Productivity of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) in coastal areas of northern Sweden

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Swedish University of Agricultural Sciences
Master Thesis no. 190
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Biography

Bo Zhang was born in the historic Chinese city of Kaifeng, in 1983. As a boy who grew up in the city, surrounded by video games throughout his childhood, he could barely recognize more than ten tree species. Therefore, he decided to learn something about nature in college, for the sake of his full-dimensional self-development. In 2005, Bo graduated from Northwest A&F University with a specialty in landscape gardening. After two years of full-time work in the China National Petroleum Corporation, as a drilling engineer, he obtained valuable tough-working experience, and earned money enabling him to change his life style; he realized his essential interests were nature-related sciences. Consequently, he started to pursue his master's studies in the Chinese Academy of Forestry (CAF), starting in 2007. During his studies at CAF, he was enrolled in the Euroforester MSc program at the Swedish University of Agricultural Sciences (SLU), through a bilateral agreement between the two institutions. He then moved to Alnarp, Sweden in 2010 to continue his master's studies. He received his master's degree in Forestry from CAF in 2010, and is currently working on another MSc degree from SLU, with the following thesis. Bo plans to follow his heart and dedicate himself to forestry research and/or practices.
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Abstract

Productivity of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) was studied on 12 sites in coastal areas of northern Sweden. On each site, sample plots were placed in adjacent Norway spruce and Scots pine stands with similar ages in between. Basal area, tree height, Site Index, volume production, simulated maximum mean annual increment (MAI_{max}) and tree vitality were compared for the two species. Average basal area at the time of measurement was 30.4% larger for Scots pine stands than for Norway spruce stands. The difference between the two species in basal area increment during the last 10 years was related to stand age. Basal area increment of Scots pine was larger than Norway spruce for young stands, and smaller than Norway spruce for older ones. Average height was 2.3 m higher for Scots pine stands than for Norway spruce stands. Height growth in the last year was also higher for Scots pine. Site Index (SI) for the two species was similar on most sites except for three sites, where SI for Scots pine was more than 10% larger than for Norway spruce. Total volume production for Scots pine stands was 29.9% higher than for Norway spruce stands. On average, simulated MAI_{max} was 13.8% higher for Scots pine than for Norway spruce, and age for reaching MAI_{max} was 16 years later for Norway spruce than Scots pine. Tree vitality was higher for Norway spruce than for Scots pine largely due to browsing by moose. Total damage rates were 16.0% and 4.6% for Scots pine and Norway spruce, respectively. The results from this study indicate that Scots pine has higher productivity than Norway spruce in coastal areas of northern Sweden. However, as is suggested by the comparison between the current results and those from a previous study in the interior northern Sweden, spruce is more recommendable in coastal areas than in interior locations from both the productivity and economic point of view. Yet, market fluctuation, climate change and/or other social matters should also be considered for selecting regeneration species.

Keywords: *Picea abies*, *Pinus sylvestris*, productivity, basal area, Site Index (SI), volume production, mean annual increment (MAI)

Sammanfattning

Produktiviteten av gran (*Picea abies*) och tall (*Pinus sylvestris*) studerades på 12 platser i kustområden i norra Sverige. På varje plats har provytor placerats i intilliggande bestånd med liknande ålder för de två trädarterna. Grundyta, trädhöjd, ståndortsindex, volymproduktion, simulerad kulmination av medeltillväxt (MAI_{max}) och trädets vitalitet jämfördes för de två arterna. Den genomsnittliga grundytan för tallbestånd var 30,4% högre än för granbestånd. Skillnaden mellan trädslagen i grundytetillväxt under de senaste 10 åren var relaterad till beståndens ålder. För yngre bestånd var grundytans ökning större för tall än för gran och för äldre bestånd var ökningen större för gran. Medelhöjden var 2.3 m högre för tallbestånden än för grabestånden. Sista årets höjdtillväxt var också högre för tall. Ståndortsindex för de två arterna var liknande på de flesta platser, förutom på tre lokaler, där ståndortsindexet för tall var mer än 10% högre än för gran. Volymproduktion för tall var 29,9% högre än för granbeståndet. Simulerad MAI_{max} var 13,8% högre för tall än för gran, och åldern för att nå MAI_{max} för gran var 16 år senare än för tall. Trädens vitalitet var högre för gran än för tall, främst på grund av älgskador. Andelen skadade träd uppskattades till 16,0% för tall och 4,6% för gran. Resultaten från denna studie indikerar att tall har högre produktivitet än gran i kustområden i norra Sverige. Tidigare studier har visat att produktion av tall är ännu mer överlägsen gran i norra Norrlands inland än vad som visas i denna studie för kustnära områden. I Norrland bör därför kustnära lokaler väljas i första hand för granplanteringar. Dock bör risk för skador, marknad, klimatförändring och en rad andra faktorer också vägas in i valet av trädslag.

Keywords: *Picea abies*, *Pinus sylvestris*, produktivitet, grundyta, ståndortsindex (SI), volymproduktion, MAI

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1. Introduction

It is an important task for forest managers and owners to decide which tree species should be used for regeneration. Selecting species with high productivity and sustainable yield has been adopted as a tradition and promoted by the relevant policies in Sweden for decades (Anon, 1998). With these two goals, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) became the two most popular tree species for both forestry industries and private owners. Norway spruce and Scots pine, respectively, consist of 41.9% and 39.0% of the total standing volume in Swedish forests. (Swedish forest agency, 2011). Therefore, knowledge of the productivity of the two species on specific sites is essential for forest management.

Historically, in order to meet the continuously increasing demands for timber and other forestry products during recent centuries, vast untouched forest resources in northern Sweden were exploited. Usually, pure coniferous stands were regenerated naturally or artificially after logging and thinning on valuable timbers. Biologically, Scots pine as a pioneer species naturally occurs on open patches created by clear-cuts, fire or other disturbances and dominates the forest successively. Norway spruce as a late succession species regenerates from under layers and then takes the dominance for longer periods (McCarthy, 2001). Norway spruce and Scots pine were favored and grew popular throughout Sweden, thanks to their fast growth and easy management. Geographically, there is a gradient that Norway spruce is more popular in the south and Scots pine in the north. In Götaland (southern Sweden), Norway spruce contributes to 47.4% of the total standing volume in all productive forest lands, while it goes down to 31.1% in the very north of Sweden. By contrast, Scots pine constitutes 30.1% in the south and rises up to 50.0% in the north (Swedish forest agency, 2011). Nowadays, monoculture coniferous plantation with clear-cutting system is the dominating management principle in Swedish forestry.

Although Scots pine is still dominating in northern Sweden, popularity of Norway spruce has increased during the last 20 years (Nilsson, 2012). Management for Norway spruce is relatively simple compared with Scots pine, and in southern Sweden, rotation for Norway spruce could be significantly shortened due to temperate site condition and fertile soil. Also, the risk of management failure is lower for Norway spruce as sawmills do not have a high requirement on the quality of Norway spruce timbers. Besides the simple management and short rotation, Norway spruce was also believed to be of greater productivity than Scots pine, especially on fertile sites. Meanwhile, there are also some practical considerations supported by scientific researches for promoting Norway spruce. Firstly, the amount of herbivores, such as moose, is increasing in the whole of Sweden due to the absence of carnivores, introduction of sex and age-specific harvesting, as well as increasing needs of hunting games (Hörnberg, 2001; Lavsund et al., 2003; Willebrand, 2009). Norway spruce stands are less browsed than Scots pine stands because herbivores, especially moose, have a strong preference for Scots pine. Browsing has caused severe damage to a large amount of young Scots pine stands in the north. According to the National Forestry Inventory, 10% of the Scots pine trees have been damaged by browsing (Swedish forest agency, 2010), which is much higher than the goal for less than 2% damaged stems. Secondly, the booming of Norway spruce plantations accelerated research and application of new technology for itself. For instance, slow initial growth was an evident drawback for Norway spruce. Now this problem has been abated significantly by the application of modern seedlings and scarification techniques (Örlander et al., 1990). Thirdly, traditional burning as a regeneration procedure in the "slash-and-burn" system, which may negatively influence the growth of Norway spruce (Elfving, 1983; Kardell & Laestadius, 1987), has been totally abandoned now.

There are several methods to compare productivities of different species under the same or similar site conditions. One way is to estimate and compare Site Index (SI) for different species among various site properties. SI is defined as the top height (the average height of, by diameter, the 100 thickest trees per hectare) at a fixed reference age. In practice, SI could be derived from the relationship between top height and age, from the intercept length of young trees or from site properties (Hägglund, 1981). The second method is to conduct long-term traditional experiment for different species on the same or similar sites. Data could be analyzed for productivity and growth potential. However, even though Swedish forestry is highly industrialized, only few experiments (Holmsgaard & Bang, 1977; Vollbrecht et al., 1995) have been established for this purpose. The wide variation in locations, site conditions, seedling types or silvicultural regimes cannot be fully covered by existing studies. As conducting long-term experiments is an intensive time consuming process, scientists invented models for simulating future growth, which is the third method for comparing productivities. With current growth status and SI, future production could be anticipated from a proper simulation model immediately. Several growth models have been established for estimating growth of Norway spruce and Scots pine stands during the last 40 years (Ekö, 1985; Eriksson, 1976; Persson, 1992; Söderberg, 1986).

Long-term experiments for comparing productivity between Norway spruce and Scots pine are rare in Sweden, especially in northern Sweden where Norway spruce has become popular just for the recent 20 years; therefore, experiments started one generation ago for comparing productivity with Scots pine are not expectable. However, several researches using temporary sample plots were carried out with SI estimation or simulation models to compare the productivity for the two species. Leijon (1979) set temporary sample plots on adjacent Norway spruce and Scots pine stands, and found that at the site where Norway spruce yielded 10-12 $m^3ha^{-1}year^{-1}$, production of Scots pine was only equal to 4-6 $m^3ha^{-1}year^{-1}$. Palo and Steijmar (1984) also set temporary sample plots in 45 pairs of Norway spruce and Scots pine neighboring stands with an age class of 25-35 years. Their simulation showed that production for Scots pine was better than for Norway spruce except for the most fertile sites, where Norway spruce can produce equally. Ekö et al. (2008) used SI to estimate production of Norway spruce, Scots pine and birch, with existing data from Swedish National Forestry Inventory. Their results showed that Norway spruce had higher yield potential than Scots pine in southern Sweden, but they were of equal productivity in the north. In the study performed by Nilsson (2012), temporary sample plots from 12 pairs of neighboring Norway spruce and Scots pine stands in interior areas of northern Sweden have be examined. The results showed the productivity of Scots pine was superior to that of Norway spruce in all pairs but one. In summarizing these studies, no consensus could be found regarding the productivity of the two species. In spite of the discrepancy among previous studies, it is generally perceived that productivity for Norway spruce is greater than for Scots pine in southern Sweden, whereas in the north, Scots pine is superior on most sites except for the most fertile ones where they are equally productive.

This study aims to compare the productivity of Norway spruce with Scots pine in coastal areas of northern Sweden. Results will be compared with previous studies, especially with the research conducted in the interior of northern Sweden by Nilsson (2012), to obtain an integrated understanding of productivity of the two species in northern Sweden.

2. Materials and methods

2.1. Site description

This study was carried out in coastal areas of northern Sweden. All Norway spruce and Scots pine stands were located along the western coast of the Baltic Sea, with longitude between 63°13' and 64°35', altitude within the range of 31m to 321m (Fig.1). Site 702064(l52) has the longest distance, 53 km, to the coast.

Twelve pairs of Norway spruce and Scots pine stands were chosen from the company Holmen Skog's property for study. Adjacent Norway spruce and Scots pine stands on similar forest sites, and with similar ages could form a pair. Sizes of the stands were from 0.8 ha to 61.4 ha. Stem density of each stand ranged between 1500-2610 trees per hectare according to the latest existing inventory. In each Norway spruce stand, Norway spruce constituted at least 59% of the basal area; the corresponding figure was 73% in Scots pine stands (Table 1).

All of the Norway spruce and Scots pine stands were planted. The total age of Norway spruce stands varied between 20 and 52 years, corresponding figures were 20-47 years for Scots pine stands. Within the 12 pairs, 6 pairs had the same total age for both Norway spruce and Scots pine. Five pairs had age differences between 1 and 5 years, and on site 715077-2(h35), Norway spruce stand was 10 years older than Scots pine stand (Table 1). Commercial thinnings were found at two stands, 58163 and 61877. According to the later calculation, 12% and 32% of the total volume were thinned in stand 58163 and 61877, respectively.

According to Hägglund's categorizing methods, the ground vegetation (Hägglund & Lundmark, 1987) was dominated by lingon berries (*Vaccinium vitis-idea*) and blueberries (*Vaccinium myrtillus*) on most sites (Table 1). However, some moderate nutrient-demanding herbaceous and moisture-indicating moss-species were also found as dominating ground vegetation on some sites. The soil moisture class (Hägglund & Lundmark, 1987) of most stands was ranked as mesic within 4 classes scale (dry, mesic, moist or wet). The soil texture (Hägglund & Lundmark, 1987) of each stand was registered as clay, fine texture or coarse. Most stands had fine soil texture, but coarse soil texture was recorded in few sites (Table 1). The groundwater availability, which refers to the potential for lateral soil water movement, was assessed with topographical gradient and the length of the slope above the site location. Three classes (S, K or L) were used for registering groundwater availability, in which S indicated poor groundwater availability, whereas K and L indicated the soil moisture class cannot be "dry" even if the groundwater level is deeper than 2m (Hägglund & Lundmark, 1987). Most sites were registered with K, which indicated moderate groundwater availability (Table 1).

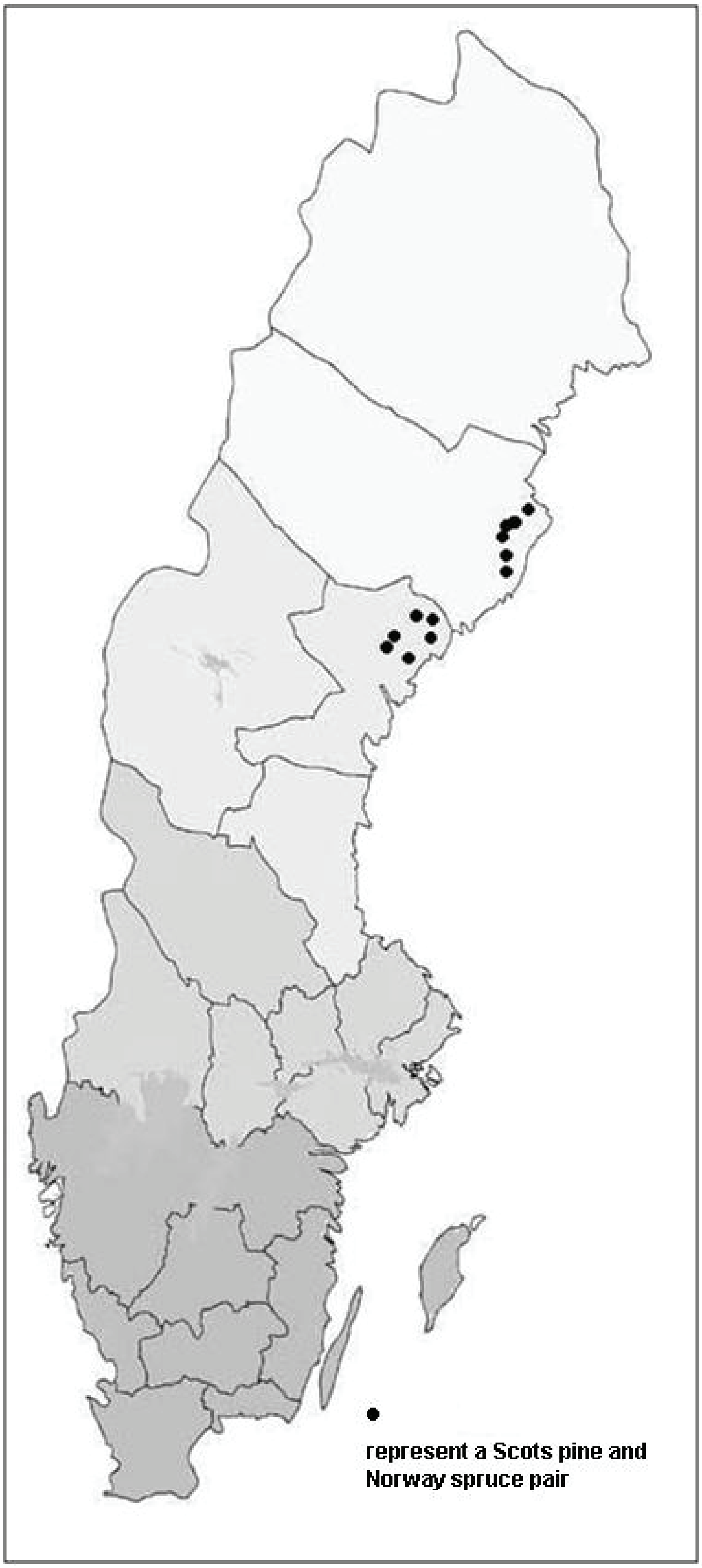

Fig. 1. Location of study sites

Table 1. Description of Norway spruce and Scots pine stands

Site ID (Code & Age)	Stand ID	Lat.	Long.	Elevation (m)	Stand size (ha)	Main Species[a]	Total age	Stems $ha^{-1,b}$	BA of main species (%)	Ground water [c]	Soil moisture[d]	Soil texture[e]	Vegetation type[f]
701068(a20)	57314	63°15'	18°44'	40	2.3	NS	20	2469	62.8	K	Mesic	Coarse	Lingon berry
	177389	63°13'	18°43'	31	4.3	SP	20	2907	95.5	K	Moist	Fine T	Blue berry
710077(b20)	103079	63°55'	20°39'	39	2.9	NS	20	1901	96.2	L	Moist	Fine T	Narrow-leaf grass
	106615	63°56'	20°33'	48	27.0	SP	20	3050	100	K	Mesic	Coarse	Lingon berry
711077(c21)	107192	64°00'	20°35'	73	12.2	NS	21	2432	73.4	L	Moist	Fine T	*Polytrichum commune*
	109997	64°01'	20°40'	56	14.4	SP	20	2741	93.6	K	Mesic	Fine T	*Polytrichum c.*& Lingon
715077-1(d21)	133993	64°24'	20°40'	203	7.4	NS	21	2697	90.5	K	Mesic	Fine T	Lingon berry
	133995	64°24'	20°40'	199	8.7	SP	21	2476	98.8	K	Mesic	Fine T	Lingon berry
703070(e22)	62586	63°20'	19°04'	54	4.5	NS	20	2918	94.4	K	Mesic	Fine T	Lingon berry
	62686	63°21'	19°06'	54	38.0	SP	22	1923	99.8	K	Mesic	Fine T	Lingon berry
704070(f27)	66953	63°28'	19°08'	86	28.3	NS	26	3151	93.2	K	Mesic	Fine T	*Polytrichum commune*
	66954	63°28'	19°08'	102	30.6	SP	27	2793	96.4	K	Mesic	Fine T	Lingon berry
705068(g29)	72648	63°32'	18°39'	251	24.6	NS	29	3050	66.9	K	Mesic	Fine T	Lingon berry
	72688	63°33	18°40'	242	61.4	SP	25	3183	81.4	S	Mesic	Fine T	Lingon berry
715077-2(h35)	134172	64°25'	20°45'	140	8.0	NS	35	3378	84.8	K	Mesic	Coarse	Blue berry
	134214	64°26'	20°46'	151	1.9	SP	25	2875	84.7	S	Mesic	Coarse	Blue berry
715077-3(i36)	134179	64°25'	20°44'	168	13.6	NS	36	2696	92.3	K	Mesic	Fine T	Blue berry
	134163	64°25'	20°45'	162	31.5	SP	36	1786	96.4	K	Mesic	Fine T	Lingon berry
703065(j43)	61851	63°22'	18°02'	269	2.7	NS	43	1865	87.4	S	Mesic	Fine T	Lingon berry
	61877	63°22'	18°00'	160	2.4	SP	43	1156	87.9	S	Mesic	Fine T	Lingon berry
717079(k44)	145576	64°35'	21°14'	75	0.9	NS	44	3515	59.0	K	Mesic	Fine T	Lingon berry
	145578	64°35'	21°13'	65	1.0	SP	44	3515	82.8	K	Mesic	Fine T	Lingon berry
702064(l52)	58235	63°18'	17°49'	321	0.8	NS	52	2412	86.5	K	Mesic	Fine T	Blue berry
	58163	63°18'	17°49'	266	5.3	SP	47	1728	73.7	K	Mesic	Fine T	Lingon berry

Note: **a**. *NS*-Norway spruce, *SP*-Scots pine; **b**. stem number was calculated by summing tree number from sample plots **c**. *S*, *K* and *L* represent different groundwater availabilities; see detail descriptions for *c-f* in *2.1 site description*

2.2. Sample plots and measurement

Four fixed-radius circular sample plots were placed in each stand. The radius of the sample plots varied between 6-8 meters depending on stem density recorded in the latest inventory. The goal was to include 20-40 trees in each sample plot. All sample plots were systematically distributed through each stand.

In the fields, soil moisture, soil texture, ground vegetation type, groundwater availability and thinning status were noted for each sample plot. Also, geographical coordinates and elevation of every sample plot center was recorded. All standing trees in the sample plot were callipered for diameter at breast height (DBH, 130cm above ground level).

Six trees were chosen as sample trees from the standing trees within each sample plot. After listing DBH of all callipered trees in a decreasing series, 2 trees with the largest DBH and another 4 trees whose DBH distributed in the series with an even interval were chosen as sample trees. For every sample tree, total height (H), height to last year (H-1) and height to the living crown (HL) were measured. At the same time, all sample trees were cored at breast height for measuring the ring widths for the last 5 years and 10 years. Moreover, in the two stands where commercial thinnings were carried out, all stumps were callipered for ground diameters. Sample trees were also callipered for ground diameters for establishing a regression function between ground diameter and DBH for that stand. Then each of the stumps would be assigned for a "DBH" derived from the function, which enabled them to be treated as a standing tree in the later analysis.

Besides productivity factors, tree vitality were recorded for all of the callipered trees in a four level scale: Dead, Severely Damaged, Slightly Damaged or Good. The vitality scale was constructed to reflect damage that had impact on volume production (Table2).

Table 2. Criteria for setting vitality scales

Vitality scale	Criteria
No damage	No damage
Slightly damaged	Canker, broken top, stem wound, crooked stem, fork stems
Severely damaged	Suppressed tree, stem breakage, leaning tree, felled but alive
Dead	Snag, high stump

2.3. Calculation and simulation

Basal area (BA) is the cross-sectional area (over the bark) at breast height (1.3 m above the ground) measured in meters squared (m^2ha^{-1}). BA can be used to estimate tree or stand volumes and competition (West, 2009). BA of each tree in the sample plots was calculated from its DBH. Also, basal area increments in the last 5 and 10 years were calculated from the measurement of ring width. Basal area per hectare was calculated for each stand by summarizing the BA of all callipered trees in its 4 sample plots, then dividing the summarized number by the area of the 4 sample plots in that stand.

Mean height of each stand was calculated by averaging heights of all callipered trees within the stand. The total height (H) of each callipered tree was derived from a regression function between DBH and the height of all sample trees within the stand. Height to last year (H-1) and height to the living crown (HL) of each callipered tree were derived in the same way.

Site Index (SI) of each stand was estimated from equations (Hägglund, 1972, 1974) that contain 2 parameters, dominant height and the stand age. Dominant height is generally defined as the average height of the 100 trees per hectare with the largest DBH (West, 2009). In this research, the dominant height was calculated by averaging the heights of the 8 sample trees with the largest DBH in the sample plots (2 sample trees with the largest DBH in 4 sample plots). Stand age was determined by the planting year from the silvicultural history records in Holmen's database.

Volume production per hectare of each stand was calculated in the following steps. First, the volume of each sample tree was calculated with one of four functions depending on the tree species and tree size. DBH, H and HL of each sample tree were used in these functions. After that, a regression function was built up between DBH and the volume for each individual tree. Lastly, volume of all callipered trees was estimated by using the regression function. Volume production per hectare of each stand was determined by summarizing the volume and the area of the 4 sample plots in the stand.

The 4 functions were used for estimating volume of individual sample trees (Andersson, 1954; Brandel, 1990):

Norway spruce (function group 100-02), if DBH>4.5cm

$$V=10^{-0.66277}\times DBH^{2.16277}\times(DBH+20)^{-0.81628}\times H^{2.92136}\times(H-1.3)^{-1.71059}\times HL^{0.04501}$$

Norway spruce, if DBH<4.5cm

$$V= 0.22+ 0.1086DBH^{2}+ 0.01712DBH^{2}*H+0.008905DBH*H^{2}$$

Scots pine (function group 100-2), if DBH>4.5cm

$$V=10^{-1.13921}\times DBH^{2.00449}\times(DBH+20)^{-0.12515}\times H^{1.50539}\times(H-1.3)^{-0.63102}\times HL^{0.05011}$$

Scots pine, if DBH<4.5cm

$$V= 0.22+ 0.1066DBH^{2}+ 0.02085DBH^{2}*H+ 0.008427DBH*H^{2}$$

where V (dm^3) is volume above stump for each sample tree. DBH (cm), H (m) and HL (m) are measured values which introduced previously.

Stand age varied between the two species in some pairs. In order to compare the volume production, current annual increment (CAI) was calculated by comparing current volume and volume till last year, which derived from H and H-1, respectively. Extra volume production estimated from CAI and age difference was added to the younger tree species for balancing the age difference.

Mean Annual Increment (MAI) refers to the average growth per year a stand at a specified age. Because typical growth patterns of most trees is sigmoidal, usually MAI starts out small, increases to a maximum value (MAI_{max}) as the tree matures, then declines slowly over the remainder of the tree's life (Avery, 2002). MAI_{max} is an effective factor for comparing the productivity of different species. In order to estimate MAI_{max}, volume growth of each stand was simulated with a growth model *Deep Thoughts* (Bergh *et al*., 2010). Plant density, total age, SI and mean BA from the field inventory were used as starting values in the simulation. Mean BA and variation in DBH would be replaced by mean height and variation in height in the simulator if the dominant height of the stand was below 9 meters. Tree growth was simulated until 100 year of total age. Commercial thinning was conducted during simulation to avoid self-thinning which meant volume loss in MAI estimation. At the same time, basal area was allowed to vary between 35-45 m^2ha^{-1} in the simulating process to keep a high stem density for a high growth rate. During each thinning, 10%-15% of BA was removed. Minor species had priority to be thinned, and thinning was done from below.

The SAS general linear model (Anon, 1998) was used to perform statistical tests. The following model was used:

$$Y_{ij}=m+A_i+B_j+e_{ij}$$

where A_i=effects of site (block) and B_j=effects of tree species. Correlations and significant differences of correlations were determined with the software Minitab® by *p* value ($p<0.05$) of Pearson's correlation coefficient.

3. Results

3.1. Basal area and basal area increment

Average basal area of Scots pine stands ($23m^2ha^{-1}$) was 30.4% larger than that of Norway spruce stands ($16m^2ha^{-1}$). BA of Scots pine stands was significantly larger than Norway spruce stands (Fig. 2) ($p<0.01$). BA of Scots pine stand was larger in all pairs except on site 703065(j43) and 702064(l52), where BA were similar for the two species (Fig. 2). The difference in basal area between the two species did not correlated with stand age ($p=0.679$).

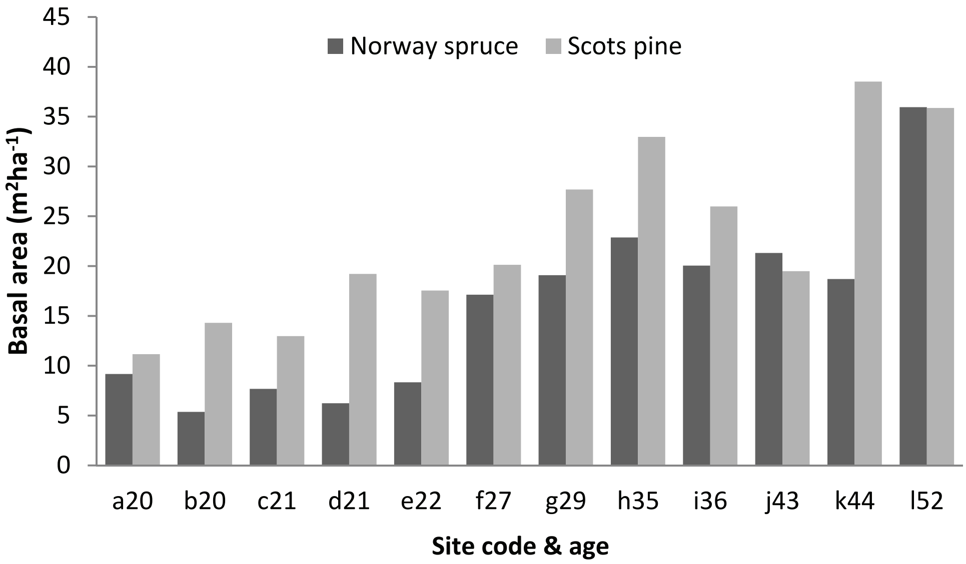

Fig. 2. Basal area of each stand

Basal area increments of the two species in the last 5-10 years were related to stand age. A general trend was that the superiority of Scots pine was decreasing with age (Fig. 3). Generally, the BA increment of Scots pine was larger than Norway spruce in younger stands and opposite trend was shown from older pairs.

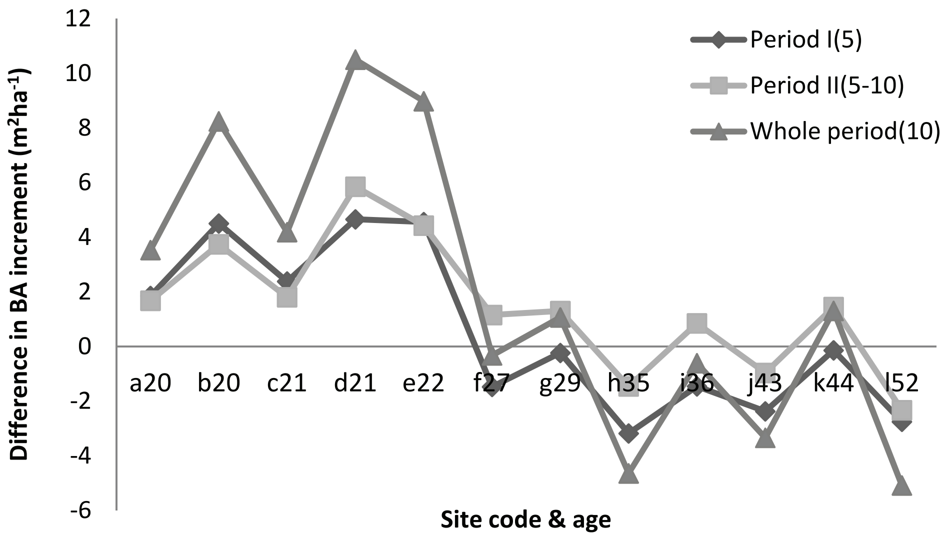

Fig. 3. Difference in BA increment for Norway spruce and Scots pine (pine minus spruce) in the last 10 years

3.2. Height and last year height growth

Average height of all Scots pine stands was 2.3m higher than Norway spruce stands. Mean height of Scots pine stand was higher than Norway spruce stand in all pairs but site 701068(a20), where the mean height of Norway spruce was 0.1m higher than Scots pine (Fig 4). The difference in average height between the two species was positively correlated with stand age (Correlation coefficient was 0.672, p=0.017). The height growth during the last year was also higher for Scots pine than for Norway spruce in all pairs except site 701068(a20) (Fig 5).

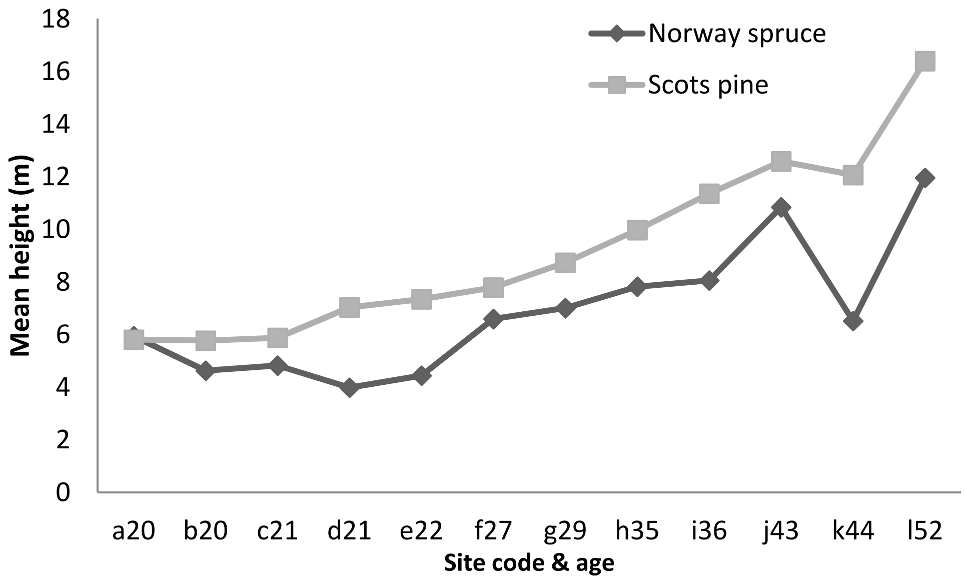

Fig. 4. Mean height of each stand

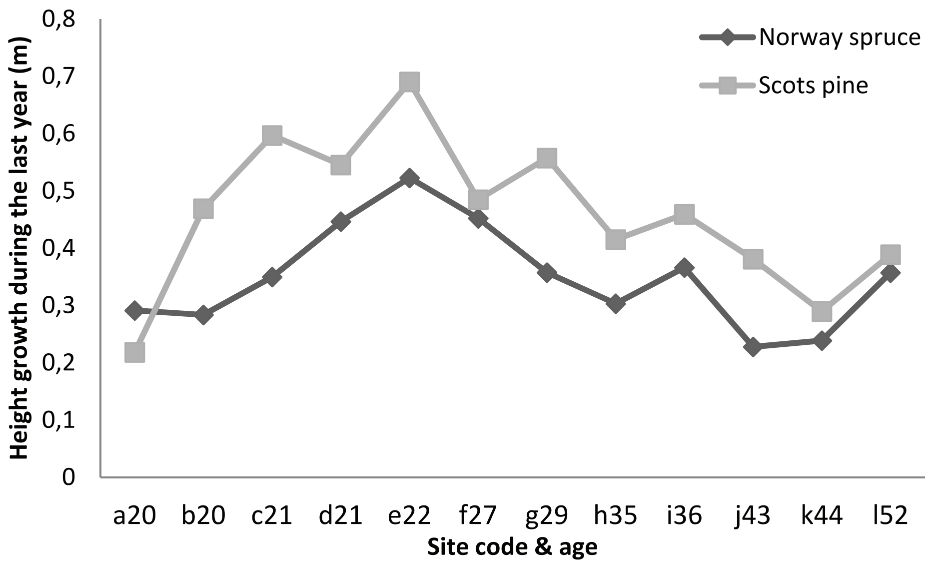

Fig. 5. Height growth in the last year

3.3. Site Index

The range of SI was between T25.2 to T32.0 for Scots pine stands and between G21.1 to G29.0 for Norway spruce stands (Table 3). Average value of SI for all Scots pine stands (27.7) was 2.9% higher than it was for all Norway spruce stands (26.9). SI for the two species was similar on most sites, significant difference occurred on sites 715077-1(d21), 715077-2(h35) and 717079(k44), where SI for Scots pine stand was 12.7%, 14.7% and 16.6% higher than for the Norway spruce stands (Table 3).

3.4. Volume production

Volume production at the last measurement for Scots pine were significantly larger than for Norway spruce (Fig. 6) ($p<0.01$). Total volume production for Scots pine was 29.9% higher than for Norway spruce. Scots pine was superior to Norway spruce in all pairs (Fig 6). The difference between the two species was not correlated with stand age (correlation coefficient was 0.16, $p=0.62$). The least difference occurred on site 701068(a20), where volume for Scots pine was only $1.65m^3ha^{-1}$ larger than Norway spruce. The two largest difference occurred on site 717079(k44) and 715077-2(h35), where Scots pine were superior to Norway spruce by 89.2 m^3ha^{-1} and 84.9 m^3ha^{-1}.

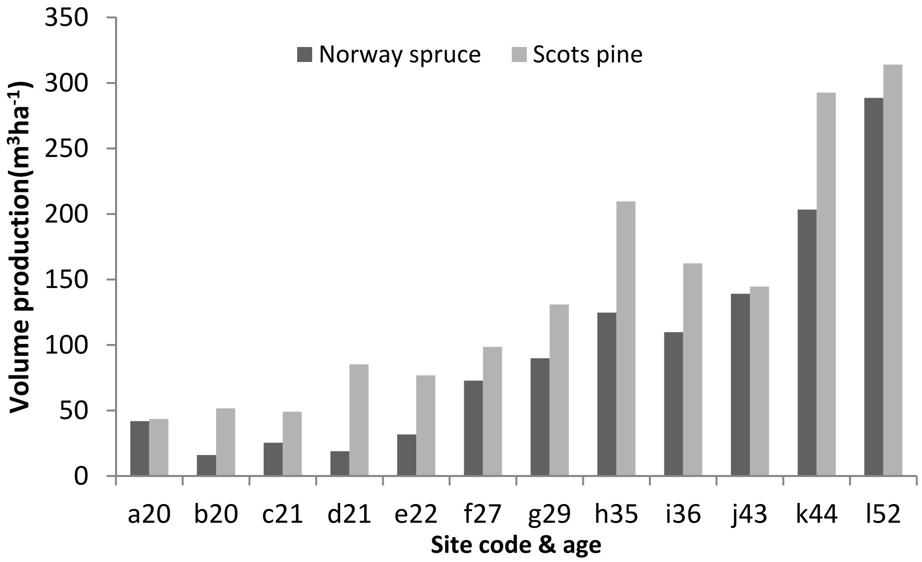

Fig. 6. Volume production of each stand

3.5. MAI_{max} and age for MAI_{max}

On average for all 12 pairs, simulated MAI_{max} was 13.8% higher for Scots pine than for Norway spruce (Table 3). Within the 12 pairs, simulated MAI_{max} for Scots pine were considerably higher in 9 pairs, whereas at sites 705068(g29) and 703065(j43), MAI_{max} for the two species were similar. At site 702064(l52), MAI_{max} was marginally greater for Norway spruce than for Scots pine. MAI_{max} differences of the two species were not correlated with SI of Scots pine (correlation coefficient 0.46, p=0.135).

According to the simulation, Scots pine stand reached its MAI peak at an average total age of 72 years. The corresponding age for Norway spruce was 88 years, which was 16 years later than Scots pine (Table 3). This difference was presented in all pairs except on site 701068(a20), where MAI_{max} for the two species appeared at the same age.

Table 3. Site Index, basal area, MAI_{max}, age for MAI_{max} and damage rate of each stand

Site ID	Norway spruce						Scots pine					
(Code & Age)	SI	Mean height(m)	BA (m^2ha^{-1})	MAI_{max} (m^3ha^{-1})	Age for MAI_{max}	Damage rate (%)	SI	Mean height(m)	BA (m^2ha^{-1})	MAI_{max} (m^3ha^{-1})	Age for MAI_{max}	Damage rate (%)
701068(a20)	28.0	6.0	9.2	8.1	80	6.5	27.6	5.8	11.2	8.7	80	7.3
710077(b20)	26.2	4.6	5.4	7.3	85	0	25.2	5.8	14.3	9.0	70	1.4
711077(c21)	27.5	4.8	7.7	8.1	86	0.9	26.5	5.9	13.0	8.8	75	5.6
715077-1(d21)	26.1	4.0	6.2	7.2	99	0.8	29.9	7.0	19.2	10.7	61	19.6
703070(e22)	29.1	4.4	8.3	8.7	80	13.6	31.1	7.4	17.5	9.7	62	52.9
704070(f27)	27.1	6.6	17.1	8.2	76	2.1	26.6	7.8	20.1	9.0	67	17.4
705068(g29)	29.0	7.0	19.1	8.9	84	2.9	27.1	8.7	27.7	9.0	55	5.6
715077-2(h35)	27.3	7.8	22.9	8.1	95	0	32.0	10.0	33.0	11.9	60	18.6
715077-3(i36)	26.5	8.1	20.0	7.5	91	1.2	26.3	11.4	26.0	8.3	81	25.5
703065(j43)	27.2	10.8	21.3	7.2	88	10.0	27.5	12.6	19.5	7.2	83	19.5
717079(k44)	21.1	6.5	18.7	6.1	99	9.4	25.3	12.1	38.5	8.3	84	3.1
702064(l52)	27.3	12.0	36.0	8.2	92	7.2	27.8	16.4	35.9	8.0	82	15.2
Average	26.9	6.9	16.0	7.8	88	4.6	27.7	9.2	23.0	9.1	72	16.0

MAI_{max} were positively correlated with SI for both Scots pine and Norway spruce (Fig. 7). The correlation coefficients were 0.73 ($p=0.007$) and 0.65 ($p=0.023$) for Scots pine and Norway spruce, respectively. At the same time, age for MAI_{max} was negatively correlated with SI for both species with correlation coefficients -0.54 ($p=0.067$) for Scots pine and -0.26 ($p=0.423$) for Norway spruce (Fig. 8). Moreover, age for MAI_{max} was also negatively correlated with the value of MAI_{max} for both Scots pine and Norway spruce (Fig. 9), and correlation coefficients were -0.75 ($p=0.005$) and -0.63 ($p=0.027$) for the two species, respectively.

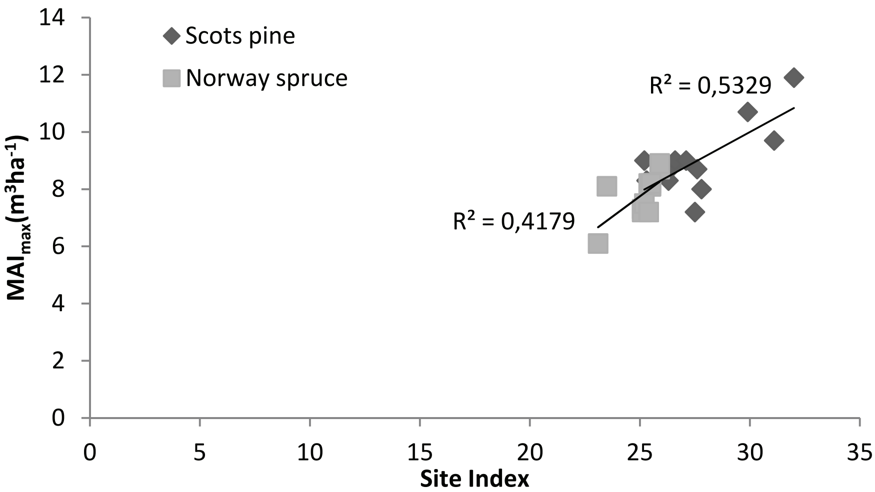

Fig. 7. Correlation between MAImax and Site Index

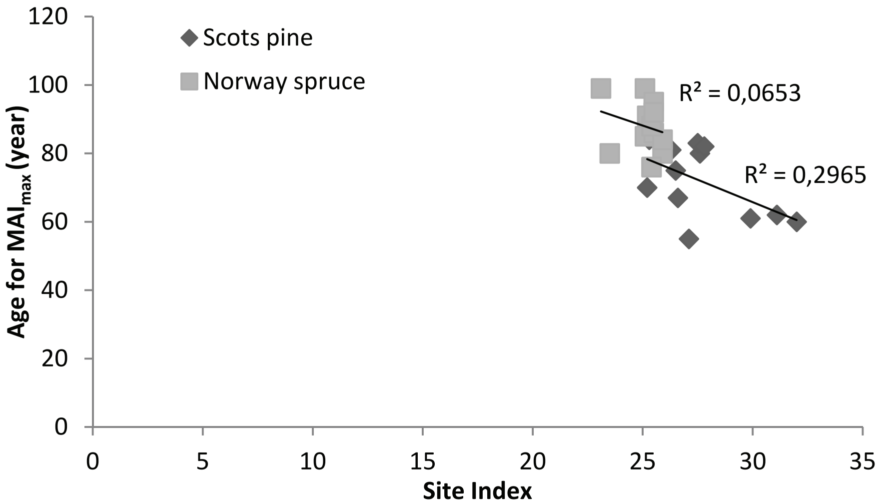

Fig. 8. Correlation between age for MAI_{max} and Site Index

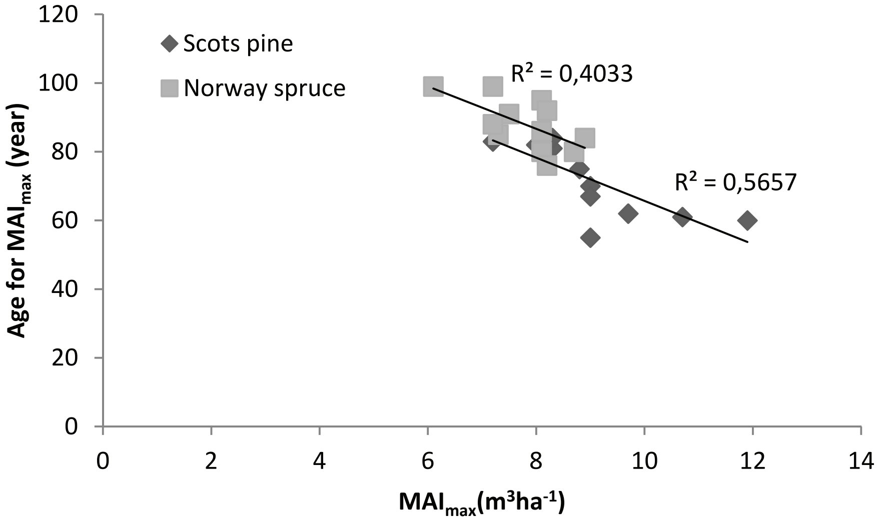

Fig. 9. Correlation between age for MAI_{max} and value of MAI_{max}

3.6. Tree vitality

Tree vitality was described by summarizing the damage records of all callipered trees. Results showed that the damage was higher in Scots pine stands than in Norway spruce stands. Combining three levels of damage, total damage rates were 16.0% and 4.6% for Scots pine and Norway spruce, respectively (Table 3). Percentage of Dead, Severely damaged and Slightly Damaged trees recorded in Scots pine stands were all higher than in Norway spruce stands (Fig. 10). Especially for trees recorded as Slightly Damaged, the rate for Scots pine stands was 5.6 times greater than for Norway spruce stands. The damage rate of Scots pine was higher than Norway spruce in all pairs except on site 717079(k44), where the damage rate for Norway spruce was 6.3% higher than Scots pine.

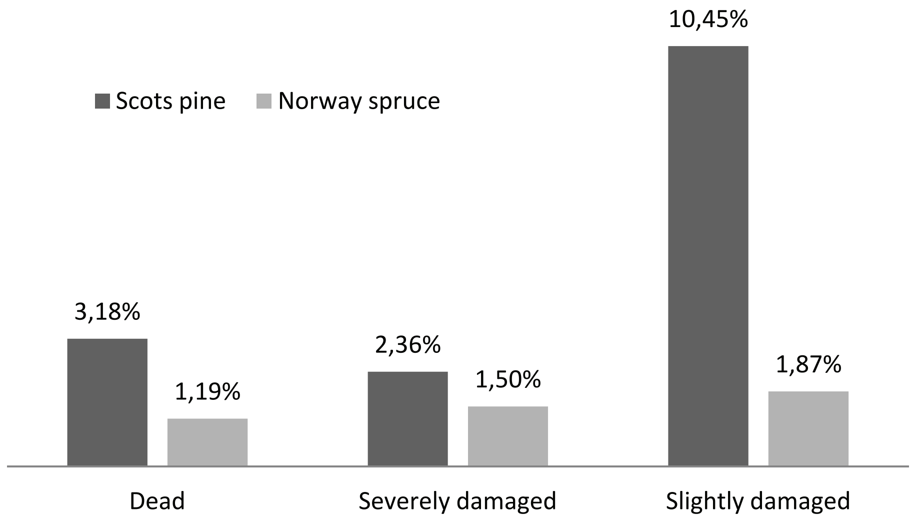

Fig. 10. Percentage of damage trees of the two tree species in three levels

4. Discussion

Analysis of BA increment in the last 10 years showed that Scots pine had larger increments in younger pairs, whereas Norway spruce had larger increments in older pairs. It indicates a larger initial growth for Scots pine, but Norway spruce caught up with time. The results of the present BA also supports this hypothesis. Basal area of Scots pine stands were larger than Norway spruce stands in most pairs due to its larger initial growth. However, Norway spruce had almost the same basal area in two of the three oldest stands, 703065(j43) and 702064(l52). The trendlines in Fig 3 indicate that Norway spruce can have a similar BA increment to Scots pine after about 25 years after planting; then, as growth continues, achieves a higher BA increment than Scots pine. However, due to the accumulation effect of Scots pine's larger initial growth, Norway spruce stands may present superior or similar BA only after 40-50 years after planting compared with Scots pine stands with the same age.

The values of SI were similar for the two species in most pairs except for three sites, where the SI for the Scots pine stand was more than 10% larger than for Norway spruce stand. Thus, it is difficult to make a conclusion based on the SI comparison from this study. Also, the results of the SI estimation from different equations could largely differ from one another (Hägglund & Lundmark, 1987). However, the estimated SI in this study was generally higher than the common perception for both species in the north, especially for Scots pine. This could be explained by either a higher fertility in costal northern Sweden or a general underestimation on productivity of the two species there. Further studies are also expected to provide possible explanations for the high SI for both species in this region.

The total volume production of Scots pine was 29.9% higher than Norway spruce. However, this difference is apparently smaller than that in the previous study performed by Nilsson (2012) in the interior northern Sweden, where volume production for Scots pine was about 70% higher than Norway spruce. Besides the difference of locations, the range of this stand age was 20-52 years in this study, while the corresponding range in Nilsson's study was 52-82 years. However, no clear correlation between volume production and stand age were displayed in any of the studies. Possible explanations for the difference from two studies will be further addressed in the discussion on MAI later.

The largest differences in volume production occurred on site 717079(k44), 715077-2(h35) and 715077-1(d21). According to Table 3, the three largest SI differences occurred on the same three sites. Higher SI for Scots pine stands, which means more fertile site condition for Scots pine than for Norway spruce within the same pair, may explain the larger volume production. In northern Sweden, blueberries and lingon berries, which indicate moderate to poor fertility, are the dominating ground vegetation on majority of forest sites. Results in this study showed that Scots pine had larger volume production than Norway spruce in this type of forest sites.

On average, simulated MAI_{max} were 9.1 m^3ha^{-1} and 7.8 m^3ha^{-1} for Scots pine and Norway spruce, respectively. Both of them are larger than the results from Nilsson's (2012) study conducted in interior areas, in which the corresponding figures were 7.1 m^3ha^{-1} and 4.4 m^3ha^{-1}. The difference of simulated MAI_{max} between the two species was mostly smaller in this study than it was in the interior locations. Simulated MAI_{max} for Scots pine was 13.8% higher than for Norway spruce in coastal areas in this study, while a 60% difference occurred in the interior areas. This "catch-up" trend for MAI_{max} and volume production in coastal areas could be explained with several hypotheses. Firstly, almost all investigated stands in Nilsson's (2012) study were regenerated before 1950s, whereas the stands in this study were more recently regenerated with new technology. The application of modern seedlings and scarification techniques for Norway spruce could largely improve its productivity (Örlander et al., 1990). Secondly, SI for both Scots pine and Norway spruce stands were generally higher in the current study than in the former one. This difference may indicate a general higher fertile site condition in coastal areas than in interior locations. It is supported by several studies that Norway spruce has better growth than Scots pine on fertile sites (Ekö et al., 2008; Leijon, 1979; Öyen & Tveite, 1998). Additionally, regarding MAI_{max} simulation, different simulation functions could influence the results too. The main factor that is responsible for the difference between two studies should be further examined in the future.

Simulated MAI_{max}, appeared in age 72 and 88 for Scots pine and Norway spruce, respectively. The corresponding ages in Nilsson's (2012) study were 82 and 134. Moreover, in this study, simulated MAI_{max}, appeared 16 years later for Norway spruce than Scots pine. The corresponding figure was 52 years in Nilsson's research. It suggests higher MAI_{max} occurred on more fertile sites, and the years for reaching MAI_{max} were shorter on fertile sites than on poorer sites too.

Combining results on simulated MAI_{max} together, it could be assumed that in costal northern Sweden, both Scots pine and Norway spruce have higher productivity in terms of MAI_{max} than in interior northern Sweden. At the same time, years for reaching MAI_{max} were shorter for both species at coastal locations too. Simulated MAI_{max}, for Norway spruce was dramatically higher in costal locations, which largely increased its competitiveness against Scots pine. At the same time, the year for Norway spruce to reach its MAI_{max} was significantly shorter in coastal locations than in interior ones. Therefore, regeneration of Norway spruce in coastal northern Sweden would be more recommendable than in interior northern Sweden from an economic point of view.

Tree vitality was lower for Scots pine stands than for Norway spruce stands largely due to damage from browsing by moose and other herbivores. In particular, this could be used for explaining that slight damage occurred significantly more in Scots pine stands, because most damage could be identified as typical browsing damage by moose. Lower mortality for Norway spruce plantation was also found in Nilsson's (2012) study. The high damage rate for Norway spruce on site 717079(k44) may be imputed to its mixed tree species composition. In the Norway spruce stand in this pair, basal area consist of 59% of Norway spruce, 13.6% of Scots pine and 27.3% of birch and other broadleaves. Also, it is worthy to point out that damage by browsing probably affected the comparison of productivity. Without damage by browsing, it is likely that the estimate of Scots pine production would have been higher.

During field inventory in Scots pine stand on site 717079(k44), which is one of the three oldest sites, some older trees may be included in the sample plots by mistake. Thus, the large difference in BA and volume production between the two species on this site should be considered critically. On site 715077-2(h35), the Norway spruce stand was 10 years older than the Scots pine. The difference in age was compensated by adding volume that was estimated from CAI calculation to Scots pine. Yet, adding 10 years' estimated volume would influence the result in volume comparison to a large extent. Also, on the two sites where commercial thinnings had been done, volume for thinned stumps was estimated from a regression function and added to the total volume production, the accuracy of volume comparison between the two species could also be influenced by the estimated volume.

In Sweden, 69% of net value from annual felling was from sawlogs and 23% from pulpwood (Swedish Forest Agency, 2011), and high quality Scots pine timber is generally more valuable than spruce timber (Table 4). Nowadays, it is forecasted that long-fiber pulpwood, such as those from Norway spruce, may face a market shrinking due to the decreasing needs of newsprints caused by internet applications. By contrast, printer paper, which is mainly made from short-fiber pulpwood such as eucalyptus, would be increasingly needed in the future, especially in developing economies. However, short-fiber pulpwood is produced faster and cheaper in tropical areas thanks to the shorter rotation and lower costs. Thus, Scots pine may be more profitable and suit this market change to some extent. Furthermore, an assessment conducted in Finland indicated the growth of Scots pine would more positively react to the climate change, i.e., warmer and more temperate climate in Scandinavia, than Norway spruce (Briceno-Elizondo et al., 2006). It is anticipated that growth of Scots pine would be increased up to 28% in the southern Finland and up to 54% in northern Finland due to the climate change; the corresponding figures for Norway spruce were 23% in the south and 40% in the north. In another simulation study in Sweden, increase of volume production caused by the elevated temperature and CO_2 was greater for Scots pine than for Norway spruce in southern Sweden but smaller in northern Sweden (Bergh et al. 2010).

Table 4. Average sawtimber and pulpwood prices (Euro per m^3) in Sweden 1999 (Egnell, 2000)

	Scots pine	**Norway spruce**
Saw timber Class1	87	65
Saw timber Class2	65	56
Saw timber Class3	68	54
Saw timber Class4	57	43
Pulpwood	24	27

In conclusion, this study provides evidence that Scots pine has higher productivity than Norway spruce in the coastal areas of northern Sweden over a wide range of sites which varied in level of fertility. In comparing results from this study with the previous study conducted in the interior areas of northern Sweden, the advantage of Scots pine was significantly lower from a production point of view. Therefore, Norway spruce could be more considered as an alternative in the coastal locations than it is in interior ones, but only if advanced seedling materials and proper scarification treatments are used. For

Scots pine, browsing damage by moose may increase in the future as the moose population is increasing due to the absence of predators, hunting restrictions and increasing demands of hunting games. An important question to consider is if the negative effects on timber production and timber quality from moose browsing can be compensated with higher production of Scots pine than Norway spruce? This should be studied via integrated research with forestry and economical concerns in the future. Last but not least, as a long-term investment, it is also valuable to consider market fluctuation, climate change and/or other social matters for determining the species to be regenerated.

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