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Reassessing Potential for Exotic Larch in Northern United States

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Abstract

Field measurements of operational plantations and research plots demonstrate that growth rates of exotic larches in unmanaged stands can exceed 12 m^3 per hectare per year in Maine and elsewhere. This paper briefly reviews the recent history of exotic larch (*Larix decidua*, *L. kaempferi*, and *L.* × *marschlinsii*) in northeastern United States and Canada. Stands can be commercially thinned as early as 15 years; further thinnings add to significant volume accumulation, based on stand table projections. Genetic development of the hybrid (*L.* × *marschlinsii*) could yield additional volume. Even at current low stumpage values, exotic larch plantations offer positive returns at realistic discount rates. In map form, we report a current inventory of known trials and operational plantings across the Northern United States, including adjacent Canada.

Keywords: larch, exotic larch, *Larix*, hybrid larch, *Larix decidua*, *Larix kaempferi*, *Larix* × *marschlinsii*, stand table projection, northern United States, thinning

A severe infestation of spruce budworm (*Choristoneura fumiferana*) in the 1970s and 1980s caused the Maine (and Canadian) paper industry to look for solutions to an expected softwood shortage. One approach was to plant fast-growing conifers to augment supply once salvage and presalvage harvests of impacted spruce and fir were completed. An attractive option was exotic larches. Exotic larches include European larch (*Larix decidua* Mill.), Japanese larch (*L. kaempferi* [Lam.] Carrière), and their hybrid (*L.* × *marschlinsii*).

This paper summarizes the potential of exotic larch in the northern United States as an important planted timber species. We perform the analysis based on extensive literature review of larch; historic conversations and notes made by field foresters and researchers in the last 50 years; numerous remeasurements of mature stands; and analysis of exotic larch as a timber species based on other species with similar wood uses and prices. We provide an economic analysis of potential returns of larch. By this, we hope to encourage further research and investment in establishing exotic larch plantations.

Development of Exotic Larches as a Plantation Species in the United States

European larch has been planted in the United States since the 1850s (Nyland 1965). Cook (1939) reports,

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Management and Policy Implications

Exotic larch has been widely planted, mostly as trials, across northeastern United States, the Lake States, and eastern Canada. It has demonstrated exceptional growth on good soils, yet it remains largely ignored as a viable plantation species. Limited genetics work has demonstrated that the hybrid (*Larix* × *marschlinsii*) between the European larch (*L. decidua*) and Japanese larch (*L. kaempferi*), sometimes called "Dunkeld larch," provides improved growth over either parent. We provide up-to-date information on growth and yield as well as economics in this paper to encourage landowners, foresters, and investors to consider these species in their management schemes.

however, that it was not planted extensively for reforestation until the 20th century. The oldest existing trial of European larch of which we are aware is at the Marsh-Billings-Rockefeller National Historic Park in Woodstock, Vermont. Records indicate that the small plantation was planted in 1887. This plantation still exists and is being monitored; recently thinnings have been conducted (notes on Stand 1 from Ben Machin, pers. commun., Redstart Consulting, Corinth, VT, March 10, 2016). Small research trials had been established in New England and Lake States by the forest industry in the 1930s through 1960s and University of Maine researchers (Carter 1981). Provenance trials for both European and Japanese larch were conducted by International Union of Forest Research Organizations (IUFRO 2007) as well in the 1940s and 1950s. One chief forester had experience with European larch in his native Finland[1]. Another company developed a Japanese larch seed orchard in Maine in the 1980s with plantings on their land.

Investigation into exotic larch by the principal author and associates during the years of spruce budworm infestation (1970s and 1980s) found positive results with exotic larches. However, a basic understanding of silvics, cultural practices, growth and yield, wood properties, and economics was not readily available. Existing larch plantations were sought out and measured, and a stem analysis of available plantations was conducted. These confirmed Stone's (1957) and Shipman et al.'s (1989) studies on site index and yield.

At this time, the Institute of Paper Chemistry, located then in Appleton, Wisconsin, having advanced hybrid aspen as a short-rotation hardwood, wanting to offer a softwood as well, formed the Aspen-Larch Genetics Cooperative (ALGC), with exotic larch as the alternative softwood. The staff in their genetics program had been making plus tree selections for a number of years. They offered a high-quality genetics program with sufficient expert staff to support the industrial genetics cooperative. The ALGC provided significant research and advice in the 1980s and 1990s, as well as seedlings for an early species trial planted at the Unity Seed Orchard in Maine. Later they provided scions for an exotic larch seed orchard consisting of Japanese larch clones, which were surrounded by European larch clones. General seed collection would then provide open-pollinated largely hybrid seed for operational plantings. Further, ALGC staff designed and aided layout of progeny tests designed to rogue the orchard in later years. As the forest industry changed priorities and ownerships, however, interest in intensive forest management, and exotic larch in particular, faded. A number of legacy research studies and operational plantings remain, but only a few received any management attention.

A small group of dedicated volunteers has recently remeasured many of these early trials and operational plantings, and collected observations and informal literature on others. To our surprise, growth and yield of exotic larches and their hybrid have exceeded expectations. The Larch Virtual Experiment Station (LVES) website (www.larchresearch.com) lists pictures, research notes, publications, photographs, and participants.

The map (Figure 1) shows approximate locations of many of the trials and operational plantings from Nova Scotia to North Dakota and Quebec to Maryland. Unfortunately, we were not able to confirm the location of many trials, which we believe are in the Maritimes and Ontario.

Roughly 20,000 acres (8,100 hectares) of exotic larch were planted in Maine in the 1980s, 1990s, and early 2000s. An estimated 16,000 acres (6,500 hectares) were planted in Michigan during this time. New York Department of Environmental Conservation has records of roughly 23,000 acres (9,300 hectares) planted on State Forests since the 1930s; many of these were in mixtures. Private landowners likely have many more plantations. At one time, nurseries provided exotic larch seedlings to private landowners in those states as well as Pennsylvania, New Jersey, Wisconsin, Michigan, Minnesota, Maryland, and the rest of New England.

Despite the fact that exotic larch must be considered a minor species, six states show Forest Inventory

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Figure 1. Map of exotic larch trials and operational plantings in North America.

Table 1. Data from Forest Inventory Assessment plots across northern United States showing range of diameters and growth.

State	No. of Forest Inventory Assessment plots	Range of diameters (in.)	Growth (cords/ac/year)	Growth (m^3/hectare/year)
Maine	2	5 to >9	1.9	11.3
New York	15	5 to >29	1.4	8.3
Pennsylvania	17	5 to >29	.9	5.4
Michigan	3	5 to >11	1.3	7.7
All states	39	5 to >29	1.2	7.1

Assessment (FIA) data of "Introduced Larch" on Forest Land (Table 1). Not surprisingly, New York and Pennsylvania have many plots that include "Introduced Larch," but it is present even in New Jersey. Growth rates, where they can be measured, range from 0.9 in Pennsylvania to 1.9 cords/ac/year (5.4–11.3 m^3/hectare/year) in Maine with an average of 1.2 cords/ac/year (7.1 m^3/hectare/year).

Current Role of Larches in Europe

In Europe, an estimated 40 million larch seedlings are planted annually. Poland, United Kingdom, Germany, Sweden, Slovakia, and Ireland do the bulk of the planting. Although European larch is the predominant planted species, the hybrid is planted in France, Ireland, Denmark, and Belgium. Japanese larch was extensively planted in the UK. However, planting has decreased in recent years in UK and Ireland because of *Phytophthora ramorum* (Luc Pacques, pers. commun., French National Institute for Agricultural Research, Orléans, France, November 16, 2018). This disease is known as sudden oak death pathogen in the United States, and its range has been limited to California and Oregon (Balci and Bienapfl 2013).

European larch is an economically and traditionally important timber species in Europe, renowned for its fast growth, high adaptability, and durable wood

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(Bergstedt and Lyck 2007). It is largely used for carpentry and naval construction. In its native range, it is used for houses, furniture, fine floors, and many weather-proof outdoor objects (San-Miguel-Ayanz et al. 2016) and commands one of the highest prices for timber in central Europe (Anton Buergi, pers. commun., Swiss Research Unit for Forest Resources and Forest Management Research Group Forestry Production Systems, Bimensdorf, Switzerland, November 2018).

Hybrid larch grows well in Europe. Eko et al. 2004 (p. 320) reports that in southern Sweden, "On fertile sites the mean annual volume growth [for hybrid larch] peaked at an age of 35 years, at a level of 13 m^3 ha^{-1} [186 ft^3/ac]." Westin et al. (2016, p. 16) states "production can be increased further by using improved plant material from the best seed orchards in Sweden and Denmark, with an annual average production of about 16 m^3 ha^{-1} [228 ft^3/ac] on fertile soils in the south of Sweden" [translated from the original]. Hybrid larch is mentioned as a potential alternative for climate change adaptation because of its flexibility, compared to native trees. An Austrian report (Geburek and Schuler 2011, p. 16) reports "proven properties of hybrid larch include a larger location tolerance, tolerance to pollutants, lower canker susceptibility and with at least equivalent properties of wood. In particular, the wide site amplitude with a frugality in water and nutrient deficiencies make larch hybrid a promising growing alternative to changing climate" [translated from the original].

Height and diameter at age 20 of hybrids compare favorably to commercially available European larch planting stock (Figure 2; Geburek and Schuler 2011).

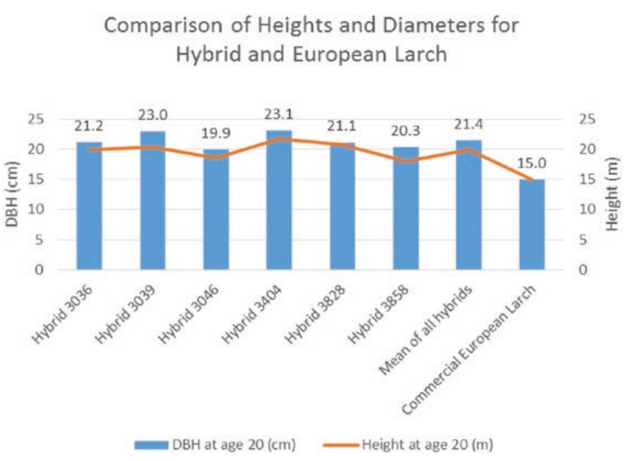

Figure 2. Comparison of diameter and heights of hybrids to commercially available European larch after 20 years (Interpretation of Figure 3 in Geburek and Schuler 2011).

These dimensions are similar to sizes we would expect from both European and hybrid larch in Maine.

Growth Rates

Unmanaged

Measurements of exotic larch growth rates are abundant in the literature. Bailey (1986) reports that the mean annual increment in the Maritimes for fully stocked native conifers is estimated to 8.1 m^3/hectare/year (115.7 ft^3/ac), whereas adjacent exotic larches are expected to produce 11.1 m^3/hectare/year (161 ft^3/ac). Jacobs (1983) reported in a trial in Lacrosse, WI that European larch had 33 percent more volume than red pine and 50 percent more volume than white pine after 19 years. Similarly, Jeffers and Isebrands (1974) reported that Japanese larch, planted on loams or sandy loams, grew much faster than spruce or pines and appeared to be similar in growth rate to good European provenances. Again in Canada, Vallee and Stipanic (1983) reported that European and Japanese larch can produce 10–14 m^3/hectare/year (142–200 ft^3/ac) on good-quality sites.

In a comprehensive study from southern Ontario to Minnesota, Gerlach (2001) compared productivity of European larch to red pine on 27 paired sites. Examining many site factors of soil, climate and weather, he concluded that "Larch had higher productivity than red pine over the entire site quality gradient" (Gerlach 2001, p. 101).

In Chase Stream Township (Somerset County, Maine), a trial was established as part of a larger trial to compare growth of softwood species and site characteristics (Maass and Staton, in preparation and Giffen et al. 2016). A randomized complete block design with three replications for each species/stock combination was established to compare conifer growth on three different sites. The Chase Stream test was on a good to better site at 1,250 feet elevation and was measured at stand ages 5, 10, 16, and 27. Merchantable volume (above a 6 in. [15 cm] stump to a 3 in. [9 cm] d.i.b. top) at age 27 for the hybrid larch had significantly more volume than black spruce, white spruce, jack pine, tamarack, and red pine (Figure 3). Hybrid larch volume exceeded European larch by 12 percent and Japanese larch by 24 percent.

Other results from Maine plantations were similar, based on data from 95 plots from a number of plantations (Figure 4) measured across Maine and northern New Hampshire. Sources are identified in Table 3. Height and diameter data from all plots were used to

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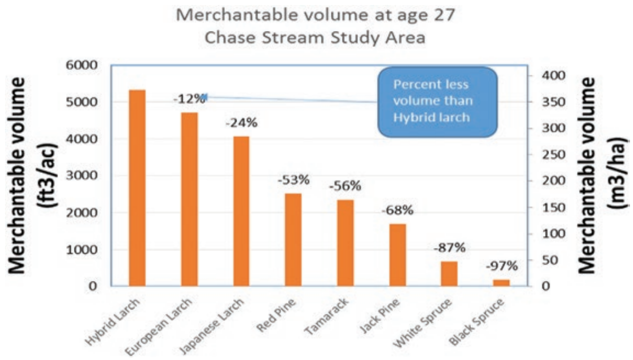

Figure 3. Merchantable volume of several softwood species after 27 years of growth.

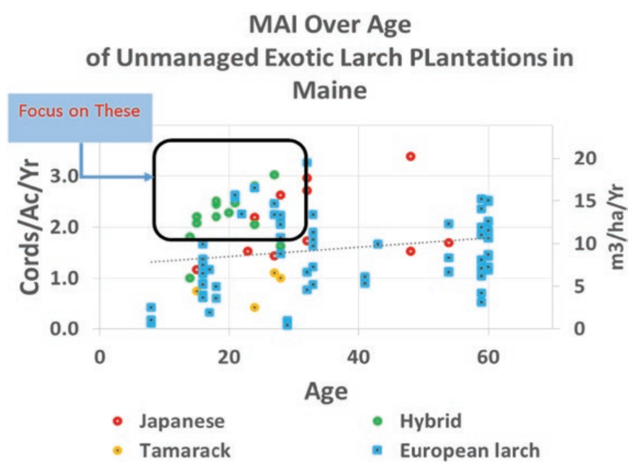

Figure 4. Merchantable mean annual increment of 95 stands of exotic larch.

calculate merchantable volume above a 15-cm (6-in.) stump to a 9-cm (3.5-in.) top diameter using Kozak volume equations (Li et al. 2012). It is clear that not all stands demonstrate extraordinary growth. However, except for a few, all of the measured stands exceed the average growth for all species for Maine of 0.54 cords/acre/year (Butler 2018).

The emphasis box in Figure 4 shows that many of the stands exceeded 2 cords/ac/year (12 m^3/hectare/year). This means that at age 30, we could expect 60–90 cords per acre or 360–540 m^3/hectare. These are successful plantations on good sites. Without repeated measures, the age at maximum mean annual increment is unknown at this time, but we estimate it to be around age 30.

These growth rates compare favorably to those used broadly for loblolly pine across the south. Amateis et al. (1984) developed a model to predict volume for unthinned loblolly pine. In the example used in the publication, the yield for stands in the coastal plain at age 30 for SI of 70 and 400 surviving trees was 6,041 ft^3/acre or an MAI of 201 ft^3/ac/year (14.1 m^3/hectare/year.) Similarly, Dr. Fred Cubbage at North Carolina State (pers. commun., March 4, 2018) uses 13, 10, and 7 m^3/hectare/year (186, 143, 100 ft^3/ac) for analysis for timberland investment of loblolly pine for high-intensity, medium-intensity, and low-growth and low-intensity models.

Larch growth rates also are comparable with other world-class plantation yields. Maclaren (1996, p. 109) reports, "The area-weighted average for total recoverable volume in all of New Zealand, for a modern intensively tended non-production thinned radiata pine regime, is 581 m^3/hectare (8,300 ft^3/ac) at age 30. This equates to 19.3 m^3/hectare/year [275.7 ft^3/ac/year], compared to 13.7 [186.7 ft^3] for Douglas-fir, 10.2 [145.7 ft^3] for other softwoods, and 15.3 [218.6 ft^3] for hardwoods (mostly eucalyptus) for same age see supplementary figures S1-S3."

Thinning: A Simulation

The data from unmanaged and unthinned plantations beg the questions, "What results would we see if we were to thin the plantations at an early age? Could we see continued diameter growth on individual stems? At what age should thinning be done?" We found no thinned stands that had been remeasured, and only a few thinned so recently that measurements are not in order.

Stand table projections were developed using an Excel spreadsheet to compare thinning scenarios for each species. We followed a process outlined by Louisiana Tech Study Guide #3 (Avery and Burkhart 2002). For short projection periods, we believe that stand table projection is a suitable method for modeling thinning results. Stand table projections use trees per acre and diameter growth rates by diameter class to project future stand structure. Growth rates are applied to current stand conditions to allocate trees by diameter class. Once future stand tables are modeled, other stand parameters such as basal area and volume per acre can be calculated. Three basic aspects are required for the projections, namely (1) current stand diameter distribution, (2) expected diameter growth rates, and (3) mortality. Three plantations were selected for stand table projections (Table 3). This provides the current stand diameter distribution (#1 above).

Second, periodic (5-year) diameter growth was derived from Chase Stream plots mentioned above

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Table 2. Source data for Figure 3 from across Maine and northern New Hampshire.

Species	No. of plots measured	Age range (years)	OF or FS	Reference
EL	49	8–50	OF	Gilmore et al. (2003) (ME)
EL, JL	14	24–54	OF	Unpublished (legacy Scott in ME)
EL, JL, HL, T	8	27	FS	Greenwood et al. (2015) and Giffen et al. (2016) (ME)
EL, JL, HL, T	4	24	OF	Maass and Laustsen (2015) (ME)
JL, HL, T	3	15	FS	McConville (2003) (ME)
HL	3	14–15	FS	Maass and Simonds (2016) (ME & NH)
JL	1	23	FS	Unpublished (Seboeis, ME)
EL, HL	7	18–24	FS	Maass (2018a and b) (ME)
HL	1	20	FS	Unpublished (Corinna, ME)
JL	1	51	OF	Irland et al. (2016) (ME)
EL, JL, HL, T	4	27	OF	Unpublished (Skowhegan, ME)

Note: EL, European larch; FS, forest soils; HL, hybrid larch; JL, Japanese larch; OF, old field; T, tamarack.

Table 3. Indicative analysis of thinning potential: characteristics of three stands selected for stand table projections.

Species	Age	Basal area (ft^2/ac)	Trees per acre	Height (ft)	Quadratic mean diameter (in.)	Volume (ft^3/ac)	Reference
European	16	112.7	567	44.5	6.00	2251	Gilmore (2003) (plot S01)
Japanese	15	80.2	512	35.8	5.35	1253	McConville (2003)
Hybrid	15	120	394	49.4	7.64	2780	Maass and Simmonds (2016)

(Giffen et al. 2016). Five-year growth was determined as the average of the difference between age 16 diameters and age 10 diameters adjusted to 5 years for each of the three species. Because there were no data for the larger-diameter classes, these were estimated (and shown in bold in Table 4.)

Third, limited mortality data were available from two Maine FIA data plots containing exotic larch as well as the Chase Stream plots over a 27-year period. Also, mortality curves were provided by Aaron Weiskittel (pers. commun., University of Maine, Orono, January 3, 2017). Data were adjusted to smooth curves and to increase mortality in smaller diameters as stands aged.

Using an Excel spreadsheet, a stand table was prepared for each of the three stands. Mortality was deducted. The upward movement of the trees into larger-diameter classes was calculated using a growth-index ratio (GIR), GIR = periodic diameter growth/diameter class size. Because 1-in. diameter classes were used, the equation reduces to: GIR = periodic diameter growth.

For each diameter class, the number of trees was allocated to future diameter classes for moving 0 through 4 diameter classes. Then, the total number of trees for each of the future classes was added together to create the future stand table.

For example, European larch diameter at breast height (dbh) class 6 has a diameter growth estimated to be 1.68 in. (or a GIR of 1.68) for 5 years, and for dbh class 7, the diameter growth is 1.33 in. (Table 4). From the formula above, GIR is 1.68 for diameter class 6. This indicates that 32 percent (calculated 100 percent–68 percent) of the trees in diameter class 6 moved one diameter class (dbh class 7), and 68 percent of the trees moved two diameter classes (dbh class 8). Similarly, for the dbh class 7, the GIR is 1.33, meaning that 67 percent (calculated 100 percent–33 percent) of the trees move to dbh class 8, and 33 percent of the trees move to dbh class 9 in 5 years. The trees in the future class 8 (some from the earlier dbh class 6 and some from the earlier dbh class 7) are added together to create the number of trees in the future dbh class 8. This calculation was applied to other diameter classes.

These growth rates were then applied to the three stands starting at a stand age of 15 (or 16 in the case

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Table 4. Five-year individual tree diameter growth used in the stand table projections for thinning analyses.

Diameter at breast height class	European larch	Japanese larch	Hybrid larch
	Diameter growth (in.)		
1	3.11	2.78	2.80
2	3.28	2.75	3.33
3	2.30	2.21	2.69
4	1.65	2.02	1.29
5	1.66	1.85	1.47
6	1.68	1.26	1.59
7	1.33	1.12	1.43
8	1.23	1.29	1.25
9	1.42	1.41	1.47
10	1.46	2.14	1.44
11	1.91	**1.91**	**1.91**
12	**2.25**	**2.15**	**2.15**
13	**2.56**	**2.56**	**2.56**
14	**3.06**	**3.06**	**3.06**
15	**3.65**	**3.65**	**3.65**
16	**3.65**	**3.65**	**3.65**
17	**3.65**	**3.65**	**3.65**
18	**3.65**	**3.65**	**3.65**

Note: Extrapolated data are shown in bold.

of Japanese larch) and projected for another 15 years. Height is required for volume calculations (Li et al. 2012). Height growth was assumed to be 3.0 feet/year for hybrid larch, 2.85 feet/year for European larch, and 2.55 feet/year for Japanese larch based on average height growth for the Chase Stream plots from age 16 to 27.

Ken Laustsen (Maine Forest Service Biometrician, retired) developed a static Excel spreadsheet to calculate board foot volumes in International Scale ¼" kerf from the Li et al. (2012) Excel macro. This model yielded board foot volume estimates of at least a 16-foot log to a 10-in. top diameter. The spreadsheet also calculated the number of cubic feet represented by the volume, so that the remaining topwood volume might be assigned as a pulpwood product.

Stand table projections were set on a European larch stocking guide developed by Gilmore et al. (2003). It was assumed that three plantations were planted initially at an 8 foot by 8 foot spacing (680 trees per acre). The three stands were allowed to grow 1 year at a time until they reached the self-thinning line as established by Gilmore et al. (2003). Then, sufficient volume was removed until they reached the lower line in the graph at 60 percent of the self-thinning line. The

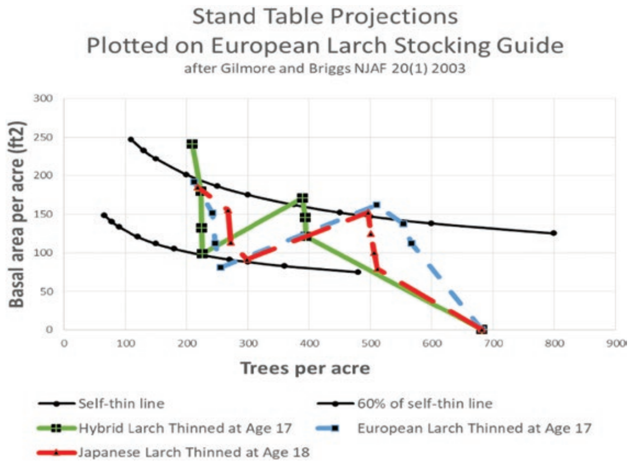

Figure 5. Stand table projections for European, Japanese and hybrid larch stands. After surpassing the self-thin lines, the points represent 5-year projections.

stands were projected for 15 more years. The Japanese larch needed to grow for 3 years until it was above the self-thinning line, unlike the European and hybrid larch, which only needed 2 years (Figure 5).

Given these assumptions, the hybrid larch yields significantly faster growth post-thinning than either the European or Japanese larch (Figure 6). Close examination of the stocking guide indicates that a second thinning of the hybrid larch might be possible at age 32 (Figure 5). Many measurements show that larches grow rapidly beyond age 30. Older unthinned plantations often contain suppressed individuals exhibiting diminished growth and poor form, as would be expected in any plantation.

Not All Hybrids Are the Same

The stand table projections use the von Lochow hybrid, which is commercially available (Langer and Schneck 1998). In a progeny test from Unity Seed Orchard, individual tree volumes (calculated from Li 2012) were compared to the von Lochow checks in a progeny test. Open-pollinated hybrids (19 sources, 571 trees in 30 reps) had 51 percent, and the full-sib hybrids (10 sources, 300 trees in 30 reps) had 124 more volume at age 20 than the von Lochow checks (two sources, 57 trees in 30 reps) (Maass and Nelson, in preparation) (Figure 7). Deliberate crosses can increase volume significantly and are likely to improve other characteristics as well (Luc Pacques, pers. commun., French

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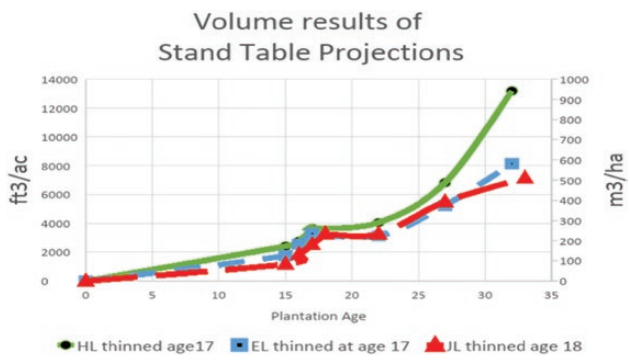

Figure 6. Merchantable volume for stand table projections of hybrid, European and Japanese larch.

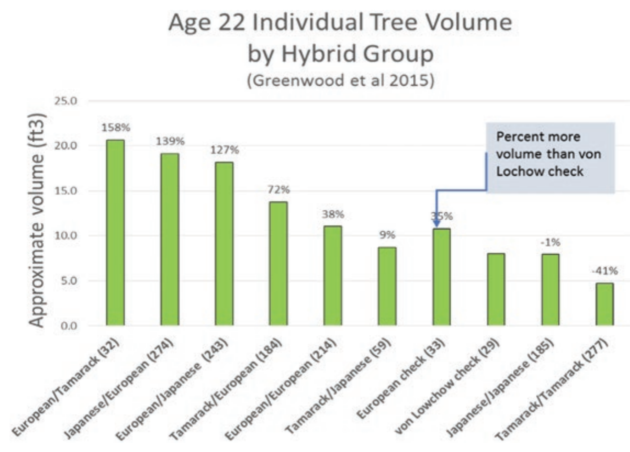

Figure 8. Comparison of age 22 individual tree volume of different hybrid crosses (numbers of surviving trees used to calculate volumes are in parentheses adjacent to group).

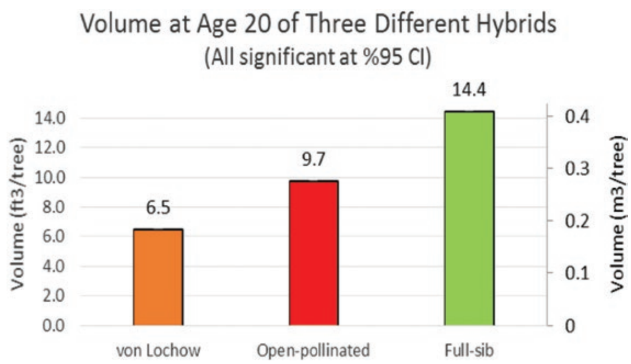

Figure 7. Volume at age 20 of three different hybrids. Open-pollinated hybrids included 19 sources, 571 trees in 30 reps. Full-sib hybrids included 10 sources, 300 trees in 30 reps. Von Lochow check included two sources, 57 trees in 30 reps.

National Institute for Agricultural Research, Orléans, France, September 5, 2019).

Similarly, Greenwood et al. (2015), and the methodology described in Baltunis et al. (1998), compared intraspecific hybrids between European larch and Japanese combinations. After 22 years, Greenwood concluded that "Crosses between J[apanese] and E[uropean] parents outperformed either of their parents (heterobeltiosis), and the locally produced hybrids were 30 percent taller than the XLD-LL-89 hybrid check [von Lochow] lot that has been extensively planted in Maine and elsewhere with excellent results" (Greenwood et al. 2015, p. 79). Calculating volume using an approximate individual tree volume of $1 / 3 \times \pi \times (dbh / 2)^2 \times ht$ shows the large differences between hybrids. In Figure 8, the groupings are shown by male/female (i.e., European/Tamarack means European male and tamarack female). Although the combinations of European and tamarack showed promise in terms of volume, these crosses were plagued with poor form and low seed set. The best hybrids were specific full crosses between Japanese and European species.

Economic Analysis

Extraordinary growth demonstrated by exotic larch is one important factor in considering whether a species is suited for planting. Another important factor is economics. Many harvests of small volumes show that the wood is of high quality, and taper is much lower than in domestic conifers. Because larch, and especially exotic larch, is a small fraction of overall total timber volume in the northeast, to date it has only found use in niche markets, including bridge timbers, decking, and interior products (Irland and Maass 2016). Therefore, markets are largely underdeveloped, and the exotic larch is frequently used as a substitute for other species.

Three scenarios were developed to compare economic results of the three stand projections described above. The first and most conservative scenario assumes that land for the project is purchased at the beginning of the rotation and sold at termination of the project at US$290 per acre (no inflation). In this scenario, we use statewide prices for hemlock listed in the 2015 Maine Forest Service (MFS) Stumpage Price Report as a proxy for larch prices, as larch is commonly used as a substitute for hemlock. The second scenario is similar and also assumes the 2015 MFS prices, but does not include the land purchase and sale.

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The third scenario also assumes that no land is purchased or sold, but that prices instead follow those calculated by Anderson et al. (2018). Anderson et al. (2018) used *k*-nearest neighbors to map physical properties of larch to those of other species widely sold in the market following process described by Altman (1992). Using this mapping process, larch prices are estimated as an average of the prices of commercial species with comparable physical properties (Appendix 2). This novel approach is supported by UNB study (Peters 1994), indicating that European larch had properties comparable to spruce and balsam fir and superior specific gravity despite faster growth rates.

Stumpage prices for the three scenarios are summarized in Table 5. Finally, we assume that larch is established and managed in 5,000 acre plantations (1/3 hybrid larch, 1/3 European larch, and 1/3 Japanese larch). Present values across scenarios are summarized in Table 6 (See other assumptions for the scenarios in Appendix 1). Growth rates are those projected under the thinning scenarios above.

Even at current low stumpage prices, all three of these scenarios provide a suitable return on investment (Figure 9 and Table 6). Owners that would include the cost of land purchase in calculating their returns would follow scenario 1. This analysis demonstrates that the internal rate of returns would be 4.7 percent. For owners who would forgo the land value in their calculations, we would expect their return to be 6.8 percent. If prices increase as anticipated, returns are 8.9 percent. By comparison, it is our understanding that current Timberland Investment Management Organizations discount rates are around 6 percent, although they have been highly volatile over the last few years.

Discussion

Numerous measurements, cited in our references, show that larch stands outgrow native conifers on similar soils. How do these species grow so rapidly? Larch grows rapidly because of "free growth," in that growth occurs in both preformed buds and internodal growth. Larch trees form both long and short shoots. Long shoots continue to form new leaves and internodes after the preformed leaves and internodes have elongated. Short shoots on the other hand are always lateral, only producing preformed leaves, where some of these short shoots may form male or female strobili. Free growth occurs later into the growing season than shoots that only elongate leaves and internodes preformed the previous year (fixed growth). Baltunis and Greenwood (1999) demonstrated that the faster-growing families in the Johnson Mountain (Maine) test tended to elongate later in the growing season. Furthermore, diameter growth extends from May to October (Moser et al.

Table 5. Stumpage prices used for three economic scenarios.

Species and product	Current prices (hemlock sawlogs and pulpwood)	Imputed prices based on Anderson et al. (2018) and App. 2.
European larch (US$/mbf)	73	151.80
Japanese larch (US$/mbf)	73	163.60
Hybrid larch (US$/mbf)	73	154.60
Pulpwood (US$/ton)	6	2.94 (biomass)

Table 6. Results of economic analysis for 5,000 acres larch plantation (one third hybrid, one third European, and one third Japanese larch) calculated on a per-acre basis.

Discount rate	Imputed prices	Current prices	Current prices + land purchase
4 percent	US$1,120	US$378	US$162
6 percent	US$409	US$44	US$(200)
8 percent	US$79	US$(103)	US$(357)
10 percent	US$(69)	US$(161)	US$(417)
Internal rate of returns	8.9 percent	6.4 percent	4.7 percent

Note: Discount rates range from 4 percent to 10 percent for three price scenarios. Internal rate of returns for each price scenario is shown in the last row (Numbers in parentheses are negative).

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Figure 9. Comparison of net present value and discount rate for three ownership scenarios with three pricing scenarios for 5,000 acres of larch plantation (one third hybrid, one third European, and one third Japanese larch) calculated on a per-acre basis.

2010). Other conifers may show a different seasonality. For example, white spruce ceases diameter growth in August (Frank 1973).

Any of these larch species, especially the hybrids, offer fast growth and development of high-quality sawlog size material at ages earlier than native species. To be clear, the best growth for these species occurs on deep, well-drained soils. Good sites would be similar to Site Classes 1 and 2 and possibly 3 as described by Briggs (1994). We would expect species planted on shallower soils, poorly drained, or excessively drained soils to have diminished growth rates and lower returns. Gilmore et al. (1993) developed site index curves for European larch. He further determined site index at age 20 could be determined by knowing solum thickness, B horizon clay content, and B horizon exchangeable K (Gilmore et al. 1994).

Further, these species are shade-intolerant. Plantations need to have competing vegetation under control for the first few years before and after establishment. Secondary competition control measures may be needed (see Gilmore and David 2002, recommendations for management).

Exotic larches might be considered for timberland rehabilitation where high grading has been practiced. Degraded stands on suitable soils might be replaced with exotic larch plantations. These plantations offer a faster return on the investment through early thinnings and shorter rotations than native species. As the exotic larch plantations are thinned, their light shade nurses other long-term shade-tolerant commercial species.

The growth rates documented here invite the suggestion that larches might be well suited to carbon sequestration, especially since the wood is likely to find its way into long-lived uses after harvest. We intend to pursue this in more depth ourselves and invite others to do so.

In the literature, supplemented by our field observations, virtually all of the older trials examined missed opportunities for improved quality and volume growth rates because of a failure to follow through with management. Perhaps this is an inevitable lesson learned with any fast-growing plantation species. Discouragingly, many examples occurred within Research Forests, where one ought to expect systematic re-measurement instead of mere abandonment of trials established at some effort and cost. We believe that a selection of stands across the region would support careful thinning trials. These would give future managers insight into likely rotation lengths based on culmination of MAI, as well as timing, density guides, and likely responses to thinning.

Although most major landowners in northern United States rely on natural regeneration to re-establish their forests, clearcutting, weed control, and planting are still being practiced. At least one major landowner in Maine is currently planting improved white spruce seedlings. Planting white spruce that can yield a first thinning at age 25 or so produces promising yields that potentially can be competitive with larches (Greg Adams, pers. commun., J.D. Irving, January 21, 2019).

Also, we believe that major gains could be made by reviewing the existing literature on larches in Japan, China, and Korea (and possibly Russia). It is our understanding that there are significant larch plantings in northeast China. The literature is surely large. This should be undertaken with the aid of persons qualified in those languages. Although larches are abundant

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Table 7. Data set for calculation of imputed prices.

Larch species	Contributing Maine Merchantable Species Group Prices (2015)					Average (US$)
	1st closest group (US$)	2nd closest group (US$)	3rd closest group (US$)	4th closest group (US$)	5th closest group (US$)	
European larch	205 (from spruce/fir)	71 (from red pine)	73 (from hemlock)	205 (from spruce/fir)	205 (from spruce/fir)	151.80
Japanese larch	118 (from cedar)	205 (from spruce/fir)	73 (from hemlock)	172 (from white pine)	205 (from spruce/fir)	154.60
Hybrid larch	118 (from cedar)	118 (from cedar)	205 (from spruce/fir)	172 (from white pine)	205 (from spruce/fir)	163.60
Tamarack	205 (from spruce/fir)	205 (from spruce/fir)	73 (from hemlock)	205 (from spruce/fir)	205 (from spruce–fir)	178.60

Note: After table 2 in Anderson et al. (2018). LVES #9. See Altman (1992) regarding calculations of *k*-neighbor analysis.

in Russia, we have not explored to what extent they may be in use there as plantations or whether climatic conditions differ from our region so as to render their results inapplicable. In addition to plantation yields, an effort to scan overseas literature for details on sawing, drying, and product use of larch would be worthwhile.

Clearly significant potential exists for exotic larch. Why, then, has exotic larch not been more widely adopted? We have heard contentions that exotics are not compatible with certification schemes and have no known markets, as well as concerns about introducing exotic species.

We have reviewed the certification standards for both Sustainable Forestry Initiative and Forest Stewardship Council. Neither of these standards prohibit the use of exotic species. A specific scenario in these schemes is for fast-growing exotics to replace native forests to reduce the harvests on other endangered habitats.

Although it is true that there are no widespread robust markets for exotic larch, it does not mean there are none. Local mills have used exotic larch wood for decking, bridge timbers, siding, barn boards, cladding, fences, foot bridges, and flooring. We have been told that it holds up better than hemlock. These exotic larch species lack a grade stamp. However, larch lumber can be used for structural purposes without association grade stamps in local areas depending on local building codes and regulations (Matt Pomeroy, pers. commun., NELMA August 6, 2019).

Given the overall size of the resource in the United States, perhaps 100,000 acres (40,500 hectares)—we are aware of at least 59,000 acres (24,000 hectares)—spread across New England, New York, Pennsylvania, and the Lake States, it would be difficult to assemble all the volume to use it efficiently. However, if we assume that this acreage averages 320 board feet/ac/year (2 m^3/hectare/year) (average growth of sawlogs in Maine [Butler 2018]) of growth, that is still 32 million board feet (81,000 m^3) of good-quality lumber that is being underused. Given the size of the resource, and the scattered locations, we can only expect niche or local market uses for these species. In the short term, we can look to Europe for ideas of potential products.

There are broad and sincere concerns about widespread planting of non-native trees. However, there are extensive examples, such as radiata pine in Chile and New Zealand, and eucalyptus in South America, Europe, South Africa, and elsewhere. Some of these plantations have been Forest Stewardship Council-certified. This paper has not considered the environmental effects of widespread planting of larch. At

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present, the outlook for planted area in the north is that it will remain at moderate levels and occur largely in small and scattered patches.

Biodiversity is one of the concerns about both native and non-native plantations. A recent study in Quebec found "that fast-growing hybrid [poplar and larch] plantations do not present lower taxonomic and functional alpha-biodiversity indices, but may harbor more diverse communities, in part through the introduction of plant species that are associated with open habitats" (Royer-Tardif et al. 2017). Further research in this area needs to be done.

All planted species are susceptible to insect, disease, and animal predators, and exotic larch is no exception. Cook (1969), Robbins (1985), and Gilmore and David (2002) review the risks of planting non-native larches to the plantation itself. A search of global scientific literature in English located very little recent North American research on larch pests. Although insect and disease surveys regularly note damage to native tamarack, because of the limited commercial importance of any of these larch species, little active research has been done. A perusal of 2016, 2017, and 2018 Maine Forest Service Insect and Disease Conditions reports found occasional mention of pests on Larix.

Larch sawfly (*Pristiphora erichsonii* [Hartig]) is recognized as a serious pest, but it occurs only periodically and has not reached outbreak conditions in the northeast during the years since significant forest plantations of exotic and hybrid larches were established. In Minnesota, however, stands of European larch in the Sand Dunes State Forest have been attacked by the sawfly, but survived in good health (Mike Peltier, MN DNR, pers. commun. September 20, 2019). Humphreys (1985) observed sawfly defoliation in a University of British Columbia research stand. Although western larch was heavily defoliated, defoliation on the exotics was light.

Whether plantations in the northeast might be vulnerable is thus unknown. A widespread and lethal outbreak of eastern larch beetle (*Dendroctonus simplex* LeConte) on tamarack is under way in Minnesota and elsewhere (Seybold et al. 2002). There are no observations known to us as to whether this pest affects hybrids or exotics (Brian Schwingle, Minnesota DNR, pers. commun. September 20, 2019, (https://www.dnr.state.mn.us/treecare/forest_health/elb/index.html). The larch beetle has been observed in Maine, but no instances of damage are known. European larch canker, (*Lachnellula willkommii* [Hartig] Dennis) was first noticed in eastern Maine in 1981. It was later detected in European larch ornamental trees on a golf course in midcoast Maine (Ostrovsky, 2008). Infected trees were felled and slash-burned; logs were sawn for onsite use. In that instance, the canker did not affect nearby native tamaracks. In coastal eastern Maine, however, the disease has been found on tamarack. A European larch canker quarantine zone was ordered in 1984 along the mid- and eastern Maine coast (Houston and Ostrovsky 2017). Inquiries concerning this quarantine have been few, because of the small area involved and limited commercial use of tamarack in the zone. The order is to be reviewed in 2020 (Michael Parisio, MFS Entomology Division, pers. commun., September 18, 2019).

Whether exotic larches might host damaging pests needs more attention and study. From what is now known, they are not more vulnerable to damaging agents than native conifer species being widely planted in the region now. Whether the European or Japanese larches would share the same insect and disease agents with their hybrids, or even encounter new ones, is not known. Nor have all the possibilities been studied for shared vulnerabilities with native tamarack.

Existing planted larch stands are small in area and widely dispersed so that transmission of insect or disease pests from one location to another is unlikely. Many are of merchantable age—salvage of these small patches would not be burdensome. In some places, as in New York, the larches are in mixtures with other species, which would be expected to reduce their vulnerability and susceptibility to pests. In Maine, anecdotes are heard of hybrid larches suffering ice damage or injury by porcupines, but the authors have observed only one ice-damaged plantation in many visits to these stands during this research.

Finally, we observed repeatedly in the field that these larches will reproduce naturally outside plantations, at fairly young ages, where suitable unshaded mineral soils are present nearby. This phenomenon has been reported for European larch in the literature (Cook 1939, Nyland 1965). We observed several instances where larch volunteers were outgrowing native conifers in an adjacent plantation where larch had previously been harvested. We have also observed volunteer seedlings on exposed mineral soils adjacent to roads. This trait does not necessarily qualify the larches as invasive, but it is clear in any case that exotics are naturally under suspicion from the start. However, despite the large number of trials across a huge swath of the United States and Canada, little has been reported on this issue.

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Conclusions

Exotic larch has significant growth potential across the northeastern United States. Field studies in Maine are similar to others in the Lake States and eastern Canada, showing that growth can exceed 12 m^3/hectare/year (2 cords/acre/year or 170 ft^3/ac/year). Commercial thinning is possible as early as age 15. The hybrid of Japanese and European larch (*Larix* × *marschlinsii*) can add significant growth potential. Further genetics work is likely to improve growth rates and other desirable characteristics. Many individual examples show that log quality is excellent. Economics of plantation grown exotic larch are positive even at today's low stumpage prices. Stumpage prices could increase if these species are actively marketed for their desirable physical characteristics. Obviously, not all trials have been successful, and ready markets are not currently available in many areas. Furthermore, environmental impacts of large-scale plantations are uncertain and need more research. However, evidence summarized in this paper demonstrates that exotic larch deserves further consideration and could have significant benefits to landowners.

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Endnote

1. Mr. Oscar Silen of Georgia Pacific Co., now deceased; former colleagues consulted are unable to report locations of any surviving trials.

Appendix 1

Assumptions for economic calculations are as follows:

- 5,000 acres of exotic larch
- Site preparation 2 years prior to planting is US$77 per acre
- Planted at 450 trees per acre
- Release treatment at 6 years after planting at US$200 per acre
- Management cost is US$5,000 per year (US$1 per acre per year)
- Annual property taxes at US$2.50 per acre
- Harvest supervision at 12 percent of stumpage value
- Separate planting costs for European, Japanese and hybrid larch
    - a third of the area for each species
    - seed cost: US$3,000 per pound for hybrid, US$309 per pound for European, and US$106 per pound for Japanese
    - seeds per pound: hybrid: 100,550; European: 77,100; Japanese: 124,000
    - percentage viability: hybrid: 30 percent; European: 50 percent; Japanese: 50 percent
    - seed cost per viable seed: hybrid: US$0.099; European: US$0.008; Japanese: US$0.002
    - seedling cost: hybrid: US$1.00; European: $0.20; Japanese: US$0.20
    - planting cost: all species US$0.20 per tree
    - planting cost at 450 seedlings per acre: hybrid: $540; European: US$180; Japanese: US$180
    - total planting cost: hybrid US$899,999; European: US$300,000; Japanese: US$300,000

Appendix 2

Calculation of imputed sawlog prices based on *k*-neighbor of each larch species. For each larch variety, the five top matching species are assigned to the respective commercial species group, and the corresponding price is assigned to that larch variety. For example, European larch is most similar to black spruce, red pine, eastern hemlock, red spruce, and white spruce. See Table 7.

Supplementary Materials

Supplementary data are available at *Journal of Forestry* online.

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