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Sycamore for wood production: a combined stand density and seed source experiment

Experiments no. 8266 at Tönnersjöheden Experimental Forest
and no. 12633 at Remningstorp Forest Estate

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Cover: Sycamore in experiment 12633 at Remningstorp; 25 August 2020.

Photo: Ulf Johansson (for the whole report).

Maps: Figures 1 and 2: © Lantmäteriet.

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CONTENTS

BOX 1
Terminology

In forest research, the hierarchy of terms used to describe a forest field experiment and the statistical lay-out of an experiment may include:

- experiment
- site / location
- block
- plot

An experiment may include only one site or may be replicated on multiple sites / locations. Each site may include one or more blocks, and each block may include one or more plots. Plot is considered the unique experimental unit and may include many trees representing a stand or one individual tree (single-tree plot).

If an experiment includes multiple sites with two or more blocks on each site, the treatments are said to be replicated within site, and block is nested within site. The blocks may be laid out by geographical proximity or by a blocking variable representing, for example, site productivity (e.g., initial pre-treatment stand volume or stand top height) or site quality (e.g., soil texture or some other soil variable).

Historically, many forest field experiments had only one plot (one experimental unit) on each site or, after the introduction of statistical replications, one plot of each treatment on each site or, more rarely, partial or complete within-site replication of treatments. Traditionally, any such collection of experimental units, whether it included one or multiple units, has been, and is still, called an experiment, and multiple such experiments are said to belong to a series of experiment (for example, 'the series of thinning experiments in Norway spruce established in the 1960s').

In line with this 'classical' forest research terminology, the two *sites* in the sycamore experiment are labelled and recorded as experiment no. 8266 and no. 12633, respectively, in the national register of long-term forest field experiments in Sweden. However, in line with conventional statistical terminology we refer to both of these as belonging to *one* experiment replicated on two sites. We refer to each site by number and place name or by 'experiment no.' in quotation marks.

BACKGROUND

Sycamore (*Acer pseudoplatanus*) is currently spreading in southern Sweden, where it is considered a nuisance. The species is almost completely neglected in silviculture. However, sycamore has a good growth potential (better than beech and oak), it is easy to regenerate (hence the rapid natural spreading) and the timber fetches high prices in the European market (the market average for sycamore timber is three times higher than for beech, and veneer qualities sell at five to twenty times higher road-side prices).

Sycamore is native to mountain regions in Central and Southern Europe. The natural range of distribution stretches to northern France, Germany and Poland, and sycamore is known to grow well in Denmark and Great Britain. Sycamore is also climatically well adapted to southern Sweden. The expected future climate will further promote its spread and competitiveness.

For these reasons it is relevant and timely to test sycamore for wood production in Sweden (the background and arguments are further outlined in the Appendix). The field experiment(s) reported in this publication is a first step in this direction.

OBJECTIVE

The primary objective of the experiment is to investigate the influence of stand density on the growth, stem quality and health of sycamore in Sweden. The experiment is replicated on two sites and includes two seed sources.

Until canopy closure the experiment will be used to analyse the influence of original plant spacing on the development of sycamore. Subsequently, the experiment will be expanded to include different types of high-pruning and thinning.

The experiment will be used for testing scientific hypotheses within the scope of the objective. Additional issues may be researched, and hypotheses may be tested, as long as these do not conflict with the primary objective of the experiment.

The experiment will also be used to show forest managers, forest owners and others with an interest in forestry issues, how sycamore can be managed purposefully and what the consequences are of different management practices.

TERMINOLOGY

The two sites in the sycamore experiment are labelled and recorded as experiment no. 8266 and no. 12633, respectively, in the national register of long-term forest field experiments conducted by the Swedish University of Agricultural Sciences and coordinated by the Unit of Field-based Forest Research.

In line with conventional statistical terminology, we refer to both of these as belonging to *one* experiment replicated on two sites. We refer to each site by number and place name or by 'experiment no.' in quotation marks.

LOCATIONS

'Experiment no. 8266' is located in management unit 258 of Tönnersjöheden Experimental Forest near the road Slättvägen, approximately 4 km southwest of Simlångsdalen village and 14 km east of the city of Halmstad in Halland county (Figure 1; WGS84 coordinates: 56.69567° N, 13.10259° E, 95 m above sea level). This location is hereafter referred to as 8266 Theden.

'Experiment no. 12633' is located in management unit 447 of Remningstorp Forest Estate (belonging to the Wingquist Foundation) immediately north of the settlement Botorp, approximately 3 km north of Eggby village and 15 km northeast of the city of Skara in Västra Götaland county (Figure 2; WGS84 coordinates: 58.45292° N, 13.649139° E, 135 m above sea level). This location is hereafter referred to as 12633 Rtorp.

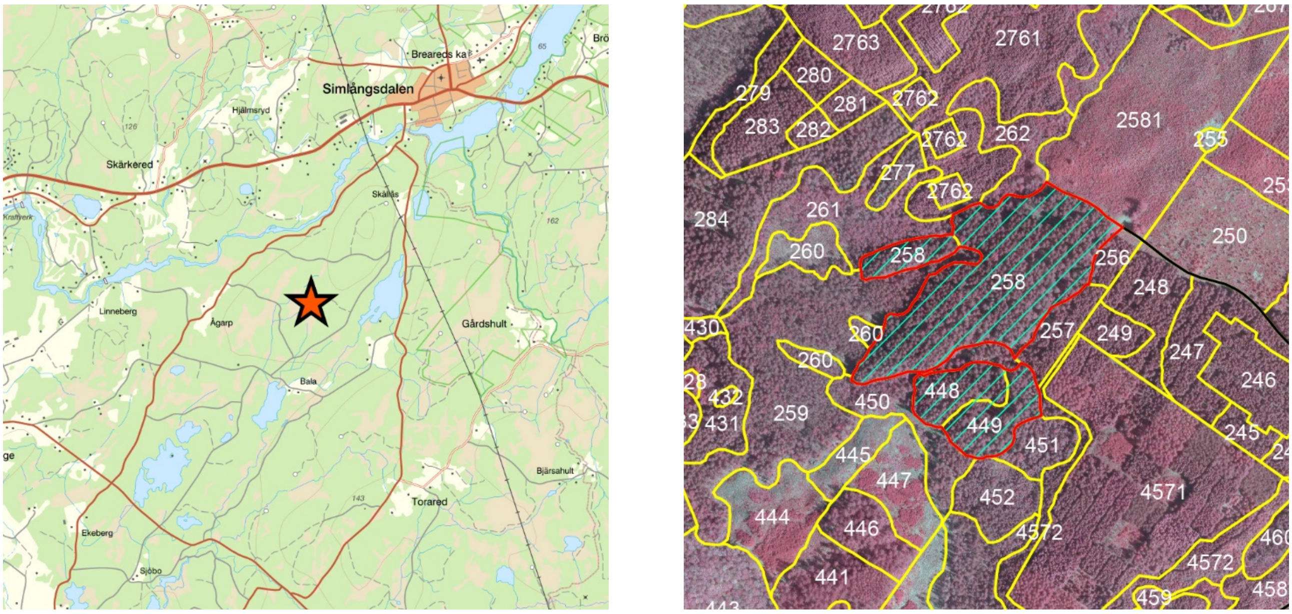

Figure 1
Location of 'experiment no. 8266' (star and green hatching).

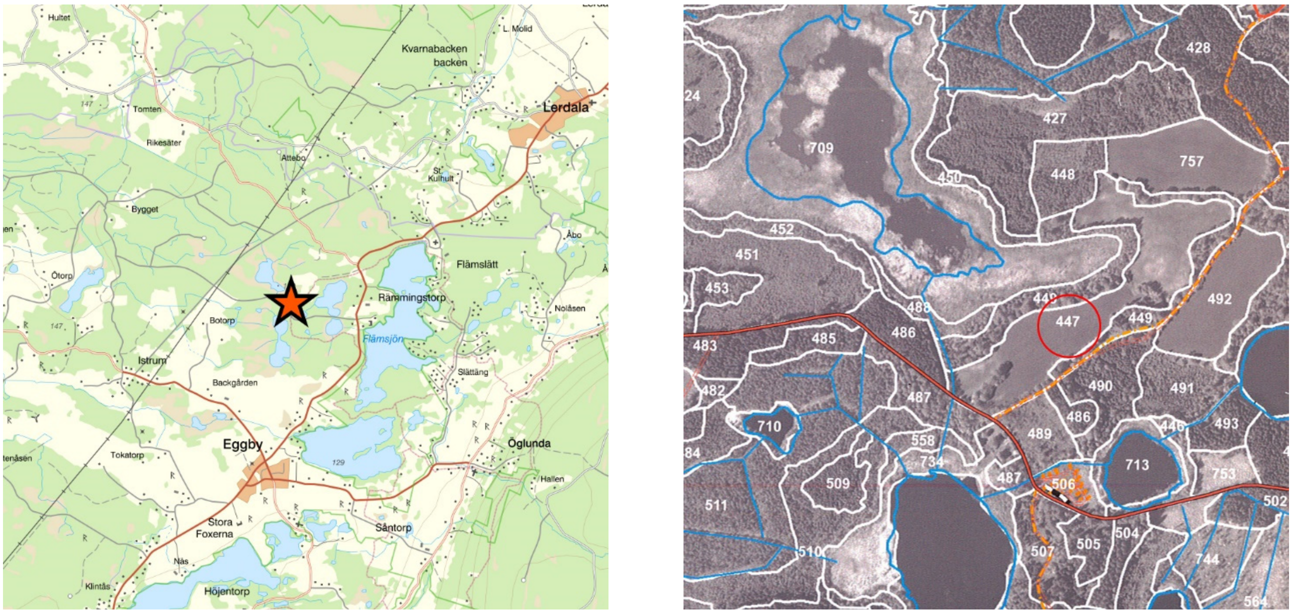

Figure 2
Location of 'experiment no. 12633' (star and red circle).

TREATMENTS AND STATISTICAL DESIGN

The experiment was laid out in a randomized complete block design on two locations (8266 Theden and 12633 Rtorp) with three blocks (replications) on each location and was planted with nursery stock originating from two different seed sources using three levels of planting distance / spacing (Figures 3 and 4). Blocking was by geographic proximity. Each plot includes a unique combination of seed source and planting distance, and plot is consequently the experimental unit.

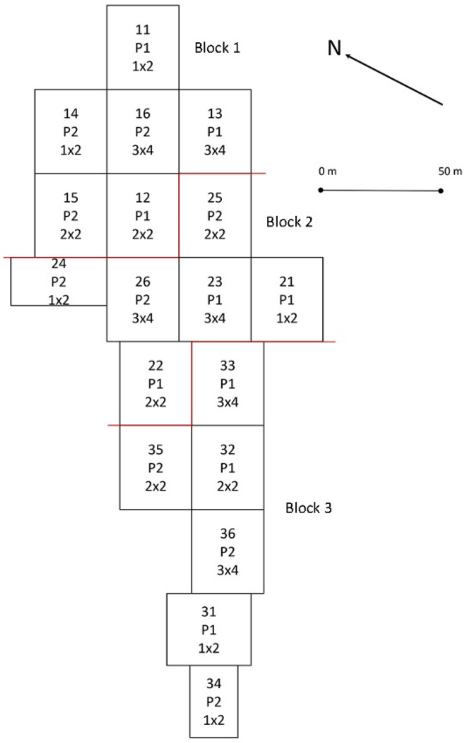

Figure 3
Location of blocks at 8266 Theden. Legend: line 1, first digit = block number, second digit = plot number; line 2, P1 = provenance / seed source F.804, P2 = F.648; line 3 = planting distance (between rows x within rows).

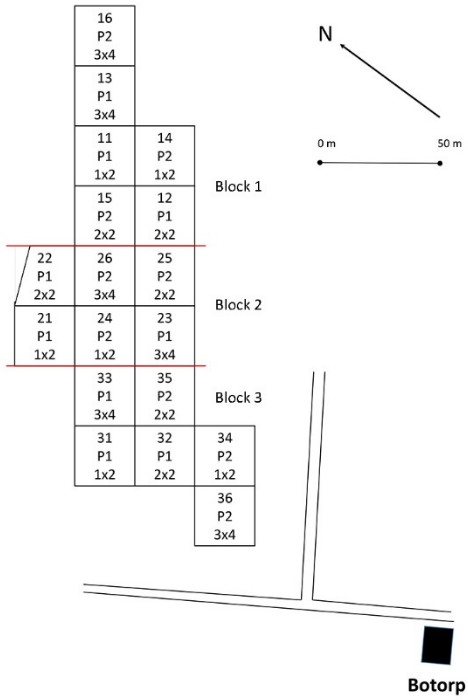

Figure 4
Location of blocks at 12633 Rtorp. Legend: line 1, first digit = block number, second digit = plot number; line 2, P1 = provenance / seed source F.804, P2 = F.648; line 3 = planting distance (between rows x within rows).

The design can be specified as follows:

Site	8266 Theden 12633 Rtorp
Block	Block 1 Block 2 Block 3
Seed source	F.804 Vestskoven, Denmark F.648 Bregentved, Denmark
Planting distance	1x2 (1 m x 2 m) 2x2 (2 m x 2 m) 3x4 (3 m x 4 m)

In summary, the experiment includes six unique treatments (combinations of seed source and planting distance) replicated in three blocks on each of two sites. Blocks are nested within site and this should be accounted for in subsequent analyses. Moreover, it may be useful to include a (continuous) co-variate representing each block or plot, for example a variable describing soil characteristics or another block- or plot-specific environmental factor.

LOCATION AND SIZE OF BLOCKS AND PLOTS
The location of experimental blocks and plots is shown in Figures 3 and 4.

SITE CONDITIONS

The experimental blocks of 8266 Theden are located on forest land and are surrounded by Norway spruce dominated forest stands of different age classes. The terrain is quite homogenous and flat with a small plateau in the southwestern part of the area. The soil is mesic and was derived from glacial sandy-loamy till overlying a bedrock of gneiss. At the time of planting the ground vegetation was dominated by mosses. Due to budget limitations, no soil analyses were performed at installation of the experiment.

The experimental blocks of 12633 Rtorp (Figure 5) are located on abandoned agricultural land and are surrounded by mixed broad-leaved dominated forest stands. The terrain is homogenous and flat with a small slope in the northernmost part of the area. The soil is mesic and was derived from coarse glacial sediments overlying a complicated mixture of bedrock including sandstone, limestone, and sedimentary shales. At the time of planting the ground vegetation was dominated by a mix of 'broadleaved' grasses and herbs. Due to budget limitations, no soil analyses were performed at installation of the experiment.

FORMER LAND-USE AND SITE PREPARATION

At 8266 Theden the area was formerly stocked with an old even-aged stand of Norway spruce, originally planted in 1894 on a former *Calluna* heathland. The spruce stand was slightly damaged by windstorms in 2005 and 2007, especially in the northern parts. It was finally harvested during the winter of 2018. Mechanised soil scarification was carried out by disc harrowing on 19 May 2019, aiming for a spacing of 2 m between planting rows.

At 12633 the area was formerly used for cattle grazing, but not during the years just before planting of the experiment. The ground vegetation was treated with Glyphosate (Round-up) on 3 June 2019. No other site preparation treatment (ploughing or harrowing) was carried out.

PLANTING STOCK, PLANTING AND FENCING

The planting stock was purchased in Denmark. Vestskoven F.804 was raised and delivered on 4 June 2019 at Tönnersjöheden Experimental Forest by Holm's Planteskole, Fjeldgårdsvej 25, DK-9750 Østervrå (un-transplanted 2-year-old root-pruned bareroot seedlings, type 2/0+, size class 40-60 cm). Bregentved F.648 was raised and delivered on 5 June 2019 at Tönnersjöheden by Højgård Planteskole, Hejlskovvej 50, DK-7840 Højslev (1-year-old bareroot seedlings, type 1/0, size class 60-100 cm).

Upon delivery from the nurseries the seedlings were kept in cool storage for 3-4 days at Tönnersjöheden until planting. Surplus seedlings were planted in a local, temporary nursery immediately outside the experimental plots to be used for replacement planting. Seedlings for 12633 Rtorp were delivered on 6 June 2019 to Remningstorp and kept in a cool storage for 6-8 days until planting.

At 8266 Theden manual planting was carried out on 7-8 June 2019. The area was fenced during 10-20 June 2019 (2 m high fence). Replacement planting took place on 5 May 2020. All dead trees were replaced. In plots designated for spacing 1 m x 2 m some missing seedlings were planted (these were missing due to an error in the original planting), and the original density was consequently restored. The seedlings were damaged by frost on 12 May 2020.

At 12633 Rtorp manual planting was carried out on 12-14 June 2019. The area was fenced during September 2019 (2 m high fence). The seedlings were browsed during the first summer due to late installation of the fence. Replacement planting took place in May 2020. All dead trees were replaced, and the original density was consequently restored.

Figure 5
12633 Rtorp. Overview of the experiment on 29 May 2020 as seen from the south (left) and of plot 34 (spacing 1 m x 2 m) on 25 August 2020 (right).

MEASUREMENTS

All plots were surveyed for homogeneity and measured for size prior to planting of the experiment (Table 1). The overall mean plot size was 816 m^2 (range: 562 m^2 – 1050 m^2).

The trees were measured for total height at planting (only 8266 Theden) and during autumn 2019 and autumn 2020 scored for survival and re-measured for height (Tables 2 and 3). Total height at planting of F.804 varied from 18 to 67 cm (mean = 39.6 cm, s = 9.6 cm) and of F.648 from 45 to 105 cm (mean = 69.2 cm, s = 11.8 cm). At 8266 Theden, one-year survival was 100 % and second-year survival 95 %. At 12633 Rtorp second-year survival was 98 %. At 8266 Theden, first-year average seedling height growth was 2.5 cm and second-year average growth was -0.6 cm (influenced by frost damage). At 12633 Rtorp, second-year average seedling height growth was 25.2 cm.

Future measurements are scheduled to include dbh, total tree height, height to lowest stem fork (if any), other stem quality indicators (straightness (tilt and bend)), and biotic and abiotic damages at regular intervals. Any additional measurements will depend on survival success, funding opportunities and possible additional interests that may arise in the future.

Table 1
Plot size (m^2) per site and block. Legend: Block 1 at 8266 Theden is labelled T1, block 2 at 12633 Rtorp is labelled R2, etc.

Treatment	Block T1	Block T2	Block T3	Block R1	Block R2	Block R3
F.804-1x2	1050	1050	1050	625	625	625
F.804-2x2	1050	1050	1050	625	562	625
F.804-3x4	1050	1050	1050	625	625	625
F.648-1x2	1050	800	600	625	625	625
F.648-2x2	1050	1050	1050	625	625	625
F.648-3x4	1050	1050	1050	625	625	625

Table 2
Average total tree height (h_m, cm) for sycamore in the year of planting, first- and second-year survival (*surv*, %) and height growth (i_h, cm). Note: 8266 Theden was first measured at planting (spring 2019), while 12633 Rtorp was measured at the end of the first growing season after planting (autumn 2019). Legend: a = autumn, s = spring, *n* = number of observations.

Site	8266						12633			
	h_m	*surv*	*surv*	i_h	i_h	*n*	h_m	*surv*	i_h	*n*
	cm	%	%	cm	*cm*		cm	%	cm	
Treatment	2019s	2019a	2020a	2019	2020		2019a	2020a	2020	
F.804-1x2	40.8	100	94	1.6	-3.1	72	64.4	97	30.3	73
F.804-2x2	36.8	100	98	2.7	-0.5	57	60.9	100	24.0	36
F.804-3x4	40.8	100	91	0.5	0.0	80	64.7	100	30.2	48
F.648-1x2	67.7	100	98	3.9	3.5	59	92.5	100	20.2	74
F.648-2x2	67.1	100	98	3.2	-0.9	54	85.3	97	30.9	39
F.648-3x4	72.3	100	92	3.3	-1.6	86	83.6	85	11.4	47
Site mean	54.0	100	95	2.5	-0.6	408	76.1	98	25.2	317

DURATION OF THE EXPERIMENT

The experiment is expected to run for a whole rotation (expectedly 60-120 years). If the plots develop successfully the experiment should be converted into a pruning and thinning experiment. This will require specification of additional treatments in terms of pruning methods and thinning practices and may require a superimposed statistical lay-out, the design of which will depend on the development of individual plots and the specific research objectives relating to pruning and thinning.

ACKNOWLEDGEMENTS

Installation of the sycamore experiment was supported by Stiftelsen Skogssällskapet during 2017-20. Permission to use land for 12633 Rtorp was granted by the Hildur and Sven Wingquist foundation.

Table 3. Seedling height (*h*) at planting (spring 2019), at re-measurement (autumn 2019 and 2020) and seedling survival (*surv*). Legend: m = treatment means.

Exp.	Plot	Prov.	Spacing	*h* 2019 spring			*h* 2019	*h* 2020	*surv*	*surv.*
				Mean	Min	Max	autumn	autumn	2019	2020
				cm	cm	cm	cm	cm	%	% [1]
8266	11	P1	1x2	38.2	18	54	41.4	40.3	100	122
8266	12	P1	2x2	34.3	27	39	36.7	38.8	100	100
8266	13	P1	3x4	42.3	28	65	43.8	48.1	100	89
8266	14	P2	1x2	62.2	45	98	67.4	71.9	100	121
8266	15	P2	2x2	64.4	48	89	69.1	68.5	100	100
8266	16	P2	3x4	69.8	51	99	74.6	84.3	100	100
8266	21	P1	1x2	36.9	19	62	40.5	40.3	100	128
8266	22	P1	2x2	33.0	23	41	35.4	33.9	100	95
8266	23	P1	3x4	42.0	23	66	43.8	41.8	100	92
8266	24	P2	1x2	74.5	60	89	79.1	78.7	100	109
8266	25	P2	2x2	66.3	52	89	67.1	60.7	100	100
8266	26	P2	3x4	76.6	48	99	80.1	73.3	100	94
8266	31	P1	1x2	47.3	32	67	45.3	37.1	100	140
8266	32	P1	2x2	43.0	27	63	46.4	44.5	100	100
8266	33	P1	3x4	38.0	24	55	36.1	33.9	100	93
8266	34	P2	1x2	66.5	55	81	68.5	74.9	100	147
8266	35	P2	2x2	70.6	51	105	74.9	79.0	100	95
8266	36	P2	3x4	70.4	50	90	72.0	64.2	100	81
8266	m	P1	1x2	40.8	23	61	42.4	39.3	100	130
8266	m	P1	2x2	36.8	26	48	39.5	39.0	100	98
8266	m	P1	3x4	40.8	25	62	41.2	41.3	100	91
8266	m	P2	1x2	67.7	53	89	71.6	75.1	100	126
8266	m	P2	2x2	67.1	50	94	70.3	69.4	100	98
8266	m	P2	3x4	72.3	50	96	75.6	74.0	100	92
12633	11	P1	1x2				57.0	74.3		96
12633	12	P1	2x2				61.6	85.8		100
12633	13	P1	3x4				59.6	79.1		100
12633	14	P2	1x2				85.3	101.3		100
12633	15	P2	2x2				89.6	90.9		100
12633	16	P2	3x4				69.0	71.6		60
12633	21	P1	1x2				72.7	115.4		100
12633	22	P1	2x2				63.5	85.2		100
12633	23	P1	3x4				67.3	98.4		100
12633	24	P2	1x2				99.5	127.9		100
12633	25	P2	2x2				79.1	115.2		92
12633	26	P2	3x4				91.4	110.9		100
12633	31	P1	1x2				63.6	94.4		96
12633	32	P1	2x2				57.5	83.6		100
12633	33	P1	3x4				67.1	107.2		100
12633	34	P2	1x2				92.6	108.3		100
12633	35	P2	2x2				87.2	142.6		100
12633	36	P2	3x4				90.3	102.5		94
12633	m	P1	1x2				64.4	94.7		97
12633	m	P1	2x2				60.9	84.8		100
12633	m	P1	3x4				64.7	94.9		100
12633	m	P2	1x2				92.5	112.5		100
12633	m	P2	2x2				85.3	116.2		97
12633	m	P2	3x4				83.6	95.0		85

[1] Spacing 1x2 m at 8266 has increased survival due to planting of missing trees in 2020.

APPENDIX
BACKGROUND AND ARGUMENTS FOR THE EXPERIMENT

Sycamore (*Acer pseudoplatanus*, in Swedish: *sykomorlönn* or *tysklönn*) is widespread in all of central and much of northern Europe where it is often a significant component in the forest and a highly valued commercial species (Hein et al. 2009, Spiecker et al. 2009). It was introduced to Sweden in the early 1770s (Retzius 1806). Sycamore is closely related to the native Norway maple (*Acer platanoides*) and to field maple (*Acer campestre*).

Spread and regeneration potential

Following early escapes to the wild beginning in the mid-1800s (Wikström 1840), leading silviculturists pointed out the unavoidable spread of sycamore in Sweden and the economic potential of the species (Wahlgren 1914). Nevertheless, sycamore was, and still is, neglected in this country rather than being explored for its ecological, silvicultural and timber characteristics.

Due to its rapid natural spreading sycamore gradually became naturalised in southern Sweden. It appears to be grown or utilized for commercial purposes only by a minority of forest managers (Madsen 2001, Sjöstedt 2011), but occurs widely throughout southern Sweden on forest edges and as a spontaneous admixture to stands of other species. Depending on the genetic origin, neglect in silviculture is the main factor responsible for the inferior timber quality of sycamore in such stands.

For more than half a century sycamore is considered a threat to other species (Lindquist 1953), to the extent that national regulations now limit the use of sycamore in forestry (Skogsstyrelsen 2009). There are well justified arguments for preventing the spread of sycamore into natural ('native') forest ecosystems, but based on its huge potential for spontaneous regeneration (Tillisch 2001) and its capacity to regrow from the stump after felling (Skovsgaard & Hausager 2011) the further spread of sycamore in regions where it is already present, is unavoidable. Consequently, in such places it would be wise to manage sycamore for the ecological benefit of the forest and the economic benefit of the forest owner.

Growth, site types and climate change

Sycamore thrives best on fertile, well-drained soils (Hein et al. 2009), but can grow on a wide range of site types, including poor, sandy, frost-exposed sites (Skovsgaard & Jørgensen 2004). It has a rapid growth in youth and is therefore easy to establish. Even in the long run sycamore generally outperforms beech in height growth (Hein 2004, Hein et al. 2009).

Experience from forestry practice as well as from commercial timber sales of sycamore in Denmark and Great Britain testify its ecological, silvicultural and economic potential in northern Europe (Bolton 1949, Evans 1984, Jensen 1983, Jørgensen 1998, Henriksen 1988, Kjølby 1958, Tillisch 2001). In Denmark, sycamore is often grown in essentially pure, even-aged stands. This is in contrast to much of central Europe, where sycamore occurs mainly as an admixture. Only few sycamore experiments are available in all of Europe (in Central Europe: mainly genetic trials (Spiecker et al. 2009), in Denmark: two thinning experiments (Bryndum & Henriksen 1988, Henriksen & Bryndum 1989, Jørgensen 1992, Plauborg et al. 2001)).

Sycamore is well adapted to the climate of southern Sweden, and the projected future climate will further promote the spread and competitiveness of sycamore in this part of the world (Hemery 2008, Kölling 2007, Morecroft et al. 2008). Considering the on-going process of naturalisation and the already proven adaptability of the species (Madsen 2001, Sjöstedt 2011), it seems timely and wise to improve the basis for understanding the possible role of sycamore in silviculture in Sweden.

Economic potential
The economic potential of sycamore can be illustrated by the matrix in Table 1 of roadside saw-log prices at commercial sales in Central and Northern Europe. Clearly, the economic revenue per cubic volume is substantially better than that of beech and may even outperform that of oak. Moreover, the economic potential from a conscious management for the production of premium timber is much better than management for 'the average'.

The highest prices for sycamore are paid for the much desired and aesthetically pleasing ripple wood. Sycamore is famous for a relatively large share of ripple wood that is used for special purposes such as fine furniture, interior decoration, violin backs, etc. The occurrence of ripple wood appears to depend on genetic origin (Weiser 1971, 1981, 1996, Tillisch 2001) and possibly also on site characteristics, but due to poor availability of clones known to produce ripple wood it is difficult for forestry practice to plan for the production of this characteristic.

Beech and oak are often managed specifically for production of premium timber, whereas sycamore is generally an available admixture that is given no special attention. Sycamore grown and managed specifically for timber production, for example through high pruning at young ages (Hein 2004, Hein & Spiecker 2007), can certainly be expected to sell at superior prices compared to other species commonly grown in Sweden.

Table 1 *Saw-log roadside prices in Europe (in units of euro per cubic metre).*
Market prices based on general sales statistics and major auction sales in Austria, Germany, France, Great Britain, Denmark and Sweden, compiled by the applicant during 2000-2016.

€ / m^3	Mid D (cm)	Top price	Veneer grade	Grade A saw-log	Grade B saw-log	Grade C saw-log	Market mean
Spruce	30+			60	45	30	45
Beech	50+	450	300	150	105	60	80
Ash	50+	600	450	225	150	75	100
Oak	60+	1800	1200	420	225	120	200
Sycamore	**50+**	**9000**	**1800**	**420**	**120**	**60**	**250**

Conclusion
Collectively, these circumstances and arguments indicate an urgent need for forest managers in southern Sweden to learn how to handle sycamore in silviculture. The large economic potential of the species and the poor quality of sycamore already available in Sweden point to two alternative approaches: 1. management of sycamore planted for the production of premium timber (full control of genetic origin by choice of provenance and of original spacing by planting), and 2. management of spontaneously regenerated sycamore.

This project focuses on planted sycamore for wood production. The underutilized resource of spontaneously regenerated sycamore involves a range of more complex forest types and circumstances that will be dealt with in a subsequent project.

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