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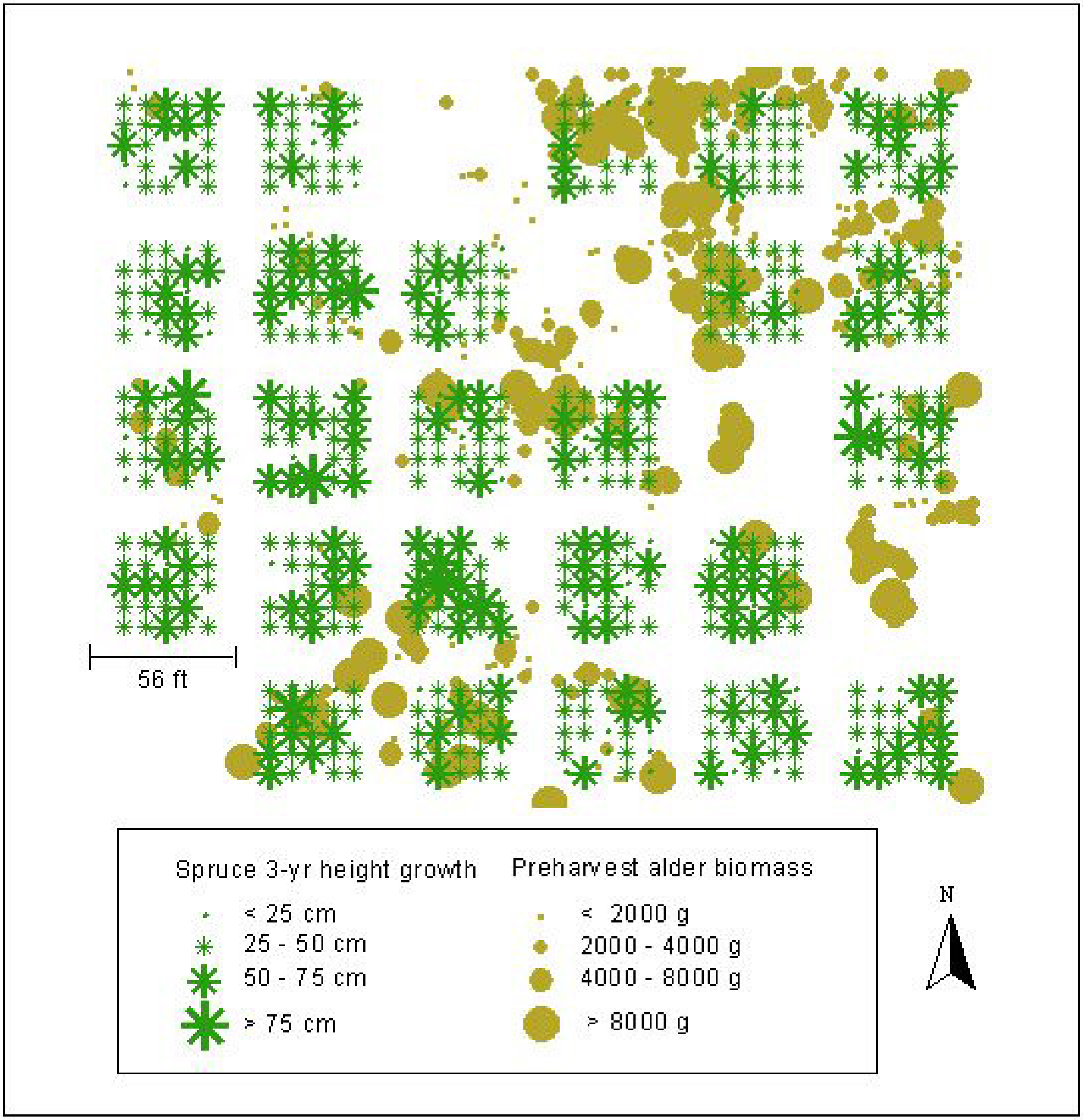
Interactions Between White Spruce and Shrubby Alders at Three Boreal Forest Sites in Alaska

Tricia L. Wurtz



Author

Tricia L. Wurtz is a research ecologist, Institute of Northern Forestry Cooperative Research Unit, Pacific Northwest Research Station, P.O. Box 756780, University of Alaska Fairbanks, Fairbanks, AK 99775-6780. This is the final report on grant number 91-1-041 from the Alaska Science and Technology Foundation.

On the cover: Distribution of green alder (*Alnus crispa* (Ait.) Pursh) stems (light green circles) that occurred in the understory of a mature boreal forest stand at Trapper Creek, Alaska, overlain with postharvest plantation of white spruce (*Picea glauca* (Moench) Voss) seedlings (darker green symbols). The estimated aboveground biomass of each alder stem is represented by circle diameter, and the size of spruce symbols represents seedling height growth during the first 3 years after planting. The growth of the spruce seedlings was not related to preharvest alder stem locations. In this figure, only the 25 measured seedlings per plot are shown; the plots lacking spruce seedlings entirely are natural regeneration plots. Alders planted with spruce in some of the plots are not shown.

Abstract

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To document possible soil nitrogen mosaics before timber harvesting on three boreal forest sites in Alaska, maps of the distribution of understory green *(Alnus crispa* (Ait.) Pursh) and Sitka alder *(A. sitchensis* (Reg.) Rydb.) stems were made. Understory alders were regularly distributed throughout the northernmost site (Standard Creek) and very irregularly distributed at the southernmost site (Cooper Landing). No consistent relations existed between alder stem location and total soil nitrogen. In undisturbed forest, soils collected beneath alders tended to have more nitrogen than soils without alder, but after the sites were harvested, soil chemistry differed. To examine the interactions of alder and white spruce (*Picea glauca* (Moench) Voss) on secondary successional sites, mixed plantations of white spruce and alder were established after each site was harvested. Despite good survival, the planted alder grew poorly. No differences were found between nursery-grown alder seedlings and alder wildlings in either growth or survival. Although fifth-year survival and growth of white spruce were excellent on all sites, they were not related to either the preharvest distribution of naturally occurring alder or to alders planted in the mixed plantations. Locational information and site maps are provided for future evaluation of these plantations.

Keywords: White spruce, green alder, Sitka alder, boreal forest, interior Alaska, mixed-species plantations, nitrogen fixation, alder wildlings, long-term ecosystem productivity.

Summary

Although alders are ecologically important in the boreal forest, their role in managed forest systems has received little attention. This study examined several aspects of the interactions between two shrubby alder species (*Alnus crispa* (Ait.) Pursh) and *A. sitchensis* (Reg.) Rydb.) and white spruce (*Picea glauca* (Moench) Voss), the primary commercial species in the boreal forest of Alaska. First, I mapped the alder stems that occurred naturally in the understory of three mature forest stands and collected soil from beneath alder clumps and from beneath other typical types of vegetation for each site. Soils also were collected after each site was harvested. In undisturbed forest, soils collected beneath alders tended to have more total nitrogen than soils without alder, but after the sites were harvested, soil chemistry differed by soil horizon and site. Alaska's boreal forest soils are relatively infertile. Because mixed plantations of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red alder (*Alnus rubra* Bong.) have increased the productivity of nutrient-poor sites in the Pacific Northwest, I established mixed plantations of white spruce and alder in the three sites. Four different distance and species-ratio combinations were planted, as well as spruce-only plots and natural regeneration plots in which no seedlings were planted. After 5 years, survival and growth of white spruce were excellent on all sites but were not related to either the preharvest distribution of naturally occurring alder or to alders planted in the mixed plantations. I had hypothesized that alders planted with spruce seedlings might

produce enough shade to slow the spread of the grass *Calamagrostis canadensis* and other species that colonize newly harvested sites. But the planted alder grew slowly; it had no effect on the percentage of cover of other plant species. From this 5-year perspective, mixed plantations of spruce and alder are not justified for forest management operations on the types of sites examined in this study. Whether they are justified from a long-term, multiple-rotation perspective remains to be seen. Toward that end, locational information, site maps, and early data summaries are provided for future evaluation of these plantations. Finally, alders are sometimes planted in site-restoration projects, and the present study used both nursery-grown, containerized alder seedlings and alder wildlings. I found no differences in the survival or growth of these two types of alder seedlings, thereby suggesting wildlings may be an inexpensive option for restoration projects involving alder.

Introduction

Alders are among the most common and widespread shrubs species in the boreal forest. They are ecologically important, fixing atmospheric nitrogen and turning it over rapidly to the soil. Conversely, white spruce (*Picea glauca* (Moench) Voss) forests and other northern conifer ecosystems are known to be nitrogen limited (Van Cleve and Zasada 1976, Weetman 1968, Yarie et al. 1990). Spruce litter decays slowly and releases nitrogen slowly. Spruce plantations established in eastern Canada between 1920 and 1932 show a growth decline beginning about 1970 that has been attributed to a gradual acidification of the soil and depression of soil nitrogen availability by litter (Brand et al. 1986, Hendrickson 1990, Pastor et al. 1987). Nutrition is an important factor in the early growth of planted spruce as well. Poor performance of planted spruce is a common problem in interior British Columbia (Ballard 1985, Swift and Brockley 1994). Harvesting itself can deplete the nutrient reserves of a site. Weetman and Webber (1972) documented the nitrogen losses caused by full-tree harvesting of red spruce (*Picea rubens* Sarg.) and black spruce *(Picea mariana* (Mill.) B.S.P.) in eastern Canada, and found that on sites with little humus, full-tree harvesting can deplete nutrient reserves to the extent that fertilization would be needed in the second rotation. Bormann and Gordon (1989) modeled the nitrogen dynamics of several silvicultural systems and found that short-rotation, whole-tree harvest systems are not self-sufficient in nitrogen, unless they include an active biological nitrogen-fixation component. Despite these findings, the role of alders in managed white spruce forests has received little attention. This study examines the role of naturally occurring understory alders and the use of planted alders in the regeneration of harvested white spruce stands.

This study had three objectives:

1. To determine whether shrubby alders occurring naturally in the understory of mature forests create localized nitrogen hot spots in the soil that improve the growth of white spruce seedlings planted after the site is harvested.
2. To determine whether spruce trees planted in mixtures with shrubby alder grow differently than trees in spruce-only plantations.
3. To determine whether alders included in mixed-species plantations might prevent other, less favorable competitors from colonizing and dominating a site.

Alder in Unmanaged Boreal Forest Stands

Alders (*Alnus* spp.) are the primary nitrogen-fixing species in Alaska's boreal forests. Alders drive the soil nitrogen dynamics and influence various other aspects of soil development in most successional sequences in the boreal forest regions of the state (Reynolds 1990, Van Cleve and Viereck 1981). Three shrub species of alder occur in Alaska: Sitka alder (*Alnus sinuata* (Reg.) Rydb.), thinleaf alder (*A. tenuifolia* Nutt., sometimes referred to as *A. incana* (L.)), and green alder (*A. crispa* (Ait.) Pursh).

On primary successional sites on the Tanana River flood plain, alders and willows (*Salix* spp.) colonize newly deposited surfaces quickly; after 10 years, there may be as many as 40,000 stems per acre (100,000 stems per ha) (Van Cleve and Viereck 1981). During this time, nitrogen can accumulate in the soil at a rate of 320 pounds • $acre^{-1}$ • $year^{-1}$ (360 kg • ha^{-1} • yr^{-1}) (Van Cleve et al. 1971). The dominant role of alders continues for the first 60 to 80 years of flood-plain succession, until the balsam poplar (*Populus balsamifera* L.), and later white spruce, canopies close overhead.

Then, though their abundance and vigor decline, alders persist in the understory. Individual alder stems can be long lived (Wilson et al. 1985); the oldest stem for which age was determined in the present study was 75 years old. As individual stems mature and die back, new ones sprout from the same root crown.

On upland sites in interior Alaska, the most common disturbance is wildfire. In such secondary successional sequences, alders occur as a scattered shrub layer beneath paper birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.). They reach their greatest influence 50 to 100 years after fire. Soil nitrogen reserves double during this period (Van Cleve and Viereck 1981). As the upland forest becomes dominated by white spruce, the importance of alder declines. But just as on flood-plain sites, alders on upland sites persist throughout the later stages of succession as common, though scattered, components of the understory.

Not all alders found in the understory of mature forests originated in an earlier successional stage. New individuals can establish from seed where localized disturbances such as windthrow have exposed mineral soil (Gilbert and Payette 1982) and created openings in the canopy. These new establishment events, however, seem infrequent (Huenneke 1987, Huenneke and Marks 1987). For the most part, alder stems in the understory of mature boreal forests are the most recent aboveground generation of a genetic individual that has occupied that spot for decades or even centuries.

Few studies have considered the effects of shrubby alders on ecosystem nitrogen dynamics during their later understory stages. In a comparison of jack pine (*Pinus banksiana* Lamb.) stands in Canada with and without understory alder, Vogel and Gower (1998) found that stands with alder have fewer overstory stems per acre (stems per ha) but more overstory basal area than stands without alder. Overstory leaf area index, total ecosystem carbon content, and average aboveground net primary productivity all were greater in stands with understory alder than in stands lacking alder. Van Cleve et al. (1986) attributed the relatively high nitrogen supply on the balsam poplar forest floor in Alaska to the widespread occurrence of green alders in the understory of the site. Berg and Doerksen (1975) studied a heavily thinned stand of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) where red alders (*Alnus rubra* Bong.) had germinated naturally and occupied the understory until the canopy of the thinned stand closed above them. They estimated that the alders added 780 pounds per acre (873 kg per ha) of nitrogen to the soil over a 17-year period. Binkley (1982) studied the effects of naturally occurring red and Sitka alder on developing Douglas-fir stands and found that the Sitka alder added 31 pounds • $acre^{-1}$ • $year^{-1}$ (35 kg • ha^{-1} • yr^{-1}) of nitrogen to the site for a period of 23 years. Douglas-fir stem growth was 40 percent greater on sites with Sitka alder than on sites without it. Alders contribute this nitrogen to the soil through direct secretions from their roots and nodules (Zavitkovski and Newton 1968), and through the production of nitrogen-rich leaf litter (Radwan et al. 1984, Van Cleve et al. 1971). In one study, the experimental addition of alder leaves to a degenerated forest soil produced a substantial gain in total soil nitrogen (Huss-Danell and Lundmark 1988). Litter falling from a jack pine overstory was richer in nitrogen in stands where green alders occurred in the understory than in stands without alder (Vogel and Gower 1998).

I hypothesized that the soil beneath a mature white spruce stand might be a mosaic of soil nitrogen hot spots mirroring the distribution of long-lived shrubby alders on that site. If this soil mosaic persisted after timber harvest, it likely would affect the growth of spruce seedlings planted there. Seedlings planted on a spot formerly occupied by an alder might be less nitrogen limited and grow better than seedlings planted where no alder existed previously. This led to the first goal of this study, to determine whether shrubby alders occurring naturally in the understory of mature forests create localized nitrogen hot spots in the soil that improve the growth of white spruce seedlings planted after the site is harvested.

Alder in Mixed-Species Plantations

Unlike the shrubby alders of the boreal forest region of Alaska, red alder is a fast-growing species that can reach a height of 70 feet (21 m) in 30 years (Atterbury 1978, Harrington et al. 1994). It occurs in southeast Alaska, coastal British Columbia, Washington, Oregon, and California. Although red alder was viewed as a weed species for many years, over the last 20 years, a major industry has developed around its utilization. In 1991, about 475 million board feet of red alder were harvested from Oregon and Washington (Tarrant et al. 1994). This dramatic increase in utilization has increased interest in mixing red alder in plantations with Douglas-fir.

Miller and Murray (1978) studied a mixed plantation of red alder and Douglas-fir on a nitrogen-deficient site in southwestern Washington. Douglas-fir seedlings were planted in 1928, and red alder seedlings were interplanted 4 years later. (The delay was intended to prevent the alders from immediately overtopping the Douglas-fir and suppressing their early growth.) Over the next 48 years, the presence of red alder significantly increased the height of the Douglas-fir. Fifty-six percent of the Douglas-fir survived in the pure stand, as opposed to only 38 percent in the mixed stand. Yet the fir trees in the mixed stand were larger, including 50 trees per acre (123 trees per ha) in the 12-inches (30-cm) or larger diameter class. The pure stand of Douglas-fir had no trees over 12 inches (30 cm) in diameter. In the mixed stand, alders also reached saw timber size, with an average of 14 trees per acre (34 trees per ha) reaching the 12-inch (30-cm) diameter at breast height (d.b.h.) class. Based on their reconstruction of the growth of these stands, Miller and Murray suggest that Douglas-fir had begun emerging from the alder canopy when they were 30 years old. They stress that alders are most likely to increase conifer growth where soils are deficient in nitrogen and recommend including 20 to 40 uniformly distributed red alder seedlings per acre (50 to 100 seedlings per ha) in Douglas-fir plantations.

Such experiences with red alder and Douglas-fir in the Pacific Northwest led to the mixed-species plantation part of this study. Although the shrubby alders of the boreal forest have no commercial value, they are similar to red alder in their nitrogen-fixing capability. Shrubby alders likely would overtop white spruce early on, but because of their short stature, they would be unlikely to suppress the spruce for long. Harrington and Deal (1982) examined the juvenile height growth of Sitka alder and determined it is a reasonable candidate for mixtures with Douglas-fir. Thus, the second goal of this study, to determine whether spruce trees planted in mixtures with shrubby alder grow differently than trees in spruce-only plantations.

Alder as a Competitor With Other Vegetation

On many sites in the boreal forest of Alaska, the biggest obstacle to the successful regeneration of white spruce after timber harvest is competition from the grass *Calamagrostis canadensis* (Michx.) Beauv. (Eis 1981, Hauessler and Coates 1986, Hogg and Lieffers 1991). Small amounts of *Calamagrostis* occur naturally in openings of mature white spruce forests (Reynolds 1990, Viereck et al. 1983). When the trees are harvested, this grass spreads rapidly via a network of roots and rhizomes; this aggressive growth is most likely triggered by a sudden increase in available light (Powelson and Lieffers 1992). *Calamagrostis* can dominate a harvested site in 3 or 4 years, accounting for 70 percent of the plant cover present, and producing a thick, impenetrable belowground mat. In the Trapper Creek area of south-central Alaska, *Calamagrostis* can grow to 6 feet (1.8 m) tall; when the grass dies back at the end of summer, it effectively buries the crop trees beneath it. Slow-growing spruce seedlings cannot survive in this severely competitive environment.

Alders also can grow rapidly. On good sites, red alder seedlings can reach breast height in the first year after germinating; 3 to 4 years are required on poorer sites (Harrington and Curtis 1986). Five-year-old alder saplings can be 20 to 26 feet (7 to 8 m) tall (DeBell and Hibbs, summarized in Puettman 1994; Harrington et al. 1994). In interior Alaska, both green and thinleaf alders rapidly colonize new roadsides and gravel pits. Green alder wildlings collected along roadsides grew rapidly after being planted in a tilled agricultural field and kept free of competing vegetation (Wurtz 1995a). In the first year after planting, the wildlings doubled or tripled in height, and in the second year, many doubled again. At the same time, they were sprouting vigorously from the base of the main stem, so that after 3 years, individual plants had as many as 10 stems curving out and up from the base and a dense, rounded growth form.

Although dense stands of *Calamagrostis* can prevent spruce from becoming established in a secondary successional site, white spruce seems to tolerate competition from alder. In many boreal forest successional sequences, white spruce grows naturally beneath a canopy of shrubby alder for years before gradually overtopping it and becoming the dominant species (Van Cleve and Viereck 1981).

Eis (1981) studied the vegetative colonization of four harvested white spruce sites in central British Columbia supporting both thinleaf (*A. tenuifolia* Nutt.) and Sitka alders. For an alluvium-type site, he noted that “areas not occupied by shrubs, including old skid roads, were overgrown by thick mats of grasses, mainly *Calamagrostis neglecta*, *C. canadensis*, *Carex rostrata*, and *Cinna latifolia*.”

These observations led to the third goal of this study, to determine whether alders included in a mixed-species plantations might prevent other, less favorable competitors from colonizing and dominating a site. In particular, I wondered whether the shade from alders planted adjacent to spruce seedlings would prevent *Calamagrostis* from surrounding and overcoming individual spruce. Shady areas around alder seedlings might generate *Calamagrostis*-free zones and could functionally replace a severe competitor with a moderate one.

Methods

This study is being conducted at three sites along a north-south transect through central Alaska. The northernmost site, Standard Creek, is 15 miles (25 km) southwest of Fairbanks, with mean annual temperature of 26 °F (-3.2 °C) and mean annual precipitation of 10 inches (26.5 cm) (fig. 1). It is part of the “Eastern interior Alaska zone” of

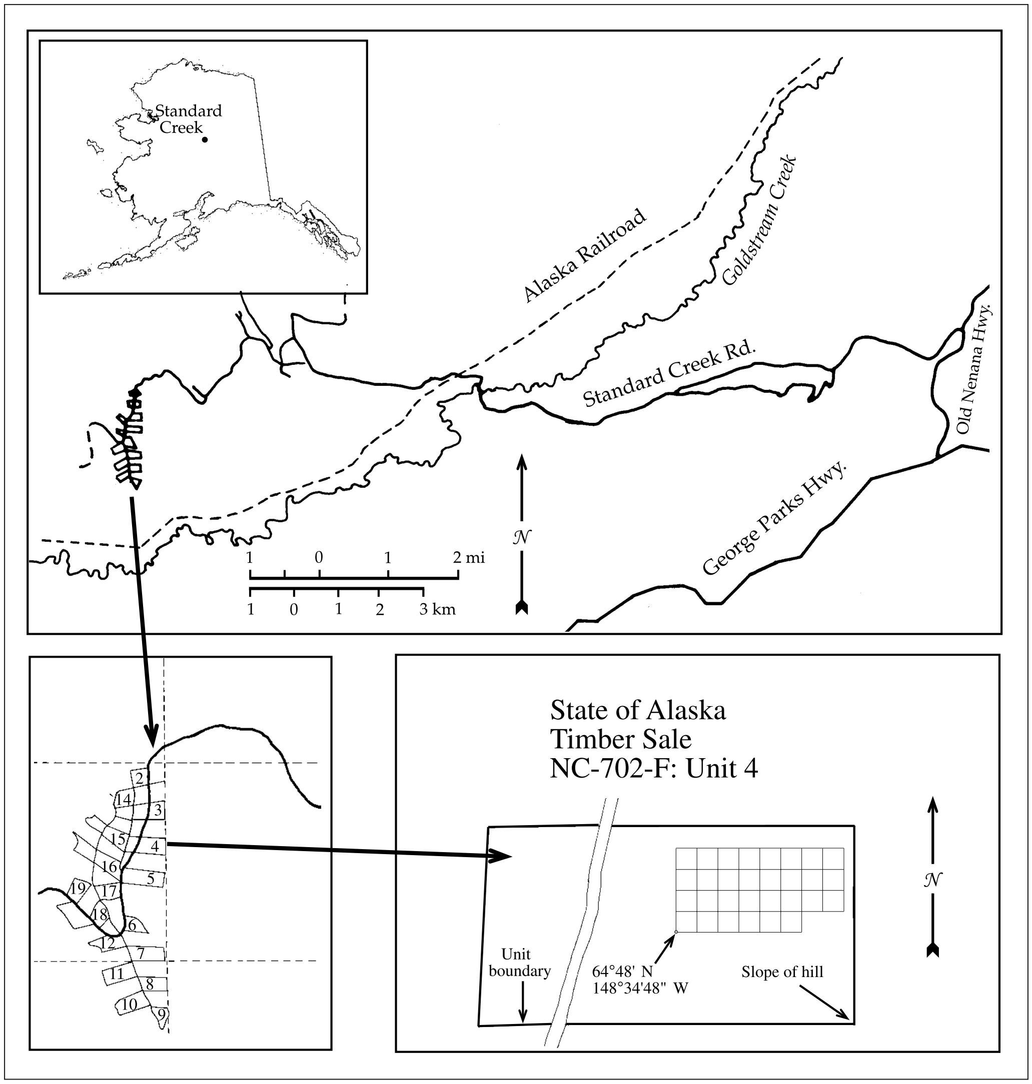

Figure 1—The Standard Creek study site area, interior Alaska.

the Northern Forest Formation (Zasada and Packee 1995). The site is on a gentle southeast-facing slope. Before harvesting, it supported a mature, productive "closed white spruce forest" (Viereck et al. 1992) with paper birch and occasional balsam poplar. Green alder was a major component of the understory, reaching a height of 16 feet (5 m). Other common understory plants were low-bush cranberry (*Vaccinium vitis-idaea* L.), fireweed (*Epilobium angustifolium* L.), *Calamagrostis*, highbush cranberry (*Viburnum edule* (Michx.) Raf.), and rose (*Rosa acicularis* Lindl.). Soils at Standard Creek are well drained, moderately deep silty loams, with a parent material of micaceous loess underlain by Birch Creek schist (Rieger et al. 1963) The mature late-successional white spruce stand at Standard Creek was likely to persist until the next major disturbance event—wildfire, insect infestation, or timber harvesting. Sites such as Standard Creek are currently the main focus of timber harvesting operations in the Fairbanks area.

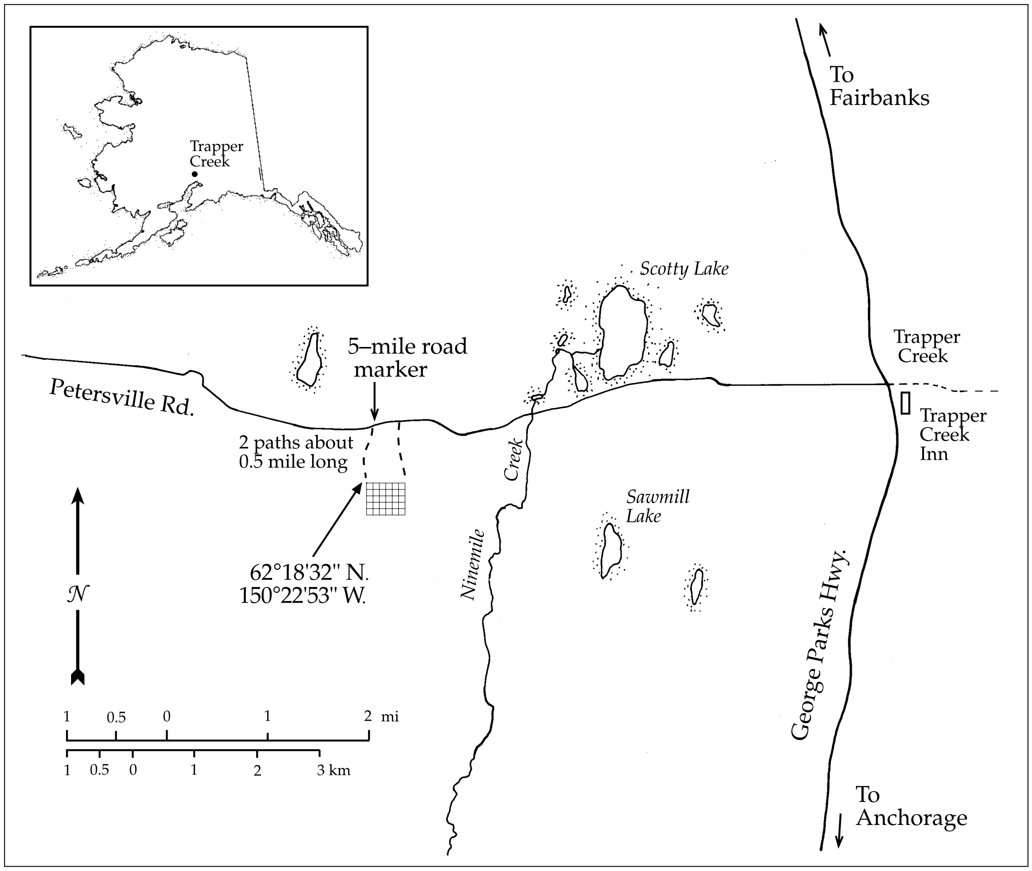

Figure 2—The Trapper Creek study site area, south-central Alaska.

The Trapper Creek site is 5 miles (8 km) west of the town of Trapper Creek (fig. 2). Mean annual temperature is 29 °F (-1.2 °C), and mean annual precipitation is 40 inches (104 cm). The site is part of the "Susitna-Matanuska valley zone" of the Northern Forest Formation (Zasada and Packee 1995). The study site is flat and moderately well drained, with silt loam soils of the Rabideau series (Schoephorster and Hinton 1973). Before harvesting, the site supported a very open, 100-year-old stand of paper birch, with occasional small-diameter white spruce. (A few large-diameter white spruce were removed in a house-log sale before this study began.) Many of the birch had been colonized by a stem-decaying fungus (*Phellinus igniarius* (L.:Fr.) Quel.). The forest understory consisted of green alder, devil's club (*Oplopanax horridus* (Sm.) Miq.), *Calamagrostis*, elderberry (*Sambucus racemosa* L.), shield fern (*Dryopteris dilitata* (Hoffm.) Gray), and woodland horsetail (*Equisetum sylvaticum* L.). The alders were 10 to 16 feet (3 to 5 m) tall. The soils at Trapper Creek have a 0.4-inch (1-cm) thick volcanic ash layer at about the 6-inch (15-cm) depth, believed to have been deposited during an eruption of Hayes volcano 3,650 (±150) years ago (Beget et al. 1991). Little information is available on the vegetation of south-central Alaska, and the successional dynamics of these very open, overmature birch stands are not well understood. Stands like the study area at Trapper Creek are the most

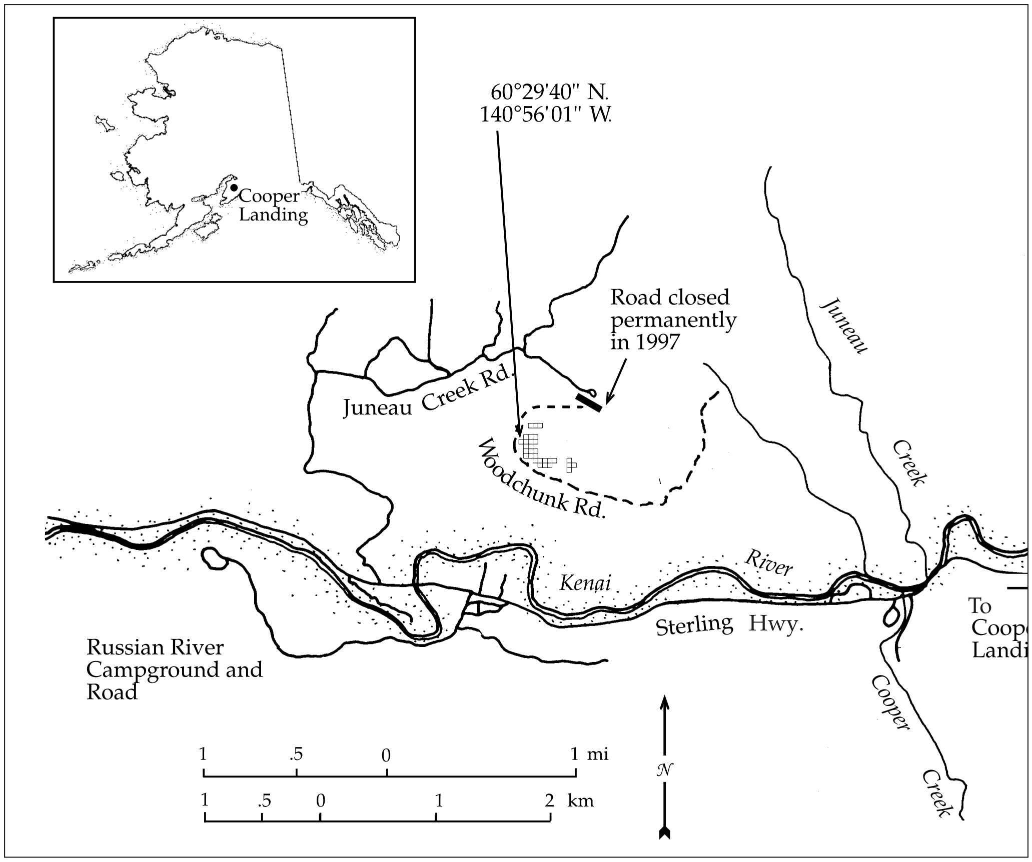

Figure 3—The Cooper Landing study site area, Kenai Peninsula, Alaska.

common forest type in that part of the state, occupying over 117,000 acres (290 000 ha) (Alaska Department of Natural Resources 1991). They typically include few young spruce trees, and stands of mature spruce are relatively uncommon in the region. Speculation on the origin of this large area of a single forest type has included catastrophic wildfire, past insect infestations, and preferential harvesting of spruce at the start of the 20th century (USDA Soil Conservation Service 1986).

The Cooper Landing site lies 1.8 miles (3 km) west of the town of Cooper Landing on the Kenai Peninsula (fig. 3). Mean annual temperature is 44 °F (7 °C), and mean annual precipitation is 26 inches (67.5 cm). The site is part of the "Kenai and Alaska Peninsulas zone" of the Northern Forest Formation (Zasada and Packee 1995). The study site is on a nearly level bench, with a parent material of silty sand underlain by glacial gravel. The soils, typical of the "alluvial and till bench land type" (USDA Forest Service 1980) are well drained, with a fine sandy loam texture. The mineral soil is capped with 4 to 6 inches (10 to 15 cm) of volcanic ash, most likely from more than one volcanic event. Before harvesting, the site supported a mature mixed stand of Lutz spruce (*Picea Xlutzii* Little) and white spruce, with occasional paper birch and mountain hemlock (*Tsuga mertensiana* Bong.) Sarg.). Lutz spruce is a hybrid of white spruce and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (Little 1953). In 1992, the stand was about 110 years old. The understory was Sitka alder, growing to a height of 12 feet (4 m), rusty menziesia (*Menziesia ferruginea* Sm.), and bunchberry (*Cornus canadensis* L.). Reynolds (1990) described this vegetation type as a "closed *Picea Xlutzii-Betula papyrifera/Menziesia ferruginea-Rubus pedatus/Gymnocarpium dryopteris/ Peltigera* spp.-*Pleurozium* spp." community. On the Kenai Peninsula, white and Lutz spruce are typically replaced by the shade-tolerant mountain hemlock (Reynolds 1990). By 1992, however, virtually all spruce trees on the Cooper Landing study site were dead, a result of a major infestation of spruce beetles (*Dendroctonus rufipennis* (Kirby)) that had affected the area for 20 years (Holsten 1994, van Hees and Larson 1991).

Preharvest Stem Mapping

At each site, a grid of thirty 56- by 56-foot (17- by 17-m) plots was established in units already laid out for timber sales. (This plot size was chosen to accommodate a post-harvest plantation of seven rows of seven trees at 8-foot (2.4-m) spacing.) At Standard Creek and Trapper Creek, grids were continuous; at Cooper Landing, the grid was broken into three sections to avoid patches of hemlock leave trees and one large, dense alder thicket containing no merchantable trees. The location of each live alder stem occurring in the 30-plot grid was recorded to the nearest foot, and its diameter at the forest floor was recorded.

Soil Sampling

Two series of soil samples were collected. In the first set, 50 cores were collected from each site: 5 from beneath each of five different clumps of alder and 5 from each of five locations supporting typical understory vegetation other than alder. Because few alders occurred within the grid of study plots at Cooper Landing, alder soils were collected outside the grid at that site. Cores extended from just below the litter layer down to and including the top 2 inches (5 cm) of mineral soil; organic and mineral layers were sieved together before analysis. After the alder stem maps were produced, and the sites harvested, a second set of samples was collected from 8- by 8-foot cells of known preharvest alder stem density. Three cores were collected at randomly chosen locations in each cell; in this series, the organic soil layers were separated from and analyzed separately from the mineral soil layers. Total nitrogen content, pH, soil organic matter content, and phosphorus and potassium concentrations were determined. A more detailed description of soil sample collection and analysis is given in Wurtz (1995b).

Harvesting Methods

The Standard Creek site was harvested by feller-buncher between November 1992 and February 1993. The harvesting operation left a heavy load of slash that would have made planting at precise spacing difficult. In May 1993, the slash was pushed into piles near the landings by using a bulldozer with a straight-edged blade. At the Trapper Creek site, trees were widely spaced and interspersed with thickets of alder. The hand-felling and rubber-tired skidding operation conducted there in March 1993 did not disturb the thickets enough to allow for planting. Consequently, the site was scarified with a bulldozer and straight-edged blade in May 1993. The operator was instructed to scrape alder stems off at the base and to tear up the vegetative mat to about an 8-inch (20-cm) depth. Trees at the Cooper Landing site were felled in September 1992 with a tracked feller-buncher and skidded to landings with a rubber-tired grapple skidder. No site preparation was done at Cooper Landing.

Seed Collection—Seedling Production Methods

Alder seed was collected near each of the three sites in September 1991. As alder cones ripen, they turn from green to brown, and the cones scales gradually separate, allowing seeds to disperse. The rate at which this happens depends on the weather: warm sunny days lead to rapid ripening and dispersal, whereas cold cloudy days lengthen ripening time. To maximize seed maturity, I delayed collecting cones as long as possible, collecting just before seed had begun to disperse. After collection, cones were spread out and air-dried at room temperature until fully brown and open. Shaking cones in paper bags separated the seeds from the cones. Seeds were stored frozen in plastic bags before sowing. Spruce seed came from collections of the State of Alaska and, for the Cooper Landing study site, the Chugach National Forest. Recommended spruce cone collection and handling methods are described in Alden (1985) and Eremko et al. (1989).

Containerized seedlings of both spruce and alder were produced on contract by Pelton Reforestation, Maple Ridge, British Columbia, in styroblock 415D containers.[1] These containers are 1.5 inches (4 cm) in diameter at the top, 6 inches (15 cm) deep, and have a volume of about 10 cubic inches (170 cm^3). There are 77 such cells per block. Because of restrictions on shipping soil from Alaska to Canada, the alder growing medium was inoculated with soil collected from a stand of green alder growing near the nursery. Seeds were sown in January 1992 in the greenhouse. Spruce seedlings were lifted in November of that year and kept frozen until shipping to Alaska in May 1993. Alder seedlings were maintained in containers from January 1992 until May 1993, when they were lifted shortly before shipping. At the time of lifting, they were 8 to 12 inches (20 to 30 cm) tall, were well nodulated, and had been leafed out for about 2 months.

This was Pelton’s first attempt at growing containerized alder, and fewer than the required number of alder were successfully produced. I therefore used alder wildlings to fill in the remaining alder locations. Wildlings were collected in April 1994 (before bud burst), along roadsides and in gravel pits near all three study sites. Such disturbed locations sometimes have large populations of 2- or 3-year-old alder seedlings, often unbranched, and often growing with little root entanglement. I grasped the alders by the stem just above the soil surface and gently pulled them up. I then shook the sand or soil from their roots. The wildlings were well nodulated. They were bundled in groups of 10 and their roots wrapped in wet newspaper followed by plastic wrap. Wildlings were refrigerated in the dark until outplanting in June 1994. At the time of collection, they ranged in height from 18 to 30 inches (45 to 75 cm).

Statistical Design, Plantation Layout, and Plot and Seedling Numbering System

Using understory alder stems collected before harvest at the Trapper Creek site, I developed an equation relating stem diameter to aboveground alder biomass (Wurtz 1995b). This model was used to estimate the total aboveground alder biomass that occurred before harvesting in each 56- by 56-foot (17- by 17-m) plot. Each plot would be planted with a 7 by 7 grid of white spruce at 8-foot spacing and a variable number of alders (table 1). To assign plantation types, the 30 plots at each site were ranked

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1— Explanation of plot planting codes

Plot code	Spruce planted	Alders planted
100	Spruce at 8-foot spacing	None
121	Spruce at 8-foot spacing	Two alders 1 foot away from each spruce
122	Spruce at 8-foot spacing	Two alders 2 feet away from each spruce
141	Spruce at 8-foot spacing	Four alders 1 foot away from each spruce
142	Spruce at 8-foot spacing	Four alders 2 feet away from each spruce
NR	None	None

Table 2— Number of stems and aboveground biomass estimates per 56- by 56-foot plot for preharvest understory alders at each study site[a]

	Standard Creek			Trapper Creek			Cooper Landing		
Block	Plot code	Alder biomass	Stem	Plot code	Alder biomass	Stem	Plot code	Alder biomass	Stem
		Kg per plot[b]	*No.*		*Kg per plot*	*No.*		*Kg per plot*	*No.*
A	NR	53	80	NR	0	0	NR	0	0
	141	69	86	121	0	0	100	0	0
	100	82	57	100	0	0	121	0	0
	142	112	92	141	3	1	122	0	0
	121	116	129	122	5	5	141	0	0
	122	116	81	142	6	6	142	0	0
B	142	131	110	142	9	11	NR	0	0
	NR	133	77	NR	14	14	100	0	0
	141	133	171	121	20	6	121	0	0
	122	134	122	141	33	30	122	0	0
	121	164	98	122	33	21	141	0	0
	100	177	98	100	34	8	142	0	0
C	142	187	175	122	36	9	NR	0	0
	141	190	207	100	48	37	100	0	0
	NR	203	200	121	50	35	121	0	0
	100	206	198	NR	55	14	122	0	0
	122	209	104	122	57	28	141	0	0
	121	213	149	142	66	32	142	0	0
D	121	225	159	NR	79	45	141	1	2
	NR	234	138	141	89	75	NR	1	1
	142	235	158	100	106	22	122	2	5
	141	242	162	121	109	47	121	4	7
	122	242	179	142	157	67	142	8	6
	100	244	266	122	159	58	100	18	11
E	141	274	142	NR	180	72	142	19	15
	NR	282	237	141	181	107	121	19	15
	122	292	201	121	182	44	122	21	15
	142	307	136	122	218	123	141	23	15
	100	317	300	142	312	139	NR	37	29
	121	521	308	100	329	187	100	43	11

[a] Plots were assigned to blocks by ranking biomass estimates, with plots supporting the least alder biomass assigned to block A and plots with the most biomass assigned to block E. At all 3 sites, plot planting codes were assigned randomly to the 6 plots in each block.

[b] Multiply kilograms by 2.21 to find pounds.

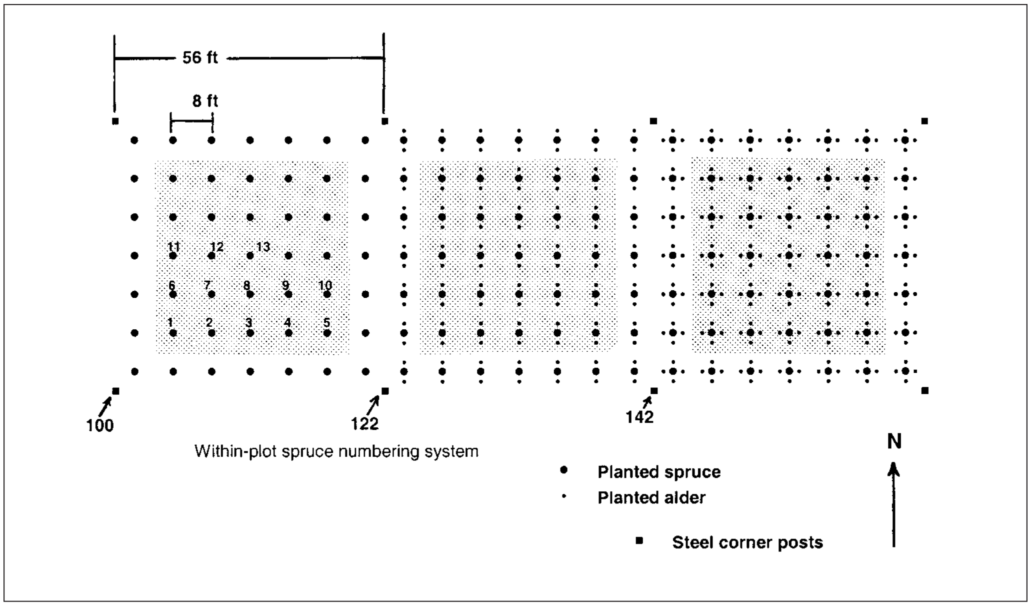

Figure 4—Seedling orientation and spacing in three types of 56- by 56-foot (17- by 17-m) plantation plots. Shaded areas indicate locations of tagged and measured spruce seedlings; seedlings outside shaded areas function as buffer strips. Plot codes for each sample plot are shown at the southwest corner post of the plot. Plot code 100=spruce planted at 8-foot (2.4-m) spacing; plot code 122=spruce at 8-foot (2.4-m) spacing and two alders planted 2 feet (0.6 m) away from every spruce; plot code 142=spruce at 8-foot (2.4-m) spacing and four alders planted 2 feet (0.6 m) away from every spruce.

according to preharvest aboveground alder biomass and divided into five blocks of 6 plots (table 2). Blocks were designated A, B, C, D, and E, with block A having supported the least preharvest alder biomass and block E having supported the most. Within each block, plantation type (plot code) was randomly assigned to plots to generate a randomized complete block statistical design. Because of significant ecological differences between the three sites, three separate analyses were done.

Containerized spruce and alder seedlings were planted in late May and early June 1993. Alder wildlings were filled in during June 1994. Nothing was planted in the "natural regeneration" plots. Within each plot, only the interior 25 planted spruce (a 5 by 5 grid) were tagged and measured, leaving a buffer strip of spruce and associated alders surrounding the measured seedlings (fig. 4). Because alders sprout readily from damaged root clumps, natural alder sprouts likely would appear in plots where alder had occurred before harvesting. No efforts were made to control or remove these natural sprouts.

Spruce seedlings were tagged with heavy-weight aluminum tags stamped with tree and plot number. Tags were attached with heavy-gauge wire coated with pink plastic; initially the wires were fastened so as to loosely encircle the main stem of each seedling. After the fifth growing season, tags were removed and reattached so as to hang from a low branch and not encircle the stem. Each plantation was marked with 8-foot steel posts at all four corners of each plot. The post at the southwest corner of each plot was labeled with an aluminum tag with plot number and location within the plantation stamped on it (figs. 5-7). Posts that were not located at the southwest corner of any plot were labeled "B" for border.

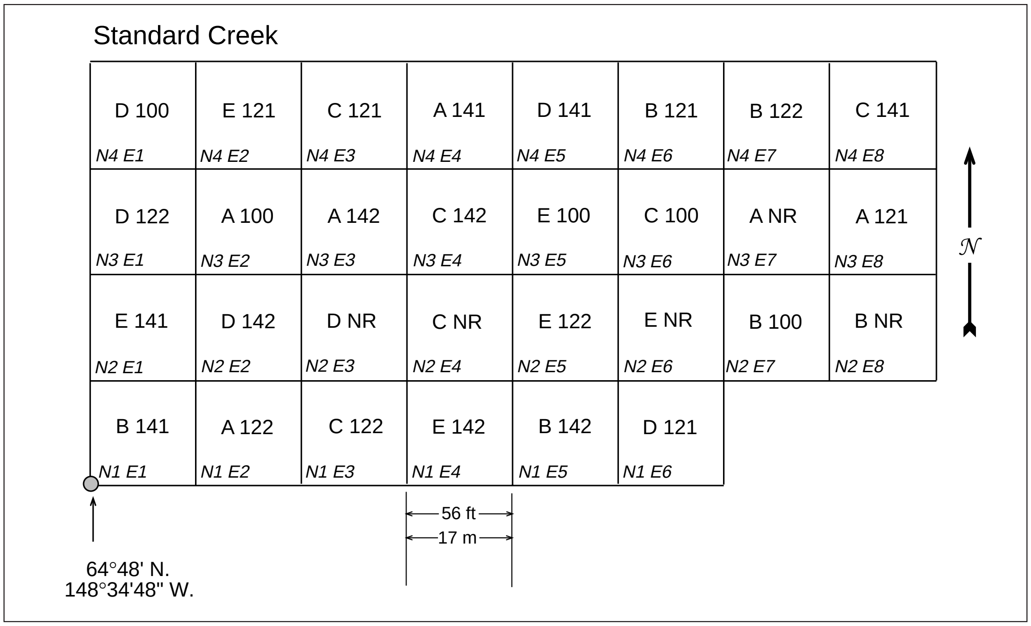

Figure 5—Plot map for the Standard Creek study site. Alphanumeric codes in the center of each plot refer to experimental block and planting combination (see table 1). Codes in the lower left corner of each plot give plot location relative to the origin.

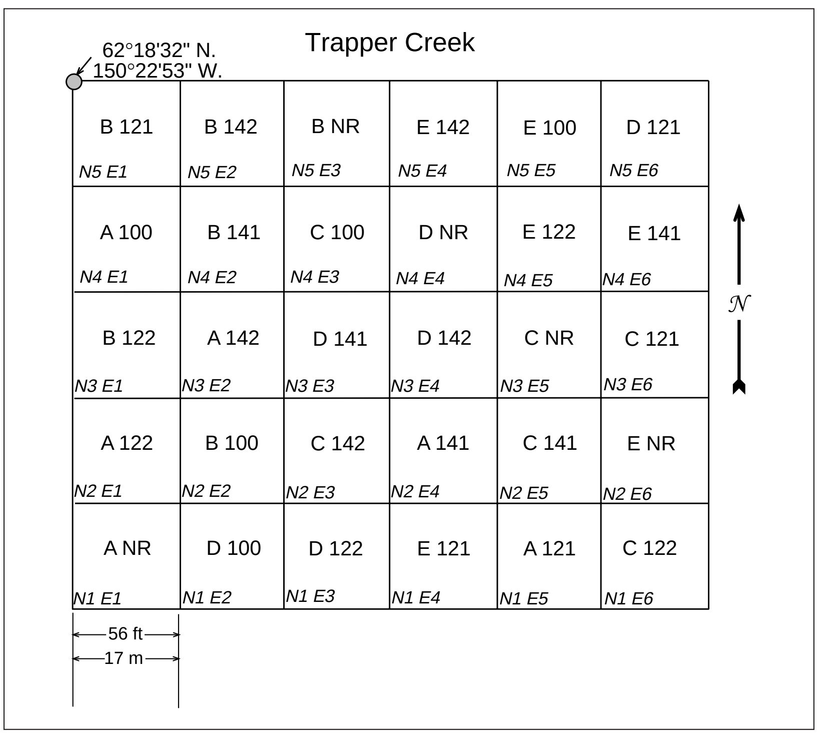

Figure 6—Plot map for the Trapper Creek study site. Alphanumeric codes in the center of each plot refer to experimental block and species combination (see table 1). Codes in the lower left corner of each plot give plot location relative to the origin.

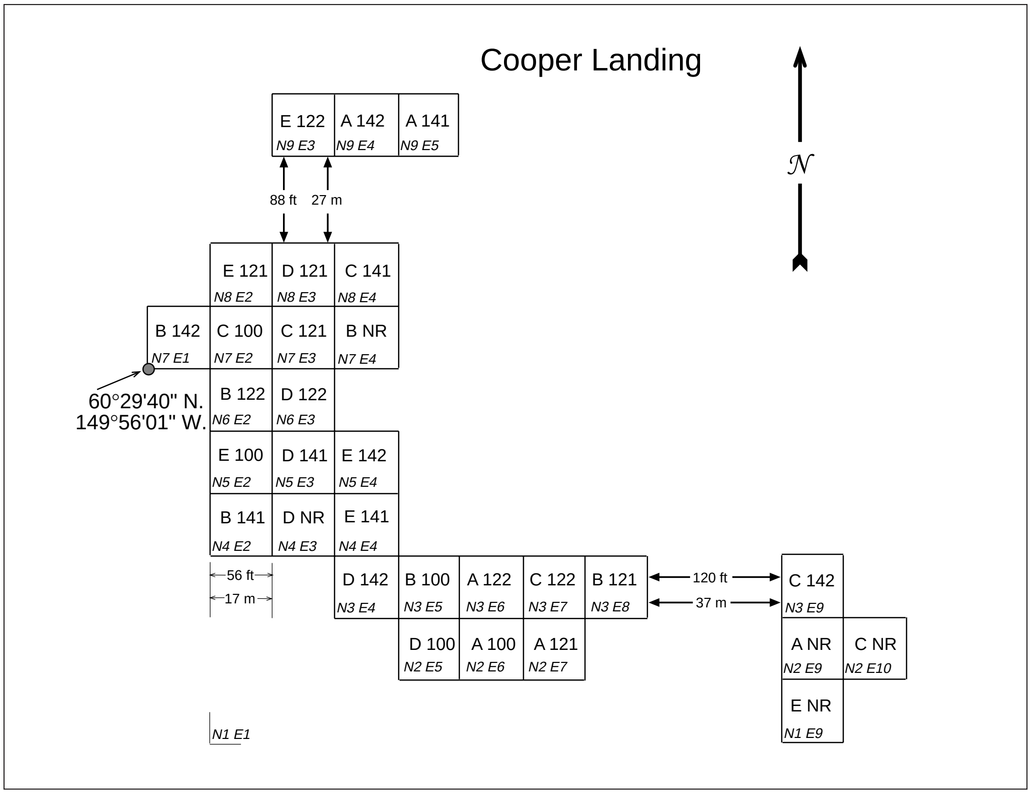

Figure 7—Plot map for the Cooper Landing study site. Alphanumeric codes in the center of each plot refer to experimental block and species combination (see table 1). Codes in the lower left corner of each plot give plot location relative to the origin.

At the Cooper Landing site, two plots on the west side of the original grid were destroyed during the logging and road-building operation. Two new plots (A121 and BNR) were established to substitute for them, but no preharvest alder data were available for the new locations (fig. 7).

Seedling Growth Measurements

Height and ground-line diameter of spruce seedlings were measured at the time of planting (before bud burst for the 1993 growing season) and again after the 1994, 1995, and 1997 growing seasons. Planted alders were neither tagged nor measured. Their survival was assessed at the end of the 1994 and 1995 growing seasons. At the end of the 1995 growing season, alders at the Cooper Landing site only were visually assessed and assigned to one of three size classes: small, medium, or large, indicating the amount of growth since planting.

Associated Vegetation

The percentage of cover of associated vegetation was estimated at all ninety 56- by 56-foot (17- by 17-m) plots during July 1994. Three planted spruce seedlings were randomly chosen in each plot, and a circular subplot of 3.28 square feet (1 m^2) was centered on each seedling. (For the natural regeneration plots, the coordinates of three sampling locations were randomly chosen.) Ocular percentage of cover estimates were made by species. Cover from the planted seedlings themselves was not included in the estimates.

Results and Discussion

Preharvest Stem Mapping

The distribution of naturally occurring alder was remarkably even at Standard Creek and noticeably clumped at Cooper Landing (as evidenced by the sparseness of alder within the plot grid and the dense alder thickets outside it). The Trapper Creek site had an intermediate distribution, with alders clumped in some areas and widely dispersed or absent in others. The Standard Creek grid had the most alder occurring in the understory before harvest, with 2,138 stems per acre (5,283 stems per ha), and the Cooper Landing grid had the fewest: 60 stems per acre (149 stems per ha). At Standard Creek, one 56-foot square plot had 308 alder stems and an estimated 1,146 pounds (520 kg) of aboveground alder biomass (table 2). In comparison, boreal jack pine stands in Manitoba and Saskatchewan, Canada, supported about 220 understory alder stems per acre (550 stems per ha) (Vogel and Gower 1998). Although alders often are associated with wet sites (Newton et al. 1968), Cooper Landing was the only site in this study where alder distribution seemed related to soil moisture; the alders there grew along a small stream skirting the northern edge of the plot grid, and in an obvious moist depression just outside the southern edge. Preharvest stand characteristics and alder stem maps for each site are given in Wurtz (1995b).

Soil Chemistry Results

The relation of total soil nitrogen to the existence or the amount of alder varied by time of sampling and by site (table 3). Before harvesting, soils with alder had higher nitrogen concentrations than soils without alder, but this difference was statistically significant only at Cooper Landing. After harvesting, soils with alder at Trapper Creek had significantly more nitrogen than soils without alder, but at Standard Creek, they had significantly less. At Cooper Landing, soils with alder collected after harvesting tended to have less nitrogen than soils without alder, but this difference was not statistically significant. In essence, there was no consistent relation between preharvest alder stem distribution and total soil nitrogen reserves. Though between-site differences could not be compared statistically, Trapper Creek soils of any origin had more nitrogen than soils from the other two sites. Complete soil chemistry results are given in Wurtz (1995b).

There are several possible reasons for the lack of a consistent alder effect on total soil nitrogen. First, any nitrogen that was added to these relatively infertile soils may have been taken up, sequestered in the overstory, and removed in the logging operation. Weetman and Webber (1972) estimated that 357 pounds per acre (400 kg per ha) of nitrogen would be removed by full-tree logging of spruce in eastern Canada. In their study of jack pine stands in Manitoba and Saskatchewan, Vogel and Gower (1998) felled trees to assay all components of the overstory. Although they found that stems, branches, and foliage of the overstory, as well as the feathermoss layer, have more nitrogen in stands with alder than in stands lacking alder, the amount of nitrogen in the overstory and moss layers was small compared to the amount in soil. The simple total soil nitrogen determination used in the present study was too limited to assess the possibility of nitrogen sequestration and removal.

A second possible reason for the lack of a consistent alder effect on total soil nitrogen is shading. Because nitrogen-fixation rates are related to photosynthetic rates (Gordon and Wheeler 1978), alders beneath a dense canopy of trees would have lower rates of fixation than if they were unshaded (Attiwell and Leeper 1987, Bormann and Gordon 1989). The sites used in this study spanned a range of overstory conditions. Trapper Creek had a very open overstory, Standard Creek had a very dense overstory, and

Table 3— Soil nitrogen values from areas with and without preharvest alder (mean ± 1 SE) during 2 sampling periods

Sampling period and vegetation type	Mean alder biomass	Total nitrogen[a]		
	Grams per square meter[b]	- - - - - - - - - - - *Percent*	- - - - - - - - - - -	
Standard Creek:				
Preharvest—			Mixed soil[c]	
Alder	—		0.60 (0.1)	
No alder	—		.56 (.0)	
			ns	
Postharvest—		Mineral		Organic
Heavy alder[d]	4491 (188)	.09 (.00)		.57 (.05)C
Moderate alder	870 (7)	.09 (.01)		.85 (.09)C D
No alder	0	.09 (.01)		.92 (.07)D
		ns		$p = 0.0154$
Trapper Creek:				
Preharvest—			Mixed soil	
Alder	—		.84 (.0)	
No alder	—		.64 (.1)	
			ns	
Postharvest—		Mineral		Organic
Heavy alder	6903 (1468)	.44 (.01)C		1.51 (.22)
Moderate alder	960 (7)	.46 (.01)C		1.65 (.27)
No alder	0	.36 (.02)D		1.32 (.18)
		$p = 0.0096$		ns
Cooper Landing:				
Preharvest—			Mixed soil	
Alder	—		.62 (.1)	
No alder	—		.33 (.0)	
			$p = 0.0393$	
Postharvest—		Mineral		Organic
Heavy alder	4029 (1268)	.15 (.01)		.50 (.06)
Moderate alder	295 (43)	.19 (.04)		.74 (.20)
No alder	0	.19 (.01)		.73 (.06)
		ns		ns

[a] Statistical comparisons were made among vegetation types within sampling periods and sites; ns = not significant; when a probability value is given, values followed by the same letter are not significantly different. p=probability.

[b] Multiply grams per square meter by 0.000204 to find pounds per square foot.

[c] During preharvest sampling, the organic and mineral portions of the soil cores were passed through a sieve and then analyzed together. During postharvest sampling, the organic and mineral portions of the cores were analyzed separately.

[d] During postharvest sampling, sampling locations were chosen based on the amount of understory alder that had been mapped there before the site was harvested.

Cooper Landing had an overstory that was shifting from very dense to very open as the beetle-killed spruce trees gradually dropped their needles. There was no clear correspondence, however, between these canopy conditions and soil nitrogen levels.

Mixing of the forest floor during the harvesting and site preparation operations also may have contributed to the lack of a relation in the postharvest samples. This seems unlikely, however, because the Trapper Creek site was both most disturbed by the timber harvesting and site preparation operation and the only site where soils with alder collected after harvesting had significantly more nitrogen than soils without alder.

In any event, much of the work documenting the ability of alders to enhance soil nitrogen has been conducted in pure stands, where soils are comparatively homogeneous. When alders occur in mixtures with other species, the underlying soil mosaic becomes more complex. Among four studies that explicitly examined a relation between alder stem locations and the spatial extent of soil nitrogen reserves (Dawson et al. 1983, Heilman 1983, Rhoades and Binkley 1992, Valentine 1990), only Rhoades and Binkley found a close relation.

Vegetation Sampling Results

By the second year after planting, total cover of all species of associated vegetation ranged from a low of 19 percent cover to a high of 54 percent (table 4). *Calamagrostis* was common at Standard Creek and Trapper Creek but was virtually absent at Cooper Landing. Other common species at Standard Creek were horsetail (*Equisetum arvense*), prickly rose, and fireweed. At Trapper Creek, common species were *Calamagrostis*, devil's club, horsetail, and elderberry. At Cooper Landing, fireweed, horsetail, rusty menziesii, and elderberry were common.

Including alder in a plantation had no effect on either the percentage of cover of any species of associated vegetation or the amount of all species combined. This likely was due to the slow growth of the planted alder (see below).

Seedling Survival

After three growing seasons, alder survival ranged from 58 to 89 percent and was highest at Trapper Creek (table 5). No differences in survival existed between nursery-grown alders and alder wildlings. After five growing seasons, spruce survival ranged from 76 to 95 percent. The spruce seedlings at Standard Creek survived as well as the highest rate of survival in a different plantation study begun near Fairbanks about the same time.[2] In that study, the survival of 415D stocktype trees differed greatly by planting unit, ranging from 25 to 85 percent after 5 years. Spruce survival in the present study, however, was lower than smaller Ray Leach-type containerized spruce seedlings planted on a flood-plain site near Fairbanks in 1983 (Youngblood and Zasada 1991). There, mean survival after 5 years was greater than 90 percent on both scarified and unscarified surfaces.

Alder Growth

Despite good survival, the growth and vigor of alders planted in this study were poor. Many grew little in the first 3 years after planting and appeared to be barely surviving. Most of the growth that occurred was elongation of the original stem; few plants produced additional stem sprouts. Alder growth data were collected at the Cooper

[2] Graham, J.; Wurtz, T.L. [In prep.] Growth of white spruce stock types in interior Alaska.

Table 4— Estimated percentage of cover (with mean ± 1 SE shown in parentheses) of all species combined and 8 individual plant species by plot code in 1994

Site	Plot code[a]	Total cover	CACA[b]	EQAR	ROAC	EPAN	OPHO	EQSI	MEFE	SARA
Standard										
Creek	100	35.6 (4.9)	11.3 (5.0)	11.0 (5.2)	7.0 (3.5)	0.6 (0.4)	0	0	0	0
	121	46.3 (9.0)	10.0 (7.7)	13.0 (6.0)	4.3 (1.5)	.3 (0.3)	0	0	0	0
	122	48.6 (7.0)	9.0 (3.5)	25.3 (7.7)	8.3 (3.3)	1.7 (1.2)	0	0	0	0
	141	32.3 (5.0)	2.6 (1.5)	8.3 (3.8)	9.6 (4.8)	1.0 (0.6)	0	0	0	0
	142	43.3 (5.4)	2.0 (1.6)	21.6 (3.8)	3.3 (1.8)	.3 (0.3)	0	0	0	0
	NR	40.6 (9.9)	2.6 (1.4)	15.6 (5.0)	9.6 (2.9)	1.0 (0.4)	0	0	0	0
Trapper										
Creek	100	25.6 (8.4)	.6 (0.6)	0	0	0	5.7 (1.6)	3.4 (2.2)	0	13.3 (7.5)
	121	40.3 (8.3)	7.3 (5.3)	0	0	0	9.6 (4.1)	9.3 (3.1)	0	12.6 (6.5)
	122	29.6 (6.5)	4.3 (1.7)	0	0	0	9.3 (3.3)	5.3 (3.6)	0	11.3 (5.3)
	141	9.6 (5.2)	3.3 (3.3)	0	0	0	8.6 (3.1)	5.3 (1.8)	0	4.3 (1.1)
	142	34.6 (8.7)	12.6 (7.1)	0	0	0	6.0 (0.8)	8.0 (1.6)	0	6.6 (3.9)
	NR	24.6 (6.7)	1.3 (0.9)	0	0	0	9.0 (2.1)	4.0 (1.1)	0	3.6 (2.8)
Cooper										
Landing	100	54.3 (9.2)	3.3 (1.8)	0 (0.0)	2.3 (2.3)	7.3 (2.7)	0	5.3 (3.4)	11.6 (4.4)	1.0 (0.6)
	121	43.3 (8.6)	1.0 (0.6)	0 (0.0)	0 (0.0)	7.3 (3.7)	0	13.3 (8.1)	4.3 (2.7)	1.6 (1.0)
	122	32.0 (3.9)	0 (0.0)	0 (0.0)	.3 (0.3)	3.3 (2.9)	0	8.6 (3.6)	7.3 (4.6)	1.3 (0.9)
	141	29.3 (9.9)	0 (0.0)	.6 (0.6)	0 (0.0)	4.3 (1.7)	0	4.3 (3.9)	2.6 (1.1)	0 (0.0)
	142	41.6 (5.6)	1.6 (1.6)	3 (0.3)	0 (0.0)	4.0 (3.5)	0	2.0 (2.0)	7.0 (3.3)	1.7 (1.6)
	NR	37.0 (8.4)	0 (0.0)	0 (0.0)	3.6 (2.9)	8.6 (3.2)	0	1.0 (0.4)	6.3 (1.9)	2.6 (1.5)

[a] Plot code 100=only spruce planted; code 121=two alders planted 1 foot away from each spruce; code 122=two alders planted 2 feet away from each spruce; code 141=four alders planted 1 foot away from each spruce; code 142=four alders planted 2 feet away from each spruce; NR=natural regeneration plot.

[b] CACA=*Calamagrostis canadensis;* EQAR=*Equisetum arvense*; ROAC=*Rosa acicularis*; EPAN=*Epilobium angustifolium*; OPHO=*Oplopanax horridus*; EQSI=*Equisetum silvaticum*; MEFE=*Menziesia ferruginea*; and SARA=*Sambucus racemosa*.

Table 5—Percentage of survival of spruce and alder during the first years after planting[a]

Species and site	1994	1995	1997
		Percent	
Alder:			
Standard Creek	63-86	58-78	—
Trapper Creek	83-94	77-89	—
Cooper Landing	68-82	67-71	—
Spruce:			
Standard Creek	84-95	81-93	80-88
Trapper Creek	94-98	88-96	76-88
Cooper Landing	97-99	96-98	89-95

[a] Values indicate the range of mean values among the 5 plot codes at each site.

Landing site only in 1995. That year, 30 percent of the alders were dead, and among the survivors, 8 percent were classed as small, 38 percent were of medium size, and only 22 percent were large. Even among stems classed as large, growth was mostly vertical. Their form was treelike rather than shrubby.

Zasada et al. (1987) document the survival and growth of containerized green alder seedlings after planting on four burned sites near Fairbanks. In that study, survival of the planted alder ranged from 30 to 50 percent after 6 years. The mean height of the planted alders after 6 years ranged from 27 to 65 inches (69 to 168 cm), with the best growth occurring on the most severely burned surfaces.

The poor growth of the alders planted in the present study contrasted markedly with the growth of the sprouts from alder root clumps mapped on these sites before harvesting. Though no data were collected on these sprouts (other than to include them in percentage of cover estimates), their vigor was readily apparent in the field. By 3 years after harvesting at Standard Creek, sprouts growing from surviving root clumps were noticeably taller and bushier than the planted alders. Similar results were reported by Zasada et al. (1987). On their least severely burned site, alder sprouts from surviving root clumps averaged 76 inches (195 cm) tall after 6 years, roughly 2.5 times as tall as the planted seedlings there. This vigorous growth of sprouts from already-established root systems and the fact that alder wildlings planted in a tilled field in another study grew vigorously (Wurtz 1995a) suggest that the poor growth of planted alders in the present study was due to competition from other vegetation. It seems the planted alders could not withstand the competitive environment on these recently harvested sites.

Although much research on alder has focused on its ability to compete with other species, notably Douglas-fir (Cole and Newton 1986, Shainsky et al. 1992, Shainsky and Radosevich 1992), a few studies have documented the reverse. When grown with salmonberry (*Rubus spectabilis* Pursh) in the Oregon Coast Range, red alders are one-tenth the biomass of those grown without salmonberry (Newton and Cole 1994). Eis (1981) followed the vegetative colonization of four clearcut areas in central British Columbia on which white spruce was planted immediately after logging. Three sites supported Sitka alder and one (the alluvium site) supported thinleaf alder, though Eis (1981) did not distinguish between alders establishing from seed and those sprouting from surviving root clumps. The ability of alders to colonize the harvested areas differed greatly by site. Six years after logging, the cover of all shrub species combined ranged from 8 to 37 percent on three of the sites. On the alluvium site, at 3 years after logging, shrub cover was 85 percent, of which 20 percent was thinleaf alder.

Spruce Growth

Analysis of variance (results not shown) indicated that the growth of the spruce planted in this study was not affected by the preharvest location of understory alder on any of the three sites (see cover figure).

In a study of growth decline in 40-year-old plantation spruce trees in Ontario, Hendrickson (1990) found that total soil nitrogen levels were not significantly correlated with tree growth. Highly significant correlations, however, were found between growth and concentrations of NH_4-N and NO_3-N. Data on available forms of soil nitrogen would have been valuable in the present study. Extending Hendrickson's result here, however, suggests that understory alder locations may have been no more associated with available nitrogen than they were with total nitrogen. Most of the nitrogen fixed by understory alders may have been sequestered in the overstory long before the site was harvested and planted.

More important from an operational standpoint, planting mixtures of alder and spruce had no statistically significant effect on 5-year spruce growth (figs. 8 and 9). In contrast, Ballard (1984) studied a harvested, scalped site in interior British Columbia where alders had invaded portions of the treated area. Spruce seedlings planted near invading alders grew faster than those planted in scalped areas without invading alder. The notable difference between the present study and Ballard's was likely the scalping treatment, which typically removes both the organic soil and much of the competing vegetation. The competitive environment was modified so that alder could become established, and the mineral soil was deficient enough in nitrogen that the alders likely fixed nitrogen rapidly and affected spruce growth directly.

In this study, the planted spruce grew vigorously at all three sites (tables 6 and 7, figs. 8 and 9) and in all planting combinations. At the time of planting, seedlings from the Cooper Landing seed source were largest, and those from Standard Creek were smallest, in both height and diameter. After two growing seasons, this advantage disappeared; Cooper Landing trees were smaller than seedlings from the other two sites. By 1997, after five growing seasons, Trapper Creek trees were the largest in both height and diameter, a trend that likely reflects the comparatively more fertile soils of the site. The seedlings at all three sites grew significantly more than containerized spruce planted in two other studies near Fairbanks. In a study of smaller Ray-Leach stocktype seedlings planted at a Tanana River flood-plain site (Youngblood and Zasada 1991), height growth ranged from 1.5 to 3 inches (4 to 8 cm) during the third growing season; stem diameters averaged 0.23 to 0.28 inch (5.8 to 7.1 mm) at the end of the fifth growing season. For comparison, in the present study, height increment during the third year ranged from 4.2 to 8.4 inches (11 to 22 cm) (table 6), and stem diameter after five seasons averaged from 0.56 to 0.8 inch (14.2 to 19.9 mm) (table 7). In a different study that included the same stock type used here, 415D seedlings had mean height of 28 inches (73 cm) and a mean stem diameter of 0.45 inch (11.4 mm) after five growing seasons (see footnote 2). This compares with a mean height that ranged from 29 to 39 inches (75 to 100 cm) and a mean diameter that ranged from 0.5 to 0.8 inch (14.1 to 19.9 mm) in the present study.

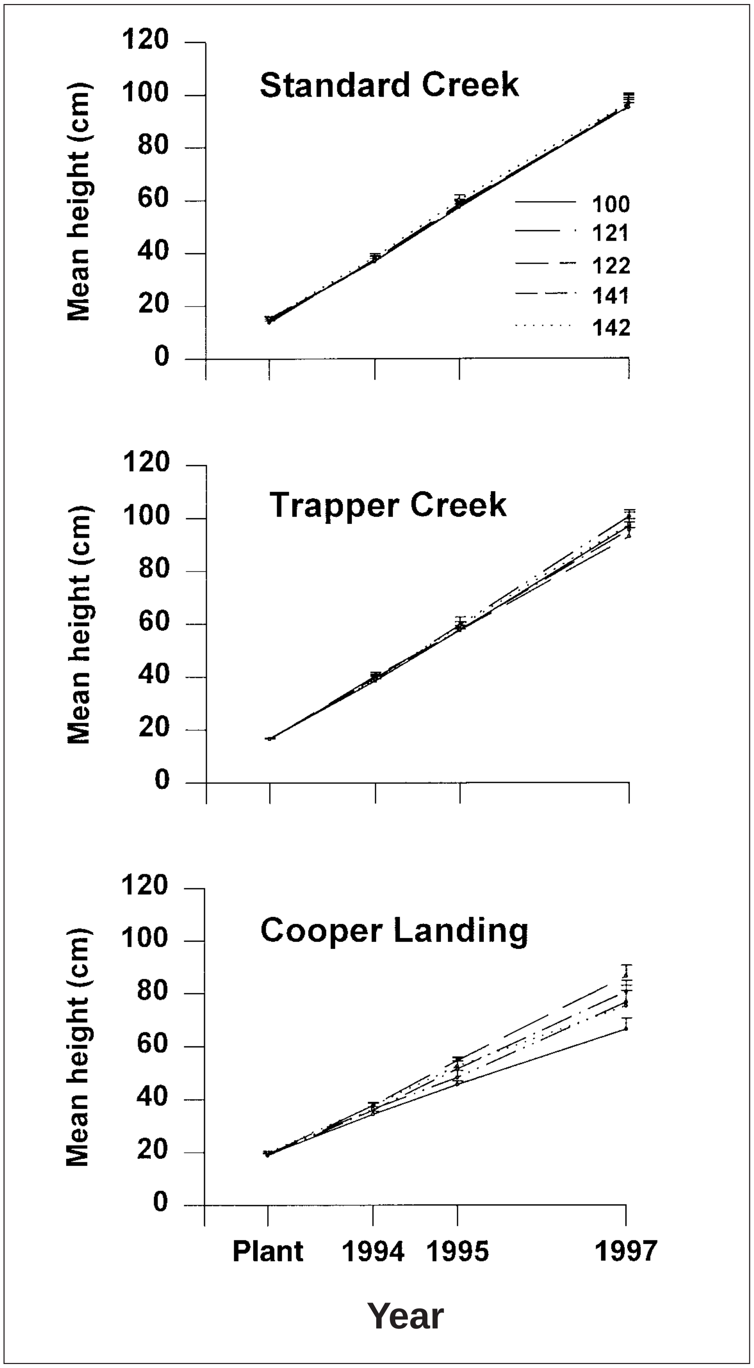

Figure 8—Height of planted spruce (mean ± 1 standard error). Plot code 100= spruce planted at 8-foot (2.4-m) spacing; plot code 121=spruce at 8-foot (2.4-m) spacing and two alders planted 1 foot (0.3 m) away from every spruce; plot code 122=spruce at 8-foot (2.4-m) spacing and two alders planted 2 feet (0.6 m) away from every spruce; plot code 141=spruce at 8-foot (2.4-m) spacing and four alders planted 1 foot (0.3 m) away from every spruce; plot code 142= spruce at 8-foot (2.4-m) spacing and four alders planted 2 feet (0.6 m) away from every spruce.

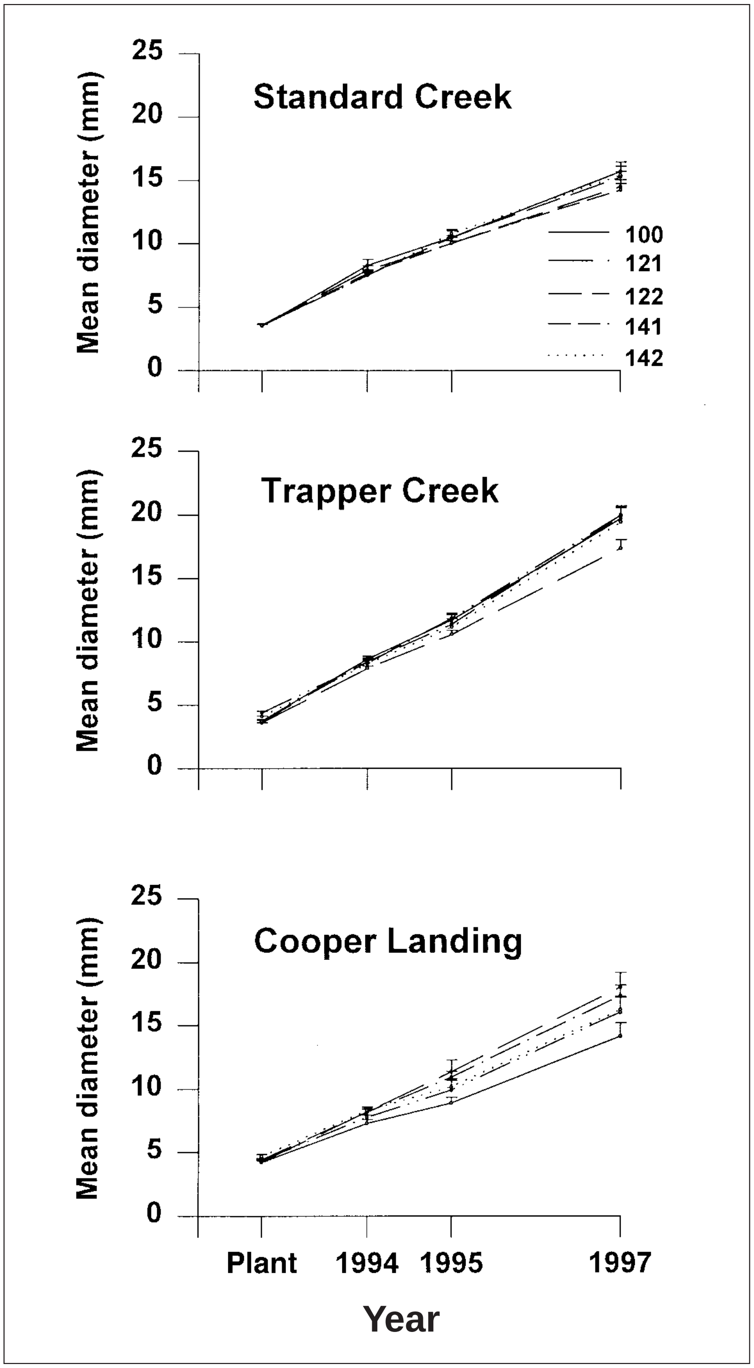

Figure 9—Diameter of planted spruce (mean ± 1 standard error). Plot code 100=spruce planted at 8-foot (2.4-m) spacing; plot code 121=spruce at 8-foot (2.4-m) spacing and two alders planted 1 foot (0.3 m) away from every spruce; plot code 122=spruce at 8-foot (2.4-m) spacing and two alders planted 2 feet (0.6 m) away from every spruce; plot code 141=spruce at 8-foot (2.4-m) spacing and four alders planted 1 foot (0.3 m) away from every spruce; plot code 142=spruce at 8-foot (2.4-m) spacing and four alders planted 2 feet (0.6 m) away from every spruce.

Table 6—Heights of planted spruce (with mean ± 1 SE shown in parentheses) at time of planting in June, 1993 and after the 1994, 1995, and 1997 growing seasons

Site	Plot code[a]	Height			
		At planting	1994	1995	1997
		Centimeters			
Standard Creek	100	15.0 (0.7)	36.8 (1.1)	57.2 (1.2)	95.1 (3.4)
	121	13.0 (.6)	37.8 (1.2)	58.6 (1.3)	95.1 (2.7)
	122	14.5 (.5)	36.9 (1.8)	58.1 (2.2)	94.8 (1.8)
	141	15.4 (.7)	37.1 (1.5)	57.6 (2.1)	96.1 (4.1)
	142	15.4 (.7)	38.5 (1.3)	60.0 (1.9)	96.5 (3.0)
Trapper Creek	100	16.7 (.2)	38.6 (.7)	57.7 (.5)	96.9 (2.8)
	121	16.5 (.3)	40.4 (1.3)	57.8 (1.8)	93.0 (3.2)
	122	16.5 (.2)	39.8 (.9)	58.1 (1.5)	95.5 (2.9)
	141	16.8 (.3)	39.4 (.8)	59.8 (1.1)	100.6 (2.5)
	142	16.5 (.2)	39.2 (1.9)	59.4 (3.3)	97.6 (4.6)
Cooper Landing	100	19.0 (.4)	34.3 (1.1)	45.5 (1.3)	66.4 (4.1)
	121	19.3 (.4)	37.5 (.5)	54.6 (2.2)	86.5 (4.3)
	122	18.8 (.7)	35.9 (1.4)	51.4 (2.9)	80.6 (4.2)
	141	19.3 (.4)	36.7 (2.2)	48.2 (2.7)	76.6 (6.5)
	142	19.9 (.6)	37.6 (1.3)	52.4 (3.1)	75.2 (5.7)

[a] Plot code 100=only spruce planted; code 121=two alders planted 1 foot away from each spruce; code 122= two alders planted 2 feet away from each spruce; code 141=four alders planted 1 foot away from each spruce; code 142=four alders planted 2 feet away from each spruce.

Conclusions

This study found inconsistent evidence for a soil nitrogen mosaic mirroring the locations of alders in the understory of mature forests. The distribution of soil nitrogen varied temporally and spatially, an indication that the factors controlling nitrogen fixation, release, and uptake in mature mixed-species forests are complex and varied. Second, alders planted in mixtures with white spruce after the sites were harvested grew too slowly to affect the rate at which other species, including *Calamagrostis*, colonized the site. Alder sprouts from root clumps that occupied the site before timber harvest grew much more vigorously than the planted alders; these sprouts are more likely than the planted seedlings to impact the nitrogen dynamics of sites where they were abundant. Finally, most likely because the alders grew so slowly, planting mixtures of alder and white spruce seedlings had no effect on spruce survival or growth in the first five seasons after planting.

Table 7—Ground-line diameters of planted spruce (with mean ± 1 SE shown in parentheses) at time of planting in June 1993 and after the 1994, 1995, and 1997 growing seasons

Site	Plot code[a]	Diameter: At planting	1994	1995	1997
		Millimeters			
Standard Creek	100	3.5 (0.1)	8.3 (0.5)	10.5 (0.5)	15.7 (0.7)
	121	3.6 (.1)	7.9 (.3)	10.0 (.2)	14.5 (.2)
	122	3.5 (.1)	7.5 (.3)	10.5 (.1)	15.3 (.4)
	141	3.5 (.1)	7.7 (.3)	10.1 (.4)	14.2 (.8)
	142	3.6 (.1)	7.5 (.2)	10.8 (.3)	15.4 (.7)
Trapper Creek	100	3.7 (.1)	8.6 (.2)	11.7 (.4)	19.7 (.8)
	121	3.6 (.1)	7.9 (.1)	10.6 (.3)	17.3 (.6)
	122	3.7 (.1)	8.4 (.2)	11.4 (.4)	19.9 (.7)
	141	4.4 (.1)	8.3 (.2)	11.8 (.3)	19.9 (.5)
	142	4.1 (.1)	8.2 (.5)	11.1 (.6)	19.4 (1.1)
Cooper Landing	100	4.1 (.1)	7.3 (.3)	8.9 (.4)	14.1 (1.1)
	121	4.2 (.1)	8.2 (.4)	11.3 (.9)	18.1 (1.1)
	122	4.4 (.1)	8.2 (.2)	10.9 (.4)	17.3 (.8)
	141	4.3 (.1)	7.8 (.2)	9.9 (.7)	16.0 (1.2)
	142	4.6 (.1)	8.3 (.3)	10.1 (.6)	16.2 (1.1)

[a] Plot code 100=only spruce planted; code 121=two alders planted 1 foot away from each spruce; code 122= two alders planted 2 feet away from each spruce; code 141=four alders planted 1 foot away from each spruce; code 142=four alders planted 2 feet away from each spruce.

Whether the alders planted in this study will affect the growth of the planted spruce over the long term will depend on whether the alders gradually become established or gradually die out. At Standard and Trapper Creeks, the planted alders likely always will be dominated by the root-clump sprouts from alders that occupied the site before harvesting. But at Cooper Landing, the planted alders are effectively the only alders within the plot grid. The soils there are nutrient-poor and have little humus. On sites in eastern Canada with little humus, full-tree logging of spruce may deplete nitrogen reserves to the extent that fertilization is needed in the second rotation to maintain tree growth (Weetman and Webber 1972). Thus, of the three sites examined in this paper, Cooper Landing is the one most likely to benefit should its planted alders gradually become established and grow. Interestingly, Cooper Landing was the only site where growth trends among the different plantation types appear to have begun to diverge (figs. 8 and 9). Whether this trend will continue remains to be seen. Cromack et al. (1999) found no correlation between total soil nitrogen and the amount of volunteer red alder occurring in a 9-year-old Douglas-fir plantation. They suggest resampling the soils in 20 to 30 years.

From this 5-year perspective, mixed plantations of spruce and alder are clearly not justified for forest management on sites similar to those used in this study. Whether they are justified from a long-term, multiple-rotation perspective, or on other types of boreal forest sites, is not yet clear. These plantations were carefully laid out and marked with heavy-duty, long-lasting materials. Locational information, detailed site maps, and early data summaries are provided here for future evaluation of these plantations.

One useful result from this study concerns the survival and growth of alder wildlings. Alders are planted in various restoration projects around Alaska (Davidson[3], Helm 1994, Helm and Carling 1993, Helm et al. 1999, Karle and Densmore 1994). For projects that can support nursery production and shipping costs, work in the Pacific Northwest with red alder has shown nursery-grown bare-root alders to be superior to both containerized alders and wildlings (Radwan et al. 1992). For restoration projects in Alaska that cannot support those costs, wildlings may be a practical, readily available, and inexpensive option.

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[3] Personal communication. 1999. Davidson, D., soil scientist, Chugach National Forest, 3301 "C" Street 300, Anchorage, AK 99503-3998.

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Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

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Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890