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REVIEW

A global review of Sitka spruce (*Picea sitchensis* [Bong.] Carr.): challenges and opportunities in European modern forest management

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Abstract

Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is one of the most important non-native conifer species in European forestry, particularly in Northwest Europe. Originally from the Pacific Northwest of North America, it has been widely introduced because of its rapid growth, high quality of timber and adaptability to a range of environmental conditions. This literature review examines the silvicultural characteristics, ecological requirements, production potential and environmental impacts of Sitka spruce in Europe. The species is valued for its economic benefits, as it contributes significantly to timber production and carbon sequestration. On suitable sites, Sitka spruce has the potential to achieve higher timber production than native Norway spruce (*Picea abies* [L.] Karst.). However, the species is highly sensitive to prolonged periods of low soil moisture, and future drought-prone conditions under climate change may severely affect its health, growth, and long-term productivity. Its widespread planting has raised concerns about biodiversity loss, windthrow susceptibility, and vulnerability to pests and diseases, particularly bark beetle outbreaks, which are expected to increase in frequency and severity under climate change. Sitka spruce demonstrates a high ecological valence, allowing it to thrive across various soil types and climatic conditions, although its resilience to climate change remains a subject of ongoing research. Mixed-species management with other conifers and broadleaves is recommended to enhance stand stability, reduce pest vulnerability, and improve ecological resilience. This review highlights management strategies, including thinning regimes and mixed-species stands, to optimize growth while mitigating ecological risks. The study provides a comprehensive evaluation of the challenges and opportunities associated with Sitka spruce in modern European forestry and offers insights into evidence-based and climate-adaptive forest management strategies, particularly for new regions with suitable moisture conditions.

Keywords Silviculture · Production · Ecological valence · Introduced tree species · Climate change

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Introduction

The silviculture of forests has long been a subject of economic and ecological discussions, particularly concerning the use of non-native tree species under climate change conditions (Felton et al. 2013; Krumm and Vítková 2016; Pötzelsberger 2018). Generally, the most attractive species for commercial forestry are those that produce large volumes of high-quality timber within relatively short rotation periods while exhibiting minimal damage from wind, snow, and pathogens (Hanewinkel et al. 2013). Often, those requirements are fulfilled by non-native species. In Europe, over 150 non-native tree species cover approximately 8.5 million ha, accounting for 4.0% of the total forest area (Brus et al.

2019). The two most common non-native conifers in Northwest Europe (United Kingdom, Ireland, Sweden, Denmark, Netherlands, Northern France, Germany) are Douglas fir (*Pseudotsuga menziesii* [Mirbel] Franco) with 0.83 million ha and Sitka spruce (*Picea sitchensis* [Bong.] Carr.) reaching 1.16 million ha, both originating from the Pacific Northwest of North America (Durrant et al. 2016; Brus et al. 2019; Nicolescu et al. 2023). Beyond timber production, non-native tree species contribute to other ecosystem services, such as carbon sequestration, mitigation of climate change, habitat provision, soil stabilization, and recreational and hydrological purposes (Hasenauer et al. 2017; Burton et al. 2018; Vacek et al. 2023a, b).

Sitka spruce is a large evergreen conifer reaching up to 90 m in height, making it the tallest spruce species and one of the largest conifers worldwide (Farjon 2010). The species was first described by Archibald Menzies in 1791 and formally named *Pinus sitchensis* in 1832 by August Gustav Heinrich von Bongard with reference to its origin from Sitka Island, Alaska (Peterson et al. 1997). It was later reclassified as *Picea sitchensis* by Elie Carrière in 1855 (Jensen and Ross 2005). Sitka spruce was introduced to Europe from the Pacific region in 1827, with the first plantings established in Scotland in 1831 (Anderson and Taylor 1967). Over the past 60 years, it has become the most significant non-native tree species in Northwest Europe, particularly in the United Kingdom and Ireland (Durrant et al. 2016; Nygaard and Øyen 2017), which covers around 50% of the total conifer area and 60% of Great Britain timber production (Forestry Commission 2020).

This tree species is highly valued in the wood-processing industry for its exceptional quality. It is used primarily in the production of paper, panels, sawn timber, and musical instruments (Macdonald and Hubert 2002; Moore et al. 2009a). Outside its native range, it is appreciated for its rapid growth and adaptability to poor soils. Its fast growth allows for high biomass production (Farrelly et al. 2009; Skovsgaard 2009), making it a significant contributor to carbon sequestration and climate change mitigation. The species can accumulate large amounts of carbon throughout its lifespan, thereby helping to reduce atmospheric CO_2 levels (Vacek et al. 2023a, b). Furthermore, Sitka spruce demonstrates relative resilience to climatic extremes, including strong winds and frost, enhancing its stability under changing conditions (Brabec et al. 2023). It is also capable of adapting to a wide range of soils and habitats, making it a promising species for future forestry in regions with a sufficient water supply, affected by climate change (Durrant et al. 2016). However, Sitka spruce is vulnerable to prolonged periods of low soil moisture, indicating that its health and productivity may be severely affected under future drought-prone conditions (Green et al. 2008). These attributes make Sitka spruce a vital component of sustainable forestry systems on suitable sites that address both production and environmental objectives.

Although Sitka spruce is well studied in its native range in North America (Comeau et al. 2010; Deal et al. 2014) and in naturalized areas of Europe (Moore et al. 2009a; Mason and Perks 2011), its potential in areas where it is not commonly distributed – such as Central and Eastern Europe, the Baltics, and Norway – remains poorly understood. In the context of climate change, which has led to increasingly large-scale disturbances and widespread decline of Norway spruce (*Picea abies* [L.] Karst.) across Europe, there is a growing need to identify alternative tree species and implement management strategies that enhance forest resilience and increase tree-species diversity (Seidl et al. 2017; Vacek et al. 2023a, b). Notably, on suitable sites, Sitka spruce has the potential to achieve a higher production than native Norway spruce, highlighting its value as a productive alternative species in European forestry (Brabec et al. 2023). This review addresses the knowledge gap by providing a comprehensive assessment of Sitka spruce specifically in Europe, evaluating not only its growth and productivity but also its ecological requirements, vulnerability to pests and diseases, wood properties, and adaptive capacity under projected climate scenarios. By integrating information from both native and introduced ranges with a critical evaluation of European experiences, this paper aims to offer novel insights into the suitability, risks, and management strategies for Sitka spruce, highlighting where and how the species could complement native forests and support sustainable forestry in Europe.

Materials and methods

The literature review for this manuscript was compiled from the Scopus, Web of Science, and Google Scholar databases. The search strategy was designed to be transparent and reproducible and followed a structured, multi-step approach appropriate for a narrative review article. The primary search was based on predefined combinations of keywords related to Sitka spruce, applied to titles, abstracts, and keywords. The core search terms included *"Picea sitchensis"* OR "Sitka spruce", which were combined using Boolean operators with thematic terms such as taxonomy, native distribution, introduced distribution, ecology, ecological requirements, silviculture, growth, production, wood properties, pests, diseases, climate change, resilience, and adaptation. Example search strings included according to chapters: ("*Picea sitchensis*" AND "ecology"), ("Sitka spruce" AND "silviculture"), and ("*Picea sitchensis*" AND "climate change"). Searches were performed iteratively

between January and May 2025, and results were refined by screening titles and abstracts for thematic relevance.

The first inclusion criterion was the language of the abstract, which had to be written in English. Eligible publication types included peer-reviewed research articles, review papers, scientific books, and conference proceedings. Technical reports, dissertations, and other grey literature were included selectively when they provided unique data (e.g., provenance trials, long-term experiments, or national forestry statistics) not available in peer-reviewed journals. Exclusion criteria comprised studies unrelated to forestry or ecology (e.g., purely horticultural studies), papers lacking species-specific information, and sources with insufficient methodological or factual reliability. When multiple publications reported overlapping results, priority was given to the most comprehensive or most recent source. Backwards and forward citation tracking was applied to key publications to identify additional relevant literature that may not have been captured by database searches alone. In the final step, additional references were incorporated in response to comments and recommendations from three independent reviewers to ensure completeness, balance, and factual accuracy of the review. In total, 289 references were included in this article, comprising 181 original research articles, 9 review articles, 49 books, 14 conference proceedings, and 37 additional sources. The temporal scope of the literature search ranged from 1950 to 2025, reflecting both foundational studies and the most recent advances. The oldest cited publication dates from 1953, while the most recent sources were published in 2025. The final literature search for this review was completed on 9 January 2026 to ensure inclusion of the most recent studies, which were systematically screened for relevance to Sitka spruce. Trends in the development of publications included in this review, together with their distribution among individual countries based on the affiliation of the first author, are presented in Fig. 1.

Species description

Sitka spruce is a tall, fast-growing conifer with a straight, cylindrical trunk. It is the tallest and largest of all spruce species (Harris 1990; Eckenwalder 2009) and can live up to 500 years (Lee et al. 2013). This tree can reach heights of nearly 100 m, although in Europe it rarely exceeds 50 m (Mitchell 1974; Farjon 2013). Trees taller than 90 m can still be found in Pacific Rim National Park and the adjacent Carmanah Walbran Provincial Park in British Columbia, as well as on Vancouver Island, in Olympic National Park, and in Prairie Creek Redwoods State Park in California, where two trees exceed 96 m. Near the Queets River in Olympic National Park stands the largest Sitka spruce in the world. It measures 76 m in height, has a volume of 337 m^3, and a diameter at breast height of 4,6 m (Van Pelt 2001). Currently, the tallest known Sitka spruce reaches a height of 100.2 m in its natural range in Redwood National Park, California, while the individual with the largest recorded trunk circumference (16.9 m) is located near Lake Quinault, Washington. In Europe, the tallest recorded Sitka spruce, measuring 65.9 m, grows near the bank of the River Findhorn in Forres, Scotland, and the tree with the largest circumference (8.7 m) is found in Fairburn, Scotland. For comparison, the largest recorded dimensions of the native Norway spruce include a maximum height of 62.7 m measured in Ribnica na Pohorju, Slovenia, and a maximum circumference of

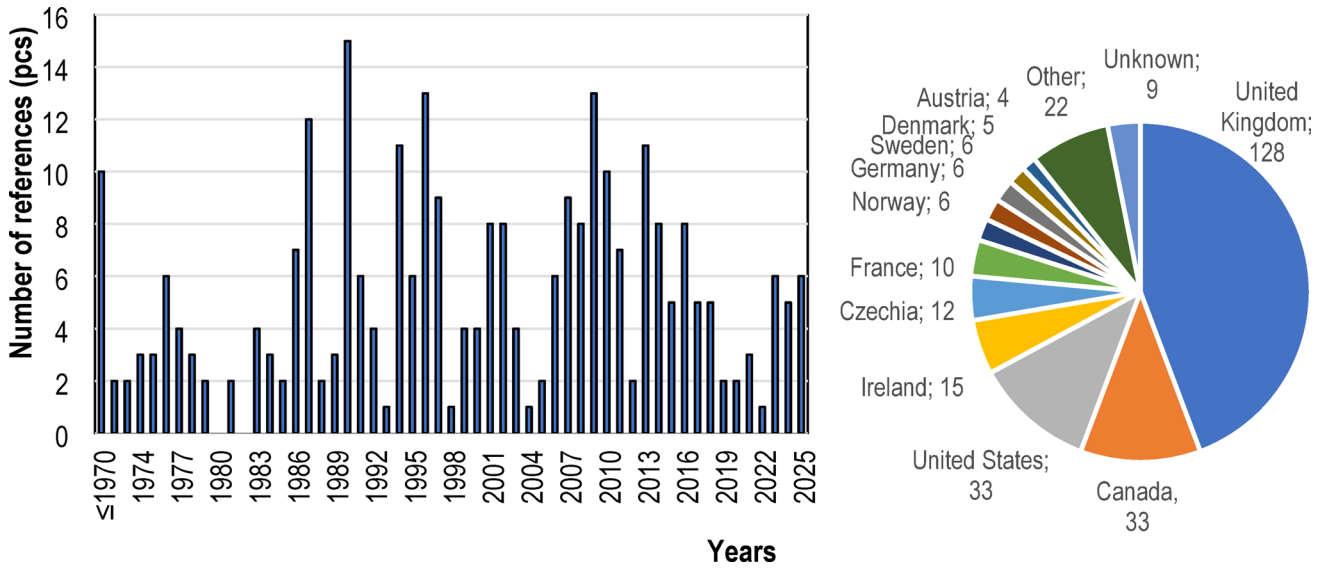


Fig. 1 Long-term temporal distribution of references related to Sitka spruce (*Picea sitchensis* [Bong.] Carr.) included in this review for the period 1953–2025 and their distribution among individual countries based on the affiliation of the first author

6.9 m recorded near Gohrersberg, Germany (Monumental Trees 2025).

The crown of young trees is broad and conical, but as the tree ages, it becomes cylindrical and consists of horizontal branches (Farjon 2010) (Fig. 2). Older trees may also lack branches on the lower 30 to 40 m of the trunk. Unusually, for a conifer, Sitka spruce can develop epicormic branches along the trunk (Savill 2013). The bark is thin and scaly, consisting of small, round plates 5 to 20 centimeters wide. The shoots are pale yellow-brown, almost white, and glabrous. The needles are thick, sharp, and needle-like, measuring 15 to 25 mm in length. They are flattened in a cross-section, grayish-blue-green on the upper side with two or three rows of stomata, and bluish-white on the lower side with two prominent bands of stomata (Farjon 2001).

Sitka spruce is monoecious, and its reproductive structures develop over a typical two-year cycle (Owens and Blake 1985). Bud scales are initiated at the terminal apex, with newly initiated axillary apices forming within enlarging vegetative buds around mid-April (Owens and Molder 1976a; Cannell and Bowler 1978). By mid-July, shoot elongation ceases, and apices differentiate as vegetative buds, pollen cones, or seed cone buds. Pollen cones typically develop from small axillary apices on vigorous distal shoots or terminal apices on less vigorous proximal shoots. Seed cones generally develop on strong shoots or from smaller terminal apices on less vigorous shoots (Moir and Fox 1976; Owens and Molder 1976b).

Gene flow in Sitka spruce is facilitated by small pollen grains measuring 70–85 µm at their widest point (Eisenhut 1961). These grains are equipped with sac-like wings, making them well-suited for wind dispersal (Di-Giovanni and Kevan 1991). Studies on pollen dispersal in conifers suggest that over 90% of pollen settles within 100 m of the source (Wright 1976). However, conifer pollen can remain viable for several days, allowing substantial quantities to travel long distances (Lindgren et al. 1995; Lindgren and Lindgren 1997). Sitka spruce is wind-pollinated and begins seed production at the age of 20–25 years (Cottrell and White 1995; OECD 2006).

Pollen cones are red and measure 2–4 cm in length (Eckenwalder 2009). Seed cones are 5–10 cm long, consisting of thin, flexible scales with wavy, irregularly toothed edges. They produce seeds 2–3 mm in length with pale brown wings approximately 8 mm long (Praciak et al. 2013). These seeds are relatively small, with a clean seed weight of approximately 2.2 g per 1,000 seeds (Safford 1974; OECD 2006). Heavy seed years occur at intervals of 3–5 years (Malcolm 1987; Philipson 1987). In the northern part of its range, intervals between seed years are longer, typically 5–8 years (Harris 1969). During a productive seed year, a stand can produce up to 14.5 kg of seeds per hectare (Peterson et al. 1997).

Taxonomy

Sitka spruce belongs to the *Pinaceae* family, within the *Picea* genus. An analysis of paternal and maternal molecular markers (chloroplast and mitochondrial DNA) of all living *Picea* species has shown that Brewer spruce (*Picea breweriana* S.Watson) and, secondarily, Sitka spruce are basal species within the genus, with other species divided

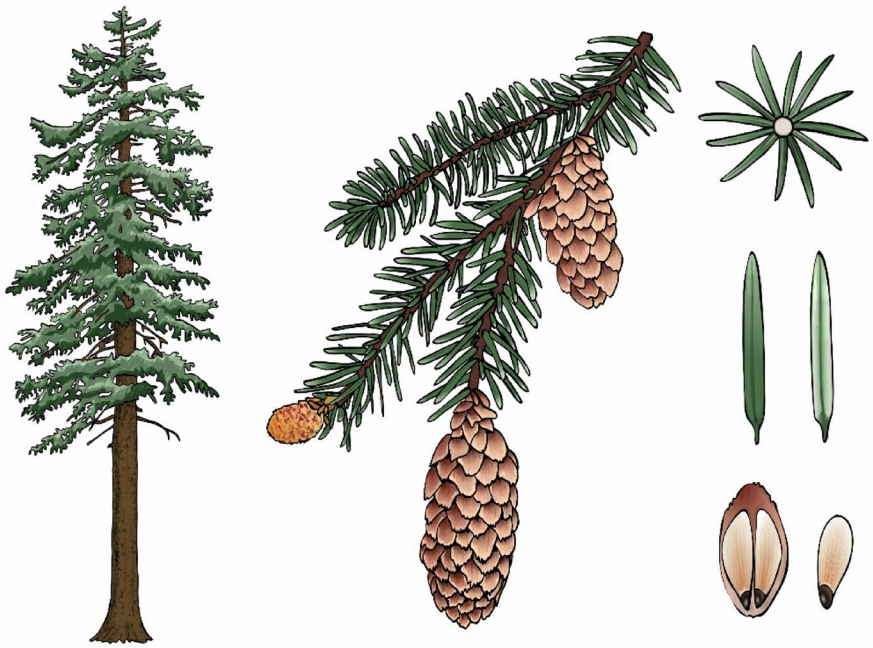


Fig. 2 Tree habitus, branch with cones, back and face of needle and scales with seed of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) (author: Josef Macek)

into three clusters derived from two episodes of dispersion into Eurasia via the Bering Land Bridge. In this phylogeny, Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and white spruce (*Picea glauca* [Moench] Voss) are equally closely related to Sitka spruce, a result consistent with hybridization patterns. The other 31 spruce species are genetically more derived, which suggests that spruces originated in North America (Ran et al. 2006).

Phylogenetic relationships within coniferous genera are commonly interpreted through studies of species crossability, where it is assumed that the closer two species are related, the more easily they can hybridize (Wright 1955; Critchfield 1975). Close phylogenetic relationships between North American spruces (Sitka, white, and Engelmann's) and the East Asian Yezo spruce (*Picea jezoensis* [Sieb. et Zucc.] Carr.) (Wright 1955; Roche 1975) support this theory, at least for members of the *Glaucoides* subsection in the *Omorika* section, indicating that speciation occurred after they arrived in North America (OECD 2006).

Introgressive hybridization between Sitka spruce and white spruce occurs in the northwest of British Columbia and Alaska, with the hybrid known as Lutz spruce (*Picea* × *lutzii* Little) (Copes and Beckwith 1977; Yeh and Arnott 1986; Woods 1988; Taylor 1993). Analysis of this introgressive zone shows that it was first colonized by Sitka spruce during the late Pleistocene deglaciation, followed by introgression when white spruce dispersed from Alaskan or eastern Canadian refugia (Hamilton and Aitken 2013).

Introgressive hybridization between white spruce and Engelmann spruce is common in western Canada, Montana, and Wyoming in the variety *Picea glauca* var. *albertiana* (S. Brown) Sarg. (Roche 1969; Daubenmire 1974; Rajora and Dancik 2000). Sitka spruce hybridizes with Engelmann spruce through controlled crosses (Fowler and Roche 1977; Kiss 1989; Sutton et al. 1994). Among hybrids between Sitka and White spruces, a range of growth forms occurs (Sutton et al. 1991a, b, 1994; Coates et al. 1994; Grossnickle et al. 1996a, b), some of which are dwarf and used in horticulture (Krüssmann 1985; Griffiths 1994).

Distribution area

Historically, Sitka spruce probably originated from the periphery of the northern Pacific (Li 1953). Fossil records show that the divergence of modern genera within the *Pinaceae* occurred around 135 million years ago during the late Jurassic or early Cretaceous period (Florin 1963). According to comparative studies, Prager et al. (1976) report that *Picea* was among the first genera to appear. Fossil records of the *Picea* genus during the Pleistocene era in North America are incomplete, but it can be assumed that many conifer populations were fragmented and isolated in various refugia during the glacial period (Critchfield 1984). Sitka spruce probably occupied roughly its current range before the glaciation, and its survival at higher elevations on hills and mountains, followed by re-colonization of lower areas along the long coastal strip in British Columbia and Alaska, occurred soon thereafter (Daubenmire 1968; Page and Hollands 1987; OECD 2006).

At present, Sitka spruce occurs along the west coast of North America (Fig. 3). Its range extends along the northern Pacific coast from the southern part of Alaska – from Kodiak Island to northern California near the town of Fort Bragg, covering a distance of 2900 km, i.e., from 61° N latitude in southern-central Alaska to 39° N latitude in northern California. Except for the coastal islands, its range extends up to 200 km from west to east (Peterson et al. 1997; Eckenwalder 2009; Praciak et al. 2013).

Its distribution is closely tied to the occurrence of Pacific temperate rainforests; in the southern part of its range, it is found only within a few kilometers of the Pacific coast. North of Oregon, Sitka spruce is also found in river floodplains, but never further inland than 80 km from the coast (Harris 1990). It grows from sea level up to 1200 m above sea level (Farjon 2013). The temperate rainforest of the Pacific Northwest is composed of relatively few tree species but has complex horizontal and vertical structures (Franklin and Dyrness 1973; Alaback and Herman 1988; Van Pelt 2007; Deal et al. 2014). The biomass production, carbon storage, and productivity in Sitka spruce forests, along with western Hemlock (*Tsuga heterophylla* Sarg.), are relatively high, significantly exceeding the accumulations in forests in other regions of the northern temperate zone (Peterson et al. 1997; Krankina et al. 2014). The coastal temperate rainforest of North America shows high species richness and supports approximately 350 species of birds and mammals, about 50 species of amphibians and reptiles, hundreds of fungi and lichen species, and thousands of insects, mites, spiders, and other soil organisms (Pojar and MacKinnon 1994; Peterson et al. 1997; Swanson et al. 2014). In its native range, two types of stands were identified within the hemlock-Sitka spruce forest types: (1) old stands following catastrophic mortality; and (2) multi-aged stands resulting from gradual, minor natural disturbances such as windbreaks, blowdowns, landslides, and occasional pathogen occurrences (Van Pelt 2007; Deal et al. 2017).

In terms of introduction, Sitka spruce has become the most significant tree species in Western Europe over the last 60 years (Joyce and O'Carroll 2002; Durrant et al. 2016). It was introduced to Europe in the first half of the 19th century and is now more widely cultivated in over 16 countries worldwide (Deal et al. 2014).

One of the first places where Sitka was introduced was the UK in 1831 (Bryan and Pearson 1955). Although the

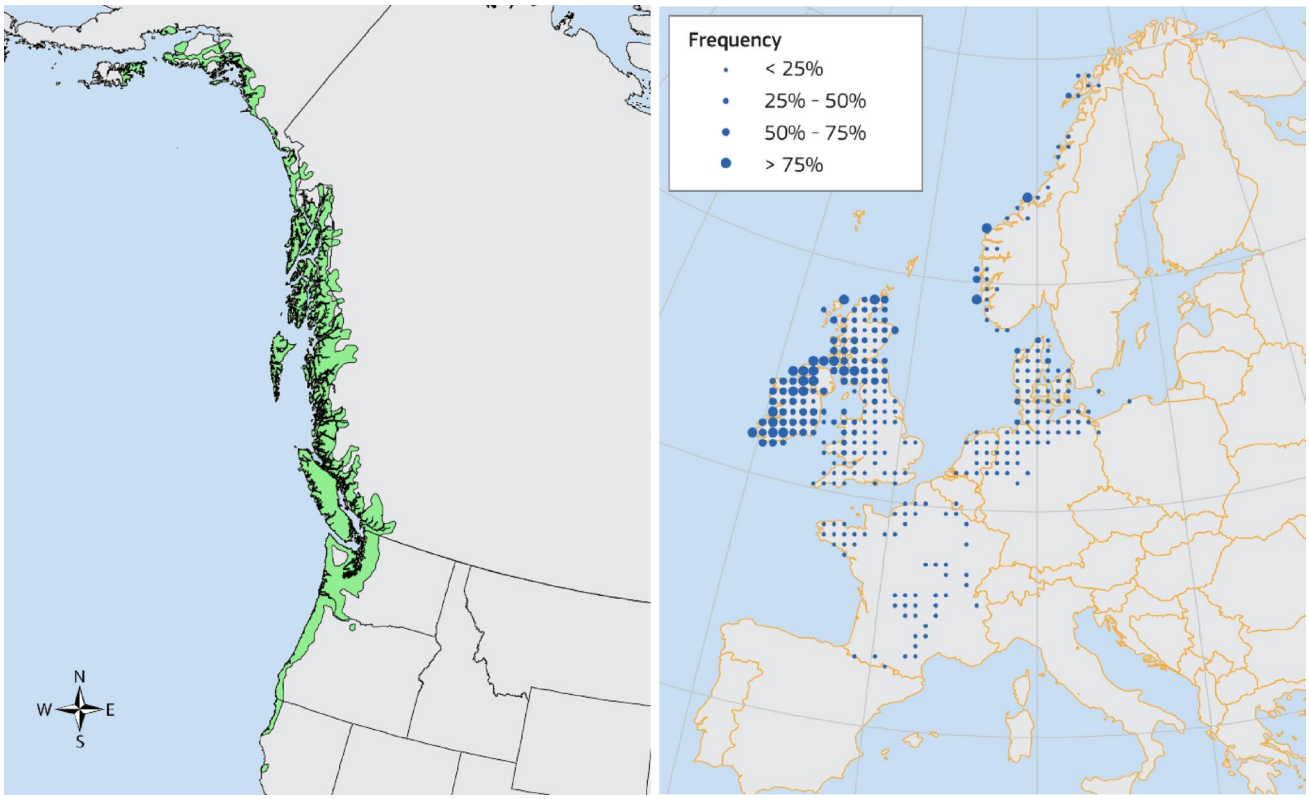


Fig. 3 Distribution map of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) according to native range (green color) in North America (Little and Viereck 1971; USGS 2013) and introduction (blue color) in Europe (Durrant et al. 2016)

commercial use of the species started as late as the 20th century (Mason 2007a). Most of the planted area is in the United Kingdom, where it makes up more than 25% of the national forests (Forestry Commission 2014) and is now the most widespread conifer there (Peterken 2001; Lee et al. 2013). In Ireland, it occupies 52% of the national forest area (OECD 2006). It is also significant in Denmark, where it constitutes 16% of softwood production (Moore 2011a). Sitka spruce was also planted in Iceland at the beginning of the 20th century (Kuckuk et al. 2021) and in Norway, where it occupies 50,000 hectares (Halldórsson et al. 2003; Nygaard and Øyen 2017). Significant commercial harvesting also occurs in France (Durrant et al. 2016). In Northwest Europe, it grows on an area of 1.3 million hectares (Nygaard and Øyen 2017). Therefore, Sitka spruce has been dispersed and naturalized in many areas outside its original range for economic reasons. Schmidt-Vogt (1977) lists its occurrence in Albania, Austria, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Estonia, Finland, France, Germany, Greece, Slovenia, Italy, Latvia, Lithuania, North Macedonia, Montenegro, Norway, Poland, Romania, Russia, Serbia, Slovakia, Sweden, Switzerland, and Ukraine. Naturalized populations are also found in Belgium, Ireland, Denmark, Hungary, Luxembourg, the Netherlands, Spain, and the United Kingdom. It has been introduced to New Zealand, where it is on the blacklist of species and is even found on the sub-Antarctic Campbell Island (OECD 2006).

Habitat and ecology

In its natural range, Sitka spruce is primarily a coastal species, but can extend inland (Harris 1990). It predominantly grows at low elevations and is rarely found above 500 m. However, it is much less constrained by edaphic factors than by climatic ones (Roche and Haddock 1987). The natural distribution of Sitka spruce is limited to areas with a maritime climate, characterized by abundant moisture year-round, relatively mild winters, and cool summers. Annual precipitation is high throughout its range, with slightly higher levels in the north, where summer rainfall often comes as drizzles and fog. Sitka spruce typically requires a minimum of 1000 mm of annual precipitation and cannot tolerate the dry Mediterranean climate (Lee et al. 2013). This tree species can grow at annual rainfall as low as 700–800 mm, provided that soil moisture remains sufficient during the growing season, which may be uncertain under future rainfall patterns (Cameron 2015). Summer air temperatures in these coastal habitats lack the extremes of continental regions, being moderated by the North Pacific

Ocean Current, and they decrease toward the north (Harris 1978).

While Sitka spruce grows on soils derived from various parent materials, it develops best on deep, moist, well-aerated soils, often podzols (Nielsen et al. 1999). In Ireland, its growth is most vigorous on grey-brown podzolic soils, followed by podzols and gleys, while lithosols and blanket peat soils are much less suitable (Farrelly et al. 2009). Growth is also poor in swampy locations but thrives on alluvial soils along streams, soils with coarse textures, or those with thick organic matter layers. Soils in their natural range are acidic, with pH values ranging from 4.0 to 5.7 (Harris 1978; Nielsen et al. 1999). In Alaska, Sitka spruce is a pioneer species on immature soils exposed by retreating glaciers or marine outwash, and it rapidly colonizes disturbed areas, such as landslides, dunes, beaches, and deglaciated terrain (Harris 1990; Quine and Malcolm 2007; Farjon 2010).

Sitka spruce is relatively nutrient-demanding, especially in its early growth stages before stand closure (Miller and Miller 1987; Iason et al. 1996; Straw and Green 2001). It is most productive on nitrogen-rich soils, but also requires relatively high amounts of calcium, magnesium, and phosphorus (Krajina 1969; Proe and Millard 1995). Unlike some other conifers, it tolerates salt spray in the coastal moisture belt (Harris 1990) but is intolerant to air pollution (Crossley et al. 1997; Savill 2013). Its needle litter acidifies the soil (Wulff et al. 1996; Augusto et al. 2002). In areas such as British Columbia and the UK, where nitrogen and phosphorus levels are lower, fertilizers may be required for successful plantation establishment (Miller and Miller 1987; Taylor 1990; Taylor and Tabbush 1990; Prescott 1996).

Sitka spruce is shade-tolerant, especially during its juvenile stage, though slightly less so than its frequent associate, western hemlock. This allows it to regenerate in small gaps caused by disturbances (Kobe and Coates 1997). In southeastern Alaska, mixed stands of Sitka spruce and western hemlock are considered a climax forest type (Deal et al. 1991; Peterson et al. 1997).

Naturally, Sitka spruce most commonly occurs in mixed stands, often with western hemlock (Harris and Johnson 1983). Red alder (*Alnus rubra* Bong.) and black cottonwood (*Populus trichocarpa* Torr. and A. Gray ex Hook.) form associations across the range of Sitka spruce. Depending on latitude, it also forms mixtures with Douglas-fir, Lawson cypress (*Chamaecyparis lawsoniana* [A. Murray] Parl.), western white pine (*Pinus monticola* Douglas ex D. Don), coast redwood (*Sequoia sempervirens* [D. Don] Endl.), and bigleaf maple (*Acer macrophyllum* Pursh) in the southern part of its range. Mixtures with shore pine (*Pinus contorta var. contorta* Douglas) and western red cedar (*Thuja plicata* Donn ex D. Don) extend into southeastern Alaska, while yellow cedar (*Chamaecyparis nootkatensis* D. Don), mountain hemlock (*Tsuga mertensiana* [Bongard] Carriére), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) are limited to northern locations and higher elevations (Harris 1978). In Alaska and British Columbia, hybrid and pure populations of white spruce occur in the valleys of the Skeena, Nass, and Bulkley Rivers (Daubenmire 1968; Roche 1969; Grossnickle et al. 1997). Pure stands of Sitka spruce are common in tidal areas, influenced by salt spray and salinized soils (Harris 1990).

Due to the variability in site conditions and exposure across its range, Sitka spruce is part of various ecological associations characterized by differing habitat and nutrient regimes. On mid- to upper slopes of the Queen Charlotte Islands, associations of western hemlock–Sitka spruce feature abundant Alaska blueberry (*Vaccinium alaskaense* Howell), red huckleberry (*Vaccinium parvifolium* Sm.), oval-leaf blueberry (*Vaccinium ovalifolium* Sm.), and several moss species (*Rhytidiadelphus loreus* [Hedw.] Warnst., *Hylocomium splendens* [Hedw.] Schimp., and *Mnium glabrescens* Kindb.). Exposed coastal sites are characterized by salt-tolerant pure stands of Sitka spruce, often associated with Nootka reedgrass (*Calamagrostis nutkaensis* [J.Presl] Steud.) and moss (*Stokesiella oregana* [Sull.] Robins.). In protected alluvial sites, Sitka spruce and associated species like western hemlock and red alder grow in understories with *Trisetum cernuum* Trin., *Gymnocarpium dryopteris* (L.) Newman, *Hylocomium splendens* (Hedw.) Schimp., and *Leucolepis acanthoneura* (Schwaegr.) Lindb. (Roche and Haddock 1987; Hanley and Hoel 1996; Hanley and Brady 1997). In drier interior valleys and eastern slopes of coastal mountains, Sitka spruce hybrids with white spruce are common. This drier zone supports mixed coniferous forests with understories dominated by Alaska blueberry, oval-leaf blueberry, and red huckleberry. In alluvial areas of the Skeena and Nass Rivers, western skunk cabbage (*Lysichiton americanus* Hultén et H. St. John) thrives, while the driest sites in flatlands are characterized by salmonberry (*Rubus spectabilis* Pursh) (Roche and Haddock 1987; Harris 1990).

Silviculture and production

Sitka spruce seeds exhibit weak dormancy, and thus, the rate and overall germination can be enhanced by exposing the seeds to low temperatures under moist conditions, i.e., cold stratification (Chaisurisri et al. 1992; Jinks and Jones 1996). In the natural environment, Sitka spruce seeds typically germinate the following spring when the soil surface is sufficiently warm and moist (Jones and Gosling 1990; Jinks and Jones 1996). Sitka spruce naturally regenerates on soil slips, newly exposed alluvial sites, and clearings created by wind (Taylor 1990; Peterson et al. 1997). It germinates

better on soil disturbed by logging than on thick layers of raw humus (Harris and Johnson 1983; Weetman and Vyse 1990). Vegetative reproduction of Sitka spruce is rare in natural conditions or plantations, but rooting may occur in moist locations (Roche 1975). Rooting is most likely to occur when lower branches of mature trees make contact with the ground and are covered with soil or organic material at the edges of swamps or near forest boundaries (Harris 1978).

Sitka spruce planting material is traditionally grown as bare-rooted stock (2+0 or 1+1 seedlings) in forest nurseries, but the proportion of containerized planting material for reforestation is still growing (Aldhous and Mason 1994; Renou-Wilson et al. 2008). Containerized planting stock of this tree species had greater root growth than bareroot seedlings (Grossnickle and El-Kassaby 2016). Sitka spruce seedlings taller than 40 cm generally exhibit better post-planting performance, particularly when site preparation is sub-optimal. Root collar diameter is considered a reliable indicator of seedling quality, with planting stock having root collar diameters above 7 mm showing higher survival and greater root mass compared to smaller seedlings (O'Reilly et al. 2002). For the most valuable populations, Sitka spruce planting material is produced through vegetative propagation (Kleinschmit 1992; Lee and Matthews 2004). In a trial stand of Sitka spruce established by direct seeding in Scotland, it was demonstrated that planted seedlings produce far fewer roots compared to individuals from seed (Coutts et al. 1990).

In terms of silvicultural interventions, moderate thinning from below was recommended for Sitka spruce (Deal and Farr 1994). Dense natural regeneration was more frequently observed after harvesting the first generation of planted stands in the UK, where up to several hundred thousand individuals per hectare were recorded, necessitating a process of longer natural self-thinning followed by stronger thinning from below and combined silvicultural interventions (Nelson 1991; Adam 1996). Increased exposure of stems to sunlight during stand management often leads to the stimulation of epicormic branching, which affects the future wood quality of trees (Farr and Harris 1971). In more exposed areas where wind damage risk is high, sparse planting without stand management is practiced (Mason 2007b), but otherwise, two to four thinning applications are performed between canopy closure and final felling (OECD 2006). Courbet et al. (2002) describe a silvicultural management approach applied to Sitka spruce stands in Brittany, combining low initial planting densities (<1,350 trees ha^{-1}) with early and intensive thinning regimes, frequently centered on approximately 250 selected crop trees per hectare, to promote rapid diameter growth, reduce height-to-diameter ratios, and enhance individual-tree stability. Similarly, analyses of dense natural regeneration indicate that early selective respacing to approximately 2,000 trees ha^{-1} at a height of 2–4 m improves subsequent stand stability and can also enhance stem quality (Stokes and Kerr 2013).

However, in the last decade, management using clear-cutting has become less common, as forest policies in the UK aim to diversify plantation forests (Forestry Commission Scotland 2006; Forestry Commission 2009; Dhubháin 2010). Current forest policies promote multifunctional management with increased tree-species and structural diversity, with continuous cover forestry representing an alternative silvicultural approach (Mason 2015). Silvicultural recommendations have increasingly emphasized the use of mixed stands to improve resilience and stability. The suitability of secondary species can be evaluated at the first thinning stage (around 20 years), when differences in growth and stem quality become apparent, and unsuitable species can be removed through thinning (Jacobsen and Thorsen 2003). The persistence of mixed structures depends on relative growth rates, with higher proportions of slower-growing species required to prevent early suppression by Sitka spruce (Cameron 2015). From the perspective of stability, shelterwood management may be appropriate, although the interaction between thinning and wind stability in irregular stands remains problematic, and suitable species for mixtures with Sitka spruce are limited (Mason 2015). Based on its intermediate shade tolerance, an irregular shelterwood system with gap sizes of 0.1–0.2 ha was proposed as the most suitable approach (Malcolm et al. 2001).

In terms of production, the annual increment of Sitka spruce in Scotland is 14 m^3 ha^{-1} yr^{-1} (Mason 2007a), with published yield tables suggesting yields of up to 24 m^3 ha^{-1} yr^{-1} (Edwards and Christie 1981), and even higher yields are achievable in Ireland (Joyce and O'Carroll 2002). On grey-brown podzolic and podzol sites in Ireland, growth reaches up to 32 m^3 ha^{-1} yr^{-1} (Farrelly et al. 2009). The highest annual increment was found in Denmark, with values reaching up to 47 m^3 ha^{-1} yr^{-1} (Skovsgaard 2009). In Central Europe, production is significantly lower, and survival is reduced due to limited moisture availability and lower rainfall (Brabec et al. 2023). Nevertheless, this case study comparing the production of Norway spruce and Sitka spruce documents that Sitka spruce exhibited 17.3% higher stand volume in England, 8.11% higher in Slovakia, and 7.3% higher in the Czech Republic compared to Norway spruce. In Sweden, Sitka spruce consistentlyexhibited higher values; for tands aged 46–55 years, the total mean annual increment (MAI) was 3.7 m^3 ha^{-1} yr^{-1}, corresponding to an 86.9% higher productivity compared to Norway spruce (Reynisson 2011). A review study also confirmed that Sitka spruce in the Noric and Baltic regions can grow (MAI) up to approximately 40% faster than Norway spruce

under comparable conditions (Rytter et al. 2016). In both the UK and Ireland, current tree breedng programs supply improved varieties that can provide volume gains of 21–29% over unbred material (Lee and Matthews 2004). A comprehensive review of available publications related to Sitka spruce production parameters on suitable sites in Europe (introduced) and North America (native) is shown in Table 1. In Europe, the average stand volume reaches 608 m^3 ha^{-1} with a maximum in Ireland of 935 m^3 ha^{-1} (Simic et al. 2018). In comparison with native regions, Sitka spruce can attain substantially higher stand volumes, for example, in coastal Oregon, where dominant stands with an admixture of western hemlock reach up to approximately 2,380 m^3 ha^{-1} (Burns and Honkala 1990).

Øyen and Nygård (2007) calculated that Sitka spruce growth in Norway would peak when trees are between 70 and 115 years old. The stronger wind climate in Northwest Europe suggests that individual Sitka spruces on the British Isles have already reached heights of 55–60 m and diameters of 150–200 cm at ages of 130–150 years (The Tree Register 2009). Given that the climatic conditions in Northwest Europe correspond to cold temperatures with high rainfall, which are typical for the original environment of Sitka spruce and characteristic of regions with the highest forest biomass in the world (Keith et al. 2009)—this introduced species is well adapted to play a significant production and sustainable role in the forests of this region.

From a silvicultural perspective, the selection of appropriate provenances is a key factor determining the growth performance, adaptability, and risk profile of Sitka spruce stands. In 1969/70, extensive sampling of seed sources from the entire range of Sitka spruce was organized by IUFRO. Ten of these sources were widely cultivated in field trials in North America and many European countries (O'Driscoll 1978). Southern coastal provenances are up to 100% taller than northern inland sources (Cannell and Willett 1975, 1976). While southern sources grow faster, they are more susceptible to frost damage, especially in forest nurseries (Magnesen 1986; Lines 1987b; McKay 1994). Provenance trials in the Federal Republic of Germany demonstrated a pronounced south-north clinal pattern in growth performance of Sitka spruce, primarily expressed in height and volume growth, with latitude explaining more than 80% of the observed variation among provenances (Kleinschmit 1992). Results from a 19 years provenance trial in Ireland showed that the most productive Sitka spruce provenances for mild coastal conditions in Ireland come from southern Washington and northern Oregon (Thompson and Pfeifer 1995; Thompson 2013). Ecotypic variation related to bioclimatic and physiographic factors of provenance was demonstrated for seed and cone traits (Falkenhagen 1977).

Regarding the cultivation possibilities for Sitka spruce and the selection of provenances, it can be stated that plantations established in areas with a strong maritime climate will grow faster if seeds are transferred from southern latitudes. Conversely, seed transfers from coastal origins to inland planting sites carry a higher risk (Lester et al. 1990; Ying and Ebata 1994). Sitka spruce seedlings from British Columbia have also been certified under the OECD scheme for sale in Europe (Pollard and Portlock 1990; Portlock 1996). In the UK, southern provenances (south of 47° N) grow fastest, but they are prone to spring and autumn frosts (Lines 1987a, b). Provenances from the Queen Charlotte Islands are generally recommended throughout much of the UK, though their origin further south, in Washington, is better suited for southwest England, Wales, and parts of western Scotland (Fletcher 1992). In northern Germany, provenances from Washington are recommended, while fast-growing sources from Oregon are considered too frost-sensitive (Stratmann and Tegeler 1987). These provenances are also recommended for use in western and north-western France, particularly in Brittany and Normandy, where Sitka spruce has been traditionally planted under oceanic climatic conditions (Bastien and Lemoine 1986; François 1986; Steinmetz 1986). In Denmark, naturalized seed sources from the second and later generations grew faster and better than trees from seeds imported directly from North America (Nielsen 1994; Nielsen and Roulund 1996).

Environmental impacts, ecosystem services and cultural value

Sitka spruce is considered one of the leading tree species for its utility, both in its native range and in Northwest Europe, where it is widely planted (Lee et al. 2013). Many European studies report positive effects of Sitka spruce afforestation on several species groups, such as wood mice (*Apodemus sylvaticus* L.) (Fernandez et al. 1994), spiders (Smith et al. 2009; Irwin et al. 2014), bats seed-eating birds (Mckenzie et al. 2007; Wilson et al. 2009; Sweeney et al. 2010a, b, c), pioneer grasses 5 years after afforestation (Buscardo et al. 2009), fungi (Humphrey et al. 2003; O'Hanlon and Harrington 2012), and ants (Procter et al. 2015). Additionally, the positive impacts reported from the British Isles may be explained by differences in silvicultural practices (Malcolm 1997; Mason 2007a), differences in prior land use and initial conditions at reference sites (Smith et al. 2006), and variations in disturbance regimes (Quine et al. 1999; Díaz-Yáñez et al. 2016). Afforestation generally leads to a decline in open-habitat species (Anderson 2003), while benefiting forest species of birds, such as raptors and seed-eaters, which hold high conservation value (Staines et al. 1987; Bibby et al. 1989; Sweeney et al. 2010a, b, c; Burton et al. 2018).

Table 1 Overview of available publications related to Sitka spruce (*Picea sitchensis* [Bong.] Carr.) production parameters

Study	Country	Altitude [m a.s.l.]	Age [yr]	DBH [cm]	Height [m]	Basal area [m^2 ha^{-1}]	Volume [m^3 ha^{-1}]	Density [trees ha^{-1}]	Annual increment [m^3 ha^{-1} yr^{-1}]	Climate classification
Europe-introduced										
Alsheimer et al. (1998)	Germany	750–800	40–140	19.1–36.6	16.1–25.7	30.9–48.8		322–1,678		Cfb
Brabec et al. (2023)	England	230	52	42.6			618		11.2	Cfb
Brabec et al. (2023)	Czechia	340	62	36.6			456		7.4	Cfb
Brabec et al. (2023)	Slovakia	440	59	34.9			506		8.6	Dfb
Comeau et al. (2010)	Great Britain		18–78	10.1–52.0				52–6172	5.0–32.0	Cfb
Dowd and Nieuwenhuis (2024)	Ireland	72–130			25.6	51.8	553	712		Cfb
Hale et al. (2012)	Wales	220–395	22–54	17.0–41.0	12.0–27.0					Cfb
Moore et al. (2009)	England, Scotland	0–545	35–50	7.6–55.5	10.9–37.3	35.4-100.6		500–3,000	6.0–24.0	Cfb
Murphy and Pommerening (2010)	Wales	25–445	35–49	10.6–29.8	10.9–31.5	27.5–83.0		1,057 − 3,133	6.0–30.0	Cfb
Nicolescu et al. (2021)	Romania	900	60	27.4	25.0	52.1	663	600		Dfb
Schaible and Gawn (1989)	Ireland		28		18.6–21.3	51.2–79.1	425–657	2,403-4,565	18.0–28.0	Cfb
Simic et al. (2016)	Ireland	100	23	18.0-25.7			904–935	1,550-3,700	39.3–40.6	Cfb
Skovsgaard (2009)	Denmark	10–45	24–42		22.2–23.6	32.0–80.0			33.0–47.0	Cfb
North America-native										
Burns and Honkala (1990)	Oregon		143	86	64		2,380			Csb
Christensen et al. (2002)	Alaska	70	90	9.1–27.7		72.8–90.4		1,224 − 10,978		Cfb
Comeau et al. (2010)	British Columbia		85–93	15.4–60.7				366-3,975		Cfb, Cfcs
Deal and Tappeiner (2002)	Alaska	< 100				48.0-98.5		240-2,200		Cfb, Cfc
Smith et al. (1984)	Oregon	< 250	83–116	22.8–28.4		40.5–48.8	1,465-1,839	410–539		Csb

Cfb, warm-summer oceanic; Dfb, warm-summer humid continental; Csb, warm-summer Mediterranean; Cfc, cold summer subpolar oceanic (Beck et al. 2018)

Several studies have shown that structural heterogeneity increases the diversity of various species groups (Ferris et al. 2000; O'Halloran et al. 2011). Therefore, management strategies in Sitka spruce stands can be used as a tool to enhance selected biodiversity (Staines et al. 1987; Humphrey et al. 2003; Sweeney et al. 2010a, b, c). On the other hand, some studies report exclusively negative effects of Sitka spruce planting on biodiversity in the context of light conditions, particularly for vascular plants and epiphytic lichens (Hill 1979; Halldorson et al. 2008; Irwin et al. 2014; Pedley et al. 2014).

With respect to litterfall impacts on soil, afforestation with Sitka spruce results in substantial carbon accumulation in the organic layer through needle litter decomposition, while soil nutrient chemistry exhibits fluctuations driven by interactions among litter input, decomposition, and acid–base dynamics. Nitrogen inputs from litterfall and aphid outbreaks influence N transformations, and long-term litter decomposition releases nutrients such as P and K back into the soil (Titus and Malcolm 1999). Compared with Norway spruce, Sitka spruce shows lower nitrogen concentrations in litterfall and reduced base-cation fluxes, whereas Norway spruce exhibits persistently higher litterfall and nutrient losses under environmental stress (Pedersen et al. 1999). In comparison with Scots pine, Sitka spruce litter demonstrates higher carbon mineralization, increased nitrogen availability, particularly as nitrate, and promotes enchytraeid activity, indicating faster nutrient release and stronger litter–soil interactions, whereas pine litter is characterized by fungal dominance and lower rates of microbial-mediated decomposition (Williams and Alexander 1991).

Due to its majestic appearance, symmetrical crown, silvery-blue-green needles, and rapid growth, Sitka spruce is also valued as an ornamental tree in parks, arboreta, and public or private spaces. In Europe, it was introduced primarily in the UK and Ireland, where it is used not only for forestry purposes but also for plantings in historical parks and gardens for aesthetic design. In arboreta (e.g., the Royal Botanic Garden Edinburgh), it has become an essential part of exotic conifer collections (Harris 1990; Savill 2013). Sitka spruce also has excellent properties for stabilizing disturbed sites and reclaiming degraded areas, making it an important tool in ecological management and soil conservation. Its root system reinforces slopes, dunes, and other erosion-prone sites, helping prevent further landslides or substrate loss. For example, in Iceland, Sitka spruce stands improve degraded lands and reduce soil erosion by increasing vegetation cover and enhancing soil quality (Duong et al. 2024). In the UK, it has been frequently used for restoring degraded areas, such as after peat extraction (Harris 1990). However, its sharp needles make it less suitable as a Christmas tree compared to the popular Norway spruce (Durrant et al. 2016).

In the past, sharp needles were believed to give the tree protective powers against evil thoughts. For the Tlingit First Nation, the tree held profound significance, forming the basis of spiritual relationships, artistic expression, and practical daily use (Tittensor 2016). Various indigenous peoples of the northwest coast consumed the inner bark or young shoots, which are excellent sources of vitamin C. The resin was chewed for enjoyment and as a remedy for skin irritations. Roots, peeled, split, and dried, were used to create woven, waterproof hats and baskets. In the 21st century, the main dietary or medicinal use of Sitka spruce is in brewing beer, which is actually a very old idea; for instance, Captain Cook gave his crews spruce beer to prevent scurvy during his 18th-century Pacific explorations (Pojar and MacKinnon 1994).

Wood properties and utilization

Sitka spruce wood is identified as softwood (conifer) with barely visible heartwood occurrence. Sitka wood is characterized by cream/white to yellow color, while heartwood can be pinkish red or light reddish brown. Although the edge between sapwood and heartwood is not clearly visible. Sitka spruce wood has a big impact on the timber market in the United Kingdom and Ireland, but also in France and Denmark (Lee et al. 2013). Wood of Sitka spruce is present in many areas of the wood industry, from paper production (Farjon 2013), panel production to sawn timber (McIntosh 1997) for the construction, packing, and fencing sectors (McIntosh 1997; Moore 2011a). Historically, it was extensively used in aircraft construction. According to Moore (2011b) the first aircraft made by the Wright brothers was manufactured using Sitka spruce wood. From 1917 to 1919, the U.S. Army operated the "Spruce Production Division," which, at its peak, employed nearly 30,000 men to produce lumber for military aircraft (Tonsfeldt 2013). Sitka spruce continued to be widely used in aircraft manufacturing until aluminium became affordable and readily available. However, it remains an important material for constructing certain experimental and hobby aircraft. Sitka wood is excellent for making ladders and is popular in shipbuilding, where it is used for masts, spars, and oars (Harris 1990). It is also suitable for structural timber, fencing, pallets, panel products, pulp, and biomass for energy (Macdonald and Hubert 2002; Moore et al. 2009a). Additionally, due to the fiber length and its excellent conductor of sound, it is highly prized for use in soundboards for pianos and various stringed instruments, such as guitars and violins (Schelleng 1973; Yano 1990; Askenfelt 2010; Phillips and Lessard 2011; Auty et

Table 2 Selected mechanical properties of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) wood and their comparison with selected coniferous tree species

Species	Density 12% (kg m^{-3})	MOR (MPa)	MOE (GPa)	Reference
Picea sitchensis	390–420	57.0–76.0	6.00–11.03	Mclean 2008; Moore 2011a; Meir 2015; McLean et al. 2016
Picea abies	341–517	52.0–84.6	5.84–8.76	Cukor et al. 2020; Zeidler et al. 2024a
Picea mariana	450–468	57.2–65.7	5.11–10.50	Meier 2015; Zeidler et al. 2024a
Picea omorika	508–534	69.2–95.1	6.67–12.16	Petrović et al. 2021; Zeidler et al. 2024a
Picea pungens	450–476	54.8	4.86	Vacek et al. 2023a, b; Zeidler et al. 2024a
Pinus sylvestris	451–458	57.0–80.7	5.74–7.95	Zeidler et al. 2024b, 2025
Pinus nigra	441–480	64.4–73.9	6.26–10.81	Meier 2015; Zeidler et al. 2024b
Pinus ponderosa	425–450	50.8–64.8	2.89–8.90	Zeidler et al. 2024b
Pinus concorta	425–470	64.8–74.5	7.14–9.24	Meier 2015; Zeidler et al. 2024b
Pseudotsuga menziesii	510–581	86.2–88.0	8.88–12.17	Meier 2015; Zeidler et al. 2025
Larix decidua	511–583	79.0–90.0	7.91–11.80	Meier 2015; Cukor et al. 2020

MOR, the modulus of rupture, MOE, modulus of elasticity

al. 2018). The main wood parameter which is used for estimating wood quality is its density. As this physical property has an influence on mechanical wood properties, it is often presented in relationship with modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength. According to the literature from the UK and Ireland (Savill and Sandels 1983; Petty et al. 1990; Moore et al. 2009b), the basic wood density of Sitka spruce varies from 272 to 431 kg m^{-3} and is decreasing from pith to bark direction. When it comes to wood properties at 12% of moisture content, the wood density varies from 390 to 420 kg m^{-3}, when MOR was from 57 to 76 MPa, and MOE around 8.50 GPa, ranging from 6.00 to 11.03 GPa (Mclean 2008; Moore 2011a; Meier 2015; McLean et al. 2016). In comparison to other native and non-native spruces, wood density obtained in cited manuscripts is lower than in the case of Norway, black (*Picea mariana* [Mill.] Britt., Sterns, et Poggenburg), Serbian (*Picea omorika* [Pančić] Purk.) and blue spruces (*Picea pungens* Engelm.) cultivated in the Czech Republic (Zeidler et al. 2024a). However, they are comparable to the results obtained in Poland by Jelonek et al. (2024) for Norway spruce. In terms of MOR and MOE, Sitka spruce exhibited superior values compared to blue spruce and ponderosa pine (*Pinus ponderosa* Douglas ex C.Lawson), while other tree species showed similar mechanical properties, with the highest values observed in Douglas-fir, European larch (*Larix decidua* Mill.), and Serbian spruce (Table 2). However, the results of such a comparison might be affected by many factors, including habitats, age, location, and others. Krajnc et al. (2019) compared wood quality parameters (wood density, MOR and MOE) of Sitka and Norway spruce in thinned and unthinned forest stands. Thinned stands of Sitka exhibited superior parameters compared with Norway spruce, whereas in unthinned stands, Norway spruce outperformed Sitka.

Threats and diseases

In terms of biotic pests, white pine weevil (*Pissodes strobe* Say) is the most severe pest affecting young Sitka spruce stands in North America (Alfaro and Ying 1990; Tomlin and Borden 1997; Hulme and Kenis 2001), but it is currently not present in Europe. The green spruce aphid (*Elatobium abietinum* Walker) can also cause significant damage through heavy defoliation of needles (Straw and Green 2001; OECD 2006; Straw et al. 2011; Kuckuk et al. 2021). The large pine weevil (*Hylobius abietis* L.) is one of the most serious pests attacking young Sitka spruce in Europe (Kennedy et al. 2006; Wallertz et al. 2014; Barredo et al. 2015). Additionally, significant damage in Sitka spruce stands can be caused locally by deer browsing (Iason et al. 1996; Duncan et al. 2001). Most species that could form stable mixtures with Sitka spruce are even more vulnerable to herbivore browsing, so the costs of protection in mixed stands are likely to be higher than in pure spruce plantations (Cameron 2015).

A significant potential threat to Sitka spruce is the eight-toothed spruce bark beetle (*Ips typographus* L.) (Webb et al. 2025), which has caused extensive damage to Norway spruce forests across Europe in recent years (Šimůnek et al. 2025). Under laboratory conditions, this bark beetle selected and colonized cut Sitka spruce as readily as Norway spruce; moreover, odors from aged wood of both species were equally attractive, while fresh Sitka spruce was even more attractive than fresh Norway spruce (Inward et al. 2025). A similar risk may also be posed by double-spined spruce bark beetle (*Ips duplicatus* Sahlberg), a species that has expanded its distribution in Europe over recent decades and is increasingly regarded as a serious threat to spruce stands, particularly under conditions of site drying and tree stress associated with climate change (Davídková et al. 2023).

Population differences in Sitka spruce susceptibility to insect attack have been demonstrated. Provenances from Kitwanga (Skeena River, inland) and Big Qualicum (southeast Vancouver Island) experience less damage (Alfaro and Ying 1990; Ying and Ebata 1994; Tomlin and Borden 1994). The density of green spruce aphid infestations in provenances in Northern Ireland was correlated with the latitude of seed origin, with southern provenances being particularly susceptible (Day 1984). Adequate lignin content in spruce bark is considered an important physical defense against insects and fungi, and lignin levels in bark increase with latitude (Wainhouse and Ashburner 1996).

Many abiotic factors interact with Sitka spruce in both natural and planted forests, and some can cause significant damage. Wind is likely the most serious damaging agent, particularly in plantations (OECD 2006). Sitka spruce plantations in the UK, established on unfavorable soils and exposures, often developed shallow root systems, making them prone to instability in strong winds (Miller 1986; Coutts and Philipson 1987; Mason and Quine 1995; Malcolm 1997; Dhubhain et al. 2001). Elsewhere in Europe, Sitka spruce plantations have suffered considerable wind damage, but the species has shown greater wind resistance than other conifers, such as Norway spruce, firs (*Abies* sp.), and Scots pine (*Pinus sylvestris* L.), for example, in France (de Champs et al. 1983; Touzet 1983), Denmark (Neckelmann 1981), and Norway (Lohmander and Helles 1987). In North America, Sitka spruce is considered less wind-resistant than Douglas fir and western red cedar but more resistant than western hemlock and Pacific silver fir *Abies amabilis* (Douglas ex J. Forbes) (Minore 1979).

On drier sites, the moisture-demanding Sitka spruce is increasingly vulnerable to drought stress in the vegetation season, exacerbated by the rising frequency and severity of drought events under climate change (Green et al. 2008; Vacek et al. 2023a, b). Signs of drought-induced stress are evident, particularly on shallow or poorly drained soils that may experience winter waterlogging followed by summer drought (Ray 2008; Cameron 2015). Elevated temperatures and drought also increase susceptibility to pests such as *Dendroctonus* spp. (Ray et al. 2008). Monospecific Sitka spruce stands can be more resilient to spring drought than mixtures with Scots pine, yet pronounced stress may necessitate more drought-tolerant species such as *Pinus* spp. or *Tsuga* spp. (Petr et al. 2014; Cameron 2015; Ovenden et al. 2022). Despite this, Sitka spruce can show good post-drought recovery, Scots pine indicating higher resilience and resistance (Ovenden et al. 2022). Assessments of potential alternative species in relation to climate change and drought in the UK suggest that no species consistently exceeds Sitka spruce in maximum mean annual increment, although grand fir *(Abies grandis* [Lamb.] Lindl.), noble fir (*Abies procera* Rehder), western hemlock, Lutz spruce, maritime pine (*Pinus pinaster* Ait.), Lawson cypress, Scots pine, Douglas-fir, and western red cedar remain viable options under changing conditions (Stokes et al. 2023). In Central Europe (Czechia, Slovakia), on suitable sites, Sitka spruce showed lower sensitivity of growth to monthly precipitation than Norway spruce (Brabec et al. 2023). Genetic variation in drought tolerance among full-sibling families of Sitka spruce is limited, so planting the most productive material maximizes gains under optimal conditions but offers little advantage under drought (Grant and O'Reilly 2017; Grant et al. 2018).

While Sitka spruce is among the least fire-resistant species in coastal forests, wildfires are not a primary cause of damage within its natural range (Minore 1979; Agee 1990). On the other hand, Sitka spruce regenerates well on burned sites (Hawkes et al. 1990; Otchere-Boateng and Herring 1990). Strong wind impacts can cause severe damage, particularly to containerized planting stock established on finer-textured soils (Shaw et al. 1987; Goulet 1995). Autumn early frost poses a challenge in the UK, where faster-growing southern provenances are particularly susceptible (Lines 1987a; Nicoll et al. 1996).

Resilience and adaptability to climate change

This species is often grown in parts of Europe with an oceanic climate for relatively safe production, fast growth, and the ability to produce high-quality wood (Moore 2011b). However, its cultivation is strongly limited in several regions of continental Europe, including much of lowland Poland, the Pyrenees, Italy, and the Balkan Peninsula, where increasing drought frequency and rising air temperatures under projected climate change substantially reduce site suitability for this moisture-demanding species (Durrant et al. 2016; Vacek et al. 2023a, b). Research based on a study with 150 bore cores comparing the growth of Sitka spruce and Norway spruce in relation to climate shows that Sitka spruce grows significantly better in Western than in Eastern Europe, and is also more resilient to climate change compared to Norway spruce (Brabec et al. 2023). Under conditions of environmental stress in Denmark, Norway spruce exhibited a more pronounced and long-lasting decline in tree health and needle loss driven by a combination of drought, sea-salt stress, and elevated transpiration, whereas Sitka spruce responded primarily with short-term, reversible needle loss, mainly associated with aphid infestations, indicating a comparatively more resilient physiological response (Pedersen et al. 1999).

However, due to considerable uncertainty regarding the potential long-term impacts of climate change, experience from the United Kingdom suggests that Sitka spruce forests be established in mixtures to spread future risks of damage. Three potentially compatible introduced species with

Sitka spruce are western hemlock, grand fir, and Douglas fir, which form natural mixtures in their native range in North America. The expected windier climate will require a range of management interventions, such as early felling of extraction racks, shortening rotation periods, and early selective thinning applications to improve mechanical stand stability (Cameron 2015). In response to changing environmental conditions, there is also growing interest in implementing continuous cover forestry aimed at developing irregular stand structures without the use of clear cuts. The increased occurrence of natural regeneration in older Sitka spruce stands, and the greater use of mixed stands are also proposed measures for adapting forests to climate change (Mason 2008; Ray 2008). Diversification of Sitka spruce stands (e.g. small blocks of single tree species) with native broad-leaved and conifer species such as sessile oak (*Quercus petraea* [Matt.] Liebl.), pedunculate oak (*Quercus robur* L.), sycamore maple (*Acer pseudoplatanus* L.), Scots pine, silver birch (*Betula pendula* Roth), European beech (*Fagus sylvatica* L.), and Norway spruce can enhance biodiversity and accelerate nutrient cycling and litter decomposition (in terms of broad-leaved), while also potentially improving resilience and ecosystem function under changing climate conditions (Mitchell et al. 2025).

Afforestation with Sitka spruce can help address climate change by carbon sequestration and mitigating biodiversity loss, for instance, in Iceland at extreme locations at high latitudes in the context of increasing air temperatures (Duong et al. 2024). Generally, regardless of tree species, in terms of forest adaptation to climate change, supporting diversity is important (Vacek et al. 2023a, b). Many studies have shown that plantation forests increase biodiversity at the landscape level, where natural or semi-natural forests are rare (Carnus et al. 2006; Brockerhoff et al. 2008). Sitka spruce plantations provide suitable habitats for a wide range of forest species, including protected species (Red List species) and also commonly occurring wildlife, such as birds and mammals (Ratcliffe and Petty 1986; Staines et al. 1987; Weir et al. 1996; Humphrey et al. 2000; Quine and Humphrey 2010; Irwin et al. 2014). Different taxa vary in their response to afforestation, and while species richness in forest plantations can be as high as in semi-natural forests, these two forest types may support different species assemblages in various growth stages of the forest, with species turnover often mentioned (Palfner et al. 2005; Arroyo and Bolger 2007; Fuller et al. 2008; Arroyo et al. 2010; Irwin et al. 2014; Burton et al. 2018). On the other hand, Sitka spruce is on the blacklist in several countries due to its invasive spread (Nygaard and Oyen 2017), which may be significantly influenced by climate change.

The use of Sitka spruce is also recognized as an effective tool for carbon sequestration and climate change mitigation (Øyen and Nygård 2007; Mason and Perks 2011). Modeling studies (Dewar and Cannell 1992) based on yield tables for even-aged stands predicted that carbon stocks during the rotation period would vary depending on thinning regimes and site productivity, ranging from 85 t C ha^{-1} for thinned stands with lower site productivity to 220 t C ha^{-1} for unthinned stands on very productive sites. These predictions are supported by field studies in the UK and Ireland in Sitka spruce stands managed with intensive forestry, which provided estimates of maximum carbon sequestration rates of 6–9 t C ha^{-1} yr^{-1} and total tree carbon stocks around 150–210 t C ha^{-1} at rotation age (Clement et al. 2003; Jarvis and Linder 2007; Magnani et al. 2007; Black et al. 2009). These higher values suggest the importance of Sitka spruce for maximizing carbon sequestration in Atlantic forests. This indicates that, on suitable sites, assuming sufficient forest management and no wind disturbances, Sitka spruce stands should achieve more than 350 t C ha^{-1}. These stands could develop into "old-growth" type structures (Deal et al. 2002; Bauhus et al. 2009), improving long-term carbon storage on the site. Similar stands have been reported in the Pacific Northwest, where total live biomass in old mixed Sitka spruce and western hemlock stands is reported to be 568–794 t C ha^{-1} for stands aged 150–300 years (Smithwick et al. 2002; Keith et al. 2009).

Conclusion

Sitka spruce is an economically important tree species native to the coastal areas of the Pacific Northwest in North America, where it grows in the specific ecosystem of the northern temperate rainforests. Due to its rapid growth, high-quality wood, and substantial carbon sequestration potential, Sitka spruce has been widely introduced in Northwest Europe, where it forms a central component of plantation forestry and contributes significantly to regional timber economies. However, Sitka spruce is highly sensitive to prolonged periods of low soil moisture, and the projected increase in the frequency and intensity of droughts under climate change may severely compromise its health, growth, and long-term productivity. On suitable sites, Sitka spruce demonstrates a production potential exceeding that of the currently widespread but declining native Norway spruce across Europe, highlighting its value as a highly productive alternative species. This potential, however, is counterbalanced by significant risks: climate change is expected to increase both the incidence and severity of bark beetle outbreaks, representing a major threat to stand stability. To mitigate these risks and ensure sustainable production, Sitka spruce should primarily be cultivated in mixed stands, combined with other coniferous and broadleaf species. Such mixtures enhance mechanical stability, reduce susceptibility to pests, and improve ecological resilience under variable

environmental conditions. Forest management should also incorporate adaptive strategies, including careful site selection with emphasis on adequate moisture availability, appropriately timed thinning application, continuous monitoring, and consideration of future climatic stresses to optimize growth and minimize vulnerability. While Sitka spruce is relatively widespread in parts of Northwest Europe, its cultivation could be expanded in regions with suitable moisture conditions, including Central Europe, the Baltic states, and other appropriate areas, providing opportunities for diversifying forest systems and strengthening climate change mitigation strategies. Overall, it is essential to approach Sitka spruce cultivation in a balanced and evidence-based manner, considering both its high productivity and economic value, as well as the ecological and climatic risks that may limit its long-term suitability.

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Data availability The data presented in this study are available on request from the corresponding author.

Declarations

Conflict of interests The authors declare no competing interests.

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References

Adam GA (1996) Mechanized respacing naturally regenerated Sitka spruce in Great Britain. pp 122–129

Agee JK (1990) The historical role of fire in Pacific Northwest forests. In: Walstad JD, Radosevich SR, Sandberg DV (eds) Natural and prescribed fire in Pacific Northwest forests. Oregon State University, Corvallis, pp 25–38

Alaback PB, Herman FR (1988) Long-term response of understory vegetation to stand density in *Picea-Tsuga* forests. Can J For Res 18:1522–1530. https://doi.org/10.1139/x88-233

Aldhous JR, Mason WL (1994) Forest nursery practice. Forestry Commission, London

Alfaro RI, Ying CC (1990) Levels of Sitka spruce weevil, *Pissodes strobi* (Peck), damage among Sitka spruce provenances and families near Sayward, British Columbia. Can Ent 122:607–615. https://doi.org/10.4039/Ent122607-7

Alsheimer M, Köstner B, Falge E, Tenhunen DJ (1998) Temporal and spatial variation in transpiration of Norway spruce stands within a forested catchment of the Fichtelgebirge, Germany. Ann Sci 55:103–123. https://doi.org/10.1051/forest:19980107

Anderson ML, Taylor CJ (1967) A history of Scottish forestry. Thomas Nelson and Sons, London

Anderson R (2003) Open ground in upland forests: a review of its potential as wildlife habitat and appropriate management methods. Report by Forest Research. Forestry Commission

Arroyo J, Bolger T (2007) Oribatid (Acari: Oribatida) and Gamasid (Acari: Gamasida) Mite Communities in an Irish Sitka Spruce Picea sitchensis (Bong.) Carr. Stand with Three First Records for Ireland. Ir Nat J 28:452–458. https://www.jstor.org/stable/25536848

Arroyo J, Moraza ML, Bolger T (2010) The Mesostigmatid mite (Acari, Mesostigmata) community in canopies of Sitka spruce in Ireland and a comparison with ground moss habitats. Graellsia 66:29–37. https://doi.org/10.3989/graellsia.2010.v.66.007

Askenfelt A (2010) The Science of String Instruments, chapter Double Bass. Springer, pp 259–277

Augusto L, Ranger J, Binkley D, Rothe A (2002) Impact of several common tree species of European temperate forests on soil fertility. Ann Sci 59:233–253. https://doi.org/10.1051/forest:2002020

Auty D, Moore J, Achim A et al (2018) Effects of early respacing on the density and microfibril angle of Sitka spruce wood. Forestry: Int J For Res 91:307–319. https://doi.org/10.1093/forestry/cpx004

Barredo JI, Strona G, de Rigo D et al (2015) Assessing the potential distribution of insect pests: case studies on large pine weevil (*Hylobius abietis* L) and horse-chestnut leaf miner (*Cameraria ohridella*) under present and future climate conditions in European forests. EPPO Bull 45:273–281. https://doi.org/10.1111/epp.12208

Bastien J, Lemoine M (1986) Les plantations comparatives. 38:101–102

Bauhus J, Puettmann K, Messier C (2009) Silviculture for old-growth attributes. Ecol Manage 258:525–537. https://doi.org/10.1016/j.foreco.2009.01.053

Beck HE, Zimmermann NE, Vergopolan N, Berg A, Wood EF (2018) Data Descriptor: Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5:180214. https://doi.org/10.1038/sdata.2018.214

Bibby CJ, Aston N, Bellamy PE (1989) Effects of broadleaved trees on birds of upland conifer plantations in North Wales. Biol Conserv 49:17–29. https://doi.org/10.1016/0006-3207(89)90110-9

Black K, Byrne KA, Mencuccini M et al (2009) Carbon stock and stock changes across a Sitka spruce chronosequence on surface-water gley soils. Forestry: Int J For Res 82:255–272. https://doi.org/10.1093/forestry/cpp005

Brabec P, Vacek Z, Vacek S et al (2023) Growth-climate responses of *Picea sitchensis* [Bong.] Carr. versus *Picea abies* [L.] Karst. in

the British Isles and Central Europe. Cent Eur Forestry J 69:167–178. https://doi.org/10.2478/forj-2022-0011
Brockerhoff EG, Jactel H, Parrotta JA et al (2008) Plantation forests and biodiversity: oxymoron or opportunity? Biodivers Conserv 17:925–951. https://doi.org/10.1007/s10531-008-9380-x
Brus R, Pötzelsberger E, Lapin K et al (2019) Extent, distribution and origin of non-native forest tree species in Europe. Scand J Res 34:533–544. https://doi.org/10.1080/02827581.2019.1676464
Bryan J, Pearson FGO (1955) The quality of Sitka spruce grown in Britain. Empire Forestry Rev 34:144–159
Burns RM, Honkala BH (1990) Silvics of North America Volume 1: Conifers. Agriculture Handbook. USDA Forest Service, pp 654
Burton V, Moseley D, Brown C et al (2018) Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom. Ecol Manage 430:366–379. https://doi.org/10.1016/j.foreco.2018.08.003
Buscardo E, Smith GF, Kelly DL et al (2009) The early effects of afforestation on biodiversity of grasslands in Ireland. In: Brockerhoff EG, Jactel H, Parrotta JA et al (eds) Plantation Forests and Biodiversity: Oxymoron or Opportunity? Springer Netherlands, Dordrecht, pp 133–148
Cameron AD (2015) Building resilience into Sitka spruce (Picea sitchensis (Bong.) Carr.) Forests in Scotland in Response to the threat of climate change. Forests 6:398–415. https://doi.org/10.3390/f6020398
Cannell MGR, Bowler KC (1978) Spatial arrangement of lateral buds at the time that they form on leaders of *Picea* and *Larix*. Can J For Res 8:129–137. https://doi.org/10.1139/x78-021
Cannell MGR, Willett SC (1975) Rates and times at which needles are initiated in buds on differing provenances of *Pinus contorta* and *Picea sitchensis* in Scotland. Can J For Res 5:367–380. https://doi.org/10.1139/x75-051
Cannell MGR, Willett SC (1976) Shoot growth phenology, dry matter distribution and root: shoot ratios of provenances of *Populus trichocarpa*, *Picea sitchensis* and *Pinus contorta* growing in Scotland. Silvae Genet 25:49–59
Carnus J-M, Parrotta J, Brockerhoff E et al (2006) Planted forests and biodiversity. J For 104:65–77. https://doi.org/10.1093/jof/104.2.65
Chaisurisri K, Edwards DGW, El-Kassaby YA (1992) Genetic control of seed size and germination in Sitka spruce. Silvae Genet 41:348–355
Christensen GA, Julin KR, Ross RJ, Willits S (2002) Volume recovery, grade yield, and properties of lumber from young-growth sitka spruce and western hemlock in southeast Alaska. For Prod J 52:81–87
Clement R, Moncrieff JB, Jarvis PG (2003) Net carbon productivity of Sitka spruce forest in Scotland. Scott Forestry 57:5–10
Coates KD, Haeussler S, Lindeburgh S et al (1994) Ecology and silviculture of interior spruce in British Columbia. BC Ministry of Forests, Victoria
Comeau PG, White M, Kerr G, Hale SE (2010) Maximum density–size relationships for Sitka spruce and coastal Douglas-fir in Britain and Canada. Forestry: Int J For Res 83(5):461–468. https://doi.org/10.1093/forestry/cpq028
Copes DL, Beckwith RC (1977) Isoenzyme Identification of Picea glauca, P. sitchensis, and P. lutzii Populations. Bot Gaz 138:512–521. https://doi.org/10.1086/336957
Cottrell JE, White IMS (1995) The use of isozyme genetic markers to estimate the rate of outcrossing in a Sitka spruce (Picea sitchensis (Bong.) Carr.) seed orchard in Scotland. New (Dordr) 10:111–122. https://doi.org/10.1007/BF00033401
Courbet F, Laugier N, Oswald H et al (2002) Sylviculture, croissance et production de l'Épicéa de Sitka. Premiers résultats du dispositif expérimental d'Ecouves (Orne). Revue forestière française 54:67–85. https://doi.org/10.4267/2042/4902
Coutts MP, Philipson JJ (1987) Structure and physiology of Sitka spruce roots. Proc Royal Soc Edinb Sect B Biol Sci 93:131–144. https://doi.org/10.1017/S0269727000006345
Coutts MP, Walker C, Burnand AC (1990) Effects of establishment method on root form of lodgepole pine and sitka spruce and on the production of adventitious roots. Forestry: Int J For Res 63:143–159. https://doi.org/10.1093/forestry/63.2.143
Critchfield WB (1975) Interspecific hybridization in *Pinus*: a summary review. In: Fowler DP, Yeatman CW (eds) Fowler DP, Yeatman CW (eds) Proceedings 14th Canadian Tree Improvement Association, Part 2, Symposium on interspecific hybridization in forest trees. Canadian Forestry Service, pp 99–105
Critchfield WB (1984) Impact of the Pleistocene on the genetic structure of North American conifers. In: Lanner RM (ed) Proceedings of the 8th North American Forest Biology Workshop. Department of Forest Resources, Logan, pp 70–105
Crossley A, Sheppard LJ, Cape JN et al (1997) Stem growth reduction in mature Sitka spruce trees exposed to acid mist. Environ Pollut 96:185–193. https://doi.org/10.1016/S0269-7491(97)00022-5
Cukor J, Zeidler A, Vacek Z, Vacek S, Šimůnek V, Gallo J (2020) Comparison of growth and wood quality of Norway spruce and European larch: effect of previous land use. Eur J For Res 139(3):459–472. https://doi.org/10.1007/s10342-020-01259-7
Daubenmire R (1968) Some geographic variations in *Picea sitchensis* and their ecologic interpretation. Can J Bot 46:787–798. https://doi.org/10.1139/b68-110
Daubenmire R (1974) Taxonomic and ecological relationships between *Picea glauca* and *Picea engelmannii*. Can J Bot 52:1545–1560. https://doi.org/10.1139/b74-203
Davídková M, Kleinová L, Doležal P (2023) Overwintering migration of the double-spined spruce bark beetle Ips duplicatus (Sahlberg, 1836) (Coleoptera; Curculionidae). Forests, 14:131. https://doi.org/10.3390/f14010131
Day K (1984) Systematic differences in the population density of green spruce aphid, *Elatobium abietinum* in a provenance trial of Sitka spruce, *Picea sitchensis*. Ann Appl Biol 105:405–412. https://doi.org/10.1111/j.1744-7348.1984.tb03066.x
Díaz-Yáñez O, Mola-Yudego B, Eriksen R, González-Olabarria JR (2016) Assessment of the main natural disturbances on norwegian forest based on 20 years of national inventory. PLoS ONE 11:e0161361. https://doi.org/10.1371/journal.pone.0161361
Deal RL, Farr WA (1994) Composition and development of conifer regeneration in thinned and unthinned natural stands of western hemlock and Sitka spruce in southeast Alaska. Can J For Res 24:976–984. https://doi.org/10.1139/x94-128
Deal RL, Hennon P, O'Hanlon R, D'Amore D (2014) Lessons from native spruce forests in Alaska: managing Sitka spruce plantations worldwide to benefit biodiversity and ecosystem services. Forestry: Int J For Res 87:193–208. https://doi.org/10.1093/forestry/cpt055
Deal RL, Oliver CD, Bormann BT (1991) Reconstruction of mixed hemlock–spruce stands in coastal southeast Alaska. Can J For Res 21:643–654. https://doi.org/10.1139/x91-088
Deal RL, Orlikowska EH, D'Amore DV, Hennon PE (2017) Red Alder-conifer stands in Alaska: an example of mixed species management to enhance structural and biological complexity. Forests 8:131. https://doi.org/10.3390/f8040131
Deal RL, Tappeiner JC (2002) The effects of partial cutting on stand structure and growth of western hemlock–Sitka spruce stands in southeast Alaska. For Ecol Manag 159(3):173–186
Deal RL, Tappeiner JC, Hennon PE (2002) Developing silvicultural systems based on partial cutting in western hemlock–Sitka spruce stands of southeast Alaska. Forestry: Int J For Res 75:425–431. https://doi.org/10.1093/forestry/75.4.425
de Champs J, Ferron JL, Michaud D, Navatier N (1983) Lecons tirer de la tempete des 6–8 novembre 1982 [France; chablis, donnees

d'enquetes sur resineux, resistance des differents genres et especes]. Annales de Recherches Sylvicoles (France). Association ForêtCellulose, Paris, pp 4–101
Dewar RC, Cannell MGR (1992) Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. Tree Physiol 11:49–71. https://doi.org/10.1093/treephys/11.1.49
Dhubhain AN, Walshe J, Bulfin M et al (2001) The initial development of a windthrow risk model for Sitka spruce in Ireland. Forestry: Int J For Res 74:161–170. https://doi.org/10.1093/forestry/74.2.161
Dhubháin ÁN (2010) An evaluation of continuous cover forestry in Ireland. Department of Agriculture, Fisheries and Food, Dublin
Di-Giovanni F, Kevan PG (1991) Factors affecting pollen dynamics and its importance to pollen contamination: a review. Can J For Res 21:1155–1170. https://doi.org/10.1139/x91-163
Dowd L, Nieuwenhuis M (2024) Assessing the accuracy of dynamic yield models (Growfor) in highly productive stands of Sitka spruce. Ir For 78:54–72
Duncan AJ, Hartley SE, Thurlow M et al (2001) Clonal variation in monoterpene concentrations in Sitka spruce (*Picea sitchensis*) saplings and its effect on their susceptibility to browsing damage by red deer (*Cervus elaphus*). Ecol Manage 148:259–269. https://doi.org/10.1016/S0378-1127(00)00540-5
Duong M, Tamayo M, Skúlason B, Sigurgeirsson A (2024) Using spruces (*Picea* spp.) for Icelandic afforestation. New (Dordr) 56:19. https://doi.org/10.1007/s11056-024-10088-0
Durrant TH, Mauri A, de Rigo D, Caudullo G (2016) *Picea sitchensis* in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz J, de Rigo D, Caudullo G et al (eds) European Atlas of forest tree species. Publ. Off. EU Luxembourg, pp 118–119
Eckenwalder JE (2009) Conifers of the world. Timber
Edwards PN, Christie JM (1981) Yield models for forest management. Forestry Commission Booklet, London
Eisenhut G (1961) Untersuchungen über die Morphologie und Ökologie der Pollenkörner heimischer und fremdländischer Waldbäume. Forstwiss Forsch 17:1–68
Falkenhagen ER (1977) Genetic variation in 38 provenances of Sitka spruce. Silvae Genet 26:67–75
Farjon A (2001) World checklist and bibliography of conifers 2nd edition. The Royal Botanic Gardens, Kew
Farjon A (2010) A Handbook of the World's Conifers: Revised and Updated Edition. Brill, Leiden
Farjon A (2013) *Picea sitchensis*. The IUCN Red List of Threatened Species 2013
Farrelly N, Dhubháin ÁN, Nieuwenhuis M, Grant J (2009) The distribution and productivity of Sitka spruce (*Picea sitchensis*) in Ireland in relation to site, soil and climatic factors. Ir Forestry 66:51–73
Farr WA, Harris AS (1971) Partial cutting of western hemlock and sitka spruce in southeast Alaska. Department of Agriculture, Forest Service, Pacific Northwest Research Station
Felton A, Boberg J, Björkman C, Widenfalk O (2013) Identifying and managing the ecological risks of using introduced tree species in Sweden's production forestry. Ecol Manage 307:165–177. https://doi.org/10.1016/j.foreco.2013.06.059
Fernandez FAS, Evans PR, Dunstone N (1994) Local variation in rodent communities of Sitka spruce plantations: the interplay of successional stage and site-specific habitat parameters. Ecography 17:305–313. https://doi.org/10.1111/j.1600-0587.1994.tb00107.x
Ferris R, Peace AJ, Humphrey JW, Broome AC (2000) Relationships between vegetation, site type and stand structure in coniferous plantations in Britain. Ecol Manage 136:35–51. https://doi.org/10.1016/S0378-1127(99)00268-6
Fletcher AM (1992) Breeding improved Sitka spruce. In: Rook D (ed) Super Sitka for the 90s. Proceedings of a meeting held in Elgin, Scotland, 2–4 October 1990. UK Forestry Commission Research Division, pp 11–24
Florin R (1963) The distribution of conifer and taxa genera in time and space. Acta Horti Bergiani 20:121–324
Forestry Commission (2009) Woodlands for Wales – the Welsh assembly government's strategy for woodlands and trees. Forestry Commission Wales, Aberystwyth
Forestry Commission (2014) Forestry Statistics 2014 Economics and Statistics. Corstorphine Road, Edinburgh
Forestry Commission (2020) Forestry Statistics 2020-A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom. Edinburgh
Forestry Commission Scotland (2006) The Scottish forestry strategy. Forestry Commission Scotland, Edinburgh
Fowler DP, Roche L (1977) Genetics of Engelmann spruce. Department of Agriculture, Forest Service, Washington, DC
Franklin JF, Dyrness CT (1973) Natural vegetation of Oregon and Washington. US Government Printing Office
François JM (1986) Provenance selection: a network of demonstration plots for foresters. Forêt Entreprise 38:33–45
Fuller RJ, Oliver TOMH, Leather SR (2008) Forest management effects on carabid beetle communities in coniferous and broadleaved forests: implications for conservation. Insect Conserv Divers 1:242–252. https://doi.org/10.1111/j.1752-4598.2008.00032.x
Goulet F (1995) Frost heaving of forest tree seedlings: a review. New (Dordr) 9:67–94. https://doi.org/10.1007/BF00028927
Grant OM, O'Reilly C (2017) Impact of genetic variation and long-term limited water availability on the ecophysiology of young Sitka spruce (Picea sitchensis (Bong.) Carr). Tree Physiol 37(4):536–549. https://doi.org/10.1093/treephys/tpw093
Grant OM, Ribeiro M, Glombik AF, P., O'Reilly C (2018) Impact of limited water availability on growth and biomass production of a range of full-sibling Sitka spruce (Picea sitchensis (Bong.) Carr.) families. Forestry: Int J For Res 91(1):83–97. https://doi.org/10.1093/forestry/cpx034
Green S, Hendry SJ, Redfern DB (2008) Drought damage to pole-stage Sitka spruce and other conifers in north-east Scotland. Scott Forestry 62(2):10–18
Griffiths M (1994) The new Royal Horticultural Society dictionary: index of garden plants. Macmillan Press Ltd., Basingstoke
Grossnickle SC, El-Kassaby YA (2016) Bareroot versus container stocktypes: a performance comparison. New Forest 47(1):1–51. https://doi.org/10.1007/s11056-015-9476-6
Grossnickle SC, Sutton BCS, Fan S, King J (1997) Characterization of Sitka × interior spruce hybrids: A biotechnological approach to seedlot determination. Forestry Chron 73:357–362. https://doi.org/10.5558/tfc73357-3
Grossnickle SC, Sutton BCS, Folk RS, Gawley RJ (1996b) Relationship between nuclear DNA markers and physiological parameters in Sitka × interior spruce populations. Tree Physiol 16:547–555. https://doi.org/10.1093/treephys/16.6.547
Grossnickle S, Sutton B, Holcomb R (1996a) Genetics and seedling biology of Sitka spruce hybrids. FRDA Memo 232. BC Ministry of Forests, Victoria, BC
Hale SE, Gardiner BA, Wellpott A et al (2012) Wind loading of trees: influence of tree size and competition. Eur J Res 131:203–217. https://doi.org/10.1007/s10342-010-0448-2
Halldorson G, Oddsdottir ES, Sigurdsson BD (2008) AFFORNORD, Effects of afforestation on ecosystems, landscape and rural development
Halldórsson G, Benedikz T, Eggertsson Ó et al (2003) The impact of the green spruce aphid *Elatobium abietinum* (Walker) on long-term growth of Sitka spruce in Iceland. Ecol Manage 181:281–287. https://doi.org/10.1016/S0378-1127(02)00658-8

Hamilton JA, Aitken SN (2013) Genetic and morphological structure of a spruce hybrid (*Picea sitchensis* × *P. glauca*) zone along a climatic gradient. Am J Bot 100:1651–1662. https://doi.org/10.3732/ajb.1200654

Hanewinkel M, Cullmann DA, Schelhaas M-J et al (2013) Climate change may cause severe loss in the economic value of European forest land. Nat Clim Chang 3:203–207. https://doi.org/10.1038/nclimate1687

Hanley TA, Brady WW (1997) Understory species composition and production in old-growth western hemlock—Sitka spruce forests of southeastern Alaska. Can J Bot 75:574–580. https://doi.org/10.1139/b97-064

Hanley TA, Hoel T (1996) Species composition of old-growth and riparian Sitka spruce–western hemlock forests in southeastern Alaska. Can J For Res 26:1703–1708. https://doi.org/10.1139/x26-193

Harris AS (1969) Ripening and dispersal of a bumper western hemlock-Sitka spruce seed crop in southeast Alaska. Pacific Northwest Forest and Range Experiment Station, US Forest Service

Harris AS (1978) Distribution, genetics, and silvical characteristics of Sitka spruce. In: Proceedings of the IUFRO joint meeting of working parties. British Columbia Ministry of Forestry, Vancouver, pp 95–122

Harris AS (1990) *Picea sitchensis* (Bong.) Carr. Sitka spruce. In: Silvics of North America. US Department of Agriculture Forest Service Washington, DC, pp 260–267

Harris AS, Johnson DL (1983) Western hemlock-Sitka spruce. In: Burns R (ed) Silvicultural systems for the major forest types of the United States. Technical coordinator: RM Burns. USDA For. Serv. Washington, DC Agric. Handb. Agricultural Handbook 445. USDA Forest Service, Washington, DC., pp 5–7

Hasenauer H, Neumann M, Moreno A, Running S (2017) Assessing the resources and mitigation potential of European forests. Energy Procedia 125:372–378. https://doi.org/10.1016/j.egypro.2017.08.052

Hawkes B, Feller MC, Meehan D (1990) Site preparation. In: Lavender DP, Parish H, Johnson C et al (eds) Regenerating British Columbia's forests. University of British Columbia, Vancouver, pp 131–149

Hill MO (1979) The development of a flora in even-aged plantations. Institute of Terrestrial Ecology, pp 175–192

Hulme MA, Kenis M (2001) *Pissodes strobi* (Peck), white pine weevil (Coleoptera: *Curculionidae*). Biological Control Programmes in Canada, 1981–2000. CABI Publishing Wallingford UK, Wallingford, pp 221–228

Humphrey JW, Ferris R, Quine C (2003) Biodiversity in Britain's planted forests. Forestry Commission, Edinburgh

Humphrey JW, Newton AC, Peace AJ, Holden E (2000) The importance of conifer plantations in northern Britain as a habitat for native fungi. Biol Conserv 96:241–252. https://doi.org/10.1016/S0006-3207(00)00077-X

Iason GR, Duncan AJ, Hartley SE, Staines BW (1996) Feeding behaviour of red deer (*Cervus elaphus*) on sitka spruce (*Picea sitchensis*): the role of carbon-nutrient balance. Ecol Manage 88:121–129. https://doi.org/10.1016/S0378-1127(96)03817-0

Šimůnek V, Vacek Z, Vacek S, Švanda M, Podrázský V, Cukor J, Gallo J, Zahradník P (2025) Bark beetle-induced salvage logging cycle is caused by weather patterns linked to the NAO and solar cycle in Central Europe. For Ecosyst 13:100328. https://doi.org/10.1016/j.fecs.2025.100328

Inward D, Vuts J, Thomas G, Barnard K, Caulfield JC, Powers SJ, Uglow A, Reed K (2025) Investigating the threat to Sitka spruce from Ips typographus: discrimination and colonization of Britain's principal commercial conifer by a damaging forest pest. Pest Manag Sci 81(11):7448–7460. https://doi.org/10.1002/ps.8644

Irwin S, Pedley SM, Coote L et al (2014) The value of plantation forests for plant, invertebrate and bird diversity and the potential for cross-taxon surrogacy. Biodivers Conserv 23:697–714. https://doi.org/10.1007/s10531-014-0627-4

Jacobsen JB, Thorsen BJ (2003) A Danish example of optimal thinning strategies in mixed-species forest under changing growth conditions caused by climate change. For Ecol Manag 180(1–3):375–388

Jarvis PG, Linder S (2007) Forests remove carbon dioxide from the atmosphere: spruce forest tales! CABI https://doi.org/10.1079/9781845932947.0060

Jelonek T, Klimek K, Naskrent B et al (2024) How the spruce ageing process affects wood. Forests 15:1737. https://doi.org/10.3390/f15101737

Jensen EC, Ross CR (2005) Trees to Know in Oregon. Oregon State University Extension Service, Corvallis

Jinks RL, Jones SK (1996) The effect of seed pretreatment and sowing date on the nursery emergence of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) seedlings. For: Int J For Res 69:335–345. https://doi.org/10.1093/forestry/69.4.335

Jones SK, Gosling PG (1990) The successful redrying of imbibed, or imbibed plus prechilled Sitka spruce seeds. Seed Sci Technol 18:541–547

Joyce PM, O'Carroll N (2002) Sitka spruce in Ireland. National Council for Forest Research and Development (COFORD), Dublin

Keith K, Mackey BG, Lindenmayer DB (2009) Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proc Natl Acad Sci 106:11635–11640. https://doi.org/10.1073/pnas.0901970106

Kennedy S, Cameron A, Thoss V, Wilson M (2006) Role of monoterpenes in *Hylobius abietis* damage levels between cuttings and seedlings of *Picea sitchensis*. Scand J Res 21:340–344. https://doi.org/10.1080/02827580600792582

Kiss GK (1989) Engelmann × Sitka spruce hybrids in central British Columbia. Can J For Res 19:1190–1193. https://doi.org/10.1139/x89-178

Kleinschmit J (1992) Use of spruce cuttings in plantations. Super Sitka for the 90s 1–10

Kobe RK, Coates KD (1997) Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. Can J For Res 27:227–236. https://doi.org/10.1139/x96-182

Krajina VJ (1969) Ecology of Western North America Vol. 2 No. 1: Ecology of forest trees in British Columbia. Department of Botany, University of British Columbia, Vancouver, B.C., pp 1–147

Krajnc L, Farrelly N, Harte AM (2019) The effect of thinning on mechanical properties of Douglas fir, Norway spruce, and Sitka spruce. Ann Sci 76:3. https://doi.org/10.1007/s13595-018-0787-6

Krankina ON, DellaSala DA, Leonard J, Yatskov M (2014) High-biomass forests of the pacific northwest: who manages them and how much is protected? Environ Manage 54:112–121. https://doi.org/10.1007/s00267-014-0283-1

Krüssmann G (1985) Manual of cultivated conifers. Timber, Portland

Krumm F, Vítková L (2016) Introduced tree species in European forests: opportunities and challenges. European Forest Institute, Prague

Kuckuk J, van Manen S, Eggertsson Ó et al (2021) Defoliation and dieback of Sitka spruce in Reykjavík, Iceland. Icel Agric Sci 34:15–28

Lee S, Matthews R (2004) An indication of the likely volume gains from improved Sitka spruce planting stock. 4 pp

Lee S, Thompson D, Hansen JK (2013) Sitka Spruce (*Picea sitchensis* (Bong.) Carr). In: Pâques LE (ed) Forest tree breeding in Europe: current state-of-the-art and perspectives. Springer Netherlands, Dordrecht, pp 177–227

Lester D, Ying C, Konishi J (1990) Genetic control and improvement of planting stock. In: Parish R, Johnson CM, Montgomery G et al (eds) Regenerating British Columbia's Forests. University of British Columbia, Vancouver, pp 180–192

Li H-L (1953) Present distribution and habitats of the conifers and Taxas. Evol (NY) 7:245–261. https://doi.org/10.2307/2405735

Lindgren D, Lindgren K (1997) Long distance pollen transfer may make gene conservation difficult. In: Kurm M, Tamm Y (eds) Conservation of forest genetic resources. Proceedings of Nordic Group for Forest Genetics and Tree Breeding Meeting in Estonia, June 3–7, 1996. pp 51–62

Lindgren D, Paule L, Xihuan S et al (1995) Can viable pollen carry Scots pine genes over long distances? Grana 34:64–69. https://doi.org/10.1080/00173139509429035

Lines R (1987a) Choice of seed origins for the main forest species in Britain. UK Forestry Commission 61

Lines R (1987b) Seed origin variation in Sitka spruce. In: proceedings of the royal society of Edinburgh. Section B. Biological Sciences, 2011/12/05. Royal Society of Edinburgh Scotland Foundation, pp 25–39

Little EL, Viereck LA (1971) Atlas of United States Trees: Conifers and important hardwoods. US Department of Agriculture, Forest Service

Lohmander P, Helles F (1987) Windthrow probability as a function of stand characteristics and shelter. Scand J Res 2:227–238. https://doi.org/10.1080/02827588709382460

Macdonald E, Hubert J (2002) A review of the effects of silviculture on timber quality of Sitka spruce. Forestry: Int J For Res 75:107–138. https://doi.org/10.1093/forestry/75.2.107

Magnani F, Mencuccini M, Borghetti M et al (2007) The human footprint in the carbon cycle of temperate and boreal forests. Nature 447:849–851. https://doi.org/10.1038/nature05847

Magnesen S (1986) Det Internasjonale Sitkagran-Proveniensforsøket pa Vestlandet [The International Sitka Spruce Provenance Trial in Western Norway]. Norwegian Forest Research Institute, Aas, Norway

Malcolm DC (1987) Some ecological aspects of Sitka spruce. Proceedings of the Royal Society of Edinburgh Section B Biological Sciences 93:85–92. https://doi.org/10.1017/S0269727000006308

Malcolm DC (1997) The silviculture of conifers in Great Britain. Forestry: Int J For Res 70:293–307. https://doi.org/10.1093/forestry/70.4.293

Malcolm DC, Mason WL, Clarke GC (2001) The transformation of conifer forests in Britain—regeneration, gap size and silvicultural systems. For Ecol Manag 151:7–23

Mason B, Perks MP (2011) Sitka spruce (*Picea sitchensis*) forests in Atlantic Europe: changes in forest management and possible consequences for carbon sequestration. Scand J Res 26:72–81. https://doi.org/10.1080/02827581.2011.564383

Mason WL (2007a) Changes in the management of British forests between 1945 and 2000 and possible future trends. Ibis 149:41–52. https://doi.org/10.1111/j.1474-919X.2007.00696.x

Mason WL (2007b) Silviculture of scottish forests at a time of change. J Sustain For 24:41–57. https://doi.org/10.1300/J091v24n01_03

Mason WL (2008) Natural regeneration of Sitka spruce in the Forest of Ae: development over 25 years. Scott Forestry 62:2–8.

Mason WL (2015) Implementing continuous cover forestry in planted forests: Experience with sitka spruce (*Picea sitchensis*) in the British Isles. Forests 6:879–902

Mason WL, Quine CP (1995) Silvicultural possibilities for increasing structural diversity in British spruce forests: the case of Kielder Forest. Ecol Manage 79:13–28. https://doi.org/10.1016/0378-1127(95)03618-0

McIntosh R (1997) Timber quality creates marketing challenge. Forestry & British Timber

McKay HM (1994) Frost hardiness and cold-storage tolerance of the root system of *Picea sitchensis*, *Pseudotsuga menziesii*, *Larix kaempferi* and *Pinus sylvestris* bare-root seedlings. Scand J For Res 9:203–213. https://doi.org/10.1080/02827589409382832

Mckenzie AJ, Petty SJ, Toms MP, Furness RW (2007) Importance of Sitka Spruce *Picea sitchensis* seed and garden bird-feeders for Siskins *Carduelis spinus* and Coal Tits *Periparus ater*. Bird Study 54:236–247. https://doi.org/10.1080/00063650709461480

Mclean JP (2008) Wood Properties of Four Genotypes of Sitka Spruce. University of Glasgow

McLean JP, Moore JR, Gardiner BA et al (2016) Variation of radial wood properties from genetically improved Sitka spruce growing in the UK. Forestry: Int J For Res 89:109–116. https://doi.org/10.1093/forestry/cpv035

Meier E (2015) Identifying and using hundreds of woods worldwide

Miller HG, Miller JD (1987) Nutritional requirements of Sitka spruce. Proc Royal Soc Edinb Sect B Biol Sci 93:75–83. https://doi.org/10.1017/S0269727000006291

Miller KF (1986) Wind throw Hazard in conifer plantations. Ir For 43:66–78

Minore D (1979) Comparative autecological characteristics of Northwestern tree species: a literature review. Portland

Mitchell A (1974) A field guide to the trees of Britain and northern Europe. Hardcover, London, Collins

Mitchell RJ, Albon SD, Bellamy PE, Cameron C, Ellis CJ, Hodgetts NG, Johnstone C, Stockan JA, Taylor AFS (2025) Sprucing up the UK's Sitka spruce (Picea sitchensis) forests: can tree species diversification benefit biodiversity? For: Int J Res. https://doi.org/10.1093/forestry/cpaf040

Moir RB, Fox DP (1976) Bud differentiation in Sitka Spruce, *Picea sitchensis*. (Bong) Carr Silvae Genet 24:193–196.

Monumental Trees (2025), December 30 MonumentalTrees.com · an inventory of big and old trees worldwide. Https://Www.Monumentaltrees.Com/En/. https://www.monumentaltrees.com/en/

Moore J (2011a) Wood properties and uses of Sitka spruce in Britain

Moore JR (2011b) Sitka spruce in Great Britain: wood properties and uses. Forestry Commission., Edinburgh

Moore JR, Lyon AJ, Searles GJ, Vihermaa LE (2009a) The effects of site and stand factors on the tree and wood quality of Sitka spruce growing in the United Kingdom. Silva Fennica 43:383–396

Moore JR, Mochan SJ, Brüchert F et al (2009b) Effects of genetics on the wood properties of Sitka spruce growing in the UK: bending strength and stiffness of structural timber. Forestry: Int J For Res 82:491–501. https://doi.org/10.1093/forestry/cpp018

Murphy ST, Pommerening A (2010) Modelling the growth of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Wales using Wenk's model approach. Allg Forst J Ztg 181:35–43

Neckelmann J (1981) Stabilisering af rande og interne laebaelter i roedgranbevoksninger paa sandjord. Dansk Skovforenings Tidsskrift 66:296–314

Nelson DG (1991) Management of Sitka spruce natural regeneration. In: Research Information Note - Forestry Commission Research Division. p 5

Nicolescu V-N, Mason WL, Bastien J-C et al (2023) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Europe: an overview of management practices. J Res (Harbin) 34:871–888. https://doi.org/10.1007/s11676-023-01607-4

Nicolescu V-N, Mihăilescu G, Andronic I et al (2021) A stand with Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Obştea Sălişte Forest District (Vâlcea County). 21:73–81. https://doi.org/10.4316/bf.2021.006

Nicoll BC, Redfern DB, McKay HM (1996) Autumn frost damage: clonal variation in Sitka spruce. Ecol Manage 80:107–112. https://doi.org/10.1016/0378-1127(95)03635-0

Nielsen KE, Ladekarl UL, Nørnberg P (1999) Dynamic soil processes on heathland due to changes in vegetation to oak and Sitka spruce. Ecol Manage 114:107–116. https://doi.org/10.1016/S0378-1127(98)00385-5

Nielsen UB (1994) Genetisk variation i sitkagran (*Picea sitchensis*. (Bong.) Carr.) i hoejdevaekst, stammeform og frosthaerdighed, vurderet ud fra danske proveniens-, afkoms-og klonforsoeg. Danish Forest and Landscape Research Institute, Lyngby

Nielsen UB, Roulund H (1996) Genetic variation in characters of importance for stand establishment in Sitka spruce (*Picea sitchensis* (Bong.) Carr). Silvae Genet 45:197–204

Nygaard PH, Øyen B-H (2017) Spread of the Introduced Sitka Spruce (*Picea sitchensis*) in Coastal Norway. Forests 8:24. https://doi.org/10.3390/f8010024

O'Driscoll J (1978) Sitka spruce international ten provenance experiment: results to end of nursery stage. Genetic Resour Inf https://doi.org/10.5555/19781670406

OECD (2006) Sect. 5 - Sitka Spruce (*Picea sitchensis* (Bong.) Carr.). In: Safety Assessment of Transgenic Organisms, Volume 2. OECD Publishing, Paris

O'Halloran J, Irwin S, Kelly DL et al (2011) Management of biodiversity in a. range of Irish forest types

O'Hanlon R, Harrington TJ (2012) Similar taxonomic richness but different communities of ectomycorrhizas in native forests and non-native plantation forests. Mycorrhiza 22:371–382. https://doi.org/10.1007/s00572-011-0412-0

O'Reilly C, Keane M, Morrissey N (2002) The importance of plant size for successful forest plantation establishment, vol 5. COFORD Connects Reproductive Material

Otchere-Boateng J, Herring L (1990) Site preparation: chemical. Regenerating British Columbia's forests. University of British Columbia, Vancouver

Ovenden TS, Perks MP, Forrester DI, Mencuccini M, Rhoades J, Thompson DL, Stokes VJ, Jump AS (2022) Intimate mixtures of Scots pine and Sitka spruce do not increase resilience to spring drought. For Ecol Manag 521:120448. https://doi.org/10.1016/j.foreco.2022.120448

Owens JN, Blake MD (1985) Forest tree seed production. A review of the literature and recommendations for future research. Chalk River

Owens JN, Molder M (1976a) Bud development in Sitka spruce. I. Annual growth cycle of vegetative buds and shoots. Can J Bot 54:313–325. https://doi.org/10.1139/b76-029

Owens JN, Molder M (1976b) Bud development in Sitka spruce. II. Cone differentiation and early development. Can J Bot 54:766–779. https://doi.org/10.1139/b76-083

Page CN, Hollands RC (1987) The taxonomic and biogeographic position of Sitka spruce. Proc Royal Soc Edinb Sect B Biol Sci 93:13–24. https://doi.org/10.1017/S0269727000006242

Palfner G, Casanova-Katny MA, Read DJ (2005) The mycorrhizal community in a forest chronosequence of Sitka spruce [*Picea sitchensis* (Bong.) Carr.] in Northern England. Mycorrhiza 15:571–579. https://doi.org/10.1007/s00572-005-0364-3

Pedersen LB, Bille-Hansen J (1999) A comparison of litterfall and element fluxes in even aged Norway spruce, sitka spruce and beech stands in Denmark. For Ecol Manag 114(1):55–70. https://doi.org/10.1016/S0378-1127(98)00381-8

Pedley SM, Martin RD, Oxbrough A et al (2014) Commercial spruce plantations support a limited canopy fauna: Evidence from a multi taxa comparison of native and plantation forests. Ecol Manage 314:172–182. https://doi.org/10.1016/j.foreco.2013.12.010

Peterken GF (2001) Ecological effects of introduced tree species in Britain. Ecol Manage 141:31–42. https://doi.org/10.1016/S0378-1127(00)00487-4

Peterson NM, Martin P, Weetman G, Martin PJ (1997) Ecology and management of Sitka spruce: emphasizing its natural range in British Columbia. UBC, Vancouver

Petr M, Boerboom LGJ, van der Veen A, Ray D (2014) A spatial and temporal drought risk assessment of three major tree species in Britain using probabilistic climate change projections. Clim Change 124(4):791–803. https://doi.org/10.1007/s10584-014-1122-3

Petrović D, Dukić V, Popović Z, Todorović N (2021) MOR and MOE of Serbian Spruce (Picea omorika Pančić/Purkynĕ) Wood from Natural Stands. Drvna Industrija 72(2):193–200. https://doi.org/10.5552/drvind.2021.2028

Petty JA, MacMillan DC, Steward CM (1990) Variation of density and growth ring width in stems of Sitka and Norway spruce. Forestry 63:39–49

Philipson JJ (1987) A review of coning and seed production in *Picea sitchensis*. In: proceedings of the royal society of edinburgh. Section B. Biological Sciences, 2011/12/05. Royal Society of Edinburgh Scotland Foundation, Edinburgh, pp 183–195

Phillips S, Lessard L (2011) Application of natural fiber composites to musical instrument top plates. J Compos Mater 46:145–154. https://doi.org/10.1177/0021998311410497

Pojar J, MacKinnon A (1994) Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia & Alaska. Ministry of Forestry, Canada

Pollard DFW, Portlock FT (1990) Certification of tree seed for export from Canada, 1980–1989: lodgepole pine, Sitka spruce, Douglas-fir, alpine fir and grand fir. In: Proceedings of the Joint Meeting of Western Forest Genetics Association and IUFRO Working Parties S. WA., Olympia, pp 247–254

Portlock FT (1996) Forest tree seed certification in Canada under the OECD scheme and ISTA rules: Summary report for 1991–1995. Information report No. BC-X-361

Praciak A, Pasiecznik N, Sheil D et al (2013) The CABI encyclopedia of forest trees. CABI, Oxfordshire

Prager EM, Fowler DP, Wilson AC (1976) Rates of Evolution in Conifers (*Pinaceae*). Evol (NY) 30:637–649. https://doi.org/10.2307/2407806

Prescott CE (1996) Salal Cedar Hemlock Integrated Research Program. University of British Columbia, Vancouver

Procter DS, Cottrell J, Watts K, Robinson EJH (2015) Do non-native conifer plantations provide benefits for a native forest specialist, the wood ant *Formica lugubris*? Ecol Manage 357:22–32. https://doi.org/10.1016/j.foreco.2015.07.034

Proe MF, Millard P (1995) Effect of P supply upon seasonal growth and internal cycling of P in Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings. Plant Soil 168:313–317. https://doi.org/10.1007/BF00029343

Pötzelsberger E (2018) Non-native Tree Species for European Forests: Book of Abstracts. Institute of Silviculture, University of Natural Resources and Life Sciences

Quine CP, Humphrey JW (2010) Plantations of exotic tree species in Britain: irrelevant for biodiversity or novel habitat for native species? Biodivers Conserv 19:1503–1512. https://doi.org/10.1007/s10531-009-9771-7

Quine CP, Humphrey JW, Ferris R (1999) Should the wind disturbance patterns observed in natural forests be mimicked in planted forests in the British uplands? Forestry: Int J For Res 72:337–358. https://doi.org/10.1093/forestry/72.4.337

Quine CP, Malcolm DC (2007) Wind-driven gap development in Birkley Wood, a long-term retention of planted Sitka spruce in upland Britain. Can J For Res 37:1787–1796. https://doi.org/10.1139/X07-051

Rajora OP, Dancik BP (2000) Population genetic variation, structure, and evolution in Engelmann spruce, white spruce, and their natural hybrid complex in Alberta. Can J Bot 78:768–780. https://doi.org/10.1139/b00-054

Ran J-H, Wei X-X, Wang X-Q (2006) Molecular phylogeny and biogeography of *Picea* (*Pinaceae*): Implications for phylogeographical studies using cytoplasmic haplotypes. Mol Phylogenet Evol 41:405–419. https://doi.org/10.1016/j.ympev.2006.05.039

Ratcliffe PR, Petty SJ (1986) The management of commercial forests for wildlife. Trees and wildlife in the Scottish uplands 177–187
Ray D (2008) Impacts of climate change on forestry in Scotland - a synopsis of spatial modelling research, vol 101. Research Note - Forestry Commission, pp 8
Ray D, Wainhouse D, Webber J, Gardiner B (2008) Impacts of climate change on forests and forestry in Scotland. Forest Research Report, Forestry Commission: Scotland, UK
Renou-Wilson F, Keane M, Farrell EP (2008) Effect of planting stock-type and cultivation treatment on the establishment of Norway spruce on cutaway peatlands. New For 36:307-330 https://doi.org/10.1007/s11056-008-9102-y
Reynisson V (2011) Comparison of yield of *Norway spruce (Picea abies) and Sitka spruce (Picea sitchensis)* in Skorradalur. SLU, Southern Swedish Forest Research Centre, West Iceland
Roche L (1969) A Genecological Study of the Genus *Picea* in British Columbia. New Phytol 68:505–554. http://www.jstor.org/stable/2431365
Roche L, Haddock PG (1987) Sitka spruce (*Picea sitchensis*) in North America with special reference to its role in British forestry. In: proceedings of the royal society of Edinburgh. Section B. Biological Sciences, 2011/12/05. Royal Society of Edinburgh Scotland Foundation, pp 1–12
Roche LR (1975) Genetics of Sitka spruce. US Forest Service, Washington, D.C.
Rytter L, Ingerslev M, Kilpeläinen A, Torssonen P, Lazdina D, Löf M, Madsen P, Muiste P, Stener LG (2016) Increased forest biomass production in the Nordic and Baltic countries—A review on current and future opportunities. Silva Fennica 50(5). https://doi.org/10.14214/sf.1660
Safford L (1974) Seeds of woody plants in the United States. In: Schopmeyer C (ed) Agricultural Handbook 450. USDA For. Serv., Washington, DC., pp 587–597
Savill P (2013) The silviculture of trees used in British forestry, 2nd edn. CABI, Wallingford
Savill PS, Sandels AJ (1983) The influence of early respacing on the wood density of sitka spruce. Forestry: Int J For Res 56:109–120. https://doi.org/10.1093/forestry/56.2.109
Schaible R, Gawn LJ (1989) Variation in timber strength of fast grown unthinned Sitka spruce in Northern Ireland. Ir For 46:43–50
Schelleng JC (1973) The bowed string and the player. J Acoust Soc Am 53:26–41. https://doi.org/10.1121/1.1913322
Schmidt-Vogt H (1977) Die Fichte. Bd. I. Paul Parey, Hamburg
Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, Wild J, Ascoli D, Petr M, Honkaniemi J, Lexer MJ, Trotsiuk V, Mairota P, Svoboda M, Fabrika M, Nagel TA, Reyer CPO (2017) Forest disturbances under climate change. Nat Clim Change 7(6):395–402. https://doi.org/10.1038/nclimate3303
Shaw CG, Sidle RC, Harris AS (1987) Evaluation of planting sites common to a southeast Alaska clear-cut. III. Effects of microsite type and ectomycorrhizal inoculation on growth and survival of Sitka spruce seedlings. Can J Res 17:334–339. https://doi.org/10.1139/x87-056
Simic K, Gendvilas V, O'Reilly C et al (2016) The effects of planting density on the structural timber properties of 23-year-old Irish-grown Sitka spruce. In: Civil Engineering Research in Ireland (CERI 2016) conference. Galway, Ireland. Galway
Simic K, Gendvilas V, O'Reilly C et al (2018) The influence of planting density on modulus of elasticity of structural timber from Irish-grown Sitka spruce. Int J Des Nat Ecodyn 12:438–447
Skovsgaard JP (2009) Analysing effects of thinning on stand volume growth in relation to site conditions: a case study for even-aged Sitka spruce (*Picea sitchensis*). For: Int J For Res 82:87–104. https://doi.org/10.1093/forestry/cpn047
Smith GF, Gittings T, Wilson M et al (2006) Biodiversity Assessment of Afforestation Sites: Bioforest project 3.1. 1 final report, May 2006. Bioforest
Smith GF, Gittings T, Wilson M et al (2009) Identifying practical indicators of biodiversity for stand-level management of plantation forests. In: Brockerhoff EG, Jactel H, Parrotta JA et al (eds) Plantation Forests and Biodiversity: Oxymoron or Opportunity? Springer Netherlands, Dordrecht, pp 67–91
Smith SH, Bell JF, Herman FR, See T (1984) Growth and yield of Sitka spruce and western hemlock at Cascade Head Experimental Forest, Oregon. Res. Pap. PNW-RP-325. US Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR, p 36
Smithwick EAH, Harmon ME, Remillard SM et al (2002) Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecol Appl 12:1303–1317. https://doi.org/10.1890/1051-0761(2002)012[1303:PUBOCS]2.0.CO;2
Staines BW, Petty SJ, Ratcliffe PR (1987) Sitka spruce (Picea sitchensis (Bong.) Carr.) forests as a habitat for birds and mammals. Proc Royal Soc Edinb Sect B Biol Sci 93:169–181. https://doi.org/10.1017/S0269727000006370
Steinmetz G (1986) Le choix des provenances et le classement des peuplements porte-graines. Revue forestière française 38:69–73
Stokes VJ, Jinks R, Kerr G (2023) An analysis of conifer experiments in Britain to identify productive alternatives to Sitka spruce. Forestry: Int J For Res 96(2):170–187. https://doi.org/10.1093/forestry/cpac035
Stokes V, Kerr G (2013) Long-term growth and yield effects of respacing natural regeneration of Sitka spruce in Britain. Eur J For Res 132:351-362 https://doi.org/10.1007/s10342-012-0679-5
Stratmann J, Tegeler R (1987) Die Sifkafichten-Provenienzversuche der Niedersächsischen forstlichen Versuchsanstalt von 1956 und 1961 in Nordwestdeutschland. Allg Jagdzeitg 158:11–18
Straw NA, Green G (2001) Interactions between green spruce aphid (*Elatobium abietinum* (Walker)) and Norway and Sitka spruce under high and low nutrient conditions. Agric Entomol 3:263–274. https://doi.org/10.1046/j.1461-9555.2001.00113.x
Straw N, Fielding N, Green G et al (2011) Defoliation and growth relationships for mid-rotation Sitka spruce attacked by the green spruce aphid, *Elatobium abietinum* (Walker) (Homoptera: *Aphididae*). Ecol Manage 262:1223–1235. https://doi.org/10.1016/j.foreco.2011.06.020
Sutton BCS, Flanagan DJ, El-Kassaby YA (1991a) A simple and rapid method for estimating representation of species in spruce seedlots using chloroplast DNA restriction fragment length polymorphism. Silvae Genet 40:119–123.
Sutton BCS, Flanagan DJ, Gawley JR et al (1991b) Inheritance of chloroplast and mitochondrial DNA in Picea and composition of hybrids from introgression zones. Theor Appl Genet 82:242–248. https://doi.org/10.1007/BF00226220
Sutton BCS, Pritchard SC, Gawley JR et al (1994) Analysis of Sitka spruce–interior spruce introgression in British Columbia using cytoplasmic and nuclear DNA probes. Can J For Res 24:278–285. https://doi.org/10.1139/x94-040
Swanson ME, Studevant NM, Campbell JL, Donato DC (2014) Biological associates of early-seral pre-forest in the Pacific Northwest. Ecol Manage 324:160–171. https://doi.org/10.1016/j.foreco.2014.03.046
Sweeney OFMD, Wilson MW, Irwin S et al (2010b) Are bird density, species richness and community structure similar between native woodlands and non-native plantations in an area with a generalist bird fauna? Biodivers Conserv 19:2329–2342. https://doi.org/10.1007/s10531-010-9844-7
Sweeney OFMD, Wilson MW, Irwin S et al (2010c) Breeding bird communities of second-rotation plantations at different stages of the forest cycle. Bird Study 57:301–314. https://doi.org/10.1080/00063651003801713
Sweeney O, Wilson MW, Irwin S et al (2010a) The influence of a native tree species mix component on bird communities in non-native

coniferous plantations in Ireland. Bird Study 57:483–494. https://doi.org/10.1080/00063657.2010.489937
Taylor CMA (1990) Survey of forest fertiliser prescriptions in Scotland. Scott For 44:3–9. https://www.cabidigitallibrary.org/doi/full/10.5555/19900644348
Taylor CMA, Tabbush PM (1990) Nitrogen deficiency in Sitka spruce plantations. Forestry Commission Bulletin, Farnham
Taylor R (1993) Flora of North America North of Mexico, Flora of North America Editorial Committee. Oxford University Press, New York and Oxford
The Tree Register (2009) The Tree Register is registered as a. Charity in England & Wales
Thompson D (2013) Development of improved Sitka spruce for Ireland. Ir Forestry 70:104–118
Thompson DG, Pfeifer AR (1995) IUFRO Sitka spruce provenance trial–19 year results. In: Evolution of breeding strategies for conifers from the Pacific Northwest, Joint meeting of IUFRO working parties S
Tittensor R (2016) Shades of green : an environmental and cultural history of *Sitka Spruce*. Oxbow Books. http://digital.casalini.it/9781909686809
Titus BD, Malcolm DC (1999) The long-term decomposition of Sitka spruce needles in brash. Forestry: Int J For Res 72(3):207–221. https://doi.org/10.1093/forestry/72.3.207
Tomlin ES, Borden JH (1994) Relationship between leader morphology and resistance or susceptibility of Sitka spruce to the white pine weevil. Can J Res 24:810–816. https://doi.org/10.1139/x94-106
Tomlin ES, Borden JH (1997) Multicomponent Index for Evaluating Resistance by Sitka Spruce to the White Pine Weevil (Coleoptera: *Curculionidae*). J Econ Entomol 90:704–714. https://doi.org/10.1093/jee/90.2.704
Tonsfeldt WA (2013) The U.S. Army Spruce Production Division at Vancouver Barracks. National Park Service, Vancouver, Washington, pp 1917–1919
Touzet G (1983) Les chablis des 6-7-8 novembre 1982 dans le Massif Central. Comptes Rendus des Séances de l'Academie d'Agriculture de France 69:722–732
USGS (2013) Digital Representations of Tree Species Range Maps from Atlas of United States Trees. USGS Geosciences and Environmental Change Science Center
Vacek Z, Vacek S, Cukor J (2023a) European forests under global climate change: Review of tree growth processes, crises and management strategies. J Environ Manage 332:117353. https://doi.org/10.1016/j.jenvman.2023.117353
Vacek Z, Zeidler A, Cukor J, Vacek S, Borůvka V, Šimůnek V, Skoták V, Gallo J (2023b) Sustainable biomass production of introduced spruce species plantations under climate change. Trees - Struct Function 37(6):1781–1799. https://doi.org/10.1007/s00468-023-02460-y
Van Pelt R (2001) Forest Giants of North America. University of Washington, Seattle
Van Pelt R (2007) Identifying mature and old forests in western Washington. Washington State Department of Natural Resources, Olympia
Wainhouse D, Ashburner R (1996) The Influence of Genetic and Environmental Factors on a Quantitative Defensive Trait in Spruce. Funct Ecol 10:137–143. https://doi.org/10.2307/2390272
Wallertz K, Nordenhem H, Nordlander G (2014) Damage by the pine weevil *Hylobius abietis* to seedlings of two native and five introduced tree species in Sweden. Silva Fennica 48:1188. https://doi.org/10.14214/sf.1188
Webb CR, Blake M, Gilligan CA (2025) Phenology of the spruce bark beetle Ips typographus in the UK under past, current and future climate conditions. Plants People Planet 7(1):284–300
Weetman G, Vyse A (1990) Natural regeneration. In: Lavender D, Parish R, Johnson C et al (eds) Regenerating British Columbia's forests. University of British Columbia, Vancouver, BC. University of British Columbia Press, Vancouver, pp 118–130
Weir AG, Ferns PN, Cowie RJ (1996) Manipulating seed production in commercial conifer plantations and the effect on vertebrate seed predators. Asp Appl Biol 17–24
Williams BL, Alexander CE (1991) Interactions on mixing litters from beneath *Sitka spruce* and Scots pine and the effects on microbial activity and N-mineralization. Soil Biol Biochem 23(1):71–75. https://doi.org/https://doi.org/10.1016/0038-0717(91)90164-F
Wilson MW, Irwin S, Norriss DW et al (2009) The importance of pre-thicket conifer plantations for nesting Hen Harriers Circus cyaneus in Ireland. Ibis 151:332–343. https://doi.org/10.1111/j.1474-919X.2009.00918.x
Woods J (1988) Nursery trials of Sitka-interior spruce hybrids. BC Ministry of Forests, Victoria, BC
Wright J (1976) Introduction to forest genetics. Academic, New York
Wright JW (1955) Species crossability in Spruce in relation to distribution and taxonomy. Sci 1:319–349
Wulff ANU, Crossley A, Sheppard LJ (1996) Fine structure of acid mist treated Sitka spruce needles: open-top chamber and field experiments. Ann Bot 77:1–10. https://doi.org/10.1006/anbo.1996.0001
Yano H (1990) Acoustic properties of wood for the top plate of guitar. J Soc Mater Sci Jpn 39:1207–1212
Yeh FC, Arnott JT (1986) Electrophoretic and morphological differentiation of Picea sitchensis, Picea glauca, and their hybrids. Can J For Res 16:791–798. https://doi.org/10.1139/x86-140
Øyen B-H, Nygård PH (2007) 4.7 Afforestation in Norway–effects on wood resources, forest yield and local economy. Effects of afforestation on ecosystems, landscape and rural development 334–342
Ying CC, Ebata T (1994) Provenance variation in weevil attack in Sitka spruce. In: Alfaro R, Kiss G, Fraser R (eds) The White Pine Weevil: Biology, Damage, and Management, Proceedings of a Meeting. BC Ministry of Forests and Lands, pp 98–109
Zeidler A, Borůvka V, Brabec P et al (2024a) The possibility of using non-native spruces for norway spruce wood replacement—a case study from the Czech Republic. Forests 15:255. https://doi.org/10.3390/f15020255
Zeidler A, Borůvka V, Tomczak K, Vacek Z, Cukor J, Vacek S, Tomczak A (2024b) The Potential of non-native pines for timber production—a case study from afforested post-mining sites. Forests 15(8):1388. https://doi.org/10.3390/f15081388
Zeidler A, Černý J, Borůvka V, Vacek Z, Cukor J, Vacek S, Šimůnek V, Tomczak K (2026) Exploring Douglas-fir as a viable alternative softwood to Scots pine at poor sandy soil sites. Scand J For Res 41:99–114. https://doi.org/10.1080/02827581.2025.2599347

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