Scandinavian Journal of Forest Research

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/sfor20

Establishment and development of hybrid aspen and poplar plantations on forest land in southern Sweden after storm Gudrun

Nils Fahlvik & Henrik Böhlenius

To cite this article: Nils Fahlvik & Henrik Böhlenius (2025) Establishment and development of hybrid aspen and poplar plantations on forest land in southern Sweden after storm Gudrun, Scandinavian Journal of Forest Research, 40:1, 16-28, DOI: 10.1080/02827581.2025.2456522

To link to this article: https://doi.org/10.1080/02827581.2025.2456522

SCANDINAVIAN JOURNAL OF FOREST RESEARCH
2025, VOL. 40, NO. 1, 16–28
https://doi.org/10.1080/02827581.2025.2456522

Taylor & Francis
Taylor & Francis Group

Establishment and development of hybrid aspen and poplar plantations on forest land in southern Sweden after storm Gudrun

Nils Fahlvik [a] and Henrik Böhlenius[b]

[a]Skogforsk, Uppsala, Sweden; [b]Southern Swedish Forest Research Centre, Swedish University of Agricultural Science, Lomma, Sweden

ABSTRACT

After storm Gudrun in 2005, which caused major losses of spruce, efforts were made to increase tree species diversity. This paper presents a survey analysing the establishment success and growth of *Populus* stands (59 hybrid aspen and 11 poplar stands) regenerated on forest land following storm Gudrun. A first inventory was carried out in 2010, 1–3 years after planting, and a second inventory in 2020. The average number of planted trees was 1290 ha^{-1}. At the first inventory, the average number of living saplings of aspen and poplar was 850 and 610 ha^{-1}, respectively. Intact fences contributed significantly to a greater number of living saplings. In 2020, the average number of living trees with a diameter at breast height >5 cm was 540 and 410 for aspen and poplar, respectively. Mean annual volume growth for aspen and poplar stands in 2020 was 3.9 and 6.6 m^3 ha^{-1} year^{-1}, respectively. Natural regeneration was abundant and contributed an average of 60% of total production in 2020. We conclude that the recommended number of plants on agricultural land is probably insufficient for the regeneration of *Populus* on forestland. Observed production was lower than on agricultural land except where poplar was planted on fertile sites.

ARTICLE HISTORY
Received 9 September 2024
Accepted 22 December 2024

KEYWORDS
Fast growing; broad leaves; pioneer tree species; wind damage; survival; increment

Introduction

Large-scale tree loss following natural forest disturbance fundamentally affects the ecosystem structure and species composition of temperate and boreal forests (McDowell et al. 2020). At present, a combination of natural disturbances such as wind throw, insect outbreaks, and fire (Schelhaas et al. 2003; Seidl and Lexer 2011) and human disturbances such as logging has resulted in 2.3 billion m^3 of wood being lost annually, equating to 0.15% of Europe's forest area (Schelhaas et al. 2003). Between 1986 and 2016, 17% of Europe's forest area experienced disturbance, and its frequency has consistently increased since 1986 (Senf and Seidl 2021). It is expected that the severity and area of disturbance will increase due to climate change, resulting in forests made up of younger and shorter trees (McDowell et al. 2020) and a decrease in the production of woody biomass. As well as increasing temperatures (Allen et al. 2010), extreme weather events such as severe storms are expected to increase as a result of climate change (Rahmstorf and Coumou 2011; Trenberth et al. 2015).

Across Central Europe and Sweden, forests' resilience to wind throw has decreased due to changing forest management practices over recent centuries. Originally, native forests were dominated by deciduous tree species such as European beech (*Fagus sylvatica*) and oak (*Quercus* spp.) but, from the late eighteenth century, the area planted with coniferous trees such as Norway Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) has increased dramatically. As a result, previously mixed and deciduous stands have been transformed into uniform, dense conifer plantations covering vast areas (Kirby and Watkins 2015). The root architecture and stability of coniferous trees means that they are more susceptible to wind throw than closed stands of deciduous trees, Norway spruce being twice as susceptible as Scots pine under comparable soil conditions (Ruel 1995). Thus, an increasing proportion of contiguous Norway spruce stands is likely to increase the risk of wind throw (Panferov et al. 2009).

Large windthrow areas can be found in Sweden, particularly in the southern region of Götaland where, on January 8–9, 2005, the exceptionally powerful storm Gudrun caused the loss of an estimated 75 million m^3 of timber. To put this in perspective, in 2013, 86.3 million m^3 were harvested in the whole of Sweden (SFA 2014). The volume of timber lost was equivalent to approximately three years' harvest in the affected area of Götaland (SFA 2006). The storm damaged around 270,000 ha (Valinger et al. 2006), of which 110,000 to 130,000 ha was considered to require reforestation.

The extent of the damage caused by storm Gudrun highlighted the risks associated with climate change, specifically to spruce-dominated forests (Lodin et al. 2017), and the presence of spruce was identified as a key factor in the level of damage sustained (Valinger and Fridman 2011). To reduce these risks the Swedish government held consultations and provided financial support to encourage regeneration using broadleaf tree species (Lodin et al. 2017). Regeneration of both trivial broadleaved species (e.g. birch (*Betula* spp.), poplar (*Populus* spp.)) and noble broadleaves (e.g. European beech, oak, wild cherry (*Prunus avium*), lime (*Tilia cordata*))

CONTACT Nils Fahlvik nils.fahlvik@skogforsk.se Skogforsk, Uppsala Science Park, 751 83 Uppsala, Sweden

were supported to increase the diversity of the forest landscape (Wallstedt et al. 2013). As a result of which thousands of hectares were planted with broadleaves, with *Populus* (hybrid aspen or poplars) regenerated on the largest area followed by birch, oak and beech. An adequate number of plants, fencing against browsers and soil preparation were normally required to obtain grants for planting broadleaves.

Earlier studies have shown that vegetation control and soil preparations are important for the establishment and early growth of *Populus* species (Böhlenius and Övergaard 2015; Coll et al. 2007; Otto et al. 2010; Tullus et al. 2012). On a typical forest clear-cut site, there is limited competition from other vegetation directly after clear cutting and over the following two years, but it increases over time (Nilsson and Örlander 1995). This suggests that poplars should be planted within this period.

However, replanting large storm-felled areas faces challenges that differ from those on sites harvested under normal conditions. Firstly, plant nurseries must increase production to meet demand from both windthrow areas and previously planned establishments, which can lead to a shortage of available planting materials. Secondly, there may be knowledge gaps among forest owners or advisors regarding the regeneration of hybrid aspen or poplars on forest land. Thirdly, the time between windthrow and planting may be longer than is ideal, as harvesting and soil preparation following storm damage is more time-consuming. In addition, the limited availability of forest machinery, which is not designed to handle 100,000 ha within a few months, can further delay the process.

This study provides insights into the challenges and practical problems of establishing hybrid aspen and poplars on forest land following windthrow events. It also examines how differences in management operations might influence their growth. The study also offers estimates of the growth performance of both species in commercial plantations located on forest land in southern Sweden.

Materials and method

Sampling of inventory stands

Approximately 1400 ha of hybrid aspen and 225 ha of poplar were regenerated using government grants to reforest storm-damaged areas following storm Gudrun (Wallstedt et al. 2013). Once grants were applied for, the National Forest Agency visited each stand twice before giving approval.

The main purpose of the first visit was to ensure the appropriateness of the planned regeneration actions and the second visit served to ensure that the prescribed actions had been carried out. These included fencing against browsing animals with an iron fence at least 2 m high and soil scarification prior to planting. Grants could be applied for from 2006 to 2010 and the last applications were approved in 2011. About 80% of applications were approved for planting in 2007–2009 with fewer at the beginning and end of the period. Having gained access to the Swedish Forest Agency's register of forest stands awarded reforestation grants after storm Gudrun, a sample of 59 stands with hybrid aspen and 11 stands with poplar as the main tree species were selected, which had been regenerated in 2007, 2008, and 2009 (Figure 1, Appendix).

Table 1. Distribution of the sampled stands by tree species, planting year, and region.

Main species	Planting year	Region West	Central	East
Hybrid aspen	2007	5	3	6
	2008	8	6	6
	2009	8	7	10
Poplar	2007	3	2	1
	2008	0	0	3
	2009	0	2	0

See Figure 1 for delineation of regions.

The intention was to achieve a sample that was balanced in terms of distribution across planting years and geographical regions (Figure 1). Both factors were judged to be possible explanatory variables. Within each combination of planting year and region stands were selected randomly. A balanced distribution was not achieved as some candidate sites were rejected in the field (e.g. due to deviation between reported and actually planted tree species, or failed attempts to contact the landowners) (Table 1). However, the sample does cover the most frequent planting years and geographical distribution of stands regenerated using these grants. The sample stands represented a total area of 150 ha of hybrid aspen and 35 ha of poplar. All stands were situated in southern Sweden (Figure 1).

All landowners were interviewed by telephone prior to the first inventory to confirm the year of planting and gather additional information about the regeneration (e.g. number of plants, plant type, soil preparation). The landowners were also asked about their motives for planting hybrid aspen and poplar. This was an open question, the answers to which were analysed and sorted into the following motives:

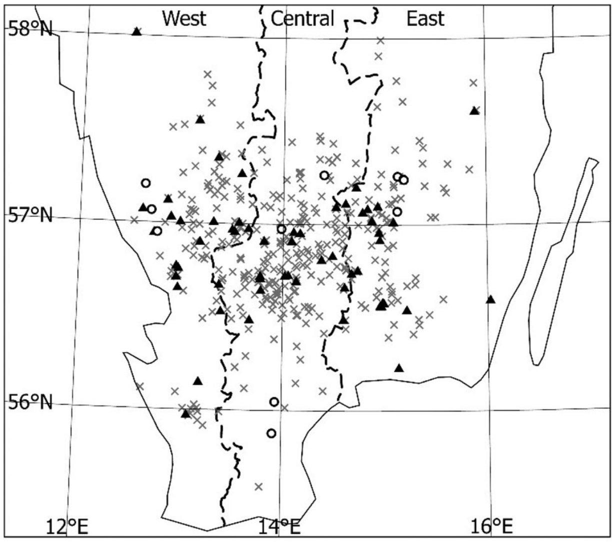

Figure 1. Stands of hybrid aspen or poplar regenerated using government grants after storm Gudrun. The regenerated area was divided into three regions (west, central, and east) in this study. The study was based on a sample of 59 stands regenerated with hybrid aspen (filled triangles) and 11 stands with poplar (unfilled circles).

spread risks, increase growth, influence species composition, curiosity, consultations advice, avoid disease, and other.

Field inventory after planting

The first inventory of the sampled stands was carried out in the spring of 2010. The borders of each stand were tracked using GPS and their areas were calculated. The centre of circular plots was then evenly plotted on the GPS and retconned in the field. The number of circular plots was 5, 7, 9, or 10 depending on the stand area ($\leq 2, -3, -4, > 4$ ha).

Site properties (soil characteristics, ground vegetation, etc.) were registered at each plot according to the site classification system established by Hägglund and Lundmark (1977).

Plant height and damage (cause and severity: undamaged, lightly, moderately, severely, or life-threateningly damaged) were registered for hybrid aspen and poplar within a radius of 6 m. Trees of other species with a height >50 cm were registered within a radius of 2.5 m from the plot centre.

The fence status of each stand was recorded, including its occurrence, height, and condition, the latter being categorised as intact, partially defective, defective and non-functional, or missing.

Re-inventory after 10 years

The sample stands were inventoried for a second time in the winter of 2019/2020 (denoted inventory 2020). As it was not possible to identify the previous circular plot centres precisely, new plots were established using the same method that was used in 2010. The number of circular plots was 6, 8, 9, or 10 depending on the stand area ($\leq 2, -3, -4, > 4$ ha).

As of 2010, site properties for each plot were registered according to the site classification system established by Hägglund and Lundmark (1977). The condition of fences was also described using the same classification as in 2010. The occurrence of pre-commercial thinning and commercial thinning were noted for the stand and each plot. The time since thinning was estimated based on the condition of the stumps and residues.

Tree species, diameter at breast height (1.3 m, DBH), and damage were registered for all living trees with a DBH ≥5 cm within a radius of 7 m from the plot centre. The heights of systematically selected sample trees were measured. On each plot, three samples trees of hybrid aspen and/or poplar were selected, and two samples of any other tree species. Trees with a DBH <5 cm within a radius of 3.5 cm from the plot centre were registered. Trees with a DBH ≥3 cm were callipered, and tree species were noted. Smaller trees were counted species wise in two diameter classes (<1 and 1–2.9 cm).

Stumps were measured on thinned plots. Tree species, diameter at 10 cm height above ground, and estimated time since thinning were registered for all stumps >7 cm within a radius of 7 m from the plot centre.

Three stands had been replanted between the first and the second inventory. One hybrid aspen stand had been planted with larch and two poplar stands had been planted with poplar and Norway spruce. These objects were excluded from the analysis of data from the 2020 inventory.

Variables and calculations

Historical maps and aerial photos provided by Lantmäteriet were used to track previous land use. The sampled stands were divided into two classes: (1) second-generation forest since conversion from arable land (1st generation having been storm felled), and (2) stands with longer continuity of forest cover.

A site index (H100) for spruce was used as a reference for site fertility. The site index was first calculated for each circular plot based on site properties according to Hägglund and Lundmark (1977) and then as an arithmetic mean for the stand.

Height-diameter relationships were calculated for each stand during the second inventory based on measurements of DBH and the height of sample trees. Näslund's (1936) function was used for Scots pine and all broadleaves and Petterson (1955) was used for Norway spruce according to:

$$h - 1.3 = \frac{x^n}{(a + b \times DBH)^n}$$

where h is tree height, DBH is diameter at breast height, a and b are coefficients, and $n = 3$ for Norway spruce and $n = 2$ for Scots pine (also used for all broadleaves in this study). The coefficients a and b were estimated for each tree species and stand using non-linear regression (*nls* function in R (R Core Team 2023)). The function was then used to calculate tree height for all trees.

Stem volumes for hybrid aspen and poplar were calculated using the equation for European aspen presented by Eriksson (1973). Volume functions for the other tree species that occurred were assigned according to Karlsson et al. (2012).

The DBH and tree height of stump inventoried trees were reconstructed as follows: First, taper functions were used to estimate the diameter at 10 cm height above the ground of sample trees. A taper function for poplar by Hjelm and Johansson (2012) was used to estimate stump diameter for both poplar and hybrid aspen. Taper functions by Lassasenaho (1982) were used for other tree species, applying birch functions to all broad leaves. A linear relationship between stump diameter and DBH was then estimated:

$$\mathrm{DBH} = \alpha + \beta \times DS$$

where DBH is diameter at breast height, DS is stump diameter, a is a constant, and β is a coefficient. The function was calculated separately for each tree species and stand. DBH was then estimated for all stumps and height was estimated using the height-diameter relationship based on sample trees.

Basal area-weighted mean diameter (D_{bw}) and height (H_{bw}) were calculated as:

$$X_{bw} = \frac{\sum X \times DBH^2}{\sum DBH^2}$$

where X_{bw} is either D_{bw} and height H_{bw}, X is either the single tree DBH or height, and DBH is the diameter at breast height.

The volume increment was calculated as:

$$MAI_{net} = \frac{V_{2020} + V_{stump}}{T_{pl}}$$

where $\mathrm{MAI}_{\mathrm{net}}$ is the net mean annual volume increment since planting, V_{2020} is the standing volume of living trees at the second inventory, V_{stump} is the estimated volume of felled trees with a stump diameter >7 cm, and T_{pl} is years since planting.

Four groups of damage and defects affecting stem quality were analysed in this study: forked stems, curved stems, stem cracks, and cambium damage. Forked stems included trees with multiple stems where the second largest stem was >3/4 of the largest. Curved stems included severe basal hooks and curved basal logs (3 m above ground) where the centre deviated more than 10 cm from a straight line between the log ends. Stem cracks were longitudinal cracks that were visible on the outside of the stem. Cambium damage was mechanical damage to the stem cambium. The presence of damage was calculated as the proportion of damaged trees relative to the total number of inventoried trees for each species.

Statistical analysis

The influence of site, stand, and regeneration parameters on the number of living stems at inventory in 2010 was analysed using Generalised Linear Mixed Models (GLMM). A Poisson distribution was assumed as the dependent variable constituted count data. The hierarchical inventory design motivated a mixed model approach. Model fitting was executed via the *glmer* function of *lme4* package in the R statistical software (R Core Team 2023). Considering the hierarchical design of the inventory with circular plots within sample stands, stand was used as a random effect in the model:

$$\begin{aligned}\log(y_{ij}) = {} & \beta_0 + \beta_1 \mathrm{POPL}_{\,i} + \beta_2 DENSE_i + \beta_3 EARLY_i + \beta_4 FENINT_i \\ & + \beta_5 AGRI_i + \beta_6 REGW_i + \beta_7 REGC_i + \beta_8 SIH_{ij} + \beta_9 SIL_{ij} \\ & + u_i + e_{ij}\end{aligned}$$

where y_{ij} is the number trees on the plot; stand wise dummy variables are: POPL for planed poplar (1 if poplar, 0 if hybrid aspen), DENSE for dense planting density (1 if >1500 stems ha^{-1}, otherwise 0), EARLY for early planting (1 if planting year 2007, otherwise 0), FENINT intact fence (1 if classed as intact or partly intact in 2010, otherwise 0), AGRI for previous agricultural land (1 if second generation forest on agricultural land, 0 otherwise), REGW for stands in the western region (1 if west in Figure 1, otherwise 0), REGC for stands in the central region (1 if central in Figure 1, otherwise 0); plot wise dummy variables were: SIH for high site index (1 if $\mathrm{SI} > 32$, otherwise 0), SIL for low site index (1 if $\mathrm{SI} < 30$, otherwise 0); β_0 is a constant, β_{1-9} are coefficients, u_i is a random stand factor and e_{ij} is residual, i is the index for sample stand, and j is the index for plot. Separate analyses were carried out for all inventoried stands and for stands of hybrid aspen, respectively. The number of poplar stands was judged to be too few for a separate analysis of this species.

Results

The average size of the inventoried stands was 2.7 ha with 90% of them being below 5 ha. Two stands had areas of more than 10 ha. Mean values for altitude, climatic variables, and site index did not differ significantly between stands with hybrid aspen or poplar as the main species (Table 2).

A classification of dominant site parameters according to Hägglund and Lundmark (1977) indicated slightly moister conditions on average for the poplar stands than the hybrid aspen stands (Table 3). There was also a tendency towards more fine-grained soils and a greater proportion of herbs for the 11 poplar stands than the 59 aspen stands.

More than 40% of fences had some kind of defect in 2010 (Table 4). In 2020, the proportion of intact fences was 46% and fences had been removed from 21% of the stands.

Based on information provided by landowners, the average number of trees planted was 1270 and 1380 stems ha^{-1} for aspen and poplar, respectively (Figure 2). The average number of living trees in the 2010 inventory was 850 and 610 for aspen and poplar stands, respectively. 18 (30%) of the aspen stands had more than 1000 stem ha^{-1} of the main species in 2010 while two of the eleven poplar stands exceeded this density (Figure 2). In 2010, early plantations of hybrid aspen were more frequent among the denser stands than the sparser stands. However, planting year was not a significant independent variable in the GLMM regression of the number of living trees in aspen stands in 2010 (Figure 3).

The indicator variable for poplar had a significant negative effect on the number of living stems in 2010 when the GLMM

Table 2. Site characteristics of the surveyed stands. Temperature sum, mean annual temperature, and precipitation between 1991 and 2020 were estimated using ClimateDT (Marchi et al. 2024).

Main species	No.		Area (ha)	Latitude (N°)	Altitude (m)	Temperature sum (ddgr)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Site index (H100)
Hybrid aspen	59	Mean	2.5	56.9	150	1540	7,3	882	31.2
		Min	0.7	56	10	1429	6,7	589	27.6
		Max	14.7	58	240	1696	8,2	1253	34.7
		SD	2.3	0.3	50	61	0,3	183	1.3
Poplar	11	Mean	3.1	56.9	190	1490	7,1	880	31.3
		Min	0.6	55.9	90	1397	6,5	718	28.1
		Max	12.7	57.3	290	1589	7,7	1178	34.4
		SD	3.5	0.5	80	79	0,5	163	2

Site index (H100) for spruce was estimated based on site properties (Hägglund and Lundmark 1977).

Table 3. Distribution of hybrid aspen and poplar stands by soil moisture, soil texture, and ground vegetation classes according to Hägglund and Lundmark (1977).

		Main species	
Site property	Class	Hybrid aspen	Poplar
Moisture	Dry	0.8	0.0
	Mesic	74.6	59.1
	Moist	24.6	40.9
Texture	Fine silty/clayey till Fine silt/Clay	8.5	13.6
	Coarse silty till Coarse silt	14.4	40.9
	Sandy-silty till Medium/Fine sand	75.4	36.4
	Peat	1.7	9.1
Vegetation	Herbs	21.2	36.4
	Grasses	75.4	54.5
	Vaccinium sp.	3.4	9.1

Each stand was classified according to the dominant class of the inventoried circular plots. Percentage distribution of the stands on each class was then calculated separately for main tree species and site properties. Based on inventory of 59 hybrid aspen and 11 poplar stands.

was applied to all inventory stands (Figure 3(a)). In the GLMM, being in the western region had a negative effect on all inventoried stands, whereas dense planting had an almost significant positive effect (Figure 3(a)). An intact fence had a significant positive effect under both regressions (Figure 3(a,b)).

Damage was noted on 55% and 33% of the inventoried living hybrid aspen and poplar saplings, respectively, in 2010. The proportion of severely and life-threateningly damaged saplings was 10% for both species. Fungal infection and wildlife were the most common agents of damage among saplings (Figure 4). Almost all noted fungal infections were located on leaves. Rodents caused damage on 9% and 6% of the aspen and poplar saplings, respectively. Presumed browsing by ungulates caused damage on 5% of the hybrid aspen saplings whereas no such impact was noted for poplar. Insect damage on living saplings was more common on aspen than on poplar, and primarily occurred on leaves (5%).

Table 4. The number of hybrid aspen (H) and poplar (P) stands within different classes describing the status of the fences at the inventory in 2010 and 2020.

	Inv. 2010		Inv. 2020	
Status	H	P	H	P
Intact	34	6	27	4
Partly defect	21	3	15 (16)	2
No function	4	2	4	1 (3)
Missing	0	0	12	2

Partly-defective fences were assumed to provide some protection against browsing, in contrast to fences with no function. Number within brackets includes replanted stands in 2020.

On average, the total number of main stems in 2020 was 40% less for poplar than for hybrid aspen, and 24% less if only those trees with a DBH of ≥5 cm were considered (Table 5). The proportion of the hybrid aspen stands where more than 500 stems ha^{-1} of the main species had a DBH of ≥5 cm was 76% while the same density was reached in four of the nine remaining poplar stands. Main stems were completely absent in two stands, one of each main species. Traces of pre-commercial thinning were registered in 91% of the inventoried stands. Four aspen stands and one poplar stand had been commercially thinned. The thinned aspen stands had an average of 590 remaining stems ha^{-1} of DBH ≥5. Birch (*Betula pendula*, *Betula pubescens*) was the most common secondary tree species in both hybrid aspen and poplar stands (Table 2). The basal area of birch was greater than that of the main species in half of the inventoried stands. In 2020, the average number of birches with a DBH of ≥5 cm was 700 stem ha^{-1}. In thinned stands birch accounted for an average of over 40% of the remaining basal area.

The average mean diameter of the main species was greater for poplar than for hybrid aspen (Table 5). The basal area weighted mean diameter of the main species for stands planted in 2007 was 10.6 ($n = 13$) for hybrid aspen and 15.9 ($n = 5$) cm for poplar.

The relative difference in average height between the main species and birch in the second inventory tended to decrease with decreasing site index (Figure 5). In all but one of the stands planted in 2007, the exception being a single poplar stand, the height of the main species exceeded the average height of the birch. In all stands with a site index

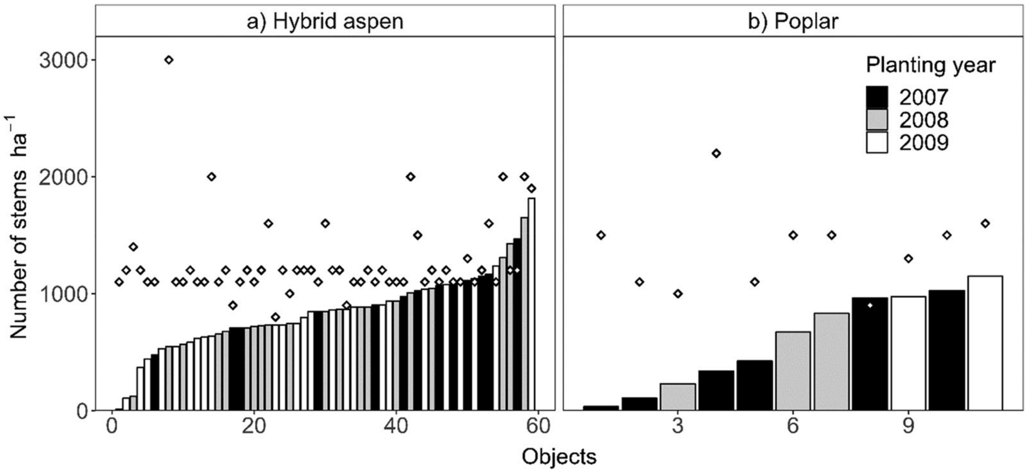

Figure 2. Number of living trees of the main tree species in the 2010 inventory, in stands regenerated with hybrid aspen (a, $n = 59$) and poplar (b, $n = 11$), respectively. The stands were regenerated in 2007 (black), 2008 (grey), or 2009 (unfilled). The number of planted trees based on information from landowners is presented for each stand (symbols).

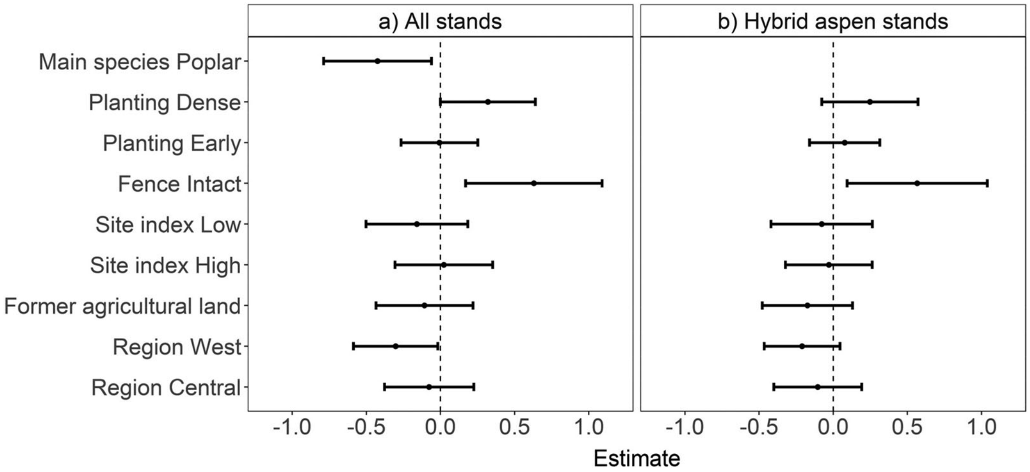

Figure 3. Regression coefficient plots show the results of the generalised linear mixed model used to analyse the influence of site, stand, and plot variables on the number of surviving stems in the 2010 inventory. Separate models were calculated for all inventoried stands (a) and for stands planted with hybrid aspen (b). All independent variables were indicator variables assigned a value of 1 if the main species was poplar (POPL), planting density was >1500 stems ha^{-1} (DENSE), planted in 2007 (EALRY), the fence was intact (FENINT), site index was >32 (SIH) or <30 (SIL), stand was second generation forest on previously agricultural land (AGRI), or the geographical region was west (REGWEST) or central (REGCENTR) (Figure 1). Points are the coefficient estimates and lines indicates the width of the 95% confidence interval.

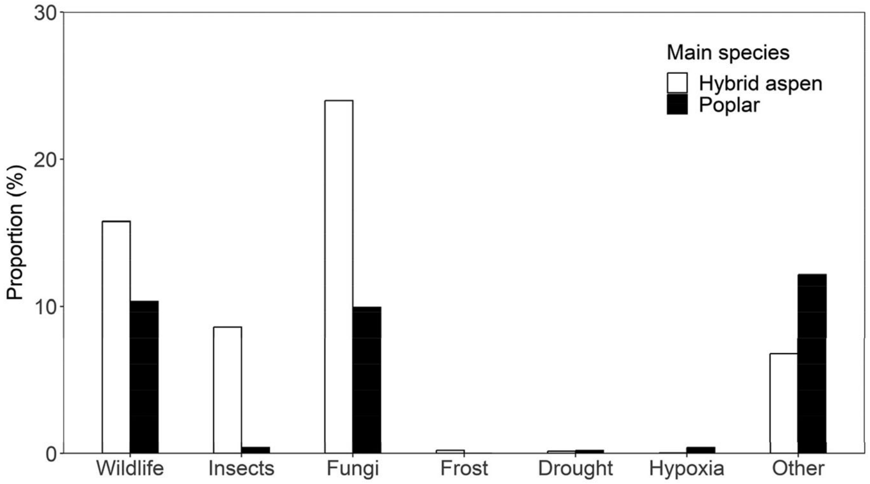

Figure 4. Proportion of all living saplings of hybrid aspen (unfilled, $n = 3251$) and poplar (filled, $n = 493$) in the 2010 inventory noted as being damaged. Multiple types of damage could be noted for each sapling. “Other” was used when the damage agent was unknown.

Table 5. Stand characteristics in the 2020 inventory.

			Main species					All species			Tree species distribution (%)				
Planted species	No.		N (ha^{-1})	N_5 (ha^{-1})	D (cm)	H (m)	BA (m^{-2})	N (ha^{-1})	N_5 (ha^{-1})	BA (m^{-2})	A	P	B	OB	C
Hybrid Aspen	58	Mean	830	540	8.9	9.2	4	6 120	1 370	9.3	43	1	46	7	4
		Min.	0	0	5.4	5.5	0	750	400	2.6	0	0	9	0	0
		Max.	2 700	1 310	13.5	13.4	10	22 370	2 720	15.6	87	18	97	41	27
		SD	490	280	1.8	1.7	2.5	5270	460	3	22	3	23	8	6
Poplar	9	Mean	500	410	11.1	10.4	6.7	4 620	1 290	12.8	0	36	41	8	15
		Min.	0	0	5.3	5.6	0	1140	760	4.6	0	0	1	0	0
		Max.	1 340	1 260	18.5	16.9	23.6	13 590	2 130	23.9	4	99	64	34	46
		SD	490	440	4.9	4.3	8.4	4130	470	6.7	1	34	23	11	17

Data are presented for the main species and for the total stand. Number of trees was calculated for all trees (N) and for trees with diameter at breast height >5 cm (N_5). Basal area-weighted mean diameter (D), height (H), and basal area (BA) were calculated for all trees. The species distribution for aspen (A), poplar (P), birch (B), other broadleaves (OB), and conifers (C) refers to their proportion of the basal area.

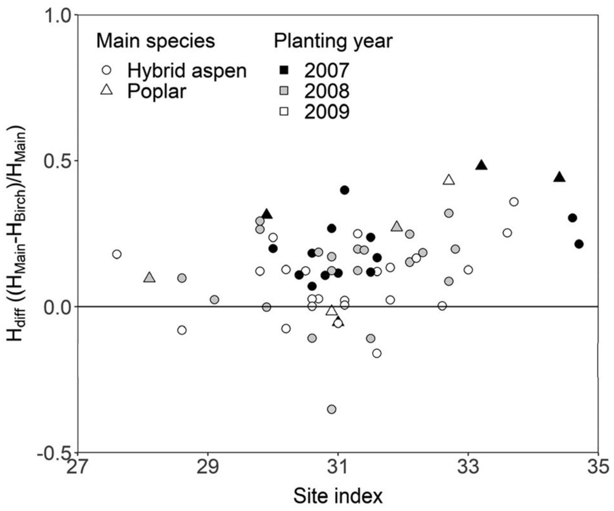

Figure 5. Relative difference in basal area weighted mean height for the main species and for birch in the 2020 inventory, plotted against estimated site index for spruce (H100, Hägglund and Lundmark (1977)). A stand wise average was calculated for stands regenerated with hybrid aspen (circles) and poplar (triangles). The stands were regenerated in 2007 (black), 2008 (grey), or 2009 (unfilled).

≥32 the height of the main species was equal or greater than that of birch.

The average standing volume of the main species in 2020 was 21 and 52 m^3 ha^{-1}, with a maximum of 62 and 187 m^3 ha^{-1}, for hybrid aspen and poplar, respectively (Figure 6). The average standing volume of all species was 43 and 78 m^3 ha^{-1}, with an average birch proportion of 42 and 35%, for hybrid aspen and poplar stands, respectively. Total MAI_{net} (all species, standing + thinned trees) for hybrid aspen and poplar stands between planting and the second inventory was 3.9 (0.8–7.5) and 6.6 (1.4–14.5) m^3 ha^{-1} $year^{-1}$, respectively.

Longitudinal stem cracks were the most frequent defects found on hybrid aspen stems. Mechanical damage to the stem cambium was more common for hybrid aspen than for poplar (Figure 7). Most of the mechanical cambium damage was associated with observations of moose damage. Curved stems were the most common defect amongst poplar.

Discussion

In this study, a sample of stands regenerated with hybrid aspen and poplar after storm Gudrun were inventoried to assess the success and growth of regeneration on forest land in southern Sweden. The results can be seen as indicative of survival rates and growth levels of these species when planted on clear cuts arising from catastrophic storm damage. Our analysis of regeneration efforts was based on information gathered through interviews with landowners. These yielded approximate numbers of planted trees for all but one of the stands identified. It is difficult to estimate mortality rates accurately from these figures.

The main reason for using interview data rather than inventory data was that dense vegetation made it impossible to assess the initial number of trees planted on each plot. However, site properties were thoroughly assessed during the inventory to describe growth conditions. Soil preparation

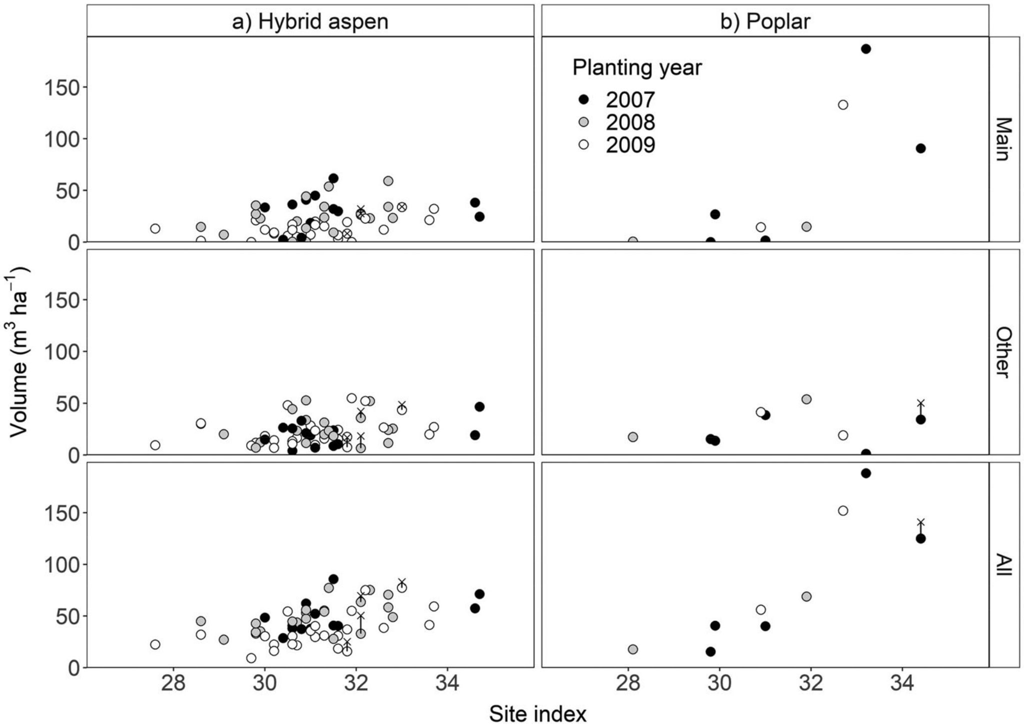

Figure 6. Standing volume versus site index in the 2020 inventory for stands regenerated with hybrid aspen (a) and poplar (b). The stands were regenerated in 2007 (black), 2008 (grey), or 2009 (unfilled). Volume is presented for the main species (Main), other tree species (Other), and all trees (All). Total volume (standing + estimated volume of felled trees with diameter at stump >7 cm) in thinned stands is shown with a cross. Lines connect standing and total volumes belonging to the same stand.

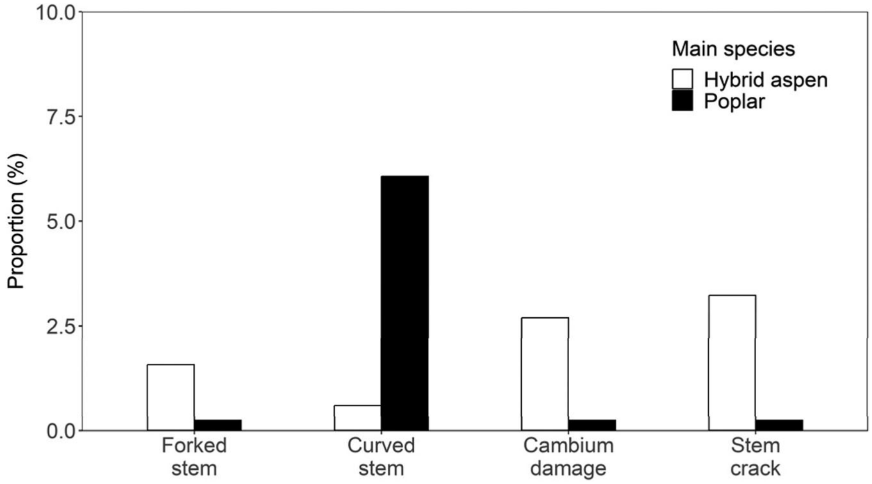

Figure 7. Proportion of all inventoried stems with diameter at breast height >5 cm observed to have defects in one or more of these categories: mechanical cambium damage, longitudinal stem cracks, trees with forked stem or multiple stems below 2/3 of the tree height, and stems with severe basal hooks or curved basal logs (0–3 m above ground). The number of inventoried trees was 3377 and 412 for hybrid aspen (unfilled) and poplar (filled), respectively.

and fencing were also evaluated carefully, as these were required to obtain subsidies and failure to meet these requirements would have led to the stand being excluded from the initial site selection.

The interviews also provided information about the landowner's motives for planting *Populus*. The most common motives were assumptions of increased growth (35% of landowners), a desire to influence the tree species distribution (35%), curiosity (34%), and advice from a consultant (11%). Spreading risks and problems with root rot in the previous stand were also mentioned as motives by 8% and 3% of landowners, respectively.

The average number of planted trees reported by the landowners aligned with current recommendations for agricultural land of 1100–1600 stems ha^{-1} (Tullus et al. 2012; Persson et al. 2015). In the first inventory, the number of living saplings corresponded to 67% and 44% of the intended planting density for hybrid aspen and poplar, respectively. One contributing factor for the low number of poplars could relate to difficulties establishing this species on acidic forest soils which are typical of Nordic countries. Earlier studies have identified that low pH values cause low survival rates when establishing poplar (Hjelm and Rytter 2016) and that this is associated with sensitivity to Aluminium (Al^{3+}). However, in this study poplar did show good growth on forested arable land which is usually less acid. In contrast, hybrid aspen has been found to be more tolerant of acidic soil conditions (Hjelm and Rytter 2018, Böhlenius et al. 2018) and therefore a higher survival compared to poplar could be expected.

According to our results, the timing of planting did not have any significant influence on the number of stems by the time of the first inventory. Planting swiftly after the removal of the previous stand can reduce competition from competing vegetation, aiding establishment (Nilsson and Örlander 1995). However, as all stands were inventoried in the same year (2010) it may be that the stands planted longer ago had experienced increased mortality, distorting the comparison between planting years. In an experiment with poplar on arable land, Hjelm et al. (2018) found that mortality was greatest during the first 2–3 years. Annual differences in climatic factors such as rain and temperature may also have influenced growth and survival. Stands planted in 2007 and early 2008 were exposed to the warm and dry summer of 2008.

Extensive soil preparation and weed control are recommended when regenerating hybrid aspen and poplar on agricultural land. This includes ploughing and harrowing in combination with using herbicides prior to planting, followed by mechanical weed control after planting (Persson et al. 2015). Soil preparation and vegetation control have been found to improve the establishment and early growth of poplar (e.g. Böhlenius and Övergaard 2015; Bilodeau-Gauthier et al. 2011; Desrochers and Sigouin 2014). At forest sites, the options for intense vegetation management are limited to soil preparation. The use of herbicides is highly restricted and the feasibility of repeated weed control after planting is also limited. Planting after storm felling further increases the challenges as tilted stumps and remaining forest residues can negatively affect the quality of soil preparation, resulting in less effective vegetation management. To counteract these limitations and the more heterogeneous site conditions on forest land, increasing the number of seedlings planted is a possible alternative approach to establish a *Populus* dominated stand.

The second inventory was carried out 11–13 years after planting, which is too early to draw conclusions about long-term stand development and growth on forest land. The stand age corresponds to an expected half rotation on fertile agricultural land (Tullus et al. 2012; Fahlvik et al. 2021). So far, the average total volume production of the hybrid aspen stands has been less than half of that observed by Rytter and Stener (2014) on experimental trials of corresponding age. This, though, would be expected given lower volume production on less fertile forest land than on arable land. In addition, experimental plots usually represent more ideal conditions than apply to real plantations. In this study, most of the poplar stands also exhibited low production although their average and maximum growth was greater than for hybrid aspen. There were two exceptions to low production on poplar stands, where production reached levels similar to those achieved through planting on arable land. It should be mentioned that these stands were planted on forested arable land, sites that were initially arable land but had already been planted with Norway spruce for one rotation. These stands demonstrated both successful regeneration and high growth.

The low production and growth noted at many sites are likely caused by poor establishment. After 11–13 years, the average number of main stems with a DBH of >5 cm was 30% and 40% compared to the planted number of stems for poplar and hybrid aspen, respectively. Consequently, a large part of the total production at the second inventory consisted of naturally regenerated trees. Although the presence of natural regeneration was important to reaching adequate stand densities, it may also have hampered the main species through competition. A comparison of the mean heights of the main species and naturally regenerated trees indicated a decreasing advantage for *Populus* at less fertile sites and with later planting. Promoting a spatial separation of the mixed tree species during early thinnings may be an option to reduce the future complexity of managing species with different growth rates (e.g. Felton et al. 2022).

The overall purpose of the government grants financing the regenerations in this study was to support less common tree species and thereby promote forest diversity (Wallstedt et al. 2013). From this perspective, most inventoried objects resulted in broadleaf-dominated stands of diverse species composition. Although birch was most frequent among the natural regeneration, less common broadleaves were also present. This included oak, rowan (*Sorbus aucuparia*), willow (*Salix* spp.) and other species that likely benefited from fencing. The natural regeneration has been an asset to mitigate the impact from high mortality among the *Populus* regenerations and has contributed to structural diversity. Given that pre-commercial thinning had been carried out in most inventoried stands, retaining naturally regenerated tree species seems to have been an active decision on the part of landowners. This reflects the adaptive capacity of mixtures to cope with abiotic and biotic risks (i.e. Jactel et al. 2017). Given the susceptibility of spruce to wind damage (Valinger and Fridman 2011), the conversion of former spruce forests to broadleaf-dominated stands might reduce the risk at future storm events.

Fungal infections were among the most common types of damage to saplings registered in the first inventory. Symptoms were primarily observed on leaves. Fungus which infects the leaves of *Populus* include the families *Melampsora* spp., *Venturia* spp., *Marssonina* spp., and *Septoria* spp. Fungal infections can reduce vitality and growth and increase susceptibility to other pathogens.

In *Populus* plantations it is important that planting material is good quality and correctly selected for climate adaptation and resistance to pathogens, and breeding strategies for hybrid aspen and poplar reflect this (e.g. Stener and Westin 2017). As storm Gudrun resulted in hundreds of hectares needing reforestation, the conventional supply chain was not always available (Wallstedt et al. 2013). This may have affected seedling quality and the availability of both appropriate planting material (i.e. earlier tested clones) and educated staff to carry out the planting. Consequently, planting of unproven material of unknown origin as well as suboptimal handling of plants prior to plantation occurred.

Conclusions

The inventory was a unique opportunity to collect experience from hybrid aspen and poplar stands on forest land. Until now, research has focused on *Populus* on agricultural land and the experience of large-scale plantations on forest land has been absent. This survey highlighted the early development of real plantations established under the unique conditions that followed storm Gudrun and brought attention to the challenges encountered in these circumstances. The supply chain of plants and the logistics of planting were both stretched after the storm. Storm-felled trees further complicated soil preparation and planting. Taking these circumstances into consideration, we conclude that:

- The establishment stage was critical. Mortality was generally high in the first years after planting and poplar yielded a lower average number of surviving trees than hybrid aspen.
- Intact fences contributed to a greater number of stems after establishment. The presence of bark damage related to ungulates in the second inventory supports the recommendation to ensure that fences remain intact during the years following the establishment of hybrid aspen stands.
- It may be necessary to plant higher numbers of trees than is currently recommended for agricultural land if the purpose is to establish Populus-dominated stands. This to counteract the limitations of site preparation and the heterogeneous site conditions found on forest land.
- Natural regeneration of birch and other species made an important contribution to achieving fully stocked forests in many stands and to the structural diversity of the stands.
- Pre-commercial thinning is probably an important tool for controlling competition around planted hybrid aspen and poplar, especially at less fertile sites. This could also include a spatial separation between the main species and the natural regeneration.
- Volume growth at the second inventory was clearly lower than that of hybrid aspen plantations on arable land. The most productive poplar stands in the survey produced more than twice the maximum found for hybrid aspen.

Acknowledgement

Rolf Övergaard and Lars Rytter initiated the first inventory in 2010. We would like to thank the personnel who carried out the field work in 2010 and 2020. NF initiated the second inventory in 2020 and coordinated the study. NF prepared the data and performed the analysis. Both authors were involved in the conceptualisation of the study and in the writing of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The first inventory in 2010 was funded by the Swedish Forest Agency and the research program Future Forests at SLU. The second inventory in 2020, data management, analysis, and preparation of this manuscript was funded by the Södra Foundation for Research, Development and Education, Utveckling och Utbildning Foundation for Research [grant number 2018-075] and Skogforsk frame programme.

ORCID

Nils Fahlvik http://orcid.org/0000-0002-2179-7800

References

Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Kitzberger T, Rigling A, Breshears DD, Hogg EH, et al. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For Ecol Manag. 259(4):660–684. doi:10.1016/j.foreco.2009.09.001.

Bilodeau-Gauthier S, Paré D, Messier C, Bélanger N. 2011. Juvenile growth of hybrid poplars on acidic boreal soil determined by environmental effects of soil preparation, vegetation control, and fertilization. Forest Ecology and Management. 261(3):620–629. https://doi.org/10.1016/j.foreco.2010.11.016.

Böhlenius H, Asp H, Hjelm K. 2018. Differences in Al sensitivity affect establishment of Populus genotypes on acidic forest land. PLoS ONE. 13(9):e0204461, 15 p. https://doi.org/10.1371/journal.pone.0204461.

Böhlenius H, Övergaard R. 2015. Growth response of hybrid poplars to different types and levels of vegetation control. Scandinavian Journal of Forest Research. *30*(6):516–525. doi:10.1080/02827581.2015.1034768.

Coll L, Messier C, Delagrange S, Berninger F. 2007. Growth, allocation and leaf gas exchanges of hybrid poplar plants in their establishment phase on previously forested sites: effect of different vegetation management techniques. Ann For Sci. *64*(3):275–285. doi:10.1051/forest:2007005.

Desrochers A, Sigouin ME. 2014. Effect of soil mounding and mechanical weed control on hybrid poplar early growth and vole damage. Écoscience. *21*(3–4):278–285. doi:10.2980/21-(3-4)-3645.

Eriksson H. 1973. Volymfunktioner för stående träd av ask, asp, klibbal och contorta-tall [tree volume functions for ash, aspen, alder and lodgepole pine in Sweden (*Fraxinus excelsior* L., *Populus tremula* L., *Alnus glutinosa* (L.) gartn., *Pinus contorta dougl*. var. *latifolia* engelm.)]. Skogshögskolan, institutionen för skogsproduktion. Rapporter och Uppsatser. 26:26.

Fahlvik N, Rytter L, Stener LG. 2021. Production of hybrid aspen on agricultural land during one rotation in southern Sweden. Journal of Forestry Research. 32:181–189. doi:10.1007/s11676-019-01067-9.

Felton A, Felton AM, Wam HK, Witzell J, Wallgren M, Löf M, Sonesson J, Lindbladh M, Björkman C, Blennow K, et al. 2022. Forest biodiversity and ecosystem services from spruce-birch mixtures: The potential importance of tree spatial arrangement. Environmental Challenges. 6:100407. doi:10.1016/j.envc.2021.100407.

Hägglund B, Lundmark J-E. 1977. Site index estimation by means of site properties. Stud For Suec. 138:38.

Hjelm B, Johansson T. 2012. Volume equations for poplars growing on farmland in Sweden. Scandinavian Journal of Forest Research. *27*(6):561–566. doi:10.1080/02827581.2012.679678.

Hjelm K, Mc Carthy R, Rytter L. 2018. Establishment strategies for poplars, including mulch and plant types, on agricultural land in Sweden. New For. *49*(6):737–755. doi:10.1007/s11056-018-9652-6.

Hjelm K, Rytter L. 2016. The influence of soil conditions, with focus on soil acidity, on the establishment of poplar (*Populus* spp). New For. *47*(5):731–750. doi:10.1007/s11056-016-9541-9.

Hjelm K, Rytter L. 2018. The demand of hybrid aspen (*populus tremula× P. tremuloides*) on site conditions for a successful establishment on forest land. Silva Fenn. *52*(5):14 p. https://doi.org/10.14214/sf.10036.id 10036

Jactel H, Bauhus J, Boberg J, Bonal D, Castagneyrol B, Gardiner B, Gonzalez-Olabarria JR, Koricheva J, Meurisse N, Brockerhoff EG. 2017. Tree diversity drives forest stand resistance to natural disturbances. Current Forestry Reports. 3:223–243. doi:10.1007/s40725-017-0064-1.

Karlsson K, Mossberg M, Ulvcrona T. 2012. Fältdatasystem för skogliga fältförsök [field data system for forest field trials]. Sveriges lantbruksuniversitet, Enheten för skoglig fältforskning. Rapport. 5:19.

Kirby KJ, Watkins C. 2015. Europe's changing woods and forests: from wildwood to managed landscapes. Wallingford: CABI.

Lassasenaho J. 1982. Taper curve and volume functions for pine, spruce and birch. Communicationes Instituti Forestalis Fenniae. 108:74.

Lodin I, Brukas V, Wallin I. 2017. Spruce or not? contextual and attitudinal drivers behind the choice of tree species in southern Sweden. Forest Policy and Economics. 83:191–198. doi:10.1016/j.forpol.2016.11.010.

Marchi M, Bucci G, Iovieno P, Ray D. 2024. ClimateDT: A global scale-free dynamic downscaling portal for historic and future climate data. Environments. 11(4):82. doi:10.3390/environments11040082.

McDowell NG, Allen C, Anderson-Teixeira K, Aukema BH, Bond-Lamerty B, Chini L, Clark JS, Dietze M, Grossiord C, Hanbury-Brown A, et al. 2020. Pervasive shifts in forest dynamics in a changing world. Science. 368(6494):eaaz9463. doi:10.1126/science.aaz9463.

Näslund M. 1936. Skogsförsöksanstaltens gallringsförsök i tallskog [The Forest Research Institute's thinning experiments in Scots pine]. Meddelanden från Statens skogsförsöksanstalt 29. 169 p. [In Swedish with German summary].

Nilsson U, Örlander G. 1995. Effects of regeneration methods on drought damage to newly planted Norway spruce seedlings. Can J For Res. *25*(5):790–802. doi:10.1139/x95-086.

Otto S, Loddo D, Zanin G. 2010. Weed-poplar competition dynamics and yield loss in Italian short-rotation forestry. Weed Res. *50*(2):153–162. doi:10.1111/j.1365-3180.2010.00763.x.

Panferov O, Doering C, Rauch E, Sogachev A, Ahrends B. 2009. Feedbacks of windthrow for Norway spruce and Scots pine stands under changing climate. Environ Res Lett. 4(4):045019. doi:10.1088/1748-9326/4/4/045019.

Persson P-O, Rytter L, Johansson T, Hjelm B. 2015. Handbok för odlare av poppel och hybridasp [Poplar and Hybrid Aspen Grower's Handbook]. Jordbruksverket, Jönköping, Sweden. 23 s. [In Swedish].

Pettersson H. 1955. Barrskogens volymproduktion [Volume production of the coniferous forest]. Meddelanden från Statens skogsforskningsinstitut 45. 391 p. [In Swedish].

Rahmstorf S, Coumou D. 2011. Increase of extreme events in a warming world. Proc Natl Acad Sci USA. 108(44):17905–17909. doi:10.1073/pnas.1101766108.

R Core Team. 2023. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Ruel JC. 1995. Understanding windthrow: silvicultural implications. The Forestry Chronicle. 71(4):434–445. doi:10.5558/tfc71434-4.

Rytter L, Stener LG. 2014. Growth and thinning effects during a rotation period of hybrid aspen in southern Sweden. Scandinavian Journal of Forest Research. *29*(8):747–756. doi:10.1080/02827581.2014.968202.

Schelhaas MJ, Nabuurs GJ, Schuck A. 2003. Natural disturbances in the European forests in the 19th and 20th centuries. Glb Chg Bio. 9(11):1620–1633. doi:10.1046/j.1365-2486.2003.00684.x.

Seidl RS, Lexer MJ. 2011. Unraveling the drivers of intensifying forest disturbance regimes in Europe. Glb Chg Bio. 17(9):2842–2852. doi:10.1111/j.1365-2486.2011.02452.x.

Senf C, Seidl R. 2021. Mapping the coupled human and natural disturbance regimes of Europe's forests. Nature Sustainability. 4(26):10–1038.

SFA (Swedish Forest Agency). 2006. Statistical yearbook of forestry 2006. Jönköping: Swedish Forest Agency.

SFA (Swedish Forest Agency). 2014. Statistical yearbook of forestry 2014. Jönköping: Swedish Forest Agency.

Stener LG, Westin J. 2017. Early growth and phenology of hybrid aspen and poplar in clonal field tests in scandinavia. Silva Fenn. *51*(3):22 p. https://doi.org/10.14214/sf.5656.

Trenberth KE, Fasullo JT, Shepherd TG. 2015. Attribution of climate extreme events. Nat Clim Change. 5(8):725–730. doi:10.1038/nclimate2657.

Tullus A, Rytter L, Tullus T, Weih M, Tullus H. 2012. Short-rotation forestry with hybrid aspen (*Populus tremula* L.× *P. tremuloides* michx.) in Northern Europe. Scandinavian Journal of Forest Research. *27*(1):10–29. doi:10.1080/02827581.2011.628949.

Valinger E, Fridman J. 2011. Factors affecting the probability of windthrow at stand level as a result of Gudrun winter storm in southern Sweden. For Ecol Manag. 262(3):398–403. doi:10.1016/j.foreco.2011.04.004.

Valinger E, Ottosson Lövenius M, Johansson U, Fridman J, Claeson S, Gustafsson Å. 2006. Analys av riskfaktorer efter stormen Gudrun [analysis of risk factors after the storm Gudrun]. Jönköping: Skogsstyrelsen. 58 p. [In Swedish].

Wallstedt A, Bergqvist J, Claesson S, Nilsson J. 2013. Återväxtstöd efter stormen Gudrun [governmental regeneration subsidies after the storm Gudrun]. Jönköping, Sweden: Skogsstyrelsen. 41 p. [In Swedish].

Appendix.

Site characteristics and information about the plantings based on interviews with forest owners. Site index (SI) was estimated in the field based on site properties (H100; Hägglund and Lundmark 1977). Scarification method (SC) was either continuous or intermittent (patch, mound, inverse) scarification. Plant types were either bare root plants (Bare) or containerised plants (Con). The planting season was either spring (up to May), summer (June–July), or autumn (August or later). The plant size was either small (<30 cm), medium (30–50 cm), or large (>50 cm).

Main species	Planting year	Area (ha)	Lat. (°N)	Alt. (m)	SI	SC	No. of plants ha^{-1}	Planting season	Plant type	Plant size
Hybrid aspen	2007	9.7	56	83	35	No info.	1100	Spring	Bare	No info.
	2007	2.1	56.2	36	35	Continuous	900	Summer	Con.	Medium
	2007	2.9	56.7	184	32	Intermittent	1100	Spring	Con.	Large
	2007	1.8	56.7	57	32	Continuous	1100	Spring	Con.	Large
	2007	1.5	56.7	144	31	No info.	1100	No info.	Bare	Medium
	2007	2.6	56.9	197	31	Continuous	1100	Spring	Bare	Large
	2007	1.3	56.9	162	32	Continuous	1200	Summer	Con.	Large
	2007	5.3	57	222	30	Continuous	1100	Spring	Bare	Large
	2007	14.7	57	60	32	Continuous	1100	No info.	Con.	Medium
	2007	1.8	57	154	31	No info.	1200	Spring	Con.	Small
	2007	4.2	57	176	31	Intermittent	1300	Spring	Bare	Medium
	2007	9.2	57.1	198	31	Intermittent	1100	Spring	Con.	Medium
	2007	1	57.1	148	30	No info.	1600	Summer	Con.	Medium
	2007	3.3	57.2	236	31	Intermittent	1500	Summer	Con.	Large
	2008	1.2	56.6	159	33	Continuous	1000	Spring	Con.	Medium
	2008	3.3	56.6	135	31	Continuous	1200	Autumn	Con.	Medium
	2008	2.5	56.6	133	31	Continuous	1200	Autumn	Con.	Medium
	2008	1.5	56.6	152	31	Continuous	1200	Autumn	Con.	Medium
	2008	2.8	56.7	142	29	No info.	1200	Spring	Bare	Medium
	2008	1.5	56.7	134	30	Intermittent	2000	Spring	Bare	Large
	2008	2.8	56.7	166	31	Intermittent	1100	Spring	Bare	Medium
	2008	1.6	56.7	152	32	No info.	1100	No info.	Con.	No info.
	2008	2.7	56.8	49	32	Continuous	2000	Spring	Bare	Small
	2008	1.3	56.8	157	32	Continuous	1200	No info.	Con.	Medium
	2008	0.8	56.9	154	31	No info.	3000	Spring	Bare	Medium
	2008	2.7	57	149	33	Continuous	1600	Spring	Con.	Medium
	2008	1.8	57	173	31	No info.	1200	Summer	Con.	No info.
	2008	0.7	57	172	31	Intermittent	1400	Spring	No info.	No info.
	2008	3.6	57.1	73	32	Continuous	1100	Spring	Bare	Large
	2008	1.8	57.1	203	31	Intermittent	2000	Spring	Bare	Medium
	2008	1.6	57.1	230	29	Intermittent	1100	Spring	Con.	Medium
	2008	0.9	57.3	176	30	Intermittent	1200	Spring	Con.	Large
	2008	0.8	57.6	167	30	Continuous	1600	No info.	Con.	Large
	2008	1.8	58	72	33	No info.	1100	Spring	Con.	Small
	2009	2.2	56.2	55	34	No info.	2000	Spring	Bare	Medium
	2009	1.4	56.5	121	31	No info.	1100	Autumn	Con.	Small
	2009	1.8	56.5	153	31	Intermittent	No info.	Spring	Con.	Medium
	2009	0.9	56.5	151	32	No info.	1200	Spring	Bare	Large
	2009	2.1	56.6	130	33	Intermittent	1200	Spring	Con.	Medium
	2009	2	56.6	131	32	Intermittent	1200	Spring	Con.	Medium
	2009	2.5	56.6	46	34	No info.	1100	Summer	Bare	Small
	2009	1.4	56.7	136	32	No info.	1100	Spring	Bare	No info.
	2009	1.3	56.7	185	32	Intermittent	1200	Autumn	Con.	Medium
	2009	2.5	56.7	152	31	No info.	1100	Spring	Bare	No info.
	2009	1.4	56.7	60	32	No info.	1100	Spring	No info.	Medium
	2009	0.9	56.8	13	33	Continuous	1200	Spring	Con.	Medium
	2009	0.9	56.8	184	29	Intermittent	1100	Spring	Con.	Medium
	2009	1.6	56.8	162	30	Continuous	1200	Spring	Bare	Large
	2009	1.3	56.9	177	30	Continuous	1100	Spring	Con.	No info.
	2009	2.8	57	157	31	Continuous	1200	Spring	Con.	Medium
	2009	1.6	57	153	30	No info.	1200	Spring	Con.	Medium
	2009	2.5	57	154	31	No info.	800	Spring	Con.	Large
	2009	2.1	57	213	30	Intermittent	1100	Spring	Bare	Medium
	2009	5.6	57	171	32	No info.	1100	Spring	Bare	No info.
	2009	2.9	57	188	31	No info.	1200	Spring	Con.	Medium
	2009	1	57.1	215	30	Continuous	1100	Spring	Con.	Medium
	2009	1.7	57.1	196	31	No info.	900	Summer	Con.	Medium
	2009	1	57.4	214	30	Intermittent	1200	Spring	Con.	No info.
	2009	1.7	57.6	117	28	Intermittent	1900	Spring	Con.	Medium
Poplar	2007	12.7	55.9	181	34	Intermittent	2200	Autumn	Con.	Medium
	2007	2.9	56	100	34	Continuous	1100	Spring	Bare	Large
	2007	5	56.9	99	33	Intermittent	900	No info.	Bare	Large
	2007	2.4	57.1	93	31	No info.	1100	Spring	Bare	No info.
	2007	1	57.2	123	30	No info.	1500	Spring	No info.	Medium

(*Continued*)

Continued.

Main species	Planting year	Area (ha)	Lat. (°N)	Alt. (m)	SI	SC	No. of plants ha^{-1}	Planting season	Plant type	Plant size
	2007	1.1	57.3	277	30	Continuous	1500	Spring	Bare	Large
	2008	1.6	57.1	197	28	Intermittent	1000	Spring	Bare	Large
	2008	1.5	57.2	280	32	Continuous	1500	Spring	Bare	Medium
	2008	5	57.2	294	29	Continuous	1500	Spring	Bare	Medium
	2009	0.8	57	144	33	No info.	1600	Spring	Bare	Large
	2009	0.6	57.3	252	31	Intermittent	1300	Spring	Bare	Large