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Productivity of Scots pine and Norway spruce in central Sweden and competitive release in mixtures of the two species

Emma Holmström[a,*], Martin Goude[a], Oscar Nilsson[a], Annika Nordin[b], Tomas Lundmark[b], Urban Nilsson[a]

[a] Southern Swedish Forest Research Centre, SLU, Alnarp, Sweden
[b] Department of Forest Ecology and Management, SLU, Umeå, Sweden

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ABSTRACT

A 53 year old growth and yield study of monocultures and mixture of two species, Scots pine and Norway spruce, was analysed. The replacement design of the experiment (at the time of establishment same density in all treatments and 50/50 proportion in the mixture) in ten blocks enables the comparison of site and species specific growth, as well as the species specific response to competition. In monocultures Scots pine, produced 126% more stem wood biomass than Norway spruce. Scots pine benefitted from the mixture and tended to grow as in a reduced spacing. Norway spruce, the subdominant tree species, suffered from the competition, and produced less than expected, with a lower mean diameter compared to the monoculture. Hence, no facilitative or complementary effects was possible to prove when growing the species in mixture. However, the experiment demonstrates that if the uncertainties in choice of species at the time of regeneration is high, then the mixture of two species could be an option. The lower density of the highest yielding species in the mixture compared to the monoculture, could be compensated in growth by the competition release.

1. Introduction

An increased understanding of growing trees in mixtures is important for many reasons in contemporary and future forest systems. Of one, mixed forest may be a measure to combine production, biodiversity and societal values on the same site. The trade-off between optimizing yield of the best growing species and manage a mixed forest, for e.g. habitat preservation, doesn't necessarily need to be highly economically divergent from traditional forestry (Pretzsch, 2009; Holmström et al., 2015; Felton et al., 2016). The main difference between monoculture and mixed stands is the inherit complexity of tree species specific response to competition and resource utilization. Trees with a higher growth rate, especially during the establishment years, tend to retain and also increase their superior volume (Harper, 1977; Stephenson et al., 2014), which has been explained by both higher resource use and use efficiency (Binkley et al., 2013; Gspaltl et al., 2013).

Recently, several surveys have found correlation between an increase in tree species richness, and an increase in biomass production (Bielak et al., 2014; Bielak et al., 2015; Pretzsch et al., 2015). These types of comparisons of subjective selections of monocultures and mixtures is sometimes also called triplets and is presented in a framework of evaluating eventual positive gain in yield by simply adding more tree species in a forest stand. An increase in yield due to species mixture is theoretically explained with either complementary effects, that the species utilize different strata of available resources although spatially growing together, or with facilitation, that one species enables an increase resource utilization for the other species (Kelty, 1992; Epron et al., 2013). Experimental results in support of these observational studies are so far missing for boreal forests in Fennoscandia. In contrary, the traditional and historical way of testing the relative yield of species in monoculture compared to mixtures is done by experiments with replacement designs and randomized treatment plots, where the total tree density is held constant while the species proportions is varied (Harper, 1977; Kelty, 1992; Fridley, 2001; Vanclay, 2006). Using the experimental set up enables a measure of the relative species yield and the total relative yield, defined as the sum of the ratio between yield for species A in mixture vs monoculture and species B in mixture vs monoculture.

Importantly, the replacement designs and measures of the total relative yield in experiments are foremost indicators of competition release, not an exact measure of resource complementarity (Hamilton,

* Corresponding author.
E-mail address: emma.holmstrom@slu.se (E. Holmström).

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Table 1
Stem number (trees ha^{-1}), basal area (m^2 ha^{-1}), quadratic mean diameter (cm), stem volume (m^3 ha^{-1}), mean top height (m) and basal area growth per tree (cm^2 tree^{-1} year^{-1}) for monocultures of Scots pine (SP.mono) and Norway spruce (NS.mono) and for the mixture of the two species. Values are given for individual blocks.

		Stem number		Basal area		Diameter		Volume		Top height	Basal area growth	
		(trees ha^{-1})		(m^2 ha^{-1})		(cm)		(m^3 ha^{-1})		(m)	(cm^2 tree^{-1} year^{-1})	
Block	Treatment	SP	NS	SP	NS	SP	NS	SP	NS		SP	NS
1	SP	1460	10	38.9	0	18.4	0.0	371.8	0	21	3.59	
	NS	0	1690	0	21.7	0.0	12.8	0	152.7	15.9		2.93
	Mix	720	780	28.7	9.1	22.5	12.2	272.1	73	20.6	5.65	2.91
2	SP	1410	30	43	0	19.7	0.0	436.5	0	22.7	3.86	
	NS	20	1800	0	21.5	0.0	12.3	0.1	156	15.7		2.81
	Mix	720	800	26.7	11	21.7	13.2	257.4	99.6	21.4	5.54	3.96
3	SP	1480	10	39.7	0	18.5	0.0	375.4	0	21.3	3.97	
	NS	0	1700	0	20.8	0.0	12.5	0	143.6	15.5		2.50
	Mix	830	820	29.3	5.9	21.2	9.6	273.1	36.1	21	5.45	2.18
4	SP	1400	0	36.6	0	18.2	0.0	338	0	20.4	4.09	
	NS	10	1380	0	26.5	0.0	15.6	0	247.6	19.9		4.07
	Mix	710	710	28.8	7.9	22.7	11.9	269.2	58.6	21	5.23	2.93
6	SP	1120	0	33.2	0	19.4	0.0	335.2	0	22.3	4.78	
	NS	0	1440	0	25.4	0.0	15.0	0	217.1	18.6		4.03
	Mix	680	580	30.2	7.7	23.8	13.0	292.9	61.1	21.8	6.17	3.68
7	SP	680	0	26.2	0	22.1	0.0	255.5	0	21.5	8.34	
	NS	30	1400	0.1	18.8	6.5	13.1	0.7	138.2	16.3		2.95
	Mix	540	530	25.9	4.1	24.7	9.9	252.5	26.6	21.8	7.88	3.86
8	SP	1110	0	31.4	0	19.0	0.0	302	0	21.6	4.99	
	NS	70	1620	0	18.4	0.0	12.0	0	116.6	14.8		2.29
	Mix	300	640	15.6	5.3	25.7	10.3	155.1	34.7	22.5	8.71	4.87
9	SP	750	140	25.2	0.3	20.7	5.2	241.3	2.6	21.9	6.40	
	NS	60	1620	0.1	19.6	4.6	12.4	0	129.5	15.3		2.50
	Mix	410	720	19.9	5.9	24.9	10.2	183.1	37.8	20.3	7.70	3.95
10	SP.	1430	0	38.8	0	18.6	0.0	358.6	0	20.1	4.57	
	NS	70	1600	0.1	14.1	4.3	10.6	0.8	79.4	12.8		2.41
	Mix	760	800	23.4	2.2	19.8	5.9	184.1	9.6	17	4.85	1.96

1994). More explicit, the increased growth of the best growing species in a mixture with a weaker competitor is not an evidence of facilitation or complementary, only an indicator of a reduced competition. The distinction might seem to be minor but is fundamental for the conclusions that can be drawn from too simplified comparisons or experiments (Snaydon, 1991). In several large scale surveys, where sample plots are used to correlate productivity to stand structures, total stand density has been found to be more important than tree species richness/mixture to explain productivity (Paquette and Messier, 2011; Vilà et al., 2013).

The boreal forest in Fennoscandia is dominated by two conifer species, Norway spruce (*Picea abies L.* Karst) and Scots pine (*Pinus sylvestris* L) and both are of major importance for a wide range of forest ecosystem services (Felton et al., 2016). During the last 100 years, a diversity of forest experiments has been established, mainly to investigate effects of management on stand growth and yield for either one of the species. However, there are few experiments with stand wise comparisons of the species on the same sites, in monoculture and/or in mixture and with a sound experimental design, using sufficient randomization and replications to elucidate species effects on stand growth. The only published experimental study that makes a pairwise comparison of the yield of the two species on a range of different sites in northern Sweden indicated that Scots pine had superior growth compared to Norway spruce on all sites with fertility ranging from relatively poor to fertile (Nilsson et al., 2012).

The mixture of Norway spruce and Scots pine is a common forest type according to the national forest inventory, approximately around 20% of the productive forest land (Nilsson, 2013). So far the research of stand growth and forest production is, however, predominantly done for monocultures of either tree-species. This study uses one of the few experiments in Sweden where two species are compared in monoculture and mixture, in a randomized block design with replications (Jonsson, 1999, 2001; Fahlvik et al., 2011). The Främlingshem site is of medium fertility where the traditional species selection with Norway spruce on more fertile and Scots pine on more poor sites, could be ambiguous. Not only the species specific growth potential in the future mature stand, but also to the uncertainties in the regeneration phase could be used as arguments in favour or disfavour of either of the two species. In this study the experiment is revisited and thoroughly measured for above-ground growth parameters.

The aim of this study was to evaluate effects of species choice and species mixture, on volume growth and diameter distribution. The replacement design of the experiment enables an analysis of how stand competition affect both the dominant and the suppressed tree species and we could therefore test the growth and yield accordingly.

Hypothesis tested were (i) stem volume growth of the mixture is higher than the mean growth of the two monocultures but lower than the best growing monoculture; (ii) growth of Scots pine and Norway spruce monocultures on medium fertile sites are not significantly different.

2. Material and methods

Measurements were done in a long-term field experiment in Främlingshem, in central Sweden (60° 30′N, 16°, 54′E). The experimental site is on altitude 70 m, with a mean annual temperature of 4.6 °C and annual precipitation 642 mm (during the period 1960–1990 at the nearest meteorological station in Gävle, about 22 km NE of the experimental site). The soil type was sandy-silty till and soil moisture-