch stay clear. This reaction is due to the fact that silver birch contains larger amounts of diarylheptanoid glucoside platyphylloside than downy birch. The laboratory tests results were 100% in agreement with the results from the visual determination of birch species.

Biomass sampling

The biomass study was carried out at four cutaway areas during the summer months (Table 1). All the trees in each 10 m^2 sampling plot were recorded and their diameter breast height (DBH) measured — the number of sampling plots varied at each site depending on the total stand area (Table 1). Ten trees representing the range in DBH values within the plot, including single and multiple stem trees, were then harvested. In total, 200 trees were felled and separated into: stem, branches, foliage

Table 1: Industrial cutaway peatland areas where various birch studies were carried out in this study.

Taulukko 1. Tutkimuksessa käytetyt koivun metsityskokeet turvetuotannosta vapautuneilla suonpohjilla Irlannissa.

Area *Alue*	Location *Sijainti*	Study *Koe*	Vegetation cover *Kasvillisuus*	No sampling plots for natural birch survey study *Koivun uudistumis-koealoja (kpl)*	No sampling plots for biomass study *Koivun biomassa-koealoja*
Lullymore	53°17'N, 6°57'W	Natural birch survey	Afforested	3	
Clonsast	53°15'N, 7°10'W	Nat. birch survey	Natural	4	
Ballybrackan A	53°12'N, 7°43'W	Nat. birch survey	Natural	4	
Ballybrackan B	53°12'N, 7°43'W	Nat. birch survey + BM sampl.	Natural	20	2
Ballybrackan C	53°12'N, 7°43'W	Nat. birch survey + BM sampl.	Afforested	10	10
Turraun	53°13'N, 7°45'W	Nat. birch survey + BM sampl.	Natural	30	3
Tumduff	53°17'N, 7°42'W	Nat. birch survey + BM sampl.	Afforested	50	5
East Boora	53°12'N, 7°43'W	Sowing experiments	Bare	See Table 3 for individual experiment *ks. yksittäiset kokeet, Taulukko 3*	

with small branches and dead wood. Branches were sorted by diameter into three size groups; <30 mm, 30–50 mm and >50 mm. Belowground biomass was estimated by removal of all roots greater than 2mm from a 2m × 2m square marked from the centre of each tree stump. The root system was extracted (including the stump) and roots were sorted on the same diameter size categories as employed with the branches. The fresh weight of all of the components was determined on site and sub-samples were taken for determination of moisture content in the laboratory. Samples were weighed and dried at 105°C until constant weight was achieved (over 72 hours). Foliage was separated from the branches and weighed independently. Samples from each component were ground to obtain 0.1 mm particle size samples for carbon (C) and N determination using a total C analyzer (Analitik Jena micro N/C Analyzer).

The most important tree parameter used in the estimation of biomass is likely to be DBH as the addition of height has been found to have only a minor effect (Schmitt & Grigal 1981, Ferm & Kaunisto 1983, Harding & Grigal 1985, Hytönen & Kaunisto 1999, Johansson 2007). This was confirmed in this study and therefore the basic model is in the form of power function:

$$BM = aDBH^b \qquad (1)$$

where BM is the total dry biomass (kg), DBH is the stem diameter (cm) at 1.3 m and a and b are coefficients. As the DBH data were not normally distributed (Kolmogorov-Smirnov test, $p < 0.05$), they were log transformed prior to the analysis in order to achieve constant deviation. The linear logarithmic relationship is therefore:

$$\ln BM = a + b\ln DBH \qquad (2)$$

A correction factor (Baskerville 1972) was calculated and used to correct the systematic bias associated with logarithmic transformations. Final estimations of biomass were calculated by applying the equations to the survey data.

Direct sowing experiments

General description

All the sowing experiments were carried out in East Boora industrial cutaway peatland which has been abandoned since 1999 when industrial milled-peat extraction for energy generation ceased. The remaining peat layer was medium-humified to well-humified Phragmites peat with some wood residues, and its physical and chemical composition (Table 2) was typical of industrial cutaway peatlands in the region (Renou-Wilson et al. 2008b). Sowing took place in spring 2003 which was drier and warmer than the 30 year average while May was more than three times wetter than the average (Table 3). Vegetation was very sparse at the time and where present, located in or near the drains. The area was divided into 6 experimental blocks (A–F). Each block was further divided following experimental designs to test fertilizer application, seed treatment, micro-forms and shelter (Table 4). The areas were all sown at a rate of 1 kg of seed per ha mixed with sand (20 kg sand per ha). Hand sowing and machine broadcasting (purposely-adjusted seed spreader) were used alternatively depending mainly on the size of the area. Birch is provenance specific (Brodie 1990) and therefore care was taken to choose a seed source from close to the sowing site. The downy birch seed originated from Templetuohy, County Laois (BC-IELAOI-B23) and was certified to contain 481,000 seeds per kg. The field experiments were monitored in 2003, 2004, 2005 and 2008; the main surveys were carried out at the end of spring 2003, autumn 2003 and spring 2004. All the live birch seedlings within a 1 × 1m quadrat were counted and one quadrat per plot (10 × 10 m) was measured. The number of plots varied depending on the size of the experimental block (Table 4).

Sowing date with seed treatment

The pre-chilling procedure used in this study was adapted from Aldhous (1994). Three volumes of cold water (8°C) were added to one volume of seed making sure to soak all the seeds in the bags. Bags were placed into refrigerator for 48 hours at

3°C to imbibe after which the excess water was drained off by making small holes in the bottom of the bags. The bags were left half open to allow the seeds to breathe but at the same time to prevent losing too much of the moisture. Seed bags were then returned to the refrigerator for pre-chilling. On the week starting 7th April 2003, the seeds were removed from the cold, and surface dried by spreading thinly on newspapers in a well-ventilated room. Occasionally, the seeds were gently stirred to ensure even surface drying. Sowing was done either in a) February, without pre-chilling, or in b) April and May with pre-chilling treatment in order to assess the effect of delayed sowing date on the emergence of seedlings.

Table 2: Physical and chemical characteristics (total nutrient content) of peat (0–20cm) at East Boora where sowing experiments were carried out. WTL= the mean depth of the water table level. Standard errors in brackets after means.

Taulukko 2. Turpeen ominaisuudet (0–20 cm) East Booran koivunkylvökokeella. Bulk density= turpeen tiheys, Thickness=turpeen paksuus, WTL=vedenpinnan syvyys. Keskivirhe suluissa keskiarvon jälkeen..

N g kg^{-1}	P g kg^{-1}	K g kg^{-1}	Bulk density g cm^{-3}	Thickness cm	pH	WTL cm
9.1 (0.8)	0.18 (0)	0.25 (0.1)	0.141 (0.04)	113 (11)	4.6 (0.1)	40 (2)

Table 3: Weather data from Birr station (Met Eireann 2006), closest meteorological station to the study areas.

Taulukko 3. Tutkimusalueita lähimpänä olevan sääaseman (Birr) kuukausittainen sademäärä ja ilman lämpötila helmi-toukokuussa v 2003 ja pitkän ajan keskiarvona.

Month: *Kuukausi*	February *Helmikuu*	March *Maaliskuu*	April *Huhtikuu*	May *Toukokuu*
Rainfall, *sademäärä (mm)*				
30 year average	53.9	60.7	52.8	31.2
2003	25.6	36.5	44.6	101.3
Mean Temperature, *keskilämpötila (°C):*				
30 year average	4.8	6.1	7.9	10.4
2003	5.4	8.1	10	11

Table 4: Summary information regarding the sowing experiments at East Boora.

Taulukko 4. East Booran kylvökokeen yhteenvetotiedot. Chilling=kylmäkäsittely.

Block *Lohko*	Effects investigated *Toimenpide*	Sub-block *Alalohko*	No sampling plots per sub-block *Koealoja alalohkossa*	Seed treatment *Siemenen käsittely*	Sowing Date *Kylvöaika*	Micro-forms *Kasvupaikka*
A	Fertilization +	A1–A2	45	No treatment	Feb-03	Low field
	Micro-forms	A3–A4	45	No treatment	Feb-03	High field
B	Fertilization +	B1	180	No treatment	Feb-03	High field
	Micro-forms	B2	180	No treatment	Feb-03	Low field
C	Sowing treatment +	C1	100	No treatment	Feb-03	-
	date	C2	100	Chilling	Apr-03	-
D	Sowing date	D1–D2	36	Chilling	Apr-03	-
E	Sowing date	E	40	Chilling	May-03	-
F	Shelter	F1–F2	40	No treatment	Apr-04	-

Fertilizer application

This study investigated fertilization effects across two sowing experiments (see Table 3) by applying two treatments: a) No fertilizer and b) 125 kg ha^{-1} of rock phosphate (15 kg of P ha^{-1}) and 100 kg ha^{-1} of muriate of potash (50 kg K ha^{-1}). It was thought that small emerging seedlings would not benefit from higher fertilizer application and on the contrary, might be damaged by it (Viro 1974, Kaunisto 1987). Experimental blocks A and B were fertilized in late July 2003. All other experimental blocks also received treatment (b) at the same time.

Site micro-forms and edaphic characteristics

The extraction of peat creates a typical micro-topography with high and low fields (also called bays). This phenomenon can have a direct impact on the emergence of seedlings due to a micro-level shelter effect. The micro-topography of these 'fields' may also reflect the edaphic characteristics as the peat found on the surface may be of different type and different pH (the deeper the peat, the more acidic it is likely to be at the surface). In this study, high and low fields were sown with similar treatments applied to both.

Shelter experiment

In this study, the potential shelter effect was tested on twenty 1 × 1 m plots, half of which were protected with two screens of green polypropylene mesh fabric (40% density), c. 1.5 × 1.5 m in size and erected at right angles on the side of the prevailing wind and mid-day sunshine. The plots were hand sown in February 2004 and fertilized in July 2004.

Statistical analysis

Due to the experimental design it was not possible to carry out statistical tests in the sowing date and treatment experiments. ANOVA was carried out to test for the effects of fertilization, micro-forms and shelter on the quantity of germinated birch seedlings, using the GLM procedure in SAS (SAS Institute Inc. 2002). Treatment effects were compared further using Fisher's protected least significant difference procedure. Average least significant differences (LSD) are presented for means in Table 9 but all comparisons were made with their corresponding exact LSD. Normal probability plots validated the assumption of normally distributed residuals for the computed models. The 5% significant level was applied in all the statistical tests.

Results

Existing natural birch stands

Stand composition, density and morphology

Downy birch was the principal birch species found on industrial cutaway peatlands. Across all sites, downy birch represented, on average, 97% of the birch population. Silver birch was almost completely absent from abandoned cutaway peatlands (1%) while it made 6% of the birch population in afforested cutaway peatlands. Given the very high proportion of downy birch, analysis of the data was carried out thereafter without separating the two species.

While it was not possible to measure the age of the trees, the stands chosen in this study have all developed from industrial cutaway peatlands which have been abandoned in the 1980s and have all formed canopy. However, their exact stage of development is unknown and thus not comparable. Substantial natural regeneration can occur on abandoned cutaway peatlands with up to 17130 trees ha^{-1} (Table 5). However, variation across the plots was large with some plots being densely regenerated (50800 trees ha^{-1}). Of the total number of trees, birch species represented at least three quarters and *Salix spp*. made for almost the totality of the rest. Scots pine (*Pinus sylvestris* L.) was found in abandoned cutaway but in very small densities. The proportion of birch and *Salix spp*. was reduced in afforested cutaway peatlands as the planted conifers accounted for some of the total.

Natural regeneration of birch on abandoned cutaway peatlands resulted in almost double the number of birch (11786 trees ha^{-1}) compared to afforested cutaway peatlands (6265 birch ha^{-1})

(Table 6). However, mean height was considerably greater in the afforested sites at 396 cm compared to 240 cm in the abandoned cutaways. Birch height was mostly found in the range 0–300 cm in abandoned cutaways while in afforested cutaways, the birch population was split between two distinct ranges: < 300 cm and > 700 cm (Figure 1). This distribution shows that abandoned cutaway peatlands have older trees as well as very young trees. The two groups of tree heights in afforested cutaways suggest two colonization events: 1) when the site was initially planted with conifers and 2) when the conifers died back, leaving open spaces for more colonization. DBH of birch was also greater in afforested cutaways, compared to abandoned cutaways but the difference was less than for height. This is probably because DBH was measured on trees greater than 7cm diameter.

The proportion of multi-stem birch trees was double in the afforested cutaways (28%) compared to abandoned cutaways. In all cases, however, the majority of the multi-stem birch trees were of double stemmed form. Tree density was positively correlated to the proportion of multi-stem trees.

Table 5: Stand composition at four cutaway peatland areas (see Table 1 for details on each area)

Taulukko 5. Puulajivaihtelu neljällä suonpohjan metsityskokeella (ks. Taulukko 1).

Site *Koe*	Peatland type *Tyyppi*	Total stem no. ha^{-1} *Runkoluku kpl* ha^{-1}			Birch, % *Koivu, %*			Salix, % *Pajut, %*			Conifer, % *Havupuut, %*		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Ballybrackan B	Abandoned	17130	4000	50800	81	69	89	17	9	30	3	0	11
Turraun	Abandoned	10160	2500	20200	74	51	99	26	0	49	1	1	1
Ballybrackan C	Afforested	5030	2100	12110	69	48	81	8	2	19	<1	0	<1
Tumduff	Afforested	13768	3100	50700	65	28	94	5	0	8	<1	0	<1

Table 6. Results from the natural birch survey (birch density, height and diameter at breast height (DBH)) from abandoned and afforested cutaway peatland areas (see Table 1 for details of each area).

Taulukko 6. Koivupuustojen tiheys, pituus ja rinnankorkeusläpimitta hylätyillä ja metsitetyillä koealuiella suonpohjalla (ks. taulukko 1).

Site *Koe*	Birch trees ha^{-1} *Koivupuita kpl* ha^{-1}			Birch stems ha^{-1} *Koivurunkoja kpl* ha^{-1}			Height (cm) *Pituus (cm)*			DBH (cm) *Läpimitta,* $d_{1.3}$ *(cm)*		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Abandoned cutaways												
Ballybrackan A	16750	15100	20000				61	10	300			
Turraun	9656	2300	16600	9800	2500	15100	225	39	742	9.31	8.3	11
Clonsast	3800	1900	6100				150	20	529	7.9	7.6	8.3
Ballybrackan B	14460	2800	44800	17100	5300	47100	287	50	757	8.4	7.5	9.6
Mean, all cutaw. areas	11786						240			9.1		
Standard error	1402						25			0.3		
Afforested cutaways												
Ballybrackan C	3340	1300	6800	4300	2300	6400	688	639	737	9.9	8.8	11.3
Tumduff	9480	1100	47600				168	80	572	11.6	10.2	14.4
Lullymore	5300	3500	6400				98	56	140	9.2	7.6	10.7
Mean, all aff. areas	6265						384			10.6		
Standard error	1950						58			0.4		

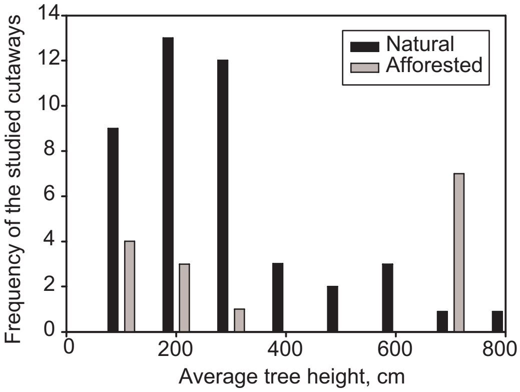

Figure 1. Frequency distribution of the average height of birch trees found across the studied natural cutaways and forested (with conifers) cutaway areas (see Table 1 for details of areas).

Kuva 1. Tutkimuksessa käytettyjen suonpohjien metsitys-kokeiden koealojen lukumäärät puuston keskipituuden mukaan (kokeet esitetty tarkemmin taulukossa 1).

Biomass production

All the logarithmic linear relationships between tree component biomass and DBH were found to be statistically significant (Table 7) and the statistical comparison of actual and modelled data showed no significant difference. The equation shown in Table 7 was applied to the survey data from the four studied areas (see Table 1). Below and aboveground tree biomass varied greatly between the four measured sites (Table 8). Belowground biomass represented approximately a quarter of the total weight. The greatest aboveground leafless biomass was in Ballybrackan (abandoned cutaway) with 115000 kg DM ha^{-1}. This site also had the highest number of birch stems (9300 ha^{-1}) and the tallest trees. At an estimated age of 20 years, the average annual biomass increment would equate to 5800 kg ha^{-1}. The lowest biomass was measured in Tumduff (afforested cutaway) with around 31000 kg ha^{-1}, where the density of birch stems was also the lowest at 1700 ha^{-1}. However, given the young age of the site, it has a 3100 kg DM ha^{-1} year^{-1} biomass increment.

Carbon stock estimations

The average percentage moisture content of stems and branches were all found to be between 40–50%. Foliage had the highest moisture content at 60% and dead branches had the lowest at 23%. The dry matter content did not vary significantly between tree components. There was no significant difference in the C content between above-ground tree components (stem, branches, foliage and dead wood). The average C content was 50.4% DM compared with 50.1% DM for

Table 7. The parameters and the validation results for the biomass equation [ln(BM) = –a + b(ln(DBH))] applied for the birch stands in the study areas on cutaway peatlands. BM= biomass (kg), DBH= the tree diameter at breast height, 1.3 m, (cm)). n=200.

Taulukko 7. Biomassamallin [ln(BM) = –a + b(ln(DBH))] parametrit eri puun ositteille suonpohjakokeiden koivikoissa. BM= biomassa (kg), DBH=puun rinnankorkeusläpimitta (cm).

Tree Component	a	b	r^2	Correction factor	p-value
Dead Branches *kuolleet oksat*	–4.0024	2.6463	0.8725	1.0024	<0.0001
Belowground *Juuret*	–2.1718	2.3227	0.9481	1.0006	<0.0001
Stem *Runkopuu*	–2.4487	2.1762	0.8964	1.0008	<0.0001
Branches *Oksat*	–4.0838	2.6448	0.9146	1.0008	<0.0001
Foliage *Lehdet*	–3.5996	1.7309	0.6775	1.001	<0.0001
Total Aboveground *Maanpäällinen yht.*	–2.1783	2.2916	0.9256	1.0004	<0.0001

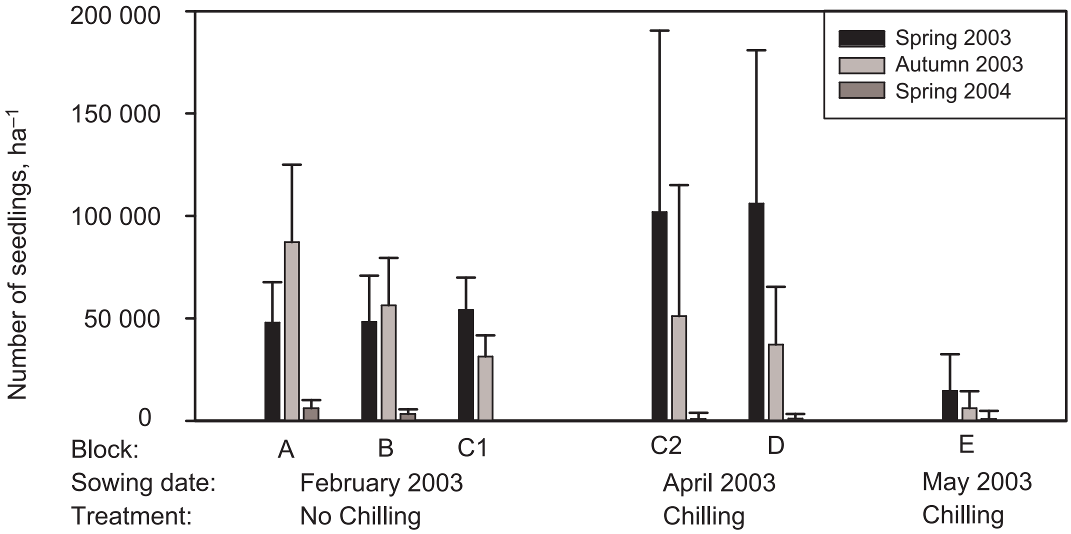

Figure 2. Effect of sowing date and seed treatment on the number of living birch seedlings recorded in spring 2003, autumn 2003 and spring 2004 in the East Boora sowing experiment. There was no living birch in block C1 in spring 2004. Error bars represent standard errors.

Kuva 2. Kylvöajankohdan ja siemenen käsittelyn vaikutus elävien koivun taimien lukumäärään East Booran suonpohjien metsityskokeilla keväällä 2003, syksyllä 2003 ja keväällä 2004. Lohkolla C1 ei ollut jäljellä eläviä taimia keväällä 2004. Keskiarvon keskivirheet esitetty kuvissa.

roots. These were used in conjunction with dry matter values measured for each component to calculate the amount of C contained in the below and aboveground birch biomass (Table 8). The Ballybrackan birch woodland contained 58000 kg C ha^{-1} in its aboveground leafless biomass and an additional 20100 kg C ha^{-1} in the belowground biomass. In terms of aboveground biomass and using the estimated age, the site accrued around 2900 kg C ha^{-1} year^{-1}. C stocks were the lowest in Tumduff with 14400 kg C ha^{-1} in aboveground biomass and 5100 kg C ha^{-1} in belowground. However annual aboveground C uptake was identical to Turraun and Ballybrackan C, at around 1500 kg C ha^{-1}.

Direct sowing

Germination and seedling mortality

The average maximum number of birch seedlings that germinated was 105000 ha^{-1}, corresponding to a 22% germination rate. Initial germination was highest when the birch seed were treated and sown in April, following a chilling treatment (Blocks C2 and D, Figure 2). Sowing in May with a chilling treatment resulted in the lowest germination rate (Block E). After one growing season (autumn 2003 survey), the effect of the sowing date was not visible anymore and the numbers of birch seedlings had decreased in all treatments except in Blocks A and B. In those sites, birch seeds sown in February without chilling treatment germinated further during the growing season.

The number of birch seedlings recorded in the following spring plummeted in all sites, demonstrating a very high mortality rate during the winter. The maximum average rate was recorded at just below 6000 birch seedlings per hectare after the first winter (Block A).

Effects of fertilization and peat surface microform

In Blocks A and B, plots which received 125 kg ha^{-1} of rock phosphate and 100 kg ha^{-1} of muriate

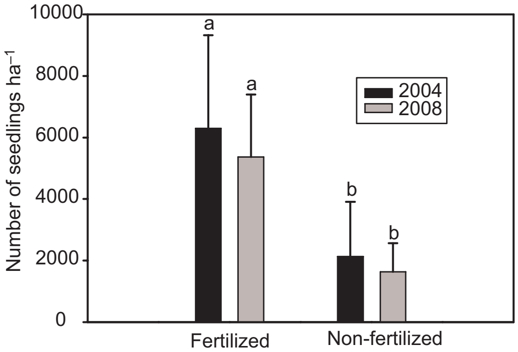

Figure 3. Effects of fertilization and time on the average number of birch seedlings in Block B in East Boora sowing experiment. Error bars represent standard errors, means with different letters are significantly different ($p<0.05$).

Kuva 3. Lannoituksen ja ajan vaikutus koivun taimien lukumäärään East Booran kylvökokeella suonpohjalla. Eri kirjaintunnus keskiarvopylvään päällä osoittaa keskiarvojen tilastollisesti merkitsevää eroa (p<0,05).

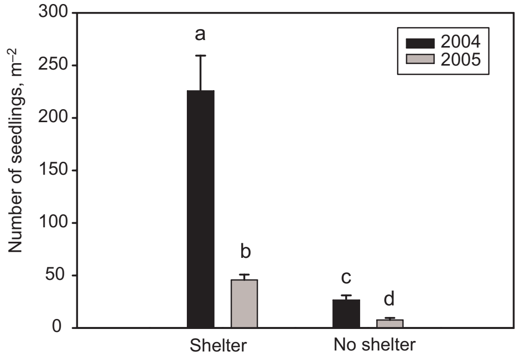

Figure 4. Average number of birch seedlings per m^2 in sheltered and non-sheltered plots after one growing season (autumn 2004) and first winter (spring 2005) in Block F of the East Boora sowing experiment. Error bars show standard errors, means with different letters are significantly different ($p<0.05$).

Kuva 4. Keskimääräinen koivun taimien määrä neliömetrillä suojatuilla ja avoimilla koealoilla ensimmäisen kylvönjälkeisen kasvukauden (syksy 2004) sekä ensimmäisen talven (kevät 2005) jälkeen East Booran kokeella. Eri kirjaintunnus keskiarvopylvään päällä osoittaa keskiarvojen tilastollisesti merkitsevää eroa (p<0,05).

of potash had a significantly higher number of birch seedlings after one growing season compared to unfertilized plots (Table 9). The hypothesis that micro-topography may have an effect on the occurrence of birch seedling was validated at Block B. There was a significantly higher number of seedlings found in low fields, compared to high fields. In both Blocks A and B, the number of birch seedlings and total number of species (other than birch) were positively correlated (Pearson's +0.70) and both were negatively correlated with the percentage of bare peat (Pearson's –0.69 and –0.70 respectively).

When comparing results from spring 2004 with a re-survey in spring 2008, fertilization was the only factor that still had a significant effect on the number of birch seedlings (Figure 3).

At Block E, where birch was sown in May 2003, the number of seedlings germinating and surviving after one growing season was very low throughout the experiment. However, there was still a higher number of birch seedlings found in the fertilized plots (6000 ha^{-1} on average)

Table 8. Biomass production and carbon content from birch stands on cutaway peatlands (see Table 1 for details of each area). BG=belowground, AG=above ground, DM= dry matter.

Taulukko 8. Koivikoiden biomassatuotos ja hiilisisältö tutkituilla suonpohjakokeilla. BG=maanalainen, AG=maanpäällinen, DM=kuivamassa, C=hiili, yr=vuosi.

Site *Koe*	Type of cutaway *Tyyppi*	Estimated age (yrs) *Ikä*	No. of stems (ha^{-1}) *Runkoluku*	Mean height (m) *Keskipituus*	Mean DBH (cm) *Läpimitta*	BG biomass DM ($t\ ha^{-1}$)	BG biomass C	AG leafless biomass DM ($t\ ha^{-1}$)	AG leafless biomass C	DM ($t\ ha^{-1}\ a^{-1}$)	C
Ballybrackan B	Abandoned	20	9300	8.2	7	40.1	20.1	115	58.1	5.8	2.9
Turraun	Abandoned	15	4867	5.5	5.8	16.5	8.3	47.1	23.8	3.1	1.6
Ballybrackan C	Afforested	17	4200	6.8	7.4	17.6	8.8	50.4	25.4	4.7	1.5
Tumduff	Afforested	10	1700	6.6	8.2	10.1	5.1	30.5	14.4	3.1	1.5

compared to 5000 ha^{-1} in the unfertilized plots, although this difference was not significant.

Effect of shelter on seedling survival

After the first growing season (autumn 2004), the sheltered plots had a significantly higher number of seedlings with on average, eight times more birch seedlings per m^2 than the non sheltered plots (Figure 4). After the first winter (spring 2005), the number of seedlings fell dramatically with less than a fifth of the seedling population surviving in all plots. However, the sheltered plots had still significantly higher number of seedlings (45 seedlings m^{-2} vs. 7.5 seedlings m^{-2}). The sheltered plots had on average 450000 seedlings ha^{-1} after one year which is the highest rate recorded across all the sowing experiments.

Discussion & recommendations

Profile of naturally regenerated birch on cutaway peatlands

When peat extraction is terminated on an industrial cutaway peatland, the landscape left behind is a flat, bare, windswept peat surface of variable physical and chemical characteristics (Renou-Wilson et al. 2008b). Spontaneous recolonization by plants and mosses usually occur along the draining ditches but this is very variable in space and time. While natural colonization by *Betula* is sporadic, it is easily one of the most common native broadleaved trees found on cutaway peatlands, along with *Salix* species. This study showed that downy birch was the only birch species found in the abandoned cutaway peatlands while a small proportion of silver birch was found in the afforested cutaway peatlands. Downy birch is also the most common birch species found on cutaway peatlands in Finland (Hytönen & Aro 2004) but silver birch has also been shown to regenerate naturally especially on fertilized peat (Kaunisto 1981). The presence of silver birch on afforested cutaway peatlands may thus be explained by the fact that these areas were fertilized at planting time. Planted silver birch has been found to be suited to drier sites (Renou et al. 2007), its roots needing well aerated soils (Miles & Kinnaird 1979). Downy birch on the other hand is more tolerant to nutrient poor conditions as well as wetter soils.

The quality of the naturally regenerated birch growing on cutaway peatlands was found to be similar to other natural birch stands growing on other generally poor substrates (Nieuwenhuis & Barrett 2002, O'Dowd 2004, O'Connor 2006). Interestingly, birch trees were more often multi-stemmed in the afforested cutaway peatlands in comparison to the abandoned cutaways. This is probably due to competition with conifers for the beginning of their development.

Advantages of natural birch as a an after-use land cover

Birch is a pioneer species that colonizes bare ground. This study showed that up to 50000 trees ha^{-1}

Table 9. Effect of fertilization and micro-forms (high and low fields) on the number of birch seedlings per hectare after one growing season in Blocks A and B in East Boora cutaway peatland area based on the Fisher´s LSD-test (see Table 3 for details of experimental blocks). SEM = standard error of mean.

Taulukko 9. Lannoituksen ja koealueen kasvupaikan sijainnin vaikutus koivun runkolukuun yhden kasvukauden jälkeen East Booran kylvökokeella suonpohjalla (lohkot A ja B). Tilastolliset testaukset on tehty Fisherin LSD-testillä (lohkojen kuvaus esitetty taulukossa 3). LS Mean: mallin keskiarvo, SEM: keskiarvon keskivirhe.

Treatment / *Käsittely*		Block A LS Mean	SEM	p-value	Block B LS Mean	SEM	p-value
Micro-form:	High field	96680	18977	0.898	39952	12385	0.001
	Low field	94236			90286		
Fertilization:	P + K	120833	20128	0.016	40571	13513	0.006
	No fertilization	70083			89667		

were recorded in some cutaway peatland sites, the great majority being birch. In southern Quebec and New Brunswick (Canada), the density of naturally regenerated birch on abandoned mined peatlands was found to reach 45000 to 600000 individuals per hectare (Fay 2006). 15 years following the cessation of peat extraction, the Turraun site had just under 18000 birch per hectare.

The bulk of such natural colonization has the potential to develop into mature forest and add to the national woodland estate that is predominantly coniferous in nature (Horgan et al. 2003). More importantly, it can be used as a matrix of shelter into which trees can be planted or its composition and stocking can be augmented by enrichment planting. Natural birch has the potential to improve a cutaway peatland by lowering the water table, at least temporarily, because a large amount of the water in the peat is absorbed by the root systems and lost by transpiration (Heathwaite 1995). In addition, birch leaves intercept precipitation and seasonally alter the amount of water reaching the ground (Ingram 1983, Bragg 2002). In Britain, a 20-year-old birch stand was found to intercept up to 30% of the precipitation and lower the water table by 20 cm in a mined peatland (Price et al. 2003). A more recent study in Canada showed that a dense population of birch on a mined peatland can influence site hydrology even at the early establishment phase (seedlings) (Fay & Lavoie 2009). This would, in effect, prevent the site from reverting to a wetland but in addition birch litter physically hinders the growth of mosses (Quinty & Rochefort 2003). Lowering the water table could in turn help the establishment of other species, for example planted commercial tree species.

Naturally regenerated birch woodland can also create an opportunity for biomass production and indeed wood for energy. This study demonstrated a huge variation in total above-ground biomass (31–115 t ha^{-1}) from various natural birch stands found on Irish cutaway peatlands. The highest above-ground biomass was recorded in a birch woodland growing an abandoned cutaway peatland. When the estimated age of the sites is considered, the annual biomass increments ranged from 1500 to 5800 kg ha^{-1}. These were in line with measurements carried out on planted silver birch on cutaway peatlands (Renou et al. 2007) whereby a 10 year old silver birch plantation (2500 stems ha^{-1}) established on uncultivated cutaway peat had an estimated annual biomass increment of 3050 kg DM ha^{-1}. Overall, these biomass increment figures are low compared to biomass production recorded in managed stands of short rotation crops on agricultural land which range from 8000 to 13000 kg ha^{-1} $year^{-1}$ (Rice et al. 1997). Hytönen et al. (1995) found that with a stocking density of 20000 trees ha^{-1}, the leafless aboveground biomass of six-year old stand varied from 13900 kg ha^{-1} to 33700 kg ha^{-1}. Ferm & Kaunisto (1983) found that mean leafless aboveground biomass of naturally regenerated mixed stand of fourteen-year old downy and silver birch growing on cutaway was 59000 kg ha^{-1}. Heavily fertilized stands of birch on cutaway peatlands in Finland gave yields of 108000 to 112000 kg ha^{-1} for silver and downy birch respectively (Hytönen & Saarsalmi 2009). The importance of natural regeneration for biomass depends on the productivity compared to other sources of biomass. It is thus important to remember that these birch stands were not fertilized and that their productivity would be considered the lowest possible. Biomass production of birch will certainly vary depending on site properties, especially the nutrient regime. Furthermore, in estimating the biomass, no account was taken of material 7 cm or less in diameter. Therefore, it is probable that the biomass values are under-estimated.

Biomass production is of interest not only for transformation (either being burned with peat in power stations or transformed in biochar), it can play an important part in the national C stocks. As bare peat surfaces result in net losses of C (Wilson et al. 2007), natural colonization and biomass production (above- and belowground) might be of interest in terms of increasing our atmospheric sinks. However, productivity would need to be increased through management input. While the majority of C is usually present in the above-ground component of a stand, there is an addition C stock in the roots. Belowground biomass was about 25% of total weight and represents an additional input ranging from 5 to 20 t C ha^{-1} at our study sites. A previous study at a natural birch stand on cutaway peatlands had estimated the below-ground biomass at almost 10000 kg C ha^{-1} in addition to the 23500 kg C ha^{-1} in the above-ground biomass (Byrne et al. 2007). This corresponded to overall total (above and belowground) annual C stock increment of 2200 kg C ha^{-1} $year^{-1}$. Wilson and Farrell (2007) demonstrated in the same study that the net loss of soil C due to decomposition of the residual peat, root biomass and litter was estimated to be 7500 C ha^{-1} $year^{-1}$. This would results in a net loss of 4600 kg C ha^{-1} $year^{-1}$. In the most productive, naturally re-colonized site investigated in our studies, the estimated net loss would be 4000 kg C ha^{-1} $year^{-1}$.

Accurate biomass estimates are difficult to obtain due to the unpredictable morphology of the regenerating trees. This study confirmed that natural birch woodlands lack uniformity. Natural regeneration produces uneven stands of trees with variable age, height, DBH and especially growth form. Almost a third of the birch had multiple stems in afforested sites but this decreased in the abandoned sites. This unpredictable morphology gives rise to problems in obtaining accurate estimates of biomass in comparison to plantation forests. By using models created for more uniform plantation forests, the biomass estimations would probably underestimate the total biomass production of the naturally regenerated woodland, for example, if all the stems of a tree are not taken into account.

Direct Sowing

Direct sowing was shown to be a possible method to establish a birch population on these sites. However, its success is dependent on several factors, namely sowing date, fertilization and shelter. Greatest seedling emergence was achieved when birch was sown in April with treated (chilled) seeds. Using treated seed means that the sowing can be carried out later in the spring when the ground has warmed up. However, later sowing (May) led to poor germination, most likely due to dry climatic conditions followed by very high precipitation. If treatment (chilling) of the seeds is not possible, the sowing should be carried out during the winter.

The number of birch seedlings alive after one growing season was improved with the application of rock phosphate (50 kg ha^{-1}) and muriate of potash (100 kg ha^{-1}) soon after germination. The fertilization effects were still visible four years later. Similar results were found in Finland where birch germination and early establishment on cutaway peatlands was improved by ash-fertilization (Huotari et al. 2008).

Cutaway areas that benefit from some protection — fields or vegetation — seem to result in a more successful establishment of birch than the ones fully exposed to sun and wind. Earlier studies suggest that even though birch requires a large amount of light to thrive, in early years some shelter is beneficial to the seedlings (Brown 1984). This study confirmed this finding as the presence of an artificial windbreak significantly increased the germination and survival rates of birch seedlings. It is the treatment that resulted in the highest number of birch seedlings to survive after one winter (just over 400000 seedlings ha^{-1}). In effect, this means that large exposed areas may not be suitable for direct sowing of birch. Finally, it should be noted that the sowing rate used in this study may not have been sufficient in order to produce an adequate number of live seedlings after the first winter.

Strategies for establishment of birch woodlands

The method by which birch is to be established (planting, natural regeneration or direct sowing) is likely to be determined by the cost and time allowed. With few exceptions, cutaway peatlands will eventually naturally re-vegetate, with birch as a main component. This is the cheapest option but one that will take a long time. Sporadic regeneration or its failure to materialize can give rise to delay in establishment, while overabundance can result in the need for costly complementary planting and extra cleaning of seedling stands. The quickest way to establish birch but also the most expensive is planting. A slower but cheaper option to achieve land cover over a reasonable timeframe is by establishing islands of birch by planting or sowing at strategic locations, thus forming seed sources from which trees can gradually colonize larger areas. Such a strategy would concentrate resources (plants, seeds, fertilizer) at selected locations to enhance the probability of local establishment. This strategy would cost less than planting of large areas but should give quicker results than unassisted natural expansion. Results from this study demonstrated that direct sowing with fertilization and shelter could be a successful and cheaper strategy to quickly establish a birch cover which would kick off the colonization process.

Conclusions

As a large proportion of industrial cutaways in Ireland will be released from peat production in the next few decades, it is important to find alternative land use options for these areas. Birch can be a feature in this new landscape and offers many possibilities: nurse species, biomass, increased woodland cover and last, but not least biodiversity. Currently, the main land use options for industrial cutaway peatlands are: creation of new wildlife habitats, natural dryland regeneration and afforestation. All of these create opportunities for birch to colonize and thus more birchwoods are likely to develop in the future.

Acknowledgements

The authors would like to acknowledge Bord na Móna in providing the sites and helping with the sowing experiments. In particular we wish to thank Tom Egan and Gerry McNally.

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Tiivistelmä: Koivun soveltuvuus suonpohjien metsittämiseen Irlannissa

Irlannissa on arvioitu poistuvan käytöstä turvetuotantoalueita yli 80000 ha parin seuraavan vuosikymmenen kuluessa ja näiden alueiden vaihtoehtoisilla käyttömuodoilla on merkittäviä vaikutuksia ympäristöönsä kuten maisemaan. Yksi paljon käytetty suonpohjien jatkokäyttömuoto on metsittäminen. Tässä tutkimuksessa selvitettiin hieskoivun (*Betula pubescens*) soveltuvuutta suonpohjien metsittämiseen perustuen järjestettyihin kylvökokeisiin ja koealainventointeihin, joilta selvitettiin puustojen tiheyttä, biomassatuotosta sekä kylvöjen onnistumista ja niihin vaikuttavia tekijöitä. Tutkimuksessa havaittiin, että hieskoivu voi uudistua luontaisesti ja muodostaa tiheitä puustoja paitsi hylätyillä kasvittomilla turvekentillä myös jo ennestään muille puulajeille metsitetyillä alueilla. Hieskoivun kylvökokeet osoittivat, että PK-lannoituksen tekeminen kylvön yhteydessä lisäsi merkittävästi taimien elossaoloa ja tuotti kelvollisen uudistamistuloksen. Myös taimien mekaaninen suojaus ensimmäisen talven aikana, jolloin taimet ovat hyvin alttiita ahavalle ja rousteelle, vähensi taimien kuolleisuutta. Luontaisesti uudistuneissa koivutaimikoissa (keskipituus 3.2 m) vuotuinen biomassatuotos (kuiva-ainetta) oli 3100–5800 kg ha^{-1}. Tätä vastaava hiilen määrän kasvu puustossa oli 1500–2900 kg ha^{-1}. Tulosten perusteella joko luontaista tai keinollista koivulle metsittämistä voidaan suositella käytettäväksi suonpohjien jatkokäyttömuotona.

Avainsanat: hieskoivu, rauduskoivu, suonpohja, biomassa, kylvö, luontainen uudistaminen, lannoitus

Received 12.10.2010; Accepted 28.12.2010