Chapter 1

Lodgepole Pine (*Pinus contorta* Douglas ex Loudon) from the Perspective of Its Possible Utilization in Conditions of Changing Central European Climate

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Abstract

This chapter provides an overview regarding the lodgepole pine (*Pinus contorta* Douglas ex Loudon) from the perspective of its ecological demands and the possibilities of its silvicultural utilization in Central European conditions. Described are its natural habitat, variability, ecological properties, and the environmental demands (natural mixtures, geological needs, soil, temperature, humidity, etc.). Attention is given to characterizing the wood in terms of its production, properties, and possible uses. Furthermore, important aspects of this pine's cultivation are described as an aspect of forest management, as well as from the viewpoint of the species' utilization in reclamation of infertile anthropogenic substrates. Particular emphasis is given to current knowledge obtained through provenance research in relevant European countries. In connection with the changing climate in Central Europe, this pine tree can gradually gain in importance because it is a tree species with wide ecological adaptability. In spite of its lower production potential, the species is capable of creating stands on habitats that will be inappropriate in the future for many autochthonous Central European species.

Keywords: *Pinus contorta*, lodgepole pine, ecological characteristics, production, provenance research, silviculture, climatic changes

1. Introduction

In selecting tree species for introduction, attention is always focused on their productive abilities, quality characteristics, and resistance to local harmful agents. However, other ecological aspects, such as suitability for stand mixtures, natural regeneration ability, and influence on stand environment, also are important. Assessing, whether a tree species or its specific subpopulation (provenance) is capable of being utilized in new conditions, is only possible on the basis of research results or practical experience—preferably local—or after a critical evaluation of foreign research and experience. An introduced species should only be planted into such habitats where it can demonstrate its positive influence and at the same time does not constitute a substantially negative element for the inanimate nature or autochthonous flora [1].

The stability of Central European forest ecosystems is diminishing with advancing climate change. In addition, the health state of certain stands of Scots pine (*Pinus sylvestris* L.) has deteriorated, having been attacked by fungal pathogens *Sphaeropsis sapinea* (Fr.) Dyko & B. Sutton 1980 and *Cenangium ferruginosum* Fr. 1818 [2] over several consecutive years. Even in the case of this autochthonous tree species that always has been relied upon for plantings in Central European locations with low soil moisture availability, it therefore seems rational preventively to consider other species that could prosper in extreme habitats. This would allow continuation of forests' nonproduction functions while retaining at least minimally acceptable production.

One possible alternative solution of this problem is lodgepole pine, *Pinus contorta* Douglas ex Loudon. Originally from western North America, it was first introduced into Europe in 1852 [3] and has since that time demonstrated a number of favorable properties.

The objective of this work is to provide comprehensive information about the character of the range, ecological properties, and growing requirements of lodgepole pine. In consideration of the latest findings from forestry and reclamation research, this allows for outlining the potential for possible use of this species in the transforming Central European conditions. The division into subsections reflects the various aspects important for judging its usefulness in regional forest management and application to reclamation.

2. Consideration of species characteristics from the perspective of possible use in Central Europe

2.1. Natural range

Forests with a predominance of *P. contorta* have an area of ca 6 million ha in the US and ca 20 million ha in Canada. In the north, the species' range is limited by 64° N (Yukon Territory) and in the South by ca 31° N (Baja California) [4]. The three currently distinguished subspecies have wide allopatric areas (**Figure 1**). The range of *Pinus contorta* subsp. *contorta* reaches from southern Alaska along the Pacific coast to northern California, including Queen Charlotte Islands and Vancouver Island. The western boundary of the subspecies *P. c.* subsp. *latifolia* traces across the Rocky Mountains from the north from Yukon and British Columbia across Washington State and Oregon to northern Utah, and the eastern from Alberta approximately to Colorado. In addition, disjunct populations of this subspecies are located in the Canadian Northwest Territories (Liard Mountains) and Saskatchewan (Cypress Hills Provincial Park),

Figure 1. Distribution area of three *Pinus contorta* subspecies according to the U.S. Geological Survey [6]; map background source: https://www.seznam.cz/.

and in the US in South Dakota (Black Hills). The range of *P. c.* subsp. *murrayana* reaches from the Cascades of southern Washington State and Oregon (Cascade Range) across the Sierra Nevada and Transverse Ranges in California to Baja California and Sierra de San Pedro Mártir in Mexico [5].

Vertically, this species grows from practically sea level altitudes on the coast up to 3400 m a.s.l. in the Sierra Nevada and in the southern Rocky Mountains [5], and according to other authors, it reaches up to 3900 m a.s.l. [4, 7]. Musil and Hamerník [8] state an altitude range of 0–3500 (−3660) m a.s.l. The *P. c.* subsp. *contorta* subspecies grows up to 600 m a.s.l., the *P. c.* subsp. *latifolia* subspecies up to 3500 m a.s.l., and *P. c.* subsp. *murrayana* from sea level also to 3500 m a.s.l. [9], and up to 3700 m a.s.l. in the Sierra Nevada [10].

The climate is considerably variable within the area, particularly in the N-S direction but also in the E-W direction. Minimum temperatures range from 7°C in the southern parts of the coast to −57°C in the Northern Rocky Mountains, while maximum temperatures extend from 27°C along the coast and in the high altitudes to more than 38°C in low inland areas. Seedlings often survive in freezing conditions where other species could not, although the individual provenances must be distinguished in this regard [8, 11]. Mean annual temperatures fluctuate between −3 and 18°C. The absolute lowest temperature is −60°C [4]. Mean July minima at higher elevations are frequently below zero. Precipitation totals fluctuate from just 250 mm in the lower elevations of the cold continental inlands to more than 2500 mm in low elevations along the relatively mild, but cold and rainy (foggy) northern Pacific coastline [4, 8, 12].

Around 1950, lodgepole pine became the main species in afforestation of peat bogs in Britain, Ireland, Sweden, and Finland. Additional plantings can be found in the Netherlands, Denmark, Iceland, Norway, Germany, Poland, countries of the former USSR, and New Zealand. Probably the largest area outside of North America is in France [13, 14]. The species' use in Great Britain has decreased over time due to frequent occurrence of malformed trunks and a propensity for defoliation caused by insects, primarily pine beauty—*Panolis flammea* (Denis & Schiffermüller) [4].

2.2. Variability

Taxonomically, the species is divided into three varieties [9, 12, 15], or, according to other authors [10, 16] into three subspecies. Other studies [4, 17] distinguish an additional subspecies (sometimes just variety) *P. c.* subsp. *bolanderi*. This is not accepted in more recent monographs, however, and the variant is considered part of the *P. c.* subsp. *contorta* subspecies. Older literature had described two separate species: (1) lodgepole pine, which currently corresponds to the subspecies *P. c.* subsp. *contorta*, including the variety *P. c.* subsp. *contorta* var. *bolanderi* and (2) Murray pine, a currently invalid species including two subspecies of lodgepole pine (*P. c.* subsp. *murrayana* and *P. c.* subsp. *latifolia*) [18].

The individual subspecies differ in some of their botanical characteristics, as well as in their growth predispositions and dimensions achieved, although these are also partially affected by environment [12]. *P. c.* subsp. *contorta* usually takes a form ranging between a stunted bush and tree (rarely up to 30 m), often with a crooked or leaning trunk. The dark green needles are 2–5(7) cm long and 0.7–1.2 mm wide. The pine cones are asymmetrical, curved back against the axis of the branch, tenacious, sometimes serotinous (opening several years after maturing, e.g., after a forest fire). The umbo has a spike 6 mm long. Coastal stands of this subspecies in Mendocino County, California are considered by some authors to be *P. c.* var. *bolanderi*. *P. c.* subsp. *latifolia* are often tall trees (exceptionally up to 50 m). Needles are (4)5–8 cm long and 1–2(3) mm wide, yellowish green in color. Pine cones grow individually or in pairs, are asymmetrical, curved back against the axis of the branch, persistent, and variably serotinous. The umbo has a short dull spike. *P. c.* subsp. *murrayana* produces tall, often slim trees, up to 40 m tall. Needles are 5–8 cm long and 1–2 mm wide, yellowish green in color. Pine cones grow individually or in pairs, are relatively symmetrical, ascending, and nonserotinous (opening early and falling off quickly). The umbo has a small spike [9, 15, 17].

Morphological differentiation of the individual subspecies has a variance-statistical character, and therefore, determination is frequently problematic in the wild and unreliable in cultures

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outside of provenance-defined plantings [10]. The species is difficult to distinguish from the closely related *P. banksiana* Lamb., with which it naturally interbreeds in the area at the foot of the Rocky Mountains in western Canada [15]. Hybrids between *P. contorta* and *P. banksiana* created in the US by controlled pollination for the purpose of plantation growing are named *P. ×murraybanksiana* [12, 15]. Successful interbreeding also has been achieved with Virginia pine *P. virginiana* Mill [4].

Auders and Spicer [9] characterize a total of 14 valid cultivars and 11 synonyms. Among the better known cultivars are 'Compacta', a shrub with dark to yellow-green needles; 'Tristan Gold', a shrub with long yellow to dark green needles later changing to tree growth; 'Span's Dwarf', a low irregular shrub [19]; and 'Pendula', with overhanging branches [20].

2.3. Ecological characteristics

Lodgepole pine grows well not only on shallow slopes and in basins, but also in rugged rocky terrains and on steep (humid) slopes and mountain ranges, including exposed gravel. It occurs more frequently in habitats with northern and eastern exposure [8]. Inland, partially also in the Rocky Mountains and in the northern part of the Yellowstone National Park in the US, it can create dense pioneering even-aged and pure stands on sterile soils despite its heliophilia, especially so in places burnt by forest fires, the periodical occurrence of which prevents the slower-growing spruces and firs from dominating. It usually is not dominant in the western mountain ranges, although it invades wildfire sites even there. In other cases, and especially in later seral succession stages, it is associated with a number of western conifers. In the coastal part of the northern Pacific region, it mixes with *Thuja plicata* D. Don, *Tsuga heterophylla* (Raf.) Sarg., *Pseudotsuga menziesii* subsp. *menziesii* (Mirbel) Franco, *Chamaecyparis lawsoniana* (A. Murray) Parl., and *Sequoia sempervirens* (D. Don) Endl. In the northern part of its area, it also frequently grows with *Picea glauca* (Moench) Voss, or alternatively with broadleaves (*Betula papyrifera* Marshall, *Populus tremula* L.), in higher elevations with *Tsuga mertensiana* (Bong.) Carr., *Picea engelmannii* Parry ex Engelm., *Abies lasiocarpa* (Hook.) Nutt., *A. magnifica* A. Murr., *Pinus jeffreyi* Grev. & Balf., *P. flexilis* James, and *P. aristata* Engelm., in the inland part of the range in middle elevations with e.g., *Pseudotsuga menziesii* subsp. *glauca* (Mayr) A.E. Murray, *Larix occidentalis* Nutt., *Abies grandis* (Douglas ex D. Don) Lindl., and *Picea pungens* Engelm., and in the lower elevations of the same part of the range with *Pinus ponderosa* P. & C. Lawson [5, 8, 12, 17, 21]. On drier slopes and on plateaus, it frequently grows with *Pinus monticola* Dougl. ex D. Don and the already mentioned *A. magnifica*. At the edges of forests, it is accompanied by *Pinus albicaulis* Engelm. and *P. balfouriana* Grev. & Balf. [22]. Diversity increases toward the south, so in California, it is a component of mixed coniferous forests and subalpine coniferous forests and meadows along with many other species. Because soils in these areas are much richer and fires are much less frequent, *P. contorta* is not dominant there [5, 12, 17, 21].

In addition to its participation in primary succession in volcanic mountain ranges and in wildfire locations, it is represented also in dry and boggy sites in communities of early-medium-, and late-stage secondary succession. In succession, it can play the role of: (1) a component of even-aged stands, which is rapidly (over 50–200 years) replaced by shade-tolerant communities, (2) a dominant species in even-aged stands with substantial undergrowth of shade-tolerating species and which is replaced over 100–200 years, (3) a dominant species of even-aged stands with only partial replacement by shade-tolerating species, and (4) in certain types of locations, the sole species capable of tree growth [4, 21].

It grows in the widest range of conditions of all North American tree species, from dry sands in the lower elevations to seasonally wet mountain meadows [17]. It creates pure stands in such meadows in California's Sierra Nevada at 2000–2700 m a.s.l. At high elevations reaching to the top of the forest boundary, however, it is considerably deformed and has the form of ground-hugging shrubs [22]. It is tolerant of flooding [4] and can be found not only in coastal, peat bog, wetland, and swampy communities, but also in coniferous and mixed and dry and mountainous forests, on poor sandy soils, rocks, and rubble [4, 21, 23]. It has modest requirements [23] that differ by individual ecotypes. The south-ranging *P. c.* subsp. *murrayana* and *P. c.* subsp. *contorta* var. *bolanderi* are undemanding of moisture and tolerate even soils that dry out in summer. The coastal subspecies *P. c.* subsp. *contorta* also requires higher air humidity [13]. The requirements of lodgepole pine are generally greater than those of *Pseudotsuga menziesii* and *Pinus ponderosa* but lower than those of *Picea engelmannii* and *Abies lasiocarpa* [8]. It is drought tolerant [4] and is intolerant only of drying sand soils [24]. It is most productive in deeper and richer soils with balanced moisture and porousness [8, 13, 23]. It fares well on granite, slate, and rough lava bedrocks. It avoids drier soils on limestone bedrock [8], although it does occur there, as well as on glacial moraine soils. It can grow on acidic, wetland, clay, gravel, mountain, peat, sandy, sandy-loamy, dusty and swampy soils, sandstone, cambisols, gley, luvisols, podzol-luvisols, podzols, and regosols [4, 13].

The root system is variable, usually shallow, but taproots or fibrous roots develop on well-permeable soil. It forms associations with ecto- and endomycorrhizal fungi [4, 8, 17].

The species does not tolerate shade and vegetation competition. It requires direct sunlight [4, 7, 8, 17] or can tolerate only slight lateral shading [13]. In lower lighting, it has a low potential for natural regeneration, which in such cases occurs only in a dry and cold climate within stand gaps [25]. Pokorný [23] characterizes it as an intermediately shade-tolerant species with slightly lower light requirements than Scots pine. Strong reproduction occurs in full sun, typically after wildfires or clear-cuts [17]. Depending upon origin, it is moderately to completely frost-resistant, being quite resilient even in St. Petersburg and Finland [23]. Corresponding provenances are resistant to winter cold, late spring frost, salty winds, and air pollution [26]. The subspecies *P. c.* subsp. *murrayana* is also relatively frost resistant [10]. The resistance of certain populations to air pollution results from the effects of long-term evolutionary adaptation in areas of the natural range with rich volcanic activity, e.g., [27, 28]. Tolerance to effects of SO_2 in Central European conditions was demonstrated in experiments established in the 1930s on the German side of the Ore Mountains [29].

Drought is the usual cause of mortality during the first years of the seedlings' lives. Losses fluctuate depending on soil type and numbers of individuals. The largest numbers of seedlings germinate and survive on disturbed mineral soil. Drought losses usually decline after the first growing season. Lodgepole pine seedlings are weak competitors, and competition with grasses is often unfavorable to them [4].

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Pine cones mature more than 1 year after pollination—earlier at higher elevations and inland than on the coast or in lowlands [25]. Even though all subspecies are exposed to periodic fires, the serotinous of the pine cones is variable across the nature range and also locally [4]. Within California populations in the Sierra Nevada (*P. c.* subsp. *murrayana*) and in coastal populations (*P. c.* subsp. *contorta*), permanently closed cones are entirely absent or are very rare [8, 15]. Nonserotinous cones dominate in Oregon [4]. Serotinous closed cones are common in *P. c.* subsp. *latifolia* in the Rocky Mountains, although their proportion can decline below 50% [8]. This type of cones accumulates for decades [4], usually for 10–20 years [25]. They are opened by heat [17]. The heat necessary for their opening ranges between 45 and 60°C. Subsequently their opening is influenced hygroscopically. In open areas (e.g., after harvesting), cones near the surface of the soil (<30 cm) can open also due to increased insolation [4]. The bark of adult trees is relatively thin (under 2 cm). After fires, however, lodgepole pines regenerate well [7], which is due not only to the opening of serotinous cones but also due to the high viability of seeds, strong initial growth, and ability to cope with a wide range of soil and other microsite conditions [25].

Due to its limited root depth, it is susceptible to wind calamities, especially after stand walls have been opened by harvesting [11]. Strong wind and heavy snow may break or bend trees, especially in excessively dense stands with narrow canopies and strong competition in the root zone. In such stands, damage may further increase if the wind or snow exposure occurs shortly after thinning [25]. Lodgepole pine suffers crown breakage due to snow much less than does Scots pine [23].

Large, dense stands of *P. contorta* are susceptible also to insect damage, which usually is followed by a new fire several years later. Even though individual trees mostly do not live long and do not reach large dimensions, the species is, therefore, able to compete against other tree species [7]. The most common pest is the mountain pine beetle *Dendroctonus ponderosae* Hopkins, which attacks pines in July and August and spreads the blue-staining fungus *Grosmannia clavigera* (Rob.-Jeffr. & R.W. Davidson) Zipfel, Z.W. de Beer & M.J. Wingf. 2006. Pine beauty *Panolis flammea* (Denis & Schüffermiller, 1775) is another pest and is the main defoliator in northern Great Britain [4]. Serious damage in Britain is caused also by the European pine sawfly *Neodiprion sertifer* (Geoffroy in Fourcroy, 1785), the bordered white *Bupalus piniarius* (Linnaeus, 1758), and the common pine shoot beetle *Tomicus piniperda* (Linnaeus, 1758) [26]. In America, an important pest is the parasitic American dwarf mistletoe *Arceuthobium americanum* Nutt. ex Engelm., which infects up to 50% of stands in certain areas. In young stands, it spreads at a rate of 0.3–0.5 m per year (the highest in dense forests), increasing mortality, decreasing height and diameter increment, wood quality, seed production, and overall vitality [4, 8]. One of the most serious fungal diseases is stem canker caused by *Atropellis piniphila* (Weir) M.L. Lohman & E.K. Cash 1940. Stem cankers caused by rusts result in increased mortality and reduced growth. The most serious of these is Scots stem pine rust *Cronartium flaccidum* (Willd.) Jørst. 1925. *Endocronartium harknessii* (J.P. Moore) Y. Hirats. 1969 can kill seedlings and saplings. Other fungal pathogens include needle cast agents such as *Elytroderma deformans* (Weir) Darker 1932 and *Lophodermella concolor* (Dearn.) Darker 1967, root rot agents such as honey fungus *Armillaria mellea* (Vahl) P. Kumm. 1871 and *Heterobasidion annosum* (Fr.) Bref. 1888, and wood-decaying fungi such as *Phellinus pini* (Brot.) Murrill 1905 and *Peniophora pseudopini* Weresub & I.A.S. Gibson 1960 [11]. Serious damage is caused also by the fungus *Dothistroma septosporum* (Dorogin) M. Morelet 1968 and by deer [26].

2.4. Wood production and uses of the species

Generally, this is a medium-sized tree, exceptionally reaching heights of 35 m and diameter at breast height (DBH) of 60 cm [4]. Among other authors, Musil and Hamerník [8] have reported heights of (1–)10–25(−30) m and DBH of 18–33(−50) cm, Úradníček [13] height of 10–25(35) m and frequently only bush growth, and Farjon [12] bush or tree growth with height up to 50 m and DBH 100–200 cm. Auders and Spicer [9] indicate sizes ranging from shrubs and crooked trees on the coast of northern California to trees more than 50 m tall in the Sierra Nevada and the subalpine inlands of the northern Rocky Mountains. Eckenwalder [15] localizes miniature shrubs of 10–20 cm in height to coastal sites where soil is unformed.

The variability of growth indicators is related to the taxonomic division of the species at lower levels. *P. c.* subsp. *contorta* with substantially crooked limbs reaches heights of up to 10 m in its natural range [23]. According to Pilát [22], it is a tree or shrub 2–5 m in height, otherwise 6–10 m. *P. c.* subsp. *latifolia* reaches 20–27(40) m [23], or mostly under 25 m and rarely up to 50 m [22]. The greatest heights (40 m) are achieved by trees within river basins in Alberta, Canada [23]. According to Farjon [12], trees of the subspecies *P. c.* subsp. *murrayana* in Oregon and California reach the largest dimensions (height > 50 m and DBH 200 cm). The dimensions and growth achieved are strongly influenced, however, by stand density and environmental factors [25].

The lodgepole pine trunk is straight and cylindrical, i.e., fully woody and with little tapering, which applies especially in dense stands with small and narrow crowns. The trunks clear poorly in the stand, but the branches are thin and short, so they do not diminish wood quality very much [4, 8]. The stems are crooked in certain cases [12], and on exposed coastlines and ridgelines, the trees are sometimes multistemmed, often with irregular crowns [9]. The bark is relatively thin, under 2 cm [4]. The outer bark starts to form early in the subspecies *P. c.* subsp. *contorta*, whereas the individuals of *P. c.* subsp. *murrayana* and *P. c.* subsp. *latifolia* have smooth bark for the first 40–50 years, and thinner scaly outer bark is formed only later [30].

Generally, the species lives to less than 300 years [25]. Musil and Hamerník [8] provide ages of 200–500 years. According to Preston and Braham [17], it can exceptionally live for more than 600 years and reaches maturity at 200–300 years.

Especially, in western North America, it is an important, even main, production tree species, providing high-quality wood that has a greater volumetric production than a number of other species from the same area of comparable height and diameter due to its rapid growth, minimal tapering, and thin bark [4, 12, 25].

Initial growth (up to 5 years) is rapid, exceeding 50 cm per year in productive sites after the third growing season [4]. Acceleration of height increment starts earlier in natural conditions than in other tree species (with the exception of larches and other pines). At 20 years of age, average height is in the range of 2–8 m. During a single vegetation season, sprouts may undergo dicyclic and polycyclic growth [8]. Nevertheless, lodgepole pine's overall growth is rather slow [17] and definitively starts to decline at ca 80–120 years [25].

Mean annual increment of old, unmanaged stands in the Rocky Mountains may be as little as 0.4–0.6 $m^3 \cdot ha^{-1}$ due to a large number of young trees and high infection by the parasitic shrub *Arceuthobium americanum*. On the other hand, total current increment after adjustment for stand density and reduction of parasitic plants may improve to 2.1–5.6 $m^3 \cdot ha^{-1}$ [4]. There can, therefore, be large differences in stand growing stocks. Maximum production in the Rocky Mountains in stands with density of 1980 $trees \cdot ha^{-1}$ is stated as 280 $m^3 \cdot ha^{-1}$, but only 21 $m^3 \cdot ha^{-1}$ at 4450 $trees \cdot ha^{-1}$. In an extreme case, in stands 70 years old with 247,000 $trees \cdot ha^{-1}$, there are trees with average height of only 1.2 m and basal diameter of <2.5 cm. In typical cases, growing stocks reached 168–224 $m^3 \cdot ha^{-1}$ for adult stands in the Rocky Mountains, although there are also known stands with growing stocks exceeding 336 $m^3 \cdot ha^{-1}$. These were achieved by synergies with a suitable initial number of seedlings, good site quality, and absence of *A. americanum* and the mountain pine beetle *Dendroctonus ponderosae* [4, 11]. From the states of Idaho and Montana, there is data available on average indicators of stands aged 80 and 140 years. In the first case, at density of 1030 $trees \cdot ha^{-1}$, height reached 18 m, DBH 20.6 cm, and growing stock 285.6 $m^3 \cdot ha^{-1}$; in the second case, at density 680 $trees \cdot ha^{-1}$, average height was 25.3 m, DBH 26.7 cm, and growing stock 448.7 $m^3 \cdot ha^{-1}$.

In lodgepole pine plantations in Great Britain at a rotation period under the age of 80 years, the annual growth can reach 4–14 $m^3 \cdot ha^{-1}$ [4]. Average production is 6–10 $m^3 \cdot ha^{-1} \cdot year^{-1}$ (with a maximum of 14 $m^3 \cdot ha^{-1} \cdot year^{-1}$), and in Ireland, it is commonly even 18 $m^3 \cdot ha^{-1} \cdot year^{-1}$ [26].

The species' wood is soft, light to medium weight, with density 380–465 $kg \cdot m^{-3}$ [25] or 470 $kg \cdot m^{-3}$ at 15% humidity [26]. It has a satisfying texture and a thin, almost white to yellowish sapwood, which is not sharply separated from the yellow-brown heartwood [4, 17], but is often overly knotty [22]. It has straight wood fibers, low warping during drying, and a relatively homogenous structure. Its wood is similar to that of Scots pine, although it has a higher proportion of heartwood. It is not resistant to rotting in contact with earth, and rotting occurs in as little as a year [26]. It is also susceptible to attacks by wood-boring insects [4].

Commercially, its wood is of intermediate importance [17]. Lodgepole pine is suitable for construction and carpentry purposes [22]. It is easy to plane, bend, color, drill, and carve [4]. Although the sapwood is highly permeable for preservatives, impregnation of the heartwood is more difficult [4, 26]. Unimpregnated wood, however, decays very rapidly [22]. It is used for producing sawmill logs and lower-quality lumber. It is used for the production of light building structures, frames, paneling, pillars, stakes, rods, poles, posts, timbering in mines, railway sleepers, floor coverings, fences, gates, crates, pallets, furniture, chipboard, plywood, etc. [11, 17]. There is an increasing trend for its modern use in the cellulose industry and composite materials [12], especially in production from plantation cultivation [4], which will apparently give priority to managing stands for rapid growth at early age [11].

In terms of nonproduction uses, this pioneering species is valued in North America for various purposes due to its quick growth and undemanding soil requirements. In volcanic mountain ranges, its vitality is used for its advantage in eliminating the influence of climatic extremes and for protecting against soil erosion [21]. It is a highly regarded species for drying out bogs. Its planting in lowlands is not appealing, however, because other species outperform it for production and stem shape. In Britain, it is grown at higher elevations on the poorest and particularly swampy soils [26]. It grows well in Ukraine, Belarus, and the northern Caucasus, but it does not fare well on the southern coast of Crimea [22]. It is being tested in forest stands in several European countries [23]. It was frequently planted in Sweden in the 1960s. Its ability to grow on poor, recultivated locations and in a cold climate attracted attention. It was also experimentally used on pollution clearings. Sometimes, it fulfills the function of a protective tree species on infertile sterile soils [12]. Provenance experiments in Europe have demonstrated that it does not have such high production potential as Scots pine, but, depending on provenance, it can handle more severe exposure to frost and drought [31]. In western North America, it is also valued for its landscaping, water management, and ecological importance. Native Americans used to consume its juicy bark [4, 8].

From a gardening perspective, lodgepole pine has a lower decorative value (*P. c.* subsp. *murrayana* creates larger and prettier trees). Nevertheless, sometimes, it can give a nontraditional impression, and in smaller spaces, it serves well as a replacement for the more robust Austrian pine. It is planted as a solitary tree or in groups, as well as for contrast together with broadleaves. The species tolerates air pollution, and therefore, it is frequently used in urban areas, on embankments, etc. It is used in recreational forests, parks, castle gardens, along roads, and in reclamations [10, 13, 19, 22, 24, 30, 32].

2.5. Use in forest reclamation

The use of lodgepole pine in forest reclamation, which is substantially different from the common forest restoration, is a separate matter. Possibilities for use of forest species on extreme sites such as spoil banks or recultivated mining areas have been studied, e.g., [33–37].

The selection of tree species suitable for forest reclamation is based on evaluations of experimental plantings and pilot experiments. A number of factors are monitored, such as (1) natural occurrence of the species in the given area, (2) ecological characteristics of the species, (3) requirements for climatic and soil conditions (in particular, the occurrence of late or early frost or drought spells spanning several days), (4) pedological characteristics of the spoil bank soils (in particular, the range of pH at which the assessed woody species is vital) and the necessity for biological amelioration, (5) survival rate, growth and development of the species, or vitality of growth in monocultures and mixed stands, (6) function of the woody species on the spoil bank site (humus-forming, soil protection, amelioration, hygienic, esthetic, economic), (7) resistance of the woody species to industrial air pollution and to biotic and abiotic agents, and (8) health status. It is very difficult to compare the findings from these investigations with the results from typical forest stands. Important questions concern the creation of suitable mixtures, chronology of regeneration, tending, silviculture techniques, and spatial organization of stands [37–40].

Special particularities of forest reclamations concern the artificially created substrate from overburden overlying soil-lacking pedogenetic characteristics, and frequently also air contamination by industrial pollution, undetermined founding and silviculture procedures, and generally poor knowledge of the trees' responses to spoil bank forest management [41]. The heterogeneity of spoil bank materials does not allow for a homogenous choice of afforestation work [38].

Considering the requirements for substrate modification, the most suitable introduced broadleaf has been found to be the northern red oak (*Quercus rubra* L.) and black locust (*Robinia pseudoacacia* L.), and among conifers Austrian pine (*Pinus nigra* J.F. Arnold) and lodgepole pine. In particular, the two conifers are, together with European larch (*Larix decidua* L.), highly tolerant to extreme soil reaction (pH < 3) of anthropogenic substrates where not even common forest weeds can grow. When other selection criteria are included (e.g., tolerance to climatic extremes, fast growth), however, relatively slowly growing lodgepole pine no longer belongs in that elite group [37].

Along with other woody species from higher latitudes, lodgepole pine demonstrates much richer foliation on anthropogenic substrates, as well as a longer vegetation period and lower transpiration. It is one of the species with the largest horizontally rooted profile [42]. It can be a truly promising conifer suitable for intentional forestation of anthropogenic substrates even where the air is rather highly polluted by SO_2 [33]. Together with some other species, if requirements for seedling quality and early, properly performed planting are fulfilled, it has an almost 100% survival rate even on such specific locations [42]. In soil substrates of the Czech Republic's Antonín reclamation arboretum, just as a number of other species, its development is not different from that on naturally developed soils [41].

Similarly to, for example, poplar cultivars, lodgepole pine requires a larger planting spacing. A shallow vertical rooting profile has been unequivocally demonstrated in this species. This means that in order to ensure lodgepole pine stands' stability against windthrow on clay anthropogenic soils, mixture with broadleaves is appropriate or even indispensable [39]. Ideal conditions for growing conifers (*Larix*, *Pinus*) are provided by the cover species European hornbeam (*Carpinus betulus* L.), which requires cyprus clays in the form of clay slate or flaky clays. Hornbeam has a high amelioration effect (heavy litterfall, good rooting), covers the soil surface well, and increases the infiltration capacity of surface layers in the soil profile. On biologically unaugmented soils, however, it only grows as a bush [38]. The selection of suitable mixtures of broadleaves and conifers is more difficult than in purely broadleaf mixtures. In selecting the conifers, one needs to consider primarily their resistance (plasticity) to industrial air pollution, in particular SO_2. In anthropogenic sites, the maximum representation of conifers in stands (20–40%) is defined by soil-forming aspects. When the conifers are planted as individual component of mixture, it is desirable for the broadleaf species in these cases to have growth vitality the same as or lower than that of the conifer. In addition to European hornbeam, this criterion is fulfilled by, for example, small-leaved lime (*Tilia cordata* Mill.), common oak (*Quercus robur* L.), and sessile oak (*Q. petraea* /Matt./ Liebl.). In establishing broadleaf/conifer mixtures by group, almost all broadleaves suitable for anthropogenic substrates can be used [39].

The most recent findings from the forest reclamation area concern growing and tending interventions. Establishing and tending of mixed stands in clusters or groups is the most suitable. A major advantage is that it is not necessary to expend labor on freeing the conifers from shading by broadleaves during the first decade. The groups of broadleaves create very good edge protection (improving moisture and microclimatic conditions), due to which the conifer groups have stable growth. To transform short-term and long-term preparatory stands, an underplanting of conifers (including *P. contorta*) can be used, in the form of circular, linear, wedge, striped, or combined removal methods [39]. Establishing mixed broadleaf-coniferous stands is realistic under the assumption that the predominance of broadleaves will be maintained [42].

Coniferous stands consisting of commonly deep-rooting species have the least stability among mixed-age stands on the clayey spoil banks because of absence of tap root formation in these conditions. This is the case especially for various species of pines, including lodgepole pine. Comparison tests have demonstrated that the thickness of heart roots and especially horizontal roots are positively influenced in this species by a selecting a wider spacing of 4×4 m. This is because in such case, stands are exposed to adverse weather conditions already from a young age, and especially to wind [42].

In 1973 at the Velký Riesel spoil bank in the Sokolov area in the Czech Republic, lodgepole pine was planted in alternating strips with common alder (*Alnus glutinosa* /L./ Gaertn.) and for comparison as underplanting of a 10-year-old chemically reduced (approximately to 50%) stand of gray alder (*A. incana* /L./ Moench.). In 1979, the height of lodgepole pine in the strips among common alder reached 298.6 cm, whereas in the underplanting into reduced gray alder, it was 272.2 cm [33]. Experimental combinations of lodgepole pine with common alder were demonstrated to be very suitable [42].

On tertiary substrates, higher mean annual increment in lodgepole pine can be assumed as compared to on quaternary substrates. In extreme conditions, packaged seedlings can be used [39].

As part of production research on a lodgepole pine monoculture at the recultivated Antonín spoil bank in the Sokolov area with average height of 15 m and diameter at breast height of 21 cm (n > 100), 10 sample trees were felled. In all 10 samples, growth increment reached its maximum in the first half of the tree's life (and in a majority already in the first third). Diameters at breast height of sample trees were in the range of 18.1–19.7 cm (mean 19.0 cm). Current diameter increment was 2.7–12.9 mm, and mean diameter increment was 6.3–9.5 mm [43]. Similar values had been determined by Bažant [44] on spoil bank sites of the Most basin in two samples of Scots pine with identical diameter at a breast height of 10.2 cm. Current diameter increments of the samples were 10.0 and 11.0 mm, and mean diameter increment was 5.0 and 5.5 mm.

2.6. Growing aspects

The growth properties of lodgepole pine may differ not only depending on the conditions of the planted site, but also by the subspecies or provenance used. The differences in production among subspecies and provenances were confirmed in conditions of three Czech research trials [45–47], which were kept intentionally intervention free until the age of 34 years. The results, thus, obtained therefore allow us to make recommendation for certain habitats regarding potentially broader use of the provenance with the largest hectare growing stock, although if common forestry management had been carried out, their order in production achieved could have been different to some degree. The literature does not specify tending interventions according to the individual subspecies of lodgepole pine, and this is why they are not differentiated in this subsection.

In the species' natural range, stands provide viable seeds from 5 to 10 years of age [11], even though male cones have been detected on seedlings in a nursery at just 2 years of age [8]. Mast years occur in intervals of 1 to 3 years, so production of reproductive material is sufficient [11]. The logging waste of branches with closed cones also can be used as a source of seeds. Serotinous cones produce 100,000–200,000 seeds·ha^{-1}·year^{-1} (total growing stock may be up to 10× greater). Nonserotinous cones produce 35,000 to 1.2 million seeds·ha^{-1}·year^{-1}. One cone (Rocky Mountains) has approximately 10–24 developed seeds, and one adult tree may have several hundred to several thousand cones [8]. Cones mature in August to October, more than 1 year after pollination. Net seed proportion differs under various natural conditions (in various provenances), although even low values of this indicator are sufficient to ensure the necessary amount of seeds. The recorded difference in number of disbursed seeds per hectare in Oregon ranged between 35,000 and 1.2 million [11]. It can be assumed that parental stands of lodgepole pine in Central Europe would have similar rates. In Britain [26], production is 245,000 to 364,000 seeds per kilo, of which ca 270,000 are viable. For various provenances, however, it is necessary to account for diverse representation of serotinous cones, which open in outdoor conditions only after being subject to intense heat [4]. In order to obtain seeds for artificial regeneration purposes, this problem is technologically solvable in seed extraction facilities.

Germination proceeds best on a mineral soil without competition from weeds and in full sun [4]. Under advantageous conditions (temperature 8–26°C, corresponding humidity), it is fast and reaches almost 100%. The seeds are usually not preserved in the soil over the long term. The seedlings are relatively tolerant to extreme temperatures. Their survival, similarly to germination, is inhibited by shading, competition, and insufficient moisture. Preparation of seeds by stratification in nurseries is not necessary. Lodgepole pine can be reproduced vegetatively by grafting and cutting, including by micropropagation *in vitro*. Coppicing also has been observed in nature. A substantial increase of growth can be achieved by fertilization [8].

Mean regeneration ensuring full use of an area is 2470 trees·ha^{-1} with subsequent reduction in order to achieve a suitable spacing. If the individual trees are equally spaced, their number at 5–20 years of age should not exceed 1200–2000 trees·ha^{-1} [4]. For artificial regeneration, at least two-year container seedlings should be used, because most one-year seedlings do not have sufficiently developed root systems and that influences their vitality and stability. Detailed investigation has furthermore confirmed that root development depends also on seed origin [31].

A general problem in the early development stages of lodgepole pine stands is excessive density. This may lead to growth stagnation, especially on poor and dry sites. Adjusting the density of young stands is the best production-increasing option among all known measures, because the culmination of total volume increment occurs in seriously stagnating stands at as early as 40 years of age and in overly dense but not too-stagnating stands at 50 to 80 years of age. In poor areas and in dense stands, intervention is necessary after a mere 10 years. Even though dense stands have a strong capability for self-thinning and low crown space requirements, the difficulty of increasing their quality through tending increases with age. Thinning out of excessively dense and stagnating stands may renew growth potential and achieve production of good commercial assortments [4]. A comparison of the rate of commercial wood acquired from tended and untended stands after 25 years of development has shown that the tended stand exceeded the untended one by 460% in this parameter [48].

Especially in excessively dense stands with narrow crowns and strong root competition, there can occur damage due to strong winds and heavy snow that cause breakage and bending of stems [4, 25]. Calamity wood needs to be processed within 1 year due to its rapid decomposition in contact with soil [26]. It is, therefore, important to consider the degree of thinning, because substantial reduction in density may substantially increase the extent of this type of damage. Diameter increment usually accelerates the most after strong interventions, whereas the values for volume increment and basal area increment usually increase after lighter thinnings [4, 25].

Lodgepole pine can be grown in a monoculture as well as in mixed stands [25]. In order to achieve well-usable assortments, a spruce-pine-fir mixture is suitable [4]. Due to declining growth at 80–120 years, the rotation period may be theoretically established at 90 years. Due to light permeability, an understory is usually well formed under the canopies of mature stands in certain areas, which may create complications for their development for purposes of natural regeneration [25]. Shelterwood cutting is usually not sufficient [8]. Clear-cutting is considered the best regeneration method and in certain cases, depending on area and economic objectives, also group selection-cutting [25]. It is apparently optimal to create a cutting face in the parental stand and subsequently prepare the soil in a suitable manner. According to the literature [4], however, the response to reproduction cutting is very slow in terms of regeneration (more than 10 years). Therefore, if necessary, harvesting should be carried out early in the appropriate part of the cutting face in order to thin the canopy. Such prepared conditions should ensure rich natural regeneration in the mast year.

In Britain, lodgepole pine was earlier used as a covering species, usually in a mixture with Sitka spruce. Rapid growth of the pines, however, frequently caused problems with the spruces being suppressed and even entirely eliminated. In some boggy areas, however, a previously unknown and still not entirely explained "caretaker" effect was attributed to this mix: in the cover of the pines (especially those of Alaskan provenance), the Sitka spruce achieved several classes greater production than when grown in a monoculture. This mechanism is probably related to intake of nitrogen and mycorrhizal ecological relationships [26].

2.7. Results of provenance experiments

In order to assess growth and adaptation characteristics of lodgepole pine in the Central European region, one can refer in particular to available findings acquired through past evaluations of long-term provenance experiments established in the Czech Republic and in Germany.

In the Czech Republic, the most recent results are from evaluations at three research trials, which were established in various site conditions by the Forestry and Game Management Research Institute in 1984 and 1985, e.g., [28, 49]. At 34 years of age, differences in the growth of subspecies and various provenances of pines were apparent. The site in an acidic oak forest

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at the Sofronka location (Plzeňsko) at 330 m a.s.l. [45] is best suited to the provenances of the subspecies *P. c.* subsp. *contorta* from the coast of Washington, Oregon, and California, whereas the conditions of a poor pine forest at the Mláka location (Třeboňsko) at 435 m a.s.l. [46] are suitable for the Oregon provenances of the subspecies *P. c.* subsp. *contorta* and *P. c.* subsp. *latifolia*. Also, the site of acidic spruce forest at the Kovářská location (Ore Mountains) at 870 m a.s.l. [47] is most suitable for the Oregon provenance *P. c.* subsp. *latifolia*. Successful growing of lodgepole pine, therefore, requires analyzing natural conditions at the place of planting and subsequent selection of a corresponding provenance.

Two-factor analysis of variance was calculated for the stem volumes from three provenance trials of lodgepole pine for provenances represented in all three trials (**Table 1**). The factors were provenance and research trial locations.

There were significant differences among both research trials and provenances. The results are graphically represented in **Figure 2**, which clearly shows that the highest values are achieved by the provenance 2091 Mount Hood from the Oregon Cascades (*P. c.* subsp. *latifolia*) at the Kovářská location, reaching mean trunk volumes of 0.210 m^3, followed by provenances 2130 Mineral from California (*P. c.* subsp. *murrayana*) and 2123 Enterprise from Oregon (*P. c.* subsp. *latifolia*) at the same location, reaching 0.169 and 0.161 m^3, respectively. The provenance 2089 Chemult from Oregon (*P. c.* subsp. *contorta*) was also noteworthy, being the only one to achieve above-average production in all three trials. It, therefore, has the potential for universal use from lowlands to mountain areas. From the perspective of altitude range, the subspecies *P. c.*

Provenance		Origin	Subsp.*	Altitude (m a.s.l.)	Latitude N	Longitude W
1901	Chetwynd	British Columbia (BC)	L	700–1000	55°37′	121°40′
1902	Mile 86	British Columbia (BC)	L	752–900	56°48′	121°35′
1903	Upper Liard	Yukon Territory (YT)	L	701–761	60°05′	129°18′
1904	Wonowon	British Columbia (BC)	L	825–950	56°46′	121°53′
2089	Manzanita	Oregon (OR)	C	30	45°43′	123°56′
2091	Mount Hood	Oregon (OR)	L	1280	45°18′	121°45′
2098	Chemult	Oregon (OR)	M	1675	43°19′	121°39′
2120	St. Regis	Montana (MT)	L	945	47°22′	115°24′
2123	Enterprise	Oregon (OR)	L	1310	45°38′	117°16′
2126	Prairie City	Oregon (OR)	L	1490	44°32′	118°34′
2130	Mineral	California (CA)	M	1490	40°21′	121°29′
2133	Truckee	California (CA)	M	1830	39°13′	120°12′
2138	Mineral King	California (CA)	M	2410	36°27′	118°36′
2234	Kananaskis	Alberta (AB)	L	1524	51°05′	114°45′
2235	Calling Lake	Alberta (AB)	L	1005	55°38′	113°27′

*L = *P. c.* subsp. *latifolia*, C = *P. c.* subsp. *contorta*, M = *P. c.* subsp. *murrayana.*

Table 1. Characteristics of provenances represented in all three trial sites.

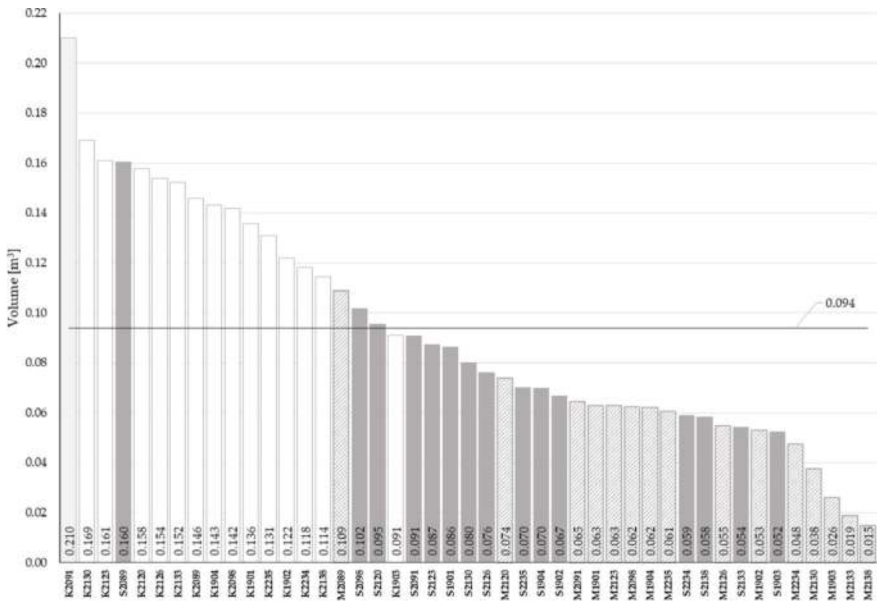

Figure 2. Trunk volume by provenances and locations (K = Kovářská, S = Sofronka, M = Mláka).

subsp. *contorta* appears to be universal, whereas *P. c.* subsp. *latifolia* and *P. c.* subsp. *murrayana* are more suited to middle to mountainous elevations. All provenances achieved their best values at the Kovářská location, followed by Sofronka, where trunk volume of most provenances was below average. The provenances grew slowest at the Mláka location. Generally, provenances from Oregon can be evaluated as the best without regard to subspecies or locations (2089, 2091, 2098).

In the acidophilic oak forest at the Sofronka location, the greatest heights were determined in *P. c.* subsp. *contorta* and the lowest in *P. c.* subsp. *murrayana*. In the subspecies *P. c.* subsp. *latifolia*, which has the largest natural range, it seems the heights of provenances decrease in the direction of gradient of the position of their parental locations from the ocean to the inland. Provenances from the coast of Washington, Oregon, and California demonstrated rapid growth. A similar result was determined on an extremely dry site with a minimum of nutrients at Mláka, where the best results were achieved by provenances 2089 Manzanita from the coast of Oregon (*P. c.* subsp. *contorta*) and 2091 Mount Hood from the Oregon Cascades (*P. c.* subsp. *latifolia*). On the other hand, in the Ore Mountains, especially the provenances of *P. c.* subsp. *latifolia* from middle elevations showed above-average growth. Among provenances of the subspecies of *P. c.* subsp. *contorta*, only the Oregon provenance 2099 Port Orford had positive results, and among those of *P. c.* subsp. *murrayana,* it was 2098 Chemult, also from Oregon.

Relative yield class was used to compare the growth of lodgepole pine provenances with the local type of Scots pine at the Mláka location. Relative yield class of neighboring Scots pine stands reaches 2–3. In the lodgepole pine provenance 2089 Manzanita *P. c.* subsp. *contorta*, which has the largest growing stock of 175 $m^3 \cdot ha^{-1}$, the tabular relative yield class for Scots pine [50] corresponds to 4, which is an interesting result in the given location. Average relative yield class of lodgepole pine had a value of 6 whereas in the case of the poorest provenance 9. Results comparable with those of local pine were, therefore, provided only by the best provenances of the introduced species. Furthermore, a comparison of lodgepole pine's growth with that of Scots pine in the conditions of acidic spruce forests, poor sands [46], and oak-beech forest [29] demonstrated that the native species can be equaled only by the best provenances of the introduced tree. Different results, however, were provided by a comparison of Scots pine with Norway spruce on a series of experimental trials in Germany [51], where lodgepole pine unequivocally had outgrown both autochthonous species at 23 years of age.

Research on lodgepole pine is also being conducted in Germany [52]. Undoubtedly, the best height growth at 8 years of age has been demonstrated by provenances originating from the coast of Oregon, Washington, and southern British Columbia. In comparison with the earlier results from the Mláka and Sofronka trials at 7 years of age, the result was similar. A distinction in Czech trials is the positive evaluation of provenance 2120 from Montana.

At the Adorf, Hundhübel, and Steinbach research trials on the German side of the Ore Mountains, average heights of lodgepole pine at 32 years of age were determined to be 10.0, 11.3, and 13.0 m [53]. These values are also comparable to those from the Kovářská trial at 34 years (12.9 m). Replacement stands of lodgepole pine established in the past in polluted areas of the Ore Mountains in Saxony are still expected to perform productively [54].

On a series of six German experimental trials with 11 provenances of *P. contorta* [55] at 15 years of age, coastal provenances of *P. c.* subsp. *contorta* and several inland ones of *P. c.* subsp. *latifolia* fared the best. Provenances of *P. c.* subsp. *latifolia* from further inland grew at average rates, and inland provenances of *P. c.* subsp. *murrayana* grew unsatisfactorily. On another German series of eight IUFRO trials with 140 provenances of lodgepole pine [52] at 8 years of age, provenances of *P. c.* subsp. *contorta* from the coast of Oregon, Washington, and the south of British Columbia also grew the best, as did certain inland provenances of *P. c.* subsp. *latifolia* from southern and central British Columbia. Provenances from northern British Columbia, Alberta, Yukon, and Alaska grew unsatisfactorily, as did the mountain provenances of *P. c.* subsp. *murrayana*. Even though ecological conditions are different on German trials, the above-average growth of inland provenances of *P. c.* subsp. *latifolia* corresponds with the results from the Kovářská location.

The results of provenance experiments from the two countries are comparable and can serve as recommendations for the growing of *P. contorta* in Central Europe. A selection of suitable provenances in the current conditions of climate change ensures a certain stand quality, vitality, and productivity as well as other nonproduction functions.

2.8. General assessment

Lodgepole pine well tolerates the Central European climate and grows relatively well, especially when young. The subspecies *P. c.* subsp. *latifolia* and *P. c.* subsp. *murrayana* are grown most frequently there. The species is suitable for poorer sandy to sterile, dry to fresh sunny locations. It is resistant especially at oak to beech vegetation levels, but is considered for forestry uses also in submountainous areas. The species does not suffer from snow damage here. In contrast to originally high-elevation mountainous locations (around 2800 m a.s.l.) of certain provenances, the species does not have sufficient air humidity in common Central European forests. That may have an effect on its vitality only after a certain time has passed after planting. Whether it can handle the new conditions depends on provenance and specific genotypes. Previous experimental applications of this species in forests (e.g., the Ore Mountains) can be considered successful. German experiments have demonstrated that it can be used, for example, to improve perennial spruce cultures. Its addition into mixtures is appropriate 4–6 years later, however, due to its rapid growth. Monocultures must be planted in a denser canopy, because in a more open spacing, it spreads its branches and suppresses neighboring trees [20, 22, 23, 30].

The species is reliably frost resistant in the conditions of Central European winters [13, 19]. Based on findings from research trials in the Czech Republic, the coastal *P. c.* subsp. *contorta* seems to be more suitable for poor locations at lower elevations, although it is only rarely grown in Central Europe [23, 24]. It is a resistant pioneering species suitable for polluted areas [13, 30]. In comparison with autochthonous and introduced pines, it tolerates, in particular, higher doses of SO_2 [24]. On the other hand, it is relatively sensitive to pollution by F_2 and HF [20]. Damage by game is not considered to be too substantial [13], although deer remain the main problem for experimental plantings in the Ore Mountains [8].

Based upon a critical assessment of information assembled in the previous sections, the potential for possibly broader forestry use of lodgepole pine in the Central European Region in future is summarized in **Table 2**. The principle is to consider the extent to which characteristics crucial for forestry usability are present or absent.

This subjective assessment can be supported by the following notes to the individual criteria. 1: lodgepole pine does not reach excellent production, although some of its provenances equal Scots pine. Therefore, an overall negative score is not justified. 2: the wood has larger heartwood and narrower sapwood; i.e., it has decorative qualities and can be used for paneling and staining. It is, therefore, well usable, although not for building and construction purposes. 3: the species' wide ecological valence enables the use of appropriate provenances in many location types. 4: as true of other pines, it acidifies the soil, and humification of its litterfall is

Species/criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Pinus contorta	0	+	++	—	+	+	0	++	?	+	+

Criterion: 1 production capacity, 2 wood usability, 3 suitability in various types of locations, 4 amelioration effects, 5 drought resistance, 6 resistance to other abiotic factors (frost, snow, wind, etc.), 7 resistance to biotic pests, 8 possibility of cross-breeding with local species, 9 invasiveness, 10 suitability for mixture, and 11 capability for natural regeneration.
Species manifestation (at current level of knowledge): ++ very positive, + positive, 0 neutral, – negative, – – very negative, ? unknown.

Table 2. Assessment of important decision criteria for potential forestry use of lodgepole pine in Central European conditions.

Species/criterion	1	2	3	4	5	6	7	8
P. c. subsp. *latifolia*	No	Yes	Yes	Excellent	No	Tree	Yes	Rich

Criterion: 1 requirements for substrate modifications, 2 microclimate demandingness, 3 tolerance to pollution load, 4 growth vitality, 5 requirements for biological substrate preparation, 6 growth, 7 demandingness for protection from game damage, and 8 foliation.

Table 3. Assessment of important decision criteria for potential reclamation use of lodgepole pine [37, 38].

imperfect. 5: it is resistant to drought, which is especially true for certain provenances. This was confirmed in the Czech Republic e.g., in the extreme conditions of the Mláka research trial. 6: it has a stabilizing effect on stands. It is relatively resistant to frost in the Central European region. It grows well even in mountainous conditions (Ore Mountains), even though a certain proportion of crown breakage does occur. 7: insect pests are similar to those on Scots pine. Serious damage has not yet been observed. 8: it cross-breeds only with Jack pine, whereas hybridization with Central European pine species has not been documented. 9: applying the pioneering strategy of the species known from North America was not studied in Europe so far. 10: it is able to create excellent mixtures with European hornbeam, and northern red oak, among other broadleaves. In mixtures, however, it requires a larger insolated growth space. 11: natural regeneration does occur, although more-detailed findings are not yet available.

Regarding lodgepole pine's importance in terms of forest reclamations, it is one of the most suitable species, e.g., [33, 34, 39, 42]. In the Czech Republic, it has been proven successful in afforestation of barren clay soils, such as brown coal dumps in the Under Ore Mountain Basin and in the upper Ohře/Eger River area, and in reclamation of exploited peat bogs in the Třeboň Basin. In general, the findings suggest that it is possible not only to survive on substrates with insufficient nutrients but that it even can create a continuous-canopy stand there. Štrudl [43] has pointed out, for example, that in addition to being capable to create a canopy, it is tolerant of inhospitable environments, adapts speedily to substrate, and has a favorable initial growth. Despite later slowing growth, based upon a growth analysis that determined satisfactory dimensions, he regards the species as having potential for wider use.

A collective assessment of selected species characteristics based upon results of the so-called "Czech" reclamation school that began taking shape after World War II is presented in **Table 3**.

The positive verification of lodgepole pine's species characteristics on extreme locations of forest reclamation can be, to a certain degree, an indicator for its selection into the species range of plantings in suburban vegetation areas within industrial urban areas, protective forest bands, etc. [39].

3. Conclusion

Lodgepole pine is interesting for forestry use in Central Europe especially due to its resistance to biotic and abiotic factors (e.g., drought) and due to its outstanding pioneering properties, including the ability to colonize areas disturbed by human activities. In forestry reclamations, it has already been proven to be one of the best introduced species and that, in addition to meeting basic requirements, it can satisfactorily fulfill also the production function. In future, it will undoubtedly gain in importance for the ability of certain provenances to grow in locations that are already today unfavorable for growing native forest species, including Scots pine. These are in particular extremely dry, poor, and warming locations on sandy soils. Other provenances can be utilized in mountainous areas, on locations with anthropogenically polluted air, and in urban green areas. In addition, if the scenarios assuming substantial changes of basic climatic characteristics in Central Europe are fulfilled, then its currently low evaluation for production capacity can be viewed differently.

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