The Kuril Larch (*Larix gmelinii* var. *japonica* (Regel) Pilger) at Järvselja

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The article analyses the productivity, growth and yield of the Kuril larch compared with other larch species at Järvselja Training and Experimental Forest District in East Estonia. Five stands on *Myrtillus* site were examined. Height, diameter, density, basal area and volume of these stands have been recorded at different ages. A few trees were felled for stem analysis by Hohenadl method. It was revealed that the Kuril larch in Estonia is hardy, resistant to larch cancer, and fast growing. It gives seeds abundantly and at the early stage. In comparison to the Russian and European larches, the needs of the Kuril larch in habitat fertility are less. The Kuril larch on *Myrtillus* site is superior to the Russian larch according to all estimated indices. Up to the age of 70, the growth of the Kuril larch on *Myrtillus* site does not lag behind European and Russian larches. The difference equation method was used to approximate the height, diameter and volume data series. However, the future growth of the Kuril larch is uncertain because there are no older cultures of the species in Estonia.

Key words: Kuril larch, *Myrtillus* site type, cultivation, growth and yield, difference equation

Introduction

Up to now the European larch (*Larix decidua*) and the Russian larch (*L. russica*) have been the most widely cultivated larch species in Estonia. The Kuril larch is relatively less cultivated. At the same time it has several advantages over the other larches as tolerance to a habitat, fast growth at the early stage, greater shade tolerance, etc. It can grow in a rather poor habitat as in *Myrtillus* site type where Russian and European larches would grow worse.

In the present article the productivity, growth and yield of the Kuril larch are analysed in comparison with other larch species at Järvselja Training and Experimental Forest District. The forest district is located in East Estonia on a comparatively even plain reaching 30-40 metres above the sea level. The depth of the ground water in *Myrtillus* site type is approximately 1.1 - 1.3 m.

The long-term mean temperature by Järvselja Observatory data is 5.7°C (1960-1998). The absolute minimum of the last decades has been -38.7°C, the absolute maximum +34.8°C. Although in spring night frosts are usually over by 15 May, and in autumn they do not start before the end of September, there have been some late frosts even at the beginning of June and early frosts in the first half of September. The frost-free period, on average, lasts for 136 days. The average precipitation in recent years has been 650 mm. Due to a large bog area and Lake Peipsi in the vicinity, the relative atmospheric moisture is 80% throughout the year. The vegetation period lasts for 175 days. The winds are mostly westerly or south-westerly.

The Kuril larch and its distribution

The Kuril larch grows in wild on the South-Kuril islands, Sakhalin, in the central part of Kamchatka and on the coast of the Okhota Sea. Its habitats are mainly low plains, sea and river terraces and low hills rising up to 350 m above the sea level. It is widely spread on boggy soils and peat moors. It can also grow on sandy and volcanic soils. It forms pure stands but can grow in mixed stands with *Picea glehnii, P. jezoensis, Abies sachalinensis, Betula ermanii*. If the soil is fertile with good drainage, it grows fast, forming stands of high productivity (quality class I-II), but on boggy soils the stands are poor (quality class IV-V) (Dylis, 1961). In 1890 H. Mayr described the Kuril larch as a separate species - *Larix kurilensis* Mayr. He proved it was identical to *L. dahurica* var. *japonica* on Jezo island identified by C. Maximowitz. In Latin the Kuril larch also has been called *L. kamtschatica* (Rupr.) Carr. C. Ostenfeld and C. Larsen (1930) found that considering the Kuril larch as a separate species was not motivated. V. Komarov considered the Kuril larch a geographical variety of the Dauria larch (Kapper, 1954).

Recently the Latin name for the Kuril larch has been *Larix gmelinii* var. *japonica* (Regel) Pilger.

N. Dylis (1961) has divided the Kuril larch into two races: the southern race (*ssp. kurilensis*) and the northern race (*ssp. glabra*). The southern race is characterized by short needles (about 1 cm), small cones (1-1.5 cm) and young downy shoots. It grows in South-Sakhalin and South-Kuril islands. The northern races have longer needles (1.5-2.5 cm), bigger cones (1.5-2 cm) and its young shoots are nearly naked. It grows in the central part of Kamchatka, on the northern tip of Sakhalin and the northern part of the Okhota Sea coast.

The data on the maximum height of the Kuril larch vary. A. Tolmatchev (1956) and N. Usenko (1984) have stated it can reach the height of 20 m. By C. Schenk (1939) the tallest one has been 25 m, by D. Vorobjov (1968) 20-25 m, rarely 30 m. After M. Eiselt (1960) and J. Morgenthal (1964) the tallest tree has been 30 metres high. By "Derevja i kustarniki" (1949) the Kuril larch can grow up to 30-35 m, but N. Dylis (1961) has doubted it. The same authors have given the maximum breast height diameter as 70-80 cm, sometimes 100 cm. Although the Kuril larch was introduced in Europe as early as in 1888, it has seldom been cultivated. H. Mayr (1901) and L. Beisner (1909) stated that in Germany the Kuril larch grew faster than other larch species. By H. Schilcher (1917), however, in Upper Bavaria the species grew more slowly than the Japanese larch.

Materials and methods

The Kuril larch cultures at Järvselja were planted in the 1930s on an area of 0.79 ha, mainly on *Myrtillus* site. There were mainly 5-year-old transplants with the spacing of 2.5 x 2.5 m. The seeds were obtained from Mustila arboretum (Finland) and Rafn Seedshop (Denmark). The mother-tree seeds of Mustila had come from Iturup island in South-Kuril. On a neighbouring growing plot Russian and European larches were planted for comparison. For protection against wildlife most cultures were surrounded by pole fences. All broadleaved species were cut down while cleaning the cultures. By now, five Kuril larch stands have remained. In section 273 the European larch stand next to Kuril larches has practically perished. There are only a few larches in the naturally permeated pine stand. In section 286 both European and Russian larches have died, only some single trees have remained. In sections 263 and 308 the European larch culture planted next to the Kuril larch has perished as well. In sections 103, 136, 275 and 284, founded in the 1930s, only some Kuril-larch groups have remained. The damages have been caused by wildlife and to a certain extent by insufficient care, especially at the initial stage. In a small group in section 275, the maximum height of 70-year old Kuril larches is 34 m and the breast height diameter 48 cm. The side twigs and tops damaged by wild animals were cut back as the larch bears it well.

In section 261 2-year-old seedlings with a spacing of 2 x 2 m were planted in the spring of 1957. Due to great damage by wild animals the culture was ruined. A few larches have remained, the tallest ones with a height of 29 m and with a breast height diameter of 32 cm.

In Agali Arboretum (section 337) the Kuril larch was planted on a former field in 1969. 4-year-old transplants with a spacing of 2 x 3 m were cultivated. In the first years after planting row spaces were harrowed by a cultivator. The transplants had been grown from the seeds of local origin. The two growing mother trees at Järvselja have a different shape of the crown, one with straight, the other with a curved top. The arboretum has successors of both mother trees.

Table 1 presents the current data on Kuril larch stand variables (age, mean height, breast height diameter, number of trees per hectare, basal area and growing stock) of all five stands at Järvselja. These stands have been measured 3-7 times. As an example of remeasured data, Table 2 presents the measurement records of these variables from different years in section 286. A few trees selected by Hohenadl method (Krigul, 1959) were also felled for stem analysis. According to this method, the breast height diameter of an analysis tree is the mean of the stand plus standard deviation. In section 273 a European larch having the same diameter was chosen for stem analysis, in

Table 1. Mean stand characteristics of the Kuril larch in *Myrtillus* site type in Järvselja

section 286 a Russian larch was chosen for the same purpose.

For modelling of larch stand height (H), diameter (D) and volume (M) one of the oldest growth functions ¾ Hossfeld function (Peschel, 1938) was selected:

$$H = \frac{b_0}{1 + \frac{b_1}{A^{b_2}}},$$

where A – stand age; b_0, b_1, b_2 – parameters.

Traditionally, in the case of limited amount of measurement data, the guide curve method is used for smoothing variable-age data. The guide curve method generates a set of anamorphic (proportional) growth curves. By function (1), knowing height H1 at age A1, height H2 at age A2 can be calculated as

$$H2 = H1 \cdot \frac{1 + \frac{b_1}{A1^{b_2}}}{1 + \frac{b_1}{A2^{b_2}}}.$$

Cieszewski and Bella (1989) transformed function (1) to the difference equation

$$H2 = \frac{H1 + d + r}{2 + 4 \cdot \beta \cdot \frac{A2^{-b_2}}{(H1 - d + r)}}, \qquad (2)$$

where H1 – known stand height at any age A1, H2 – stand height prediction for desired age A2, $d = \beta \cdot Asi^{-b_2}$, $r = \sqrt{(H1-d)^2 + 4 \cdot \beta \cdot H1 \cdot A1^{-b_2}}$, Asi, β, b_2 – function parameters.

The difference equation (2) has been applied for modelling of site indexes of pine (Elfving and Kiviste 1997) and birch stands (Eriksson *et al.* 1997) in Sweden and for modelling of Estonian stands height, diameter and volume (Kiviste 1997).

For parameter estimating, stand measurement data were rearranged by measurement periods so that each data vector consisted of a start-situation (A1, H1, D1, M1) and an end-situation (A2, H2, D2, M2). Altogether, 19 data vectors were formed. Fit of constructed curves was evaluated with the root mean square error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (H2_i - f(A2_i, A1_i, H1_i))^2}{n - k}}, \qquad (3)$$

where f(A2, A1, H1) – the difference equation (2), n – number of periods, k – number of estimated parameters.

The non-linear regression procedure NLIN of the SAS program package (SAS Institute Inc. 1989) was used for estimation of model parameters.

Results

Kuril stands height, diameter and volume measurement data arranged by measurement periods were smoothed by the difference method and by the traditional guide curve method. Parameter estimates, their standard errors and root mean square errors (RMSE) of the models are presented in Table 3. The difference model of Estonian pine stand height, diameter and volume adapted for *Myrtillus* site type (Kiviste, 1997) was used for comparison.

Table 3. Parameter estimates, their standard errors and root mean square errors (RMSE) of models

Statistic	Height m	Diameter cm	Volume m^3/ha
The difference model (2)			
Parameter Asi	10	10	10
Parameter β	903 (208)	811 (227)	157000 (116000)
Parameter b_2	1.38 (0.15)	1,00 (0.18)	2.38 (0.39)
RMSE	1.3	1,9	58
The Estonian pine stand model (2) for *Myrtillus* site type			
Parameter Asi	50	50	50
Parameter β	7137	5317	250223
Parameter b_2	1.58	1.33	1.93
RMSE	1.4	2.1	83
The guide curve (1)			
Parameter b_0	42, (8.7)	166 (713)	755 (391)
Parameter b_1	180 (86)	205 (758)	2293 (4239)
Parameter b_2	1.33 (0.22)	0.87 (0.31)	1.90 (0.70)
RMSE	1.8	2.4	72

The difference model (2) had the smallest residual variation. Using the non-linear regression procedure NLIN in the SAS program package (SAS Institute Inc. 1989), instability of estimating parameters of the model (2) appeared because of the strong relationship between parameters and limited number of observations. To cope with the problem, different values of parameter Asi were tried and the other two parameters were estimated using the NLIN procedure. Asi value 10 was found to be most appropriate.

The parameter estimation of guide curve (1) converged well. Comparison of estimates of parameter b2 calculated by different methods (Table 3) revealed no significant differences. The guide curve and the average curve by the difference equation were very close together and it is difficult to distinguish them in Figures (see Fig. 1-3). However, Figure 4 shows an evident difference between those models at lower and higher site indexes. The diameter and volume models have a similar pattern. The difference equation method generates a set of polymorphic growth curves, which should be preferred to the guide curve method, which generates a set of proportional growth curves.

Figures 1, 2 and 3 present larch stand height, diameter and volume growth by measurement data and

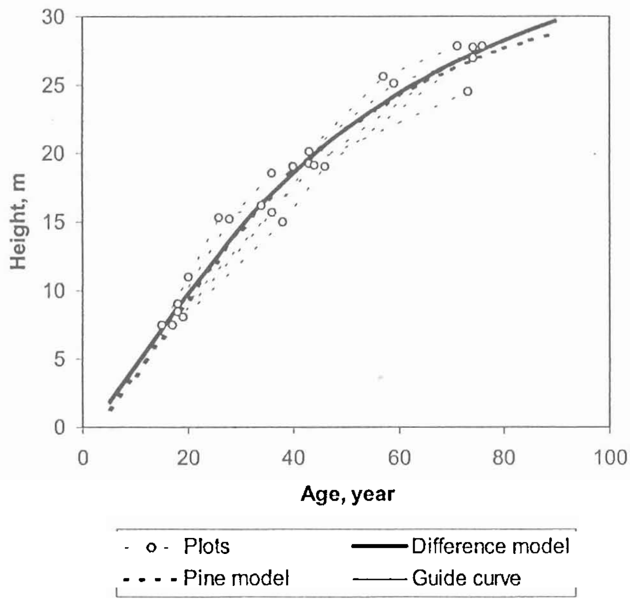

Figure 1. The Kuril larch stand height growth by permanent plot data and the average growth curve by three different models

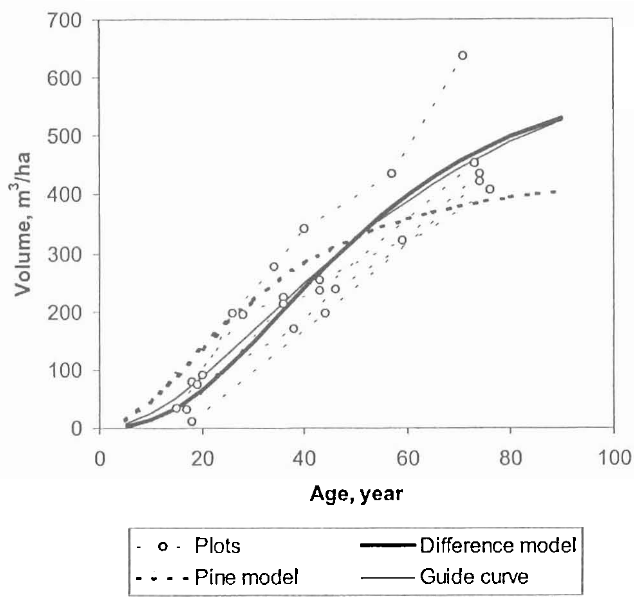

Figure 3. The Kuril larch stand volume growth by permanent plot data and the average growth curve by three different models

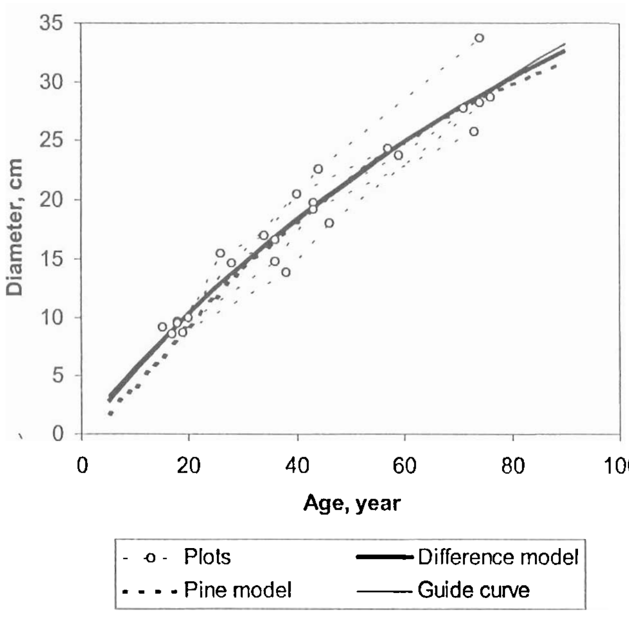

Figure 2. The Kuril larch stand diameter growth by permanent plot data and the average growth curve by three different models

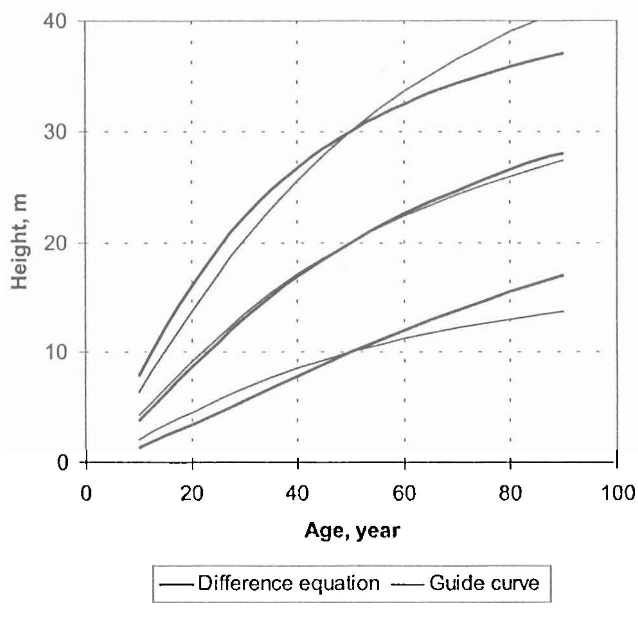

Figure 4. The height growth by the difference equation and the guide curve for three different site indices (H50 = 10, 20 and 30 m)

by all the three models. Figures 1 and 2 show no difference in height and diameter growth curves between larch and pine models, but Figure 3 reveals an evident difference in the growth pattern of larch and pine volume models.

Discussion

After Clutter et al. (1983), most techniques for stand growth curve construction can be viewed as special cases with three general methods: (1) the guide curve method, (2) the parameter prediction method, (3) the difference method.

The guide curve method is simple and has often been used for data from temporary plots. To get unbiased growth curves, stands data must be well represented in all age classes. The main drawback of the guide curve method is proportionality of the generated set of growth curves while the real stand growth series do not follow that pattern.

The parameter prediction method generates a set of polymorphic growth curves, which is much more characteristic of real growth of stands. The method has been mostly used with long height/age series from the sectioning of felled trees, long-term observations of permanent plots or grouping of temporary plots. By that method parameters of different data series are estimated separately and then smoothed as functions of the site index or other site variable. According to our experience, in the case of limited measurement data, parameter estimates included considerable errors and the smoothing procedure revealed no relationships between the parameters.

The difference equation method makes direct use of the fact that observations on a given plot should belong to the same growth curve. The general form of the difference function is: H2 = f(A2, H1, A1), where H2 is stand variable prediction for desired age A2, and H1 is known stand variable at any age A1. The expression is obtained through substitution of one parameter in the growth function. There are tens of different growth functions and several options for choosing a substituting parameter for each growth function. Substitution of the asymptote parameter produces proportional curves. Substitution of any other parameter produces polymorphic curves with common asymptote in most cases. The special solution of the difference equation (2) presented by Ciescewski and Bella (1989) creates a polymorphic set of growth curves with different asymptotes and has been proved to be the most efficient way to model a limited number of short data series.

Table 3 reveals considerable residual standard errors of model parameters (presented in parentheses). They are caused by limited measurement number and the strong relationship between model parameters. To predict Kuril larch height and diameter growth both the Estonian pine stand model and the new, difference, model can be applied. The difference in larch volume growth pattern as compared with the pine is caused by the higher density of the Kuril larch stands.

Table 1 presents the estimated stand data on the Kuril larch at Järvselja. As seen from the Table, the stand in section 286 has the biggest growing stock, which results, first of all, from the high density of the stand. The mean height of older stands is relatively similar, being considerably smaller only in section 308. The greatest breast height diameter can be found in section 45, which is caused by the sparsity of the stand.

The Kuril larch grows rather well after planting. After R. Riisberg (1933), from among the larch species cultivated at Järvselja, the Kuril and Russian larches grow better, whereas the European larch has a curved trunk, is sensitive to weather conditions and needs fertile soil.

Being not fastidious and growing fast, the Kuril larch has several advantages over the other larch species. By E. Laas (1959) the height increment of the Kuril larch in nursery was 273% as compared with the Russian larch (100%).

Figure 5 presents the growth curve of Kuril and European larches volume calculated by stem analysis in section 273. As seen from the Figure, the volume of the Kuril larch exceeds that of the European larch mainly due to the intensive growth of diameter. The Kuril larch tapers considerably less than the European larch, their form factors ($f_{1.3}$) being 0.521 and 0.452, respectively.

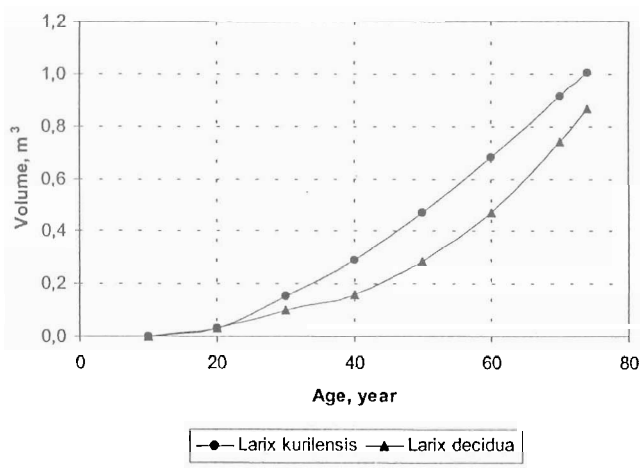

Figure 5. The volume growth of the Kuril and European larches by stem analysis in section 273.

Figure 6 presents the height growth of the Kuril and Russian larches by stem analysis. Throughout the growth period, the height of the Kuril larch exceeds that of the Russian larch. The form factor of the Kuril larch is higher than that of the Russian larch, 0.528 and 0.419, respectively.

The height and diameter increment of the Kuril larch culminates at about 15 years on *Myrtillus* site, but on *Oxalis* site it happens somewhat earlier. Figure 7 presents the height increment of the Kuril larch by stem analysis on *Myrtillus* site in section 263; Figure 8 shows the volume increment in the same sec-

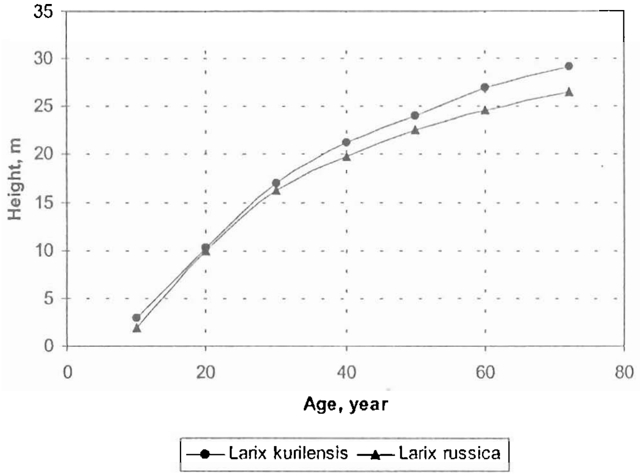

Figure 6. The height growth of the Kuril and Russian larches by stem analysis in section 286.

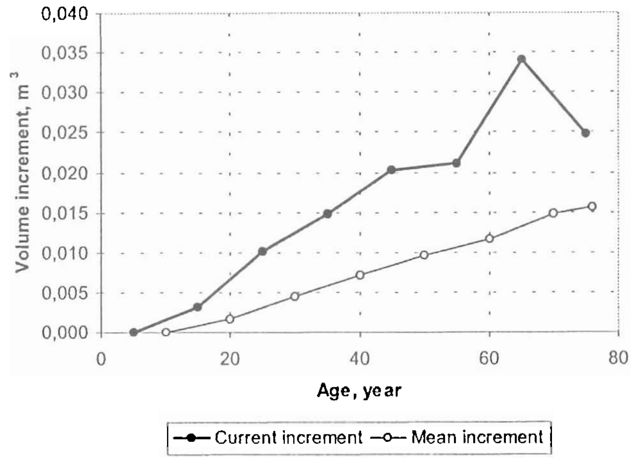

Figure 8. The volume increment of Kuril larch by stem analysis in section 263.

Figure 7. The height increment of Kuril larch by stem analysis in section 263.

tion. The current increments of both height and volume drop considerably from the age of 65.

In section 17 on *Oxalis* site 50-year-old *Larix eurolepis* and *L. kaempferi* exceed the Kuril larch by height and diameter.

According to the literature the Kuril larch may have thick bark. For example, N. Kabanov (1969) has mentioned that in Kamchatka the bark of some trees is 20-25 cm thick at breast height. The bark thickness of 60-70-year-old analysis trees measured at Järvselja at breast height was not more than 1.6 cm. Bark volume formed 15-19% of the total trunk volume. The Russian larches of the same age had considerably higher bark percentage.

The Kuril larch is considered a straight-trunked species with small tapering. On Sakhalin the mean form quotient (q2) of the Kuril larch is 0.698 (Dylis, 1981). At Järvselja the average form quotient of twenty-two 60-70-year-old model trees was 0.707.

The Kuril larch suffers little from insect pests and is nearly immune to larch cancer (*Dasyscypha Willkommii* Hart.). By L. Muiste's (1957) research European and Russian larches suffered much from larch cancer, but the Kuril larch remained nearly untouched. A. Oppermann (1928) from Denmark has mentioned the greater resistance of Kuril larch to larch cancer compared with the European and Siberian larches.

The Kuril larch grows cones from the early stage, and at the age of 10-12 seeds can germinate. By E. Laas (1984) the maximum technical germination percentage of the Kuril larch can be as much as 33, the average is much lower. The absolute germination percentage is mostly over 80. The percentage of pure seed output is high, reaching 16. The seeds ripen and fall usually in September. The weight of 1000 seeds is 2-3 g (Laas, 1987). By J. Rafn (1914) the weight of 1000 seeds of the Kuril larch was 3.0-3.8 g.

The Kuril larch is very decorative with its long horizontally directed branches and a wide conical crown. It begins flowering in spring nearly one week earlier than other larch species. A. Tigerstedt (1926) has emphasised the beauty of the Kuril larch with is emerald green needles, carmine blossoms and cedar-like form. By P. Tigerstedt (1986) the Kuril larch in Mustila Arboretum (Finland) at the age of 66 had considerably higher total yield and dominant height than the Scots pine on similar sites.

It has been supposed (Mathiesen, 1938; Ostrat, 1944) that, although the Kuril larch grows fast and gives seeds at the early stage, it may lag behind in its growth later in comparison with Russian and European larches. Judging by the Kuril larch cultures at

Järvselja, this is unfounded. As compared with other larch species, the growth of more than 70-year-old cultures in *Myrtillus* site type at Järvselja has not retarded. However, the future growth of the Kuril larch is uncertain as there are no older cultures of the species in Estonia.

Conclusions

1. The Kuril larch in Estonia is hardy and fast growing at the early stage.
2. In comparison to the Russian and European larches, the needs of the Kuril larch in habitat fertility are less.
3. The Kuril larch gives seeds abundantly and at an early stage.
4. The Kuril larch has relatively shade-bearing foliage, therefore, it can form a dense stand.
5. By stem analysis the Kuril larch on *Myrtillus* site is superior to the Russian larch in all estimated indices.
6. The Kuril larch is resistant to larch cancer, with a straight trunk and a small taper.
7. The Kuril larch is a particularly decorative species with horizontal branches. In spring it blooms earlier than other larch species.
8. Up to the age of 70 the growth of the Kuril larch on *Myrtillus* site does not lag behind the European and Russian larches.
9. The difference equation method is appropriate for modelling Kuril larch height, diameter and volume growth.
10. The future growth of the Kuril larch is uncertain as there are no older cultures of the species in Estonia.
11. As the Kuril larch thrives on less fertile soils, it can be used in forest cultivation.

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КУРИЛЬСКАЯ ЛИСТВЕННИЦА (*LARIX GMELINII* VAR. *JAPONICA* (REGEL) PILGER) В ЯРВСЕЛЬЯ

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Резюме

Продуктивность и ход роста курильской лиственницы были изучены в Ярвсельяском учебно-опытном лесничестве, которое находится во восточной части Эстонии. Ход роста курильской лиственницы сравнивается с другими видами лиственницы. Были анализированы 5 насаждений в черничном типе местопроизрастания. Таксация древостоев была проведена по общепринятой методике, деревья анализа были выбраны по методу Хохенадля. Было установлено, что курильская лиственница в Эстонии зимостойка, устойчива против рака и в молодом возрасте имеет быстрый рост. Она плодоносит рано и обильно. По сравнению с европейской и русской лиственницами курильская лиственница менее требовательна к плодородию почвы и более теневыносилива. В черничном типе местопроизрастания курильская лиственница до возраста 70 лет превышает русскую и европейскую лиственницы по основным таксационным показателям.

Для аппроксимации хода роста высоты, диаметра и запаса древостоев курильской лиственницы применялась функция роста Хосфелда. Модель разработана по данным пяти постоянных пробных площадей методом разностного уравнения. Неизвестно, каким будет ход роста курильской лиственицы в более старшем возрасте, так как старые насаждения этой породы в Эстонии отсутствуют.

Ключевые слова: Курильская лиственница, черничный тип, культивирование, ход роста, метод разностного уравнения.