Aspects of Hybrid Larch (*Larix* × *eurolepis* Henry) as a Potential Tree Species in Southern Swedish forestry

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Licentiate thesis
Swedish University of Agricultural Sciences
Alnarp 2003

ISBN 91-576-6296-7

Abstract

Larsson-Stern, M. 2003, *Aspects of hybrid larch (Larix × eurolepis Henry) as a potential tree species in southern Swedish forestry.*
ISBN: 91-576-6296-7

The interest in growing hybrid larch (*Larix* × *eurolepis* Henry) in southern Sweden has increased in recent decades, one of its assumed advantages being high volume growth. The work underlying this thesis was designed to contribute to our understanding of hybrid larch and its use in commercial forestry as a complement to Norway spruce (*Picea abies* (L.) Karst.) in southern Sweden.

A literature review supported the hypotheses that young hybrid larch stands have high growth and yield potential. In addition, it highlighted the difficulties involved in morphologically distinguishing the hybrid from its parental species and stressed the susceptibility of hybrid larch to root rot (mainly caused by *Heterobasidion annosum* (Fr.) Bref..

A survey conducted through interviews in 1993 of the opinions of forest managers with practical experience of growing hybrid larch showed that the species was considered to offer an interesting complement to other conifer tree species in southern Sweden.

In addition, a growth simulator was developed, based on data from 28 sample plots established in stands on fertile sites managed with practical forestry programs. It included regression functions for basal area increment, stand form-height and initial basal area. Top height growth curves from a Norwegian study were also included in the simulator. A yield table was calculated for the age span 15 to 45 years. The calculations showed that the yield of hybrid larch stands on fertile sites in southern Sweden was slightly higher compared to Norway spruce, and its growth rate was markedly higher in young stands. On fertile sites the mean annual volume increment peaked at an age of 35 years, at a level of 13 m^3/ha. However, the bark volume, as a proportion of total volume, was ca. 5% lower for Norway spruce than for hybrid larch.

Economic calculations using current prices and costs (year 2002) showed that cash flow for hybrid larch was slightly higher and that the soil expectation value was more than double the corresponding values for Norway spruce.

Hybrid larch stands can be damaged by root and butt rot, but there was no clear evidence that the species was markedly worse than Norway spruce in this respect. The general opinion was that well managed older larch stands were less susceptible to wind throw than old Norway spruce stands.

A general conclusion was that hybrid larch could be an interesting complement to Norway spruce on relatively rich sites in southern Sweden.

Key words: Butt rot, growth simulator, *Heterobasidion annosum*, hybrid larch, larch species identification, *Larix* × *eurolepis*, root rot, volume growth, yield.

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Contents

Appendix

Papers I-III

This thesis is based on the following papers, which will be referred to by their respective Roman numerals.

I. Larch in commercial forestry: A literature review to help clarify the potential of hybrid larch (*Larix* ×*eurolepis* Henry) in southern Sweden.

II. Practical experiences with hybrid larch in southern Sweden (In Swedish): Hybridlärk – ett lampligt trädslag för Sydsverige? Skog & Forskning, No 3, 1999, pp 44-51.

III. Growth and yield of hybrid larch (*Larix* × *eurolepis* Henry) in southern Sweden. Submitted.

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Appendices 1-4

1. Thinnings in the sample stands from establishment to 1997
2. Permanent plots and measurements from 2000/2001
3. Photographs from the permanent sample stands (1991 and 2002)
4. Cash flow and soil expectation values for hybrid larch and Norway spruce (2002).

Introduction

Larch species grow naturally in most parts of the northern hemisphere (Schmidt 1995), but only occur in planted stands in Scandinavia.

In the 18th century Carl von Linné (Linnaeus 1754) suggested that foreign tree species should be introduced into Sweden. He found larch to be fast growing and to produce durable wood that was suitable for building houses and ships. Another useful product from larch was Venetian turpentine, available in pharmacies at that time.

European larch (*Larix decidua* Mill.) was the first larch species to be introduced into Sweden, in the 18th century. Japanese larch (*Larix kaempferi* (Lamb.) Carr.) and Siberian larch (*Larix sibirica* Ledeb) were not grown as forest trees in Sweden before the end of the 19th century (Schotte 1917).

The hybrid larch (*Larix* × *eurolepis* Henry) was first found in Scotland at the beginning of the 20th century, resulting from a spontaneous cross between a Japanese larch as the female parent and a European larch, growing next to it in the park of Dunkeld Castle. It was officially named by Henry & Flood (1919). The growth of the hybrid was found to be vigorous, and its superiority in relation to the parent species has been demonstrated in several European studies since then (Ferrand & Bastien 1985, Nanson & Sacré 1978, Braun & Hering 1987). However, whether or not the high yields are maintained in older stands has not been documented. When hybrid larch seedlings are used in practical forestry, it is not possible to check the hybrid frequency by examining morphological characters. Therefore, when hybrid larch is discussed in this study, it refers to stands where the hybrid frequency is probably high but uncertain.

The total standing volume of larch in Sweden is about 1.4 million m^3 according to the National Forest Survey (SLU 2001), equivalent to only about 0.05% of the total standing stock. The most commonly used species are Japanese larch, European larch, Siberian larch, Sukaczewii larch (*L. sukaczewii* Djil.) and hybrid larch. Japanese and hybrid larch are considered to be well adapted for growth in southern Sweden and European larch for growth in southern and central parts of Sweden. Siberian and Sukaczewii larch are used mostly in northern Sweden (Kiellander 1958). Hybrid larch has been by the far most widely planted larch species in recent decades in southern Sweden.

Larch species are not generally regarded as native in Sweden, and the Swedish Forestry Act (Skogsstyrelsen 1994) restricts the use of foreign tree species. Until recently, there was no evidence that the genus had appeared in Scandinavia since the last glaciation. However, cones and wood of Siberian larch that were radiocarbon dated between 8700 and 7500 BP have recently been found at two sites in the Scandes Mountains in Sweden. This proves that larch has occurred naturally in Sweden during a period after the last glaciation (Kullman 1998). As a result of these findings, the National Board of Forestry (Skogsstyrelsen 2000)

decided that Siberian larch should be regarded as native, while the other larch species are still classified as “foreign”.

According to official statistics, approximately 150 ha of larch was planted in 1999 (Skogsstyrelsen 2000). This was probably a heavy underestimate since forest nurseries have an annual production of 1-1.5 million seedlings (Skogsstyrelsen 2000). However, larch is often planted in small patches and in nurse crops where notification is not compulsory. In relation to the total number of forest tree seedlings planted in the country (>300 million seedlings per year) larch planting represents a minor activity. Most of the larch planted in Sweden is hybrid larch and more than 95% is planted in southern Sweden (Skogsstyrelsen 2000).

Forest managers in southern Sweden have shown varying degrees of interest in growing larch in recent decades. The interest in European larch has decreased due to severe damage to the species caused by larch canker (*Lachnellula willkommii* (Hartig) Dennis). Japanese larch has a reputation for being crooked, and because it lacks hardiness it can only be grown in the southernmost part of Sweden (Kiellander 1958). However, heavy storms in the late 1960’s and problems with root and butt rot (*Heterobasidion annosum* (Fr.) Bref.) in Norway spruce increased the interest in hybrid larch (Stern 1988). The species had a reputation for being more resistant to windthrow and root and butt rot. Furthermore, it was considered to grow fast and to produce durable wood.

Lessons gained from experience and compiled literature on how to establish and grow larch were first presented in Sweden by Schotte (1917) and later by Kiellander (1958, 1965), who was very interested in the vigour of hybrid larch. Møller (1965) has discussed the way larch has been grown in Denmark, and Malmqvist & Woxblom (1991) have produced a further compilation of larch-related literature, with a focus on larch wood properties.

Hybrid larch has usually been established like Norway spruce, *i.e.* with soil scarification, plantation with about 2500 seedlings per ha, and protection against pine weevil (*Hylobius abietis* L.). As larch has high demands for light (Kiellander 1965) and grows rapidly, several heavy thinnings are often recommended, with an option of short rotation periods.

The price and market for larch wood have varied over time. However, the market has grown during the last decade, boosted by the need for environmentally friendlier alternatives to impregnated wood in outdoor constructions.

It is important to gather more knowledge about hybrid larch to evaluate the potential for the species in southern Sweden, especially with respect to its growth pattern and relation to site factors, root and butt rot, storm damage, possible genetic gains and durability of the wood.

Objectives

The overall objective of the work described in this thesis was to investigate whether hybrid larch is a suitable complement to other tree species in commercial forestry in southern Sweden, especially Norway spruce (*Picea abies* (L.) Karst.). The main focus was on growth and yield, although the risk of damage and market conditions were also considered.

Summary of the papers

The specific goals of the studies presented in Papers I, II and III were:

(I) To produce a literature review with emphasis on hybrid larch, including information related to site requirements, silviculture, volume growth, damage and wood characteristics of larch.

(II) To gather and compile practical, experience-based information on silviculture of hybrid larch in forestry in southern Sweden.

(III) To calculate a yield table for hybrid larch based on measurements on semi-permanent plots in practically managed stands.

Paper I: Larch in commercial forestry: A literature review to help clarify the potential of hybrid larch (*Larix* × *eurolepis* Henry) in southern Sweden

A review of literature related to larch in forestry with emphasis on hybrid larch in southern Sweden is presented in Paper I. The purpose was to gather knowledge from literature about the scope for growing larch in southern Sweden and problems associated with it. The study focused on how to establish and manage hybrid larch stands. The paper also contains information about larch wood properties and the uses of larch wood. The amount of scientific literature available is quite limited, although additional information was found in various forestry handbooks.

The paper considers the following issues: larch distribution and introduction into Sweden, different larch species used in Sweden, identification of hybrid larch, site requirements, seeds and seedlings, silviculture, volume growth and yield, damage in larch stands, the impact of larch stands on soil conditions, larch wood properties and applications of larch wood.

Paper II: Practical experiences with hybrid larch (*Larix* × *eurolepis* Henry) in southern Sweden (in Swedish)

Information gained from practical experience on how to manage hybrid larch stands in southern Sweden was compiled in a series of interviews.

The interview population used for the study comprised 14 forest managers who were interviewed on two occasions regarding their experience of hybrid larch silviculture. These were the forest managers who were responsible for the sample

plot stands used in Paper III, and each managed a forest area ranging from 100 to 30000 ha, 1-5% of which supported larch. The interviewees probably had extensive silvicultural knowledge and above average interest.

In the first part of the study, in 1993, the 14 managers were interviewed individually by telephone. (The answering frequency was 100%). They were interviewed for a second time in 1999 to provide complementary information. This was prompted by new scientific results published between 1993 and 1999 concerning root and butt rot in hybrid larch. The timber market had also changed somewhat during the intervening period. On this second occasion 10 out of 12 people answered the questions.

The answers were compared with documented knowledge and experience of hybrid larch. An assessment of the forest managers' collective opinions regarding hybrid larch was then made.

The main reason for growing hybrid larch for most of the interviewees was its resistance to root and butt rot. Several other potentially attractive aspects of the tree species were also mentioned *i.e.* resistance to wind-throw, the need for complementary tree species, its ease of establishment, and its potential to provide valuable timber. Problems mentioned included root and butt rot, stem crookedness and damage to seedlings by roe deer (Table 1).

Table 1. Some answers from the interview study comprising 14 forest managers with experience of silviculture of hybrid larch. HL = hybrid larch, NS = Norway spruce

Main reasons for establishing HL:		(%)	
Root and butt rot in NS		57	
Less **susceptible to storm damage than NS**		29	
Need for complementary tree species		21	
Easy to establish		21	
Problems with establishment of HL:			
Damage by wild animals		79	
Crooked stems		36	
Root and butt rot in HL		14	
Likely to plant the same area again with HL:		93	
Suitable sites for HL:			
Highly fertile sites		64	
Moderately fertile sites (SI H_{100} G30-32)		100	
Less fertile sites		50	
Overall opinion:	Yes	No opinion (%)	No
HL is of interest for forestry in S. Sweden (-93)	79	21	
HL is of interest for forestry in S. Sweden (-99)	90		10

In general, perceptions about hybrid larch from literature and practical experience correspond reasonably well, but when it comes to resistance to root and butt rot there are differences between the literature and reported experience. Research shows that hybrid larch is very susceptible to root and butt rot, whereas forest managers mention root and butt rot as being a minor problem in hybrid larch stands, even if they know that hybrid larch is not resistant.

According to the interviewees, hybrid larch is considered to offer an interesting complement to other conifers in southern Swedish forestry.

Paper III: Growth and yield of hybrid larch (*Larix* × *eurolepis* Henry) in southern Sweden

A survey of the local districts of the County Forestry Boards in southern Sweden undertaken in 1990 resulted in the identification of about 100 stands of hybrid larch that were potentially suitable for this study, which was limited to stands growing on mineral soils where hybrid larch accounted for at least 90% of the standing volume and had a total age of more than 10 years. Poorly managed or substantially damaged stands, and stands that lacked documentation proving them to be hybrid larch were also excluded. In addition, stands were sought for which the time of earlier thinnings was known and, if possible, the removed volume of the thinned trees (Appendix 1). The selection resulted in 28 stands in the southernmost part of Sweden (Fig. 1, Paper III). For all except one stand, sample plots were measured in 1991 and again in 1997. The stands were also photographically documented (Appendix 3).

In selected stands where it was possible to enlarge the sample plots for future yield measurements and the trees were undamaged, permanent sample plots were established in the year 2000 (Appendix 2).

The total age of the sample plot stands was, on average, 30 years (range 19-41 years) in 1997. The site index for Norway spruce (H_{100},, total age) according to site factors was on average 33.6 m and the corresponding figure (H_{40}, age at breast height) for hybrid larch was 28 m (Table 1, Paper III).

A distance-independent stand model (Munro 1974) was developed, for which basal area increment was chosen as the dependent variable in the growth function. The simulator includes regression functions for estimating basal area in the initial stand, basal area increment, and stand form-height. As height growth curves for hybrid larch in Sweden were not available, the simulator includes height curves derived for Japanese larch in Norway (Wielgolaski 1993). The height growth in the data agreed well with estimates derived from the height growth curves by Wielgolaski, suggesting that these curves were also applicable to hybrid larch stands in southern Sweden.

The growth simulator was used to calculate a yield table. The average site index and corresponding average data concerning the initial stands were specified in the

calculations. Thinning grades and thinning intervals were chosen that were consistent with common practice.

From the data a yield table (Table 3, Paper III) was calculated for H_{40}=28 m, which was the average *SI* for Japanese larch (Wielgolaski 1993) (Table 1, Paper III). In the initial stand the number of stems was set at 2000 stems per ha and the total age at 15 years. This corresponds to a top height of 13.0 m according to the top height growth curves for Japanese larch produced by Wielgolaski (1993) and to a basal area of 26.2 m²/ha, estimated by Function 1 (Paper III). The simulation was continued up to a stand age of 45 years, four years older than the highest age in the data set. Thinnings were simulated every fifth year. The basal area after thinning was maintained at an almost constant level, varying between 17.5 and 20.8 m²/ha. The volume removed ranged from 39 to 54 m³/ha.

The annual volume increment during the first five-year period, age 15-20 years, was 16.9 m³/ha, compared to 11.7 m³/ha during the final period, age 40-45 years. The mean annual increment (*MAI*) at the start of the simulation was 9.8 m³/ha, and it peaked at 13.0 m³/ha at an age of 35 years. The *MAI* during the two following periods dropped only slightly, to 12.8 m³/ha in the last period.

Extrapolation of the growth simulator concerning the thinning program and site index showed that the behaviour of the model is logical. A comparison with yield tables by Hamilton & Christie (1971) showed good agreement in height and basal area growth, but poorer agreement in volume growth.

The yield study confirms the hypothesis that the growth in young stands with hybrid larch is high and peaks early.

Discussion

Hybrid larch identification

Recent studies show that the output of commercial hybrid larch seed orchards in some cases have large proportions of European or Japanese larch seed (Pâques 2000). It is difficult to distinguish between the species using external characters. Therefore, Japanese and European larch individuals may be represented in the studied sample plot stands. When selecting stands for this study, a great number of stands were rejected, due to a lack of reliable records on the species planted. However, for the chosen stands the origin was documented to be hybrid larch. Most of the larch seedlings produced in Sweden originate from the Maglehem seed orchard. Others come from the Danish seed orchard Fp 203 in Holbæk. In Maglehem there is only one mother clone (Japanese larch), from which the cones are picked, and nine father clones (European larch). In Fp 203 there is one mother clone (Japanese larch) and one father clone (European larch). Therefore, from these two orchards there should be no risk of producing pure European larch seeds. There is a small risk that some Japanese larch will be produced through self-pollination. However, self-pollination often leads to lower growth and vitality, and if the seeds germinate the Japanese larch seedlings will often be sorted out in

the nursery (Brandt 1977). If there are individuals of Japanese larch in the neighbourhood they might pollinate the mother clone. In orchards where several clones are mixed and cones can be picked from either of the parent species the risk of producing pure parent material is much higher (Pâques 2000).

When the study started (in 1991) species could be identified using isoenzyme marker techniques. However, these analyses were too costly for routine use. Analytical methods giving reliable results at lower costs have been developed since then. For instance, the association of maternal mitochondrial markers and paternal chloroplastic markers can be used to identify the hybrids – only DNA is required (Acheré *et al.* 2002). The tests are regarded as fast, effective and reproducible. Such tests should be used in future studies on growth and yield of hybrid larch – including tests on the permanent experimental plots following this study.

Seed supply

In practical forestry, the demand for hybrid larch seed exceeds supply. Crops from the seed orchards are irregular and often small.

Efforts to improve the genetic material for hybrid larch that is suitable for the southern parts of Sweden were restarted in the middle of the 1990s, when plans were made to test the selected plus-tree material and to increase the number of clones in the breeding population for southern Sweden (Boije Malm & Stener 2002). Progeny tests have also been established.

Using seed from genotypically good hybrid larch clones (F_2) could be one way to meet the seed demands. Pâques (2000) found that the F_2 generation was much less vigorous than the F_1 generation, but gave better performance with respect to stem straightness and phenology, and showed considerable variation between families. Brandt (1977) did not recommend collecting seeds from hybrid larch stands for seedling production as the progeny will be a mix of high and low quality seeds.

Establishing hybrid larch stands

Hybrid larch seedlings are expensive, but normally easy to establish. They are sensitive to competition from grass and soil scarification is often needed. Established seedlings grow rapidly above a critical height when exposed to roe deer browsing and fraying damage. Cleaning is often not needed as the height growth of young hybrid larch exceeds the growth of the competing vegetation.

Growth and yield

Hybrid larch has been grown for only about the last four decades in Sweden, especially in the southernmost part and on better sites. Therefore, there was a limited population from which to choose sample plot stands. The plots are situated in practically managed stands and therefore detailed information concerning

establishment and silvicultural operations is sometimes lacking. These circumstances should be borne in mind when considering the yield table, as well as the fact that the thinning program in practice varied in intensity and thinning intervals. However, as long as the yield table is used within the parameters delimited by the data set, this should not be considered a problem.

The origin of the seedlings was known in 12 of the 28 sample plot stands. Eight of them came from the Swedish seed orchard Maglehem and four of them from the Danish seed orchard in Holbæk (Table 1, Paper III). The low variation and small number of stands with material of known origin limited the possibilities to compare the effects of genetic origin on growth and yield.

The influence of silviculture on growth and yield

The influence of initial spacing on growth and yield is well documented in Norway spruce and Scots pine (*Pinus sylvestris* L.) in Sweden (Pettersson 1992). Elfving (1985) found that increasing the density of Norway spruce and Scots pine stands (up to 80 years of age) from 500 to 1000 stems per ha increased the yield from 70 to 90% of that given by stands with 2000 stems per ha. Aldentun (1987) obtained similar results in a hybrid larch trial. When increasing the density of stems from 500 to 1000 stems per ha the yield increased from 50 to 85% of that given by stands with 3000 stems. Therefore, reductions in volume yield should not be considered a problem when establishing hybrid larch stands in commonly used densities of about 2000-2500 stems/ha.

The choice of thinning program may affect the total yield. Not all stands in the study have been thinned (Table 1, Paper III), but among the thinned stands the average age at first thinning was 17 years (range 11-24 years). The interval between thinnings was on average 5 years (range 1-11 years). In the simulated yield table (Table 3, Paper III) the thinning program starts at the age of 15 years and the stands are thinned every 5th year. The stand after thinning had a residual basal area of 17.5-20.8 m^2/ha. Less heavy thinnings may make better use of the yield capacity of the site. The thinning responses of hybrid larch are being studied systematically in an experiment located at Vedby (lat. 55°90' long. 13°11'), approx. 70 km north of Malmö, was established in 1989 by the Southern Swedish Forest Research Centre at SLU (Ekö 1999). When the experiment started, the stand was 22 years old, and had already been thinned once. Three thinning grades were applied with three replicates, leaving 1000 stems (unthinned), 750 stems and 500 stems per ha. During the first five-year observation period thinning had a significant impact on the volume increment ($p=0.018$). Compared to the unthinned stand, the increment was on average 87% after thinning to 750 stems per ha, and 82% after thinning to 500 stems per ha (Figure 1). However, no significant impact was detected during the last five years of the observation period. ($p=0.132$). The corresponding figures for this period were 100% and 92%. This indicates that young hybrid larch stands regain productivity in a short period of time after thinning.

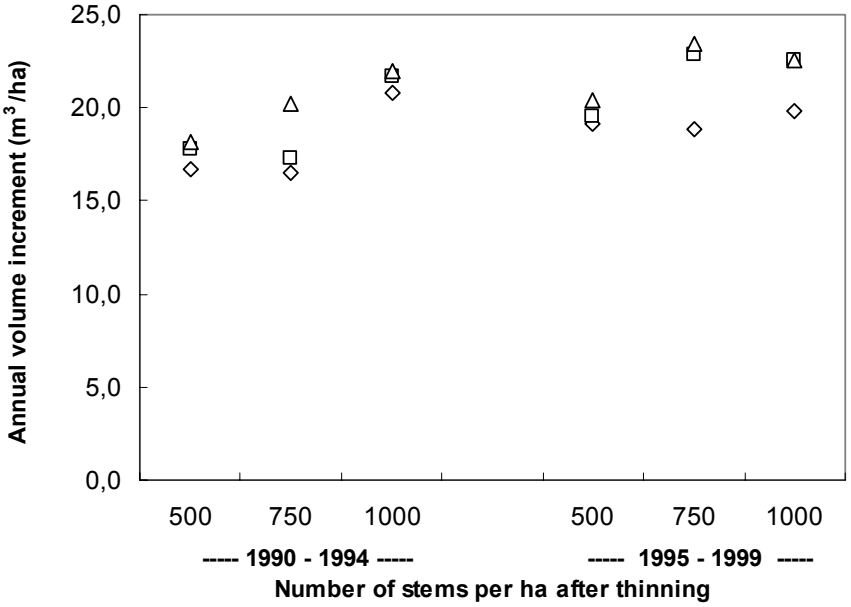

Fig. 1. Volume increment in the hybrid larch thinning experiment at Vedby, southern Sweden, in the ten years following thinning to different numbers of stems per ha.

Yield of hybrid larch compared with Norway spruce

The length of rotation period in hybrid larch could vary substantially, depending on the silvicultural objectives. Compared to Norway spruce, the hybrid larch has about the same max. *MAI*, but the growth patterns differ markedly between the two species. *CAI* peaks before the age of 20 years in hybrid larch, but only by the age of about 25-35 years in Norway spruce on similar sites (Eriksson 1976). As *MAI* peaks early in hybrid larch it is possible to get a final stand with about 300 m^3/ha by the age of 45 years. By then the total yield is equivalent to around 575 m^3/ha. On similar sites Norway spruce stands have normally at least a 20 year longer rotation period. The actual age for final felling may be affected by damage caused by agents such as root and butt rot and wind throw, as well as by market conditions.

A general comparison between the two species was made. A growth simulator for Norway spruce frequently used in Sweden (Eriksson 1976) and the yield table for hybrid larch in this study were used to compare the growth patterns (Figure 2). The growth in young stands is much higher for hybrid larch, but *MAI* is about the same as for Norway spruce on similar sites in southern Sweden. At a total age of approximately 35 years *MAI* peaks in hybrid larch, which is much earlier than in Norway spruce (80-100 years according to Eriksson 1976).

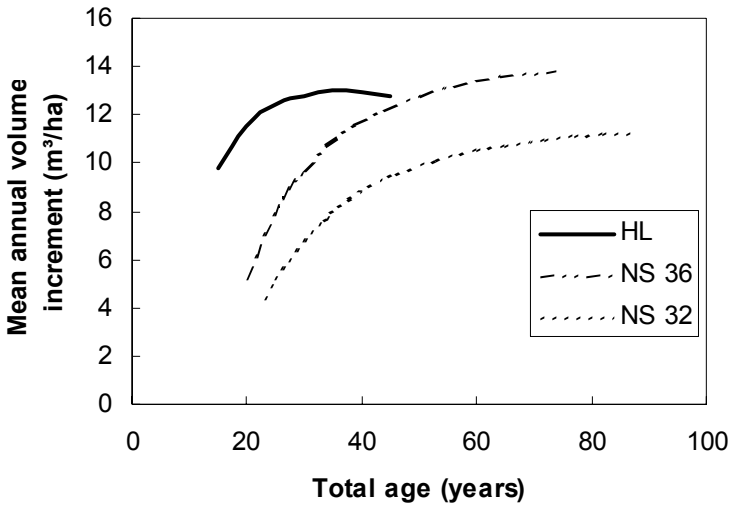

Fig. 2. Curves for Norway spruce (NS) showing *MAI* in stands with site index (H_{100}) 32 and 36 m (from Eriksson 1976) and for hybrid larch (HL) derived in this study (H_{40}, 28 m; corresponding to an estimated site index, H_{100}, for NS of 33.6 m).

Diameter growth was also compared for the two species using the growth simulator by Eriksson (1976) for Norway spruce and the yield table derived in this study for hybrid larch (Figure 3). The rapid diameter growth in hybrid larch stands is due to the high growth rate and the thinning program applied (removal of about 45 m^3 every 5^{th} year).

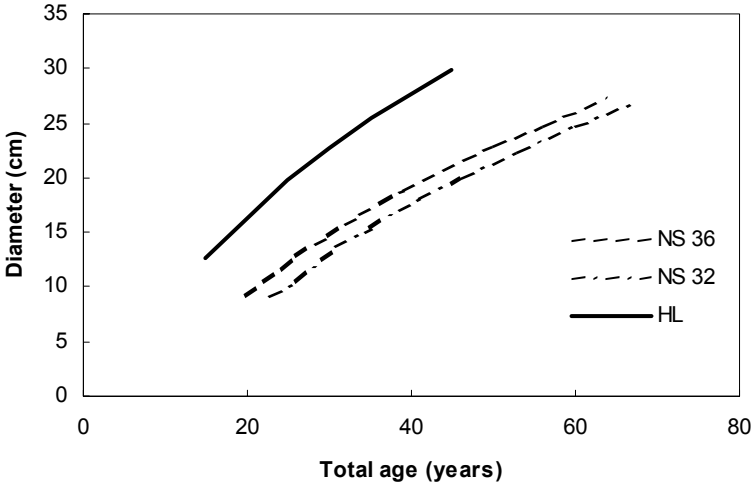

Fig. 3. Diameter growth for Norway spruce (NS) stands, with site indices, H_{100}, 32 and 36 m (from Eriksson 1976) and for hybrid larch (HL) derived in this study (H_{40}, 28 m).

Top height, *dbh* and bark thickness at breast height were measured on sample trees in the growth and yield study. Volume functions by Carbonnier (1954) were then used to estimate the volume on and under bark. On average the bark percentage of the volume was 17% (s.d. 2.6%) (Figure 4). As a comparison, top height and *dbh* were also used to calculate the bark volume, assuming the species was Norway spruce (Brandel 1990). The bark volume, as a proportion of total volume, was ca. 5% less for Norway spruce than for hybrid larch.

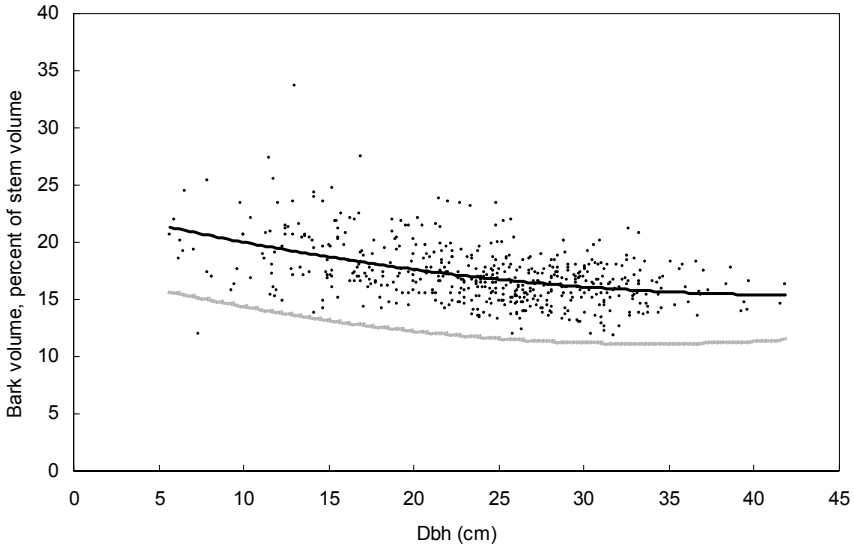

Fig. 4. Bark volume, as a proportion of stem volume. Hybrid larch: dots and black line. Norway spruce: grey line. The dots represent sample tree data. The lines are fitted with a second degree polynomial function.

Hybrid larch stands grow very fast in early years and the possibility of using short rotation periods has been discussed above. These are prerequisites for a favourable economic return, based on current price and cost levels. Table 2 (and Appendix 4) show economic calculations derived from a comparison between hybrid larch (HL) and Norway spruce (NS) on fertile sites in southern Sweden. The current prices for larch timber are high (2002), even for timber of small dimensions. The soil expectation value is 135% higher and cash flow is 7% higher than for Norway spruce grown under similar conditions. The pay-off periods are also considerably faster than for Norway spruce. The comparisons are based on figures for stands that grow without substantial damage.

Table 2. Cash flow and soil expectation values for hybrid larch and Norway spruce grown on similar sites (H_{100} 34 m) in southern Sweden. Costs and income estimated from practical experience and available price lists (year 2002). The impact of root and butt rot has not been considered. Interest rate 3%

	Tree species	
	HL	NS
Number of thinnings	4	3
Age at final felling (years)	33	65
MAI at final felling (m^3/ha)	13.0	12.8
Cash flow (SEK/ha)	2800	2600
Soil expectation value (SEK/ha at 3%)	41600	17800
Pay-off periods (years)	28	45

Yield of hybrid larch compared with Japanese and European larch

Superiority in growth in young stands of hybrid larch compared to the parent species has been found in several studies in different parts of Europe (see, for instance, Brandt 1977, Hering 2002) (Paper I).

Seven and nine permanent plots, respectively, for studying the yield of European and Japanese larch in southern Sweden were used for comparison with hybrid larch. There was no information on site index for the plots. The growth pattern for Japanese larch seems to correspond better to hybrid larch in this study than European larch (Figure 5). Differences in management regimes and damage by wind or larch canker may influence the comparison (although no such correlations were observed in this study).

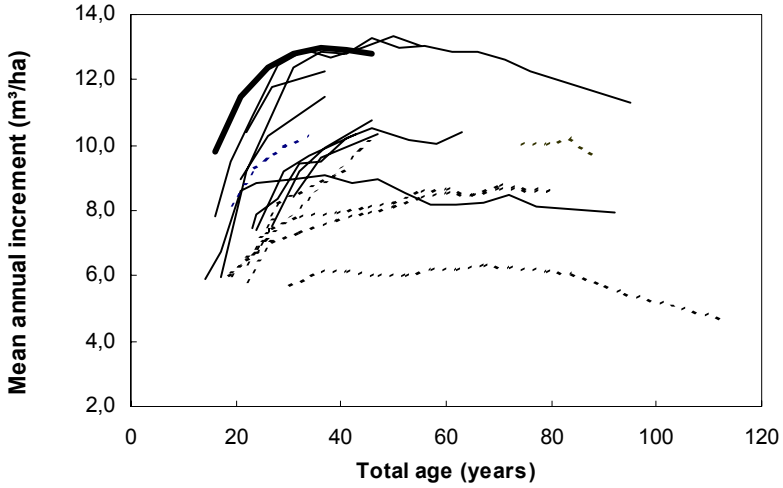

Fig. 5. Mean annual increment (*MAI*) curves for hybrid larch derived in this study (thick solid line) and for Japanese (solid line) and European larch (dashed line) on 16 permanent experimental plots in southern Sweden.

Martinsson (1991) studied four sites with Japanese larch provenance trials of 26 different provenances (4 x 4 trees per plot, six replicates at four different sites) established in the beginning of the 1960s in southern Sweden (up to the latitude of Stockholm). The plots were too small to provide reliable yield data, but they indicate that both choice of provenance and climate influence growth and yield in Japanese larch. After 30 years, *MAI* ranged between 7.1 and 13.6 m^3/ha at the four sites.

Pâques (2000) has studied four experimental sites in France, where he found that European larch of North European origin (*Larix decidua ´polonica`*) could grow as fast as, or faster, than hybrid larch up to 6-7 years. European larch has a broad genetic variability. Central European populations (from Central Poland and the Sudetan Mountains) have shown various desirable traits, such as broad ecological adaptability, good resistance to larch canker and high vigour. Japanese larch shows smaller genetic variability, so the scope for genetic improvement of Japanese larch appears to be limited (Pâques 2000). According to Schober (1981) there are considerable differences between European larch provenances with respect to growth and quality up to 30 years.

Yield tables for Japanese and hybrid larch in Norway, Denmark and Great Britain were compared with the yield table from this study. Both the top height growth curves and the *MAI* curves showed similar overall shapes, while the absolute levels differed between the studies (Figure 6 and 7). These differences mainly reflected varying site conditions. It should be noted that there were difficulties in comparing growth from different studies, mainly relating to differences in the definitions and methods used for volume estimations.

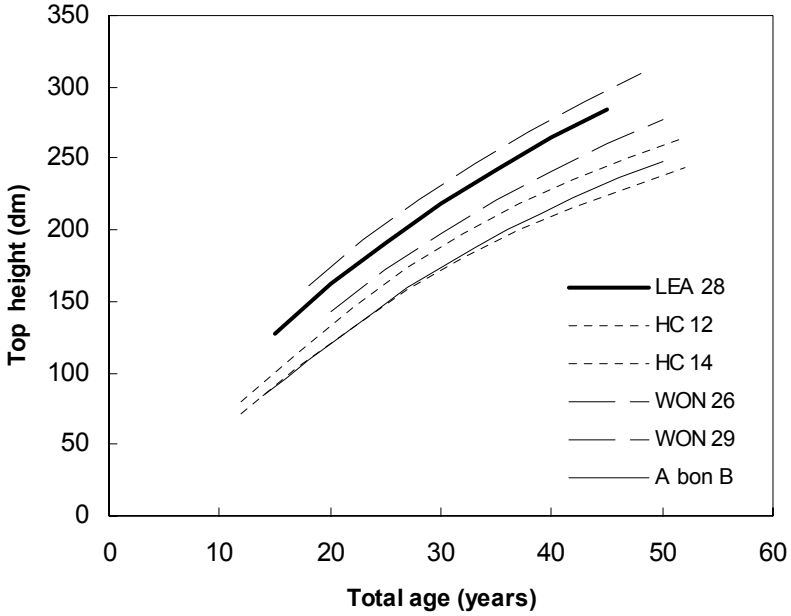

Fig. 6. Top height growth for hybrid larch stands according to this study (LEA), for Japanese larch in Denmark (A) (Andersen 1950) and Norway (WON) (Wielgolaski *et al.* 1993), and for hybrid and Japanese larch in Great Britain (HC) (Hamilton & Christie 1971).

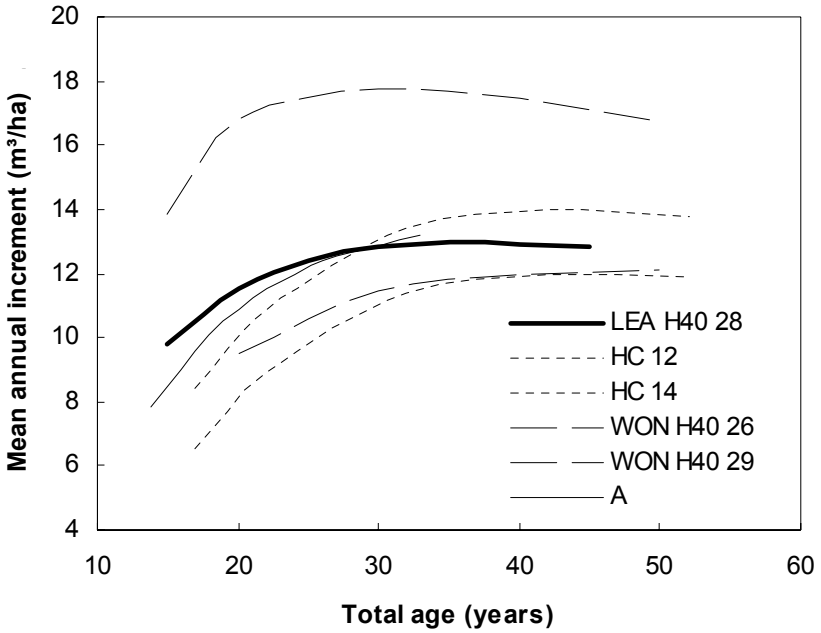

Fig. 7. Mean annual increment for hybrid larch found in this study (LEA), for Japanese larch in Denmark (A) (Andersen 1950) and Norway (WON) (Wielgolaski *et al.* 1993), and for hybrid and Japanese larch in Great Britain (HC) (Hamilton & Christie 1971).

Damage and diseases

In the 1960s hybrid larch was frequently planted after clearing wind thrown Norway spruce stands infected by root and butt rot caused by *Heterobasidion annosum* (Fr.) Bref. The general opinion was that the resistance to root and butt rot of hybrid larch was high (Stern 1988), although the parental species were susceptible (see, for instance, Vollbrecht *et al.* 1995). However, Gladman & Low (1963) reported root and butt rot in hybrid larch stands, and later studies showed that hybrid larch can be highly susceptible to root and butt rot (Rönnberg & Vollbrecht 1999, Vollbrecht & Stenlid 1999). Stener & Ahlberg (2002) mentioned that root and butt rot was a problem in 21-47 year old hybrid larch stands in southern Sweden. Stener *et al.* (2002) found that there were no significant differences among hybrid larch families in the spread of *H. annosum* mycelia in the wood, but there were indications that different families reacted differently to artificial infection with respect to the size and spread of reaction zones. Thus, breeding could enable the production of larch seedlings with higher resistance to *H. annosum*.

Root and butt rot was regarded as a minor problem by forest managers (Paper II), despite the contrary indications cited above. One reason for this discrepancy may be that the stands in the cited studies differed from commercially managed stands with respect to silvicultural programs, site index, provenances and other features that may affect susceptibility. Another reason may be the difficulty in visually detecting wood infected with butt rot without specific training. Furthermore, hybrid larch was often planted on soils that were heavily infected by root and butt rot, and were thus more exposed to infections. More research is needed to quantify the risk of root and butt rot damage in hybrid larch.

Bendz-Hellgren (1997) and Rönnberg (1999) emphasized the importance of treating commercial thinning stumps in Norway spruce stands when spores of *H. annosum* are dispersed, to avoid the spread of root and butt rot to the trees in the remaining stand. Although not studied, this recommendation is probably also valid for hybrid larch.

Kiellander (1958) stated that hybrid larch can be grown in zones I-III (Paper I, Figure 6) delimited by the Swedish Pomologic Society Scheme (Ullström 1966). These recommendations were founded mainly on practical experience related to the parent species' hardiness, and will be considered valid until new evidence is presented. Experience in nurseries and practical forestry suggests that height growth of hybrid larch seedlings often does not terminate in the autumn until after the first frost (Stern 1988). Thus, if the first frost is hard the risk of severe damage, especially to the top shoot, seems high. Given this risk, it may be preferable to plant seedlings that terminate growth earlier in the autumn, but at the risk of reduced volume growth as Boije Malm & Stener (2002) obtained indications that late growth termination in European larch was associated with increased growth. However, there are examples of successful hybrid larch plantations in zone IV in southern Sweden, indicating that it may be more important to select sites with

favourable microclimate, than to strictly follow the climate zone recommendations.

Pine weevils (*Hylobius abietis* L.) can cause great damage to seedlings of many tree species in southern Sweden (Eidmann & Klingström 1990, Stern 1988). The hybrid larch seedlings have to be protected against damage by this insect.

Young larch stands are susceptible to storm damage, but older larch stands are considered to be resistant to wind throw (Møller 1965, Henriksen 1988). Larch was considered to be more resistant than Norway spruce by forest managers (Paper II). According to Fodgaard (2001) Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) is more resistant to wind throw than larch, while Scots pine, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and Norway spruce are less resistant. This should be valid for old trees. As for other tree species, the risk of wind throw is normally higher on moist soils and sediments than on moraines.

Most tree species in southern Sweden are susceptible to damage caused by wild animals. Hybrid larch, like other tree species found in plantations that are limited in size and number, are often damaged by roe deer, fraying and browsing. Larger plantations seem to be less heavily damaged and repellent treatment after needle fall in autumn efficiently deters the animals from browsing (Stern 1988). Fencing is not common in hybrid larch plantations in Sweden and is not considered necessary by forest managers when the plantation area exceeds two hectares. However, the need for fencing is also dependent on factors such as the density of wild animals, and the availability of alternative food supplies for the animals.

Crookedness in hybrid larch is considered a problem for wood quality. There could be several reasons for such crookedness, one being genetic inheritance. However, a high crown:root ratio, which is common for bare root seedlings, could result in a stem base crook in hybrid larch. If the root system is too small for the above ground part of the seedling, it will be insufficiently stable, especially if the height growth is very high immediately after plantation. Frost and pine weevil damage, leading to top shoot die back may be other causes of crookedness.

The market for larch timber and durability of the wood

In the last decade both the interest in growing larch and the demand for larch timber have increased. The need for more environmentally-friendly alternatives to impregnated wood has contributed to the popularity of the larch timber. Today (2003), the price for larch timber in Sweden can be higher than for timber from Norway spruce.

The durability of larch wood in outdoor constructions is frequently discussed, and different authors have conflicting views on the subject (Martinsson 1996, Nilsson & Edlund 1996). However, there seems to be a general agreement with the statement by Björkman (1944) that the heartwood of larch is as durable as Scots pine heartwood. Heartwood formation in European larch starts by the age of 10-12

years, compared to 30-36 years in Norway spruce and more than 40 years in Scots pine (Kiellander 1965). Larch wood in old trees is dominated by heartwood, which can account for more than 80% of the total wood volume (Rosell 1988). The way hybrid larch is grown today, with relatively wide spacing in plantations, results in wide annual rings that may make the wood less durable, but heartwood still accounts for most of the total wood volume in older trees. It is important to use only heartwood when durability is required.

Regulations regarding larch in Swedish forestry

According to the definition by the National Board of Forestry in Sweden, all larch species except Siberian larch are regarded as foreign tree species, which means that plantations larger than 0.5 ha should be notified to the Authority. However, the Authority does not anticipate restrictions to be imposed on the use of any larch species, given their relatively low level of exploitation today. In fact, the use of larch in Swedish forestry is encouraged for its high yield and promotion of biodiversity (herb vegetation is often more diverse in larch than in Norway spruce stands) as long as steps are taken to use appropriate genetic material and plantations are established on suitable sites. However, it should be noted that natural regeneration occurs in hybrid larch stands, although the degree to which it occurs, and its likely impact on nature conservation is unclear.

Conclusions concerning the use of hybrid larch in commercial forestry

The growth of young hybrid larch stands is rapid on fertile sites in southern Sweden. On sites considered suitable for growing Norway spruce, *MAI* culminates at about 13 m^3/ha at the total age of 35 years, which is almost the same as for Norway spruce. The market for larch timber today (2003) is relatively strong, although the demand for larch pulpwood is limited. Economic calculations based on current prices and costs are favourable for hybrid larch. Hybrid larch is susceptible to root and butt rot, but there is no clear evidence that the species is markedly worse than Norway spruce in this respect. The general opinion of practical foresters is that well managed older larch stands are less susceptible to wind throw than old Norway spruce stands.

A general conclusion is that hybrid larch offers an interesting complement to Norway spruce on better sites in southern Sweden.

Future research on hybrid larch

There is a considerable genetic variability in provenances and clones of the parent species with respect to frost resistance, volume growth, root and butt rot, and wood quality. Improvement of the seedling material could therefore be very fruitful.

For the future it will be important to study the growth pattern of middle aged and older hybrid larch stands, and also the relationship between *SI* and volume growth.

In addition, more research is needed concerning silvicultural methods, *i.e.* the choice of initial spacing and reaction to different thinning program. The economy in different silvicultural models should also be analysed.

Root and butt rot cause serious economic losses. Therefore, there is urgent need to find out if stump treatment is effective in hybrid larch.

One important argument for growing larch is that the timber has high durability in outdoor constructions. However, opinions differ about its durability. Its degree of durability could be a decisive factor for the future timber market for larch.

Acknowledgements

Now that this thesis has finally become a reality, I would like to thank the following people for their contributions, help and support:

My supervisors, PM Ekö (SLU Alnarp) and Arne Albrektsson (SLU Umeå). They initiated the work and shared their deep and broad knowledge with me. Even though time flew by faster and faster from the time I started in 1990, they never showed any doubt that I would finish the task.

Ulf Johansson, at Tönnersjöheden Experimental Forest, who throughout the work has provided very helpful advice and assistance.

Lars-Göran Stener (SkogForsk) and Luc Pâques (INRA, Orléans) for valuable advice and discussions throughout the work.

Jens Peter Skovsgaard (FSL), Bo Karlsson (SkogForsk), Erik Agestam, Peter Ask, Gunilla Oleskog and Jonas Rönnberg (Southern Swedish Forest Research Center) for valuable comments on the manuscript.

The staff at the Southern Swedish Forest Research Center (SLU), Tönnersjöheden and Asa Experimental Forests (SLU) and Växjö University (School of industrial engineering) for kind help and willing assistance.

My employers during the years I carried out the research work: the County Board of Forestry; County of Östergötland (Börje Falk †) and County of Jönköping/Kronoberg (Rune Ahlander), AssiDomän (Jonas Jacobsson) and Sveaskog (Gunnar Olofsson). Their positive attitude enabled me to do the research work alongside my ordinary working activities.

The landowners and foresters who enthusiastically shared their experiences in the interviews, and hosted the sample plot stands for the growth and yield study.

Katarina Ekberg for the cover drawing and John Blackwell for linguistic revision.

My family: Jonas has been ever-present as husband, father to our children and colleague. Whenever needed he has supported me with comments, computer

assistance or encouraging hugs. Our children Jakob, Sofia and Arvid supported me with love and laughter.

Finally, many other people have helped to bring the project to completion in several ways. There are too many of you to mention individually, but I thank you all.

The work was financed by the Swedish Council for Forestry and Agricultural Research (SJFR) and the Royal Swedish Academy of Agriculture and Forestry (KSLA).

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