# Nursing effects of birch on Sitka spruce grown on an industrial cutaway peatland

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**Abstract**
The suitability of major conifer species for afforestation of industrial cutaway peatlands is limited to a narrow range of site types. There is some evidence that establishment of Sitka spruce (*Picea sitchensis*) or Norway spruce (*Picea abies*) with birch (*Betula* spp.), as a mixed stand or by under planting spruce in an established birch canopy, can improve the productivity of the conifer crop. Management of mixed Norway spruce and birch crops is now a well-established management model used in southern Sweden (Kronoberg approach). In this study, a mixed spruce-birch trial, established in 2000 under the previous BOGFOR programme, was re-evaluated to determine if there was any evidence of a nursing effect of birch on Sitka spruce. Analysis of various planting configurations showed that planting the two species at the same time in alternate rows produced the best results in terms of total basal area, top height, mean DBH and height of Sitka spruce. When compared to pure Sitka spruce stands, the productivity was c. 38% higher for trees planted at the same time in alternate rows with birch. Although the definitive physiological factors contributing to the nurse effect of birch on Sitka spruce are still unclear, these results and others suggest the nursing effect is probably due to enhanced foliage nutrition possibly associated with increased nutrient availability due to decomposition of birch litter or increased root aeration. There was no evidence of a reduction in exposure and frost stress in mixed species treatments. The implications of these findings are that the potential area suitable for Sitka spruce on cutaway industrial peatland sites can be expanded when planted in combination with birch. Moreover, the potential utilisation of birch thinnings for biomass and the final Sitka spruce crop for timber may be a particularly suitable option for Bord na Móna, since it may potentially fulfil both bioenergy and timber production objectives. Further research is, however, required to assess whether the nursing effect will continue and to evaluate the viability of the proposed silvicultural system on cutaway peats. The timing of silvicultural interventions is particularly important to ensure that a Sitka spruce crop in not suppressed whilst still preserving the birch nurse effect.

**Keywords:** *Birch, Sitka spruce, nurse species, cutaway peatlands.*

## Introduction

The afforestation of suitable industrial cutaway peatlands in the Republic of Ireland

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could make a significant contribution to attaining the targets set out in the government's forest strategy. It is estimated that between 16,000 and 20,000 ha of the Bord na Móna (The Turf Development Board) cutaway peatland resource has afforestation potential (Renou-Wilson et al. 2008). In addition to potentially providing raw materials for the timber processing sector, there is now potential for wood energy production from Bord na Móna lands close to existing end-use facilities. These woodland products are also suitable for co-firing in the peat-burning power stations and would extend these stations' working life, as well as providing employment in the harvesting and transport of wood fuel.

Bord na Móna cutaway peatlands are extremely heterogeneous below ground even though the landscape may look deceptively uniform in appearance from above. The peat varies in type, depth (because of the undulating topography of the underlying bog floor and local harvesting practices), pH, nutrient status, moisture regime (drainage) and in the geomorphology of the underlying (pre-bog) relict soils. All of these factors influence the choice of species for future afforestation. Afforestation of Irish cutaway peatlands, from the 1960s onwards, was perceived to offer good potential (OCarroll 1962, 1966, Gallagher and Gillespie 1984). A large cutaway peatland afforestation programme (mostly with Sitka spruce (*Picea sitchensis* (Bong.) Carr.)) on the cutaways, initiated in the mid-1980s to 1990s, resulted in c. 40% of crops failing to produce a commercial crop. This was mostly due to poor site selection and general sensitivity of Sitka spruce to frost, compounded by two severe late spring frosts that occurred in 1989 and 1991 (Renou-Wilson et al. 2008). Current guidelines now favour the selection of Norway spruce (*Picea abies* (L.) Karst) as the commercial conifer species of choice on these sites (Horgan et al. 2004, Renou-Wilson et al. 2008), despite the lower yield potential, when compared to Sitka spruce. More recent studies conducted on Bord na Móna experimental trials planted between 1995 and 2000 suggest that Sitka spruce and Norway spruce may only be suitable on *Phragmites* or woody fen peat-dominated sites with a maximum peat depth of 0.8 m (Black et al. 2017a, 2017b - this issue). As a natural coloniser of cutaway peatlands, birch appears to tolerate deeper peats and less well drained sites (Renou-Wilson et al. 2008, Renou-Wilson et al. 2010, Black et al. 2017a, 2017b).

The positive effects ("nursing") of growing mixed species stands have been documented in many studies (Cannell et al. 1992, Renou-Wilson et al. 2009). Horgan et al. (2004) describe why mixtures work in an Irish context and list the benefits as nutritional, improved soil aeration, providing shelter from wind or protection from frost. It has also been suggested that birch may be a suitable nurse species for Norway spruce in Nordic countries (Fahlvik et al. 2011). Johansson (2003) reported a higher total mean annual increment in mixed stands of birch and Norway spruce (11.5 $m^3$ $ha^{-1}$ $year^{-1}$) when compared with pure spruce stands (7.2 $m^3$ $ha^{-1}$ $year^{-1}$). Management of naturally regenerating birch/spruce mixtures is now a well-established silvicultural system (Kronoberg system) in southern Sweden. The density of the nurse crop and the time of thinning have been found to be critical for Norway spruce growing on Finnish peat soils (Hilli et al. 2003). The Kronoberg system, or variations thereof, may be particularly attractive in the Bord na Móna context because there is potential to produce both biomass for energy from initial birch thinnings followed by a final harvest of spruce for commercial timber (Renou-Wilson et al. 2010).

Ideally, mixed forest stands should be comprised of a shade-tolerant, late-succession species in the lower stratum and an early succession species in the upper stratum (Assmann 1970). The natural relation between birch and Norway spruce in a mixed stand, therefore, seems to be a good ecological combination. Sitka spruce is, however, generally considered a light demander (Horgan et al. 2004, Kennedy et al. 2007) and should only be used in certain circumstances in mixture with birch. This has been shown in a demonstration area, established under the BOGFOR programme, where Sitka spruce initially grew extremely well under an established birch canopy but subsequently slowed considerably when the birch canopy was not opened up (Renou-Wilson et al. 2010). Birch in mixture with Sitka spruce, Norway spruce or western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is a recommended mixture in Ireland (Horgan et al. 2004) but the authors stressed the importance of removing the birch overstorey to allow the conifers to develop as practiced in Finland (Hilli et al. 2003).

Mason (2006) describes two experiments, established in the late 1990s in the UK, to examine the response of both species in a birch/Sitka spruce mixture. Unlike the current cutaway trial, however, these UK trials examined sites where naturally regenerated birch had invaded sites already planted with spruce. Experiments were also set up in 2000 during the BOGFOR programme to investigate the potential nursing effect of naturally regenerated birch on planted Sitka spruce. Other trials included treatment plots of both species planted at the same time or Sitka spruce planted between rows of established downy birch (*Betula pubescens* Ehrh.) and pure plots of Sitka spruce after four growing seasons (Renou-Wilson et al. 2008). However, long-term assessments are required to assess the interaction between the two species over time. The long-term nursing potential of birch on Sitka spruce when planted in different configurations in relation to timing of planting and relative mixtures of the two species at planting were examined in this study.

The productivity benefit or loss to the target species (i.e. Sitka spruce in this case) in a mixed stand is a function of many interacting processes, such as different proportions of the species mixture (Mason 2006, Pretzsch 2009), resource availability, resource use efficiency, competition for stand space (packing density) and site type (for review see Assmann 1970, Pretzsch 2009). To evaluate the performance of the target species in mixed species planting configurations, some measure of the interaction between the two species is required, which is difficult to do based on once-off stand measurements. However, mixture proportions based on individual species' basal area or crown projection areas (Pretzsch 2009) and other competitive indices, such as crown competition factors, have been demonstrated to be useful to describe competition effects on tree growth (Wykoff 1990, Black 2016). It is hypothesised that the productivity of the target species (Sitka spruce) may increase or decrease under different species mixture configurations with birch depending on the availability, utilisation and competition of resources for tree growth by the two species and the extent of any protection one species may offer over the other (e.g. protection against frost). To test this hypothesis, assessments of the performance of Sitka spruce in a mixed species trial set up in 2000 under the BOGFOR programme was carried out. This study explores the use of traditional and new approaches for assessing the productivity benefit or loss due to species interaction, by extending concepts outlined by Pretzsch (2009). The other objectives of the study were to assess the potential of spruce/birch mixtures for the afforestation of industrial cutaway peatlands and to establish if any management interventions are required at the current stage of canopy development.

## Materials and methods

*Experiment KTY14/00*

The experiment was established in 2000 in the Blackwater production area of Bord na Móna's industrial cutaway peatland area near the Shannonbridge ESB peat-fired power plant (geographic coordinates at centre of experiment in ITM WGS 84 projection is 53.2938° N and -7.9794° E). The experiment was set up in a randomised block design on bare milled peat (mostly *Phragmites*) with a peat depth of 1 to >2 m over a calcareous mud sediment. The experiment was set out in three blocks, with six randomised plot treatments in each block (Figure 1): Pure Sitka spruce planted in 2000 (SS); alternate rows of birch and Sitka spruce, planted at the same time in 2000 (SB); alternate rows of birch and Sitka spruce, with spruce planted 2 years after the birch in 2002 (SB_2); alternate rows of birch and Sitka spruce, with spruce planted 4 years after birch in 2004 (SB_4); one row of birch and two rows of Sitka spruce planted at the same time in 2000 (SSB); and one row of birch and three rows of Sitka spruce planted at the same time in 2000 (SSSB).

All plots (plot size of 45 × 45 m) were planted at a density of 2,500 trees per ha at a row spacing of 2 × 2 m, comprising of pure Sitka spruce (*Picea sitchensis* origin SQ UK Scot V12) or Sitka spruce mixed with common birch (*Betula pubescens,* origin BC UK106 ZP20), when the two species were planted at the same time. There is no clear documentation that the same provenance of Sitka spruce was used in the delayed planting after 2 and 4 years, but research practice at the time would have ensured that

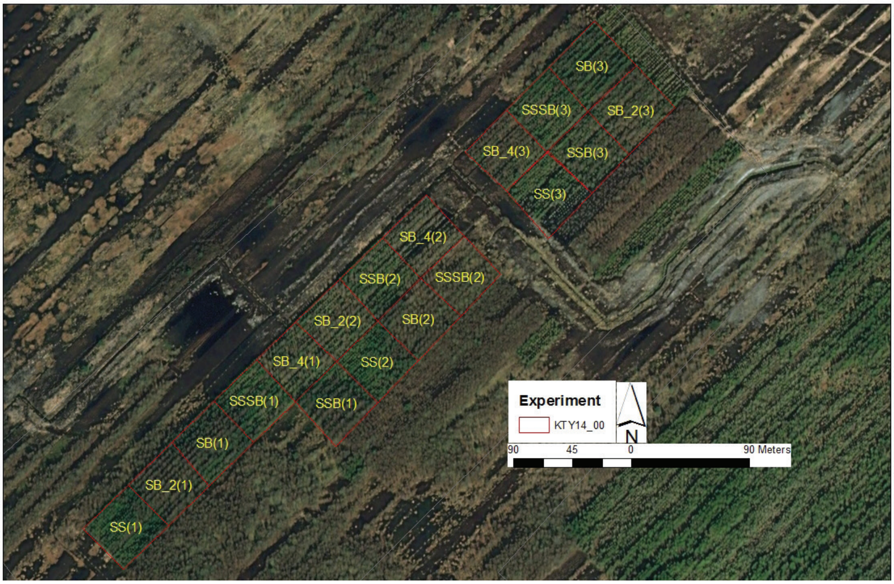


**Figure 1:** *The layout of experiment KTY14/00 established in 2000, showing treatments represented by letters and numbers (parenthesis) for the three replicated blocks. Treatments were as follows:*

- *SS = Sitka spruce planted in 2000;*
- *SB = alternate rows of Sitka spruce and birch, planted in 2000;*
- *SB_2 = alternate rows of birch and Sitka spruce, with spruce planted after 2 years in 2002;*
- *SB_4 = alternate rows of birch and Sitka spruce, with spruce planted after 4 years in 2004;*
- *SSB = two rows of Sitka spruce and one of birch planted in 2000;*
- *SSSB = three rows of Sitka spruce and one of birch planted in 2000.*

all provenances used were of QCI origin. All plants were sourced from the Coillte Ballintemple nursery in Co. Carlow. Sitka spruce was planted as bare-root stock (2+1, i.e. a 3-year-old transplanted seedling). Birch was planted as bare root stock (1U1, i.e. a 2-year-old undercut seedling).

At planting time (initial or under-crop), the plots (birch or Sitka spruce) were fertilised with rock phosphate applied in bands at a rate of 175 kg $ha^{-1}$ (21 kg P $ha^{-1}$). All plots received a second broadcasted application (175 kg $ha^{-1}$ of rock phosphate combined with 250 kg $ha^{-1}$ of muriate of potash) after 2 years. The performance of both species in this trial was evaluated after four growing seasons, as part of the BOGFOR programme (Renou-Wilson et al. 2008), but there have been no management interventions on, or reassessments of this experiment since 2004.

*Re-assessment of establishment data*

The initial assessment data from the BOGFOR project was collected by the research forester, but the data and collection protocol were developed by one

(FRW) of the authors. However, there is no detailed record of the exact sample plot locations. The original experimental plot layout did not include buffer rows to account for edge effects. However, sample plots (10 × 20 m) were established in the centre of each replicated treatment plot to ensure that edge trees were not measured. A sample of c. 50 trees per plot were measured at the end of 2002, 2003 and 2004 to assess seedling height (in cm to 0.1 cm precision) and percentage survival following planting.

*Plot surveys*

Plot surveys using 0.03 ha (10 m radius) circular subplots were established in each plot after which diameter at breast height (1.3 m, DBH in cm), individual tree height (m), top height (mean height of largest DBH tree) were assessed. The stocking level of each species in the treatment subplots was determined in February 2017. These subplots were located near the centre of each plot to ensure that the sample plot area fell completely within the experimental plot and that edge trees were not measured.

The DBH of all trees was measured (to 0.1 cm precision) within a 10 m radius from the centre of the plot. Tree height (H) was also measured for trees representing the minimum, maximum, median, 25$^{th}$ and 75$^{th}$ percentile of the DBH distribution in the plot. Tree height measurements were taken using a Haglof Vertex IV ultrasonic device (Haglof, Sweden). All plot data were collected using the Field Map system (IFER, Czech Republic).

Height (H) values for unmeasured trees in the plot were then derived from measured DBH values using a DBH-H model for Sitka spruce and birch using the function (Pienaar and Turnbull 1973):

$$H = 1.3 + a(1 - Exp(b - DBH)^{(\frac{1}{c})} \qquad [1]$$

where H is tree height, DBH is diameter and coefficients a, b and c were solved using non-linear curve least squares fitting procedures using R software. All coefficients and model fits were significant at $p < 0.05$. Additional statistical analysis of model residuals using the Shapiro-Wilk test was carried out to ensure all DBH_H model residuals were normally distributed.

Top height was estimated from the measured height of the maximum DBH tree within the sample plot. Site index (a productivity index) for Sitka spruce, which is a normalised top height at 30-years, was calculated using the GROWFOR model (Broad and Lynch 2006).

*Quantifying the interactive effect of mixed species configurations*

Mixture proportions of basal area for a species of interest (e.g. Sitka spruce, $m_{sp}$ ($BA_{obs\ sp}$))

are a convenient way of determining the share of basal area under different species mixture planting configurations:

$$m_{sp}(BA_{obs}) = \frac{BA_{obs\ sp}}{BA_{obs\ sp} + BA_{obs\ b}} \qquad [2]$$

where $BA_{obs\ sp}$ and $BA_{obs\ b}$ are the observed basal area (in $m^2\ ha^{-1}$) of Sitka spruce (*sp*) and birch (*b*), respectively.

Pretzsch (2009) suggests that a better way of assessing species and site specific growing space requirement is to adjust the observed basal area proportions in a mixed stand by the basal area of a pure stand of each species grown on the site of interest. The relationship between the basal area of both species in a pure stand, which expresses the species-specific packing density, is applied to adjust observed basal areas of Sitka spruce and birch to their share of stand space and resources. Hence, the following adjusted mixture proportion equation was applied (Prezsch 2009):

$$m_{sp}(BA_{ref}) = \frac{BA_{obs\ sp}/BA_{ref\ sp}}{BA_{obs\ sp/BA_{ref\ sp}} + BA_{obs\ bi}/BA_{refb}} \qquad [3]$$

where $m_{sp}$ $(BA_{ref})$ is the adjusted mixture proportion for Sitka spruce and $BA_{ref}$ is the observed basal area for pure spruce (*sp*) and birch (*b*) grown in the same site. The $BA_{ref\ sp}$ values were derived from the basal area of the pure Sitka spruce plots (i.e. the SS treatment). Since there was no pure birch treatment in the experiment, $BA_{ref\ b}$ was approximated based on the mean basal area of birch in the mixtures and the relative proportion of initial species stem numbers in the different treatments within each experimental block (*i*):

$$BA_{ref\ b} = \frac{(BA_{b\ SB\ (i)} \times 2) + \left(BA_{b\ SSB\ (i)} \times \frac{3}{1}\right) + \left(BA_{b\ SSSB\ (i)} \times \frac{4}{1}\right) + (BA_{b\ SB_2(i)} \times 2) + (BA_{b\ SB_4(i)} \times 2)}{5} \qquad [4]$$

where $BA_b$ is the basal area of birch in the SB, SSB, SSSB, SB_2, and SB_4 treatments within each block *(i)*. It is assumed that $BA_{ref\ b}$ derived from equation 4 would be the same as the basal area of pure birch grown in the same experimental block. It is possible that spruce may influence the basal area of birch in mixtures or that the actual basal area of pure birch, if grown in the same experimental block, may be lower due to competition between trees within the crown. However, since comparisons of $m_{sp}$ $(BA_{ref})$ are made across the different treatments this should not introduce any bias because $m_{sp}$ $(BA_{ref})$ is a ratio and $BA_{ref\ b}$ is constant for each block.

The adjusted mixture proportion ($m_{sp}$ $(BA_{ref})$) is a measure of potential basal area production, relative to pure stands of spruce and birch grown at the same site. The authors propose that the ratio of $m_{sp}$ $(BA_{obs\ sp})$ over $m_{sp}$ $(BA_{ref})$ would provide an indication of the interaction between resource utilisation or resource availability by spruce and competition for the share in stand space by the two species in a mixed stand. This is because the difference between the observed and adjusted basal area mixture proportions is a measure of the difference in the realised basal area production of spruce compared with the potential basal area production of spruce in a given treatment. Therefore, $m_{sp}$ ($BA_{obs\ sp}$) must be less than $m_{sp}$ ($BA_{ref}$), which is true given the formulation of Eqs. 2 and 3. In other words, the potential basal area productivity is always greater than the observed basal area production. Hence, a higher ($m_{sp}$ ($BA_{obs}$)/$m_{sp}$ ($BA_{ref}$) ratio would indicate that a higher proportion of potential productivity is realised because site resource utilisation is maximised and/or competition effects are minimised.

Crown competition factor (CCF) is an alternative way of assessing competition within the crown. Open-grown crown radius was derived using equations presented by Hasenauer (1997):

$$cw = e^{a} DBH^{b} \qquad [5]$$

where *cw* is the open-grown crown radius (in m) and DBH is diameter at breast height (cm). There were no data available specific to the study region to derive *cw* estimates for Sitka spruce and birch. For Sitka spruce, the coefficients *a* and *b* for Norway spruce were taken directly from Hasenauer (1997); coefficients for birch were based on corresponding estimates for other broadleaves (Hasenauer 1997). These equations provide estimates of crown width of open-grown trees of each species. *CCF* (expressed as a percentage) for each treatment plot was then derived using equation defined by Wykoff (1990):

$$\mathrm{CCF} = \frac{1}{Area} \times \sum (\mathrm{OGCA}) \times 100 \qquad [6]$$

where *Area* is the area of the sample plot (0.03 ha) and OGCA is the sum of open-growth crown areas for all trees in the plot, expressed as $m^2$ per unit of sample plot area. CCF is a relative measure of packing density in the crown space and values above 200% indicate that tree growth may be limited by light availability due to crowding of the canopy (Black 2016, Preztsch 2009).

*Foliar analysis*

Foliage samples were collected in February 2017 from Sitka spruce only to assess if any nursing effects were reflected in the nutritional status of needles. Foliage samples (4-5 tree bulked samples per replicated treatment) were collected from the top section of the canopy of 4-5 trees directly adjacent to the centre of each sample plot. The 18 bulked samples were dispatched immediately after collection to the Forestry Commission Research Laboratory Alice Holt, Farnham, Surrey, England. The following macro elements and trace elements were determined in each sample: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu) and iron (Fe). Foliar samples were dried at 70 °C prior to weighing to remove any residual moisture content. The combustion method for determination of N was done using a Carlo Erba CN analyser (Flash1112 series) using 10 mg dried and ground needle samples. For P, K and trace elements, c. 100 mg of dried sample were weighed into a 15-ml borosilicate (or quartz) tube. One ml of concentrated sulphuric acid was added to each sample with 0.8 ml of hydrogen peroxide (30%). The tubes were then incubated on a heating block at 335 °C for 30 min or until the digests were clear. The samples were made up to 15 ml with distilled water and then analyzed on a dual view ICP-OES (Thermo ICap 6500).

*Statistical analysis*

ANOVA was performed, using the General Linear Models procedure in R (v3.4.1) to evaluate (fixed) effects of treatments ($\alpha$), with sites as blocks (random effects, $\beta$) according to the following model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \qquad [7]$$

where $Y_{ij}$ is the dependent variable (stem number, basal area, DBH etc.), $\mu$ is the grand mean, $\alpha$ is the fixed effect of treatment, $\beta$ the random effect of site, $\epsilon$ the residuals for treatment i and block j.

Numerous post hoc tests were carried out to ensure that the key assumptions underlying the random block ANOVA procedure were not violated. The model residuals were studied and in a few cases, the assumption of constant variance was violated according to the Shapiro-Wilk statistical test (in R v3.4.1). In these cases, the data were logarithmically or arcsine transformed before ANOVA, which improved the distribution of the residuals sufficiently to meet ANOVA requirements. A final test was carried out to ensure that there was no interaction between the block and treatment using Tukey's test for additivity from the "asbio" library in R. The null hypothesis is that there is no interaction term.

Means effects were tested separately for each species or aggregated plot level estimates, where there was a significant treatment effect (see Figure 2) and if all post-hoc test results confirmed basic ANOVA assumptions were not violated.

Finally, once all conditions of the random block AVOVA were met, differences between mean values for treatments was determined using Tukey's HSD test in R. For all statistical tests, p values $\leq 0.05$ were considered to be significant.

## Results

*Post establishment assessments*

Analysis of variance on the early establishment data revealed that there was no significant block or treatment effect for seedling height or survival rates in 2001 and

2003 (data not shown). In 2004, the mean height of Sitka spruce was significantly lower in the SSB_2 and SSB_4 treatment, when compared to treatments where Sitka spruce was planted 2 to 4 years earlier, as expected (Figure 2A). Although survival in the pure Sitka spruce treatment (SS) and the alternate rows of Sitka and birch planted at the same time (SB) was marginally lower when compared to the other treatments, this was not significant (Figure 2B).

There was no detailed documentation of the impact of frost in different plot treatments except for the May 2004 assessment carried out after a frost event. However, no treatment-specific differences in the extent of frost damage were observed. The only available record in the research notes indicated that the research forester observed that frost damage was more evident in plots located in the mid-south eastern areas of the site (i.e. plots SSB(1), SSSB(2), SS(2) and SB(2), see Figure 1).

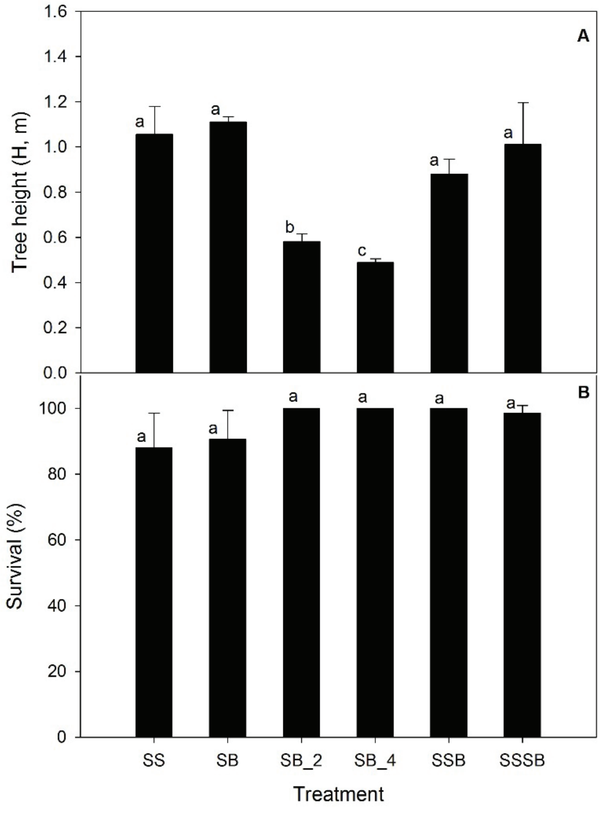


**Figure 2:** *Mean height (A) and survival (B) of Sitka spruce across the different planting treatments (see Figure 1 for code descriptions). Histograms (vertical bars indicate standard deviation) with different letters indicate that adjusted mean values are significantly different (at P <0.05).*

*Crop performance after 16 growing seasons*

The growth of Sitka spruce in the pure stand treatment (SS, no birch) was stunted, showing the characteristic P and K deficiency symptoms, based on visual observations. In contrast, the Sitka spruce trees in the mixed species plots planted at the same time as the birch showed no signs of a decrease in growth, no visual needle deficiency symptoms or signs of suppression by birch at this stage of canopy development.

The random block ANOVA model was significant for both DBH and height of Sitka spruce between the treatment and blocks (Table 1). Site index was only significant for the treatment effects (Table 1). Tukey's additive post hoc tests revealed that there was no interaction between treatments and block ($p = >0.05$).

Species was not included in the model as a factor, so mean comparisons are only valid within species (Figures 3, 4 and 5) and for total plot data (Figure 5).

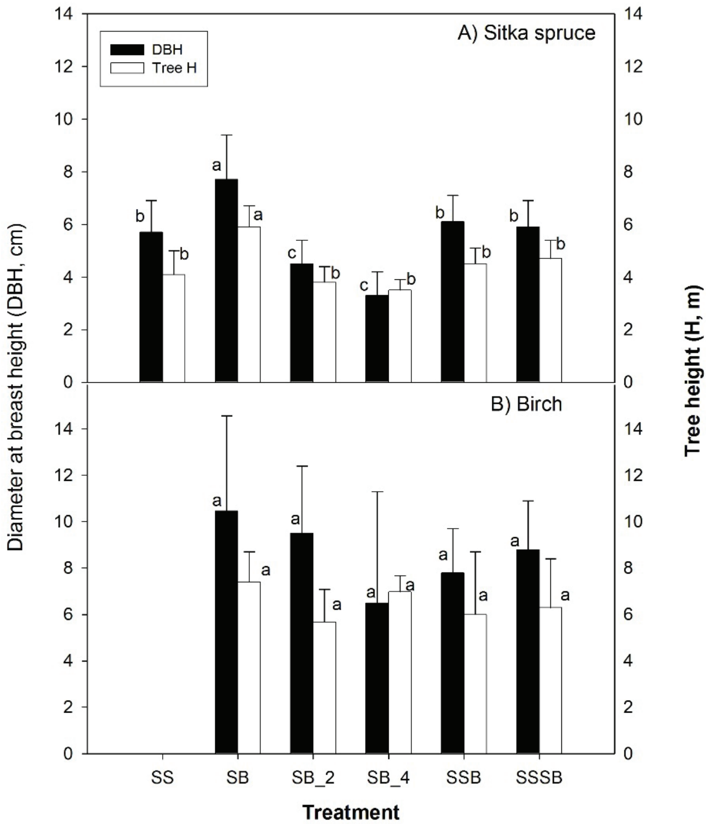


**Figure 3:** *Mean (plus one standard deviation) DBH and height values for Sitka spruce (top panel A) and birch (panel B) across the different planting treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values are significantly different (at P <0.05).*

**Table 1:** *Results from the random block ANOVA model showing the significance of the treatment (degrees of freedom = 5) and block effects (degrees of freedom = 2) on plot variables, such as DBH, and mean tree height area for Sitka spruce. All post hoc tests for normality of model residuals and treatment - block interactions were not significant (p >0.05).*

| Source of Variation | SS | df | MS | F-value | p-value |
|---|---|---|---|---|---|
| **DBH (cm)** | | | | | |
| Blocks | 10.4 | 2 | 2.2 | 4.2 | 0.011 |
| Treatments | 49.7 | 5 | 8.5 | 6.4 | 0.026 |
| Error | 14.2 | 11 | 1.6 | | |
| **Height (m)** | | | | | |
| Blocks | 3.14 | 2 | 2.5 | 3.6 | 0.03 |
| Treatments | 76.4 | 5 | 6.1 | 6.1 | 0.021 |
| Error | 31.5 | 11 | 1.9 | | |
| **Site index (m)** | | | | | |
| Blocks | 1.54 | 2 | 1.54 | 0.57 | 0.463 |
| Treatments | 62.35 | 5 | 12.47 | 4.66 | 0.015 |
| Error | 29.47 | 11 | 2.67 | | |

The mean comparison test results indicated that Sitka spruce, planted at the same time in alternate rows with birch, had a significantly greater mean DBH (from 19 to 57%) and height (from 20 to 47%), compared to those from the other treatment plots (Figure 3). When compared to the pure Sitka spruce treatment (SS), the DBH and height of Sitka spruce was c. 35% higher in the plots planted in alternate rows with birch (SB, Figure 3).

Although the height and diameter of birch trees appeared to be higher than that of Sitka spruce, there was more variation in DBH and height of birch trees, when

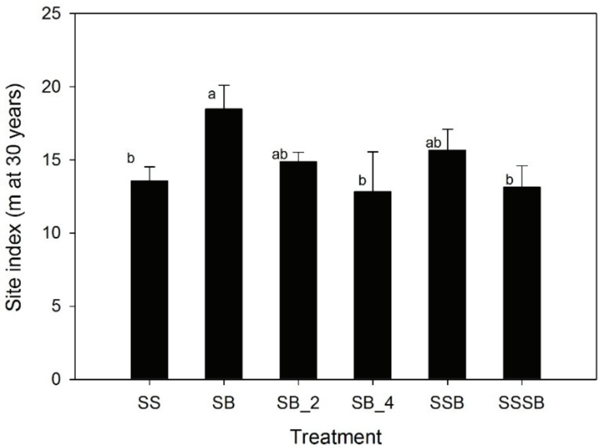


**Figure 4:** *Mean (vertical bars indicate one standard deviation) site index values for Sitka spruce across different treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values are significantly different (at P <0.05). Note: A site of index 10 and 15 is approximately equivalent to a potential yield class of 8 and 14 $m^3$ $ha^{-1}$ $yr^{-1}$, respectively.*

compared to Sitka spruce (Figure 3). There was a significant block effect for DBH and mean plot height of birch trees (data not shown), but there was no significant treatment effect for either of the variables (Figure 3).

Site index trends provide some evidence that the productivity of Sitka spruce planted in alternate rows at the same time (SB) is enhanced when compared to the monoculture (SS) plots. It is also evident that planting Sitka spruce at higher densities than a 50:50 mix with birch (SSB or SSSB) or delayed planting of Sitka spruce under birch (SB_2, SB_4) appeared to offer no significant nurse effect, when compared to pure Sitka spruce treatments (SS, Figure 4).

Stocking density (stems per ha) of Sitka spruce and birch differed between the treatments as expected, but there was no significant difference in total stems per ha across all treatments (data not shown). The mean basal area of Sitka spruce in the monoculture treatment (SS) plots was not significantly different to the spruce/birch mixture treatment, SB (Figure 5A), even though the number of stems per ha was double that present in the SS treatment plots. The mean total basal area for treatment SB (alternate rows of Sitka spruce and birch planted at the same time) was significantly higher (22 to 59%), when compared to all of the other treatments (Table 5B). This was associated with the significantly higher diameters in Sitka spruce in the mixed species treatment (SB, Figure 3).

*Nursing/competition interactions*

To establish if different planting combinations resulted in the enhancement of productivity or potential suppression of Sitka spruce, two competition indices were investigated (Figure 5C and D). Evaluation of crown competition factors showed that growth may be light limited in the treatments where Sitka spruce was planted in alternate rows with birch (i.e. SB, SB_2, and SB_4) because CCF values are above the threshold value of 200% (Figure 5C). It is also evident that birch is dominating the crown in all mixed species treatments since the birch trees were generally 20-40% taller than Sitka spruce (Figure 3) and basal area mixture ratios for spruce ($m_{sp}(BA_{obs})$) in all mixed treatments were below 0.5 (range 0.16 to 0.45, data not shown). Differences in the ratio of observed and adjusted mixture proportions ($m_{sp}(BA_{obs}/BA_{ref})$) may indicate that basal area production in spruce is affected by a combination of factors, such as resource utilisation by spruce and/or competition for light/space by both species in a mixed stand (see Material and methods section). The calculated $m_{sp}(BA_{obs}/BA_{ref})$ value for the spruce/birch treatment SB was significantly higher by 20 to 62%, when compared to all other mixed species planting configurations (Figure 5D). These trends are broadly consistent with the observed variation in site index across the different mixed species treatments. Regression analysis of the relationship between site index and $m_{sp}(BA_{obs}/BA_{ref})$ confirmed a significant $R^2$ of 0.46 at $p < 0.05$ (data not shown).

It should be stressed that interpretation of differences between the delayed Sitka

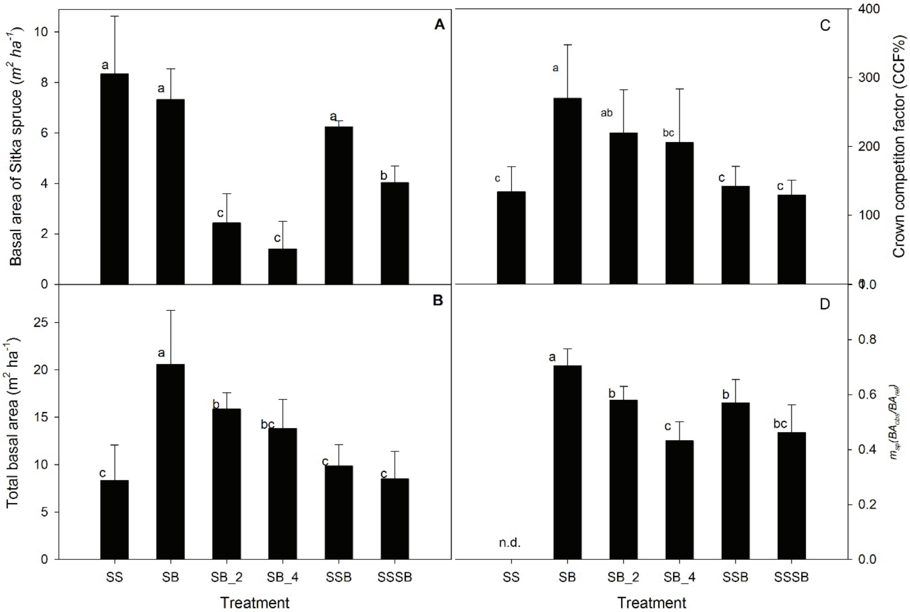


**Figure 5:** *Mean (vertical bars indicate one standard deviation) basal area (panel A), total basal area (panel B), crown competition factors (CCF, panel C) and the ratio of observed and adjusted mixture proportions ($m_{sp}(BA_{obs}/BA_{ref})$, panel D) for Sitka spruce across the different treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values were significantly different (at P <0.05).*

spruce planting treatments (SB_2 and SB_4) and the treatments planted in 2000 should be treated with caution, since differences in most cases (except for site index, Figure 4) may be associated with the differences in tree age. However, since there was a significantly lower $m_{sp}(BA_{obs}/BA_{ref})$ ratio in the SB_4, compared to other treatments, this may indicate poor resource utilisation efficiency or competition by birch in the canopy (Figure 5C and D). This would be consistent with the lowest site index value for the SB_4, compared to the other treatments.

*Effect of mixture treatments on nutrient status of Sitka spruce*

The nutrient status of Sitka spruce was investigated to assess if the apparent nursing effect by birch was related to nutritional factors. The mean foliage concentration of macronutrients and trace elements of Sitka spruce needles confirmed a significant treatment ($p < 0.05$) effect for P and iron (Fe). Comparison of plot means shows that levels of P in needles of Sitka spruce sampled from the alternate birch/spruce row treatment (planted at the same time, SB) was c. 33% higher than levels from the all the other treatments. This observation is consistent with the significantly higher productivity of Sitka spruce in the SB, compared to the other treatments (Figure 4). There was no significant treatment effect for all other trace elements and macronutrients (Table 2 and data not shown).

Based on the macronutrient concentrations in needles, both N and P levels in Sitka spruce in all of the treatments are deficient. Threshold N and P values were considered to be 1.2 and 0.13%, respectively (from Renou-Wilson et al. 2008).

**Discussion**

The results show that, on this cutaway peatland site, Sitka spruce planted with birch in alternate rows at the same time had an improved growth performance (c. 35% for both DBH and height and a 38% increase in site index) compared to pure Sitka spruce stands (Figures 3 and 4). These findings are consistent with the results of other studies conducted in naturally regenerating birch and Norway spruce stands in Sweden (Fahlvik et al. 2011, Johansson 2003), which suggested that productivity of Norway spruce was improved when grown with birch. Other studies on the effect of the birch shelter on planted Norway spruce seedlings suggest that a reduction in the risk of frost damage largely explains the nursing effect (Langvall and Ottosson Löfvenius 2002, Klang and Eko 1999). Although there was no evidence of protection against frost damage to Sitka spruce in this study (Figure 2), the results provide supporting evidence that the nutritional status of Sitka spruce is improved when planted in alternate lines at the same time as birch (Figure 4 and Table 2). It is, as yet, unknown how long this nutritional effect will last in these crops. The results presented in this study are for an experiment which was planted in 2000, so the crop is only 16-years-old. Mason (2006) suggested that Sitka, because of its greater vigour than Norway spruce, will dominate birch after 30 years, even when the birch has been established in advance of the spruce. Clearly the interaction between birch and spruce in these mixed stands would depend on site type and climatic factors. In some cases, spruce may dominate the canopy (Mason 2006). However, in less fertile sites and sites prone to frost damage, such as the stands presented in this study, birch is likely to dominate the canopy (Figures 3 and 5C). Encroachment of birch in afforested sites planted with

**Table 2:** *Mean values of selected micro- and macro- nutrients in Sitka spruce needles sampled from different treatments. Mean values (standard deviation in parenthesis) with different letters indicate that mean values are significantly different (at P <0.05).*

| **Treatment** | **N** (%) | **P** (%) | **K** (%) | **Fe** (ppm) |
|---|---|---|---|---|
| SS) Pure SS | 1.10 (0.16)a | 0.06 (0.01)b | 0.60 (0.09)a | 25.7 (2.4)b |
| SB) Alternate rows SS and BI | 1.11 (0.29)a | 0.09 (0.01)a | 0.78 (0.07)a | 32.2 (4.2)a |
| SB_2) Alternate rows, SS after 2 yrs | 1.12 (0.12)a | 0.07 (0.005)b | 0.63 (0.18)a | 26.9 (5.3)ab |
| SB_4) Alternate rows, SS after 4 yrs | 1.1 (0.09)a | 0.05 (0.02)b | 0.64 (0.07)a | 23.5 (5.3)b |
| SSB) 1 row BI 2 rows SS | 1.2 (0.09)a | 0.06 (0.01)b | 0.58 (0.18)a | 26.5 (4.9)ab |
| SSSB) 1 row BI 3 rows SS | 1.01 (0.1)a | 0.06 (0.01)b | 0.69 (0.13)a | 23.2 (3.6)b |

spruce in the mid-1980s to early 1990s and second-rotation spruce stands is very common in the midlands (Black et al. 2017a, Renou-Wilson et al. 2008).

The results from this study indicate that the proportion of species in mixed stands influences the interaction between the two species. Treatments planted with a higher proportion of Sitka spruce than 50% and where planting of spruce in alternative lines took place after 2 to 4 years did not show any increase in productivity, when compared to pure spruce treatments (Figure 4). The higher site index, $m_{sp}(BA_{obs}/BA_{ref})$ ratio and levels of foliar P in the treatments planted in alternative rows at the same time (SB, Figures 4 and 5D, Table 2) may suggest that birch may provide additional nutrient resources as a result of recycling of P in the litter layer, which is then made available to Sitka spruce, thus enhancing resource utilisation. Although it is possible that crown competition by birch has not suppressed basal area production of spruce at this stage, CCF values above 200% indicate that crown competition will supress the future growth of spruce unless some of the birch is removed.

One of the limiting factors in the design of these experiments was that that a pure birch treatment was not included in the random block design. This would be important in the design of mixed species experiments so that meaningful interactive effects between the two species could be evaluated. Although an alternative method was devised to estimate the adjusted mixture proportions described by Preztsch (2009, see Eq. 4), this estimation required the formulations of some assumptions, which in certain cases may not be realistic. The delay of planting Sitka spruce also created a statistical design problem, because apparent differences between these treatments (i.e. SB_2 and SB_4) and others may simply be an age difference effect. A complex experimental design, possibly including split plots or many more treatments may be required to address the age-effect problem. The only case where a feasible comparison could be made was when the site index was compared (Figure 4), since this is age independent. In contrast, the use of the conventional yield class assessment of productivity may introduce additional error associated with tree age (Broad and Lynch 2006). It is also important that these issues are carefully considered in advance of any planned thinning intervention in these experiments. The authors would advocate the use of split plots (i.e. no treatment and a silvicultural treatment) within the current randomised block design and the use of CCF values as a guide to crown thinning if more work is to be done on this experiment in the future.

Johansson (2003) highlighted the potential use of birch/spruce mixtures for both biomass and timber production using the Kronoberg management approach, where birch is utilised for biomass from thinnings and the final Norway spruce crop produces valuable timber. Management of the mixed spruce/birch stands, such as the SB treatment stand presented in this study, using the Kronoberg type of approach may be particularly suitable to the Bord na Móna estate since it can fulfil both bioenergy and timber production objectives. In addition, since this nursing effect of birch on spruce is evident on deeper peat sites (>1 m), this means that the range of sites suitable for commercial timber production of spruce can be increased. Recent studies on Sitka spruce across a range of peat depths on Irish cutaway peatlands suggest that pure Sitka spruce may not be suitable on peat depths greater than 0.8 m (Black et al. 2017b - this issue). The results presented in this paper suggest that the peat depths suitable for Sitka spruce can be increased to a maximum of 2 m deep, if spruce is planted in a mixture with birch at the same time. However, further research is required to assess whether the nursing effect will persist over time, so the trial needs to be re-evaluated in the future to determine the viability of the proposed spruce/birch mixed stands with some adapted version of Kronoberg silvicultural system on cutaway peats in Ireland. Although the current study suggests that increased availability of P may be the primary factor contributing to the nursing effect of birch on Sitka spruce on cutaway peatlands, foliar level of both N and P are below the deficit threshold.

The timing of silvicultural intervention is particularly important to ensure that the Sitka spruce crop in not suppressed whilst still preserving the birch nurse effect. Evidence from this study suggests that the current mixed stands (i.e. treatment SB, SB_2 and SB_4) require some thinning intervention to remove the dominating birch crown (Figure 5C). Late silvicultural intervention would also increase the risk of whipping damage (crown and leader damage) to spruce by birch (Fahlvik et al. 2011, Hilli et al. 2003).

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