Production of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, Rooted Cuttings for Reforestation by Weyerhaeuser Company

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Although most forest planting stock has historically been propagated from field-collected seed, the recent availability of high-quality genetically improved seed has spawned efforts to bulk up quantities of this material using a rooted-cutting approach. Around the world, many important timber producing conifers (*Cunninghamia lanceolata, Cryptomeria japonica, Pinus radiata, Picea mariana, P. sitchensis, P. abies*) and hardwoods (*Populus* spp., *Salix* spp., *Eucalyptus* spp.) are being propagated in this manner.

At Weyerhaeuser Company, in western Washington state and Oregon, an effort has been underway since 1986 to develop a system for commercial production of coastal Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, planting stock through cuttings. The system is being applied to bulk up seed from elite, control-pollinated (CP) families. The three-year propagation regime begins with greenhouse production of stock plants, followed by rooting of cuttings under fog, and finally finishing the rooted cuttings in an outdoor bare-root nursery. Production is currently running at about 1 million per year—enough to plant about 2000 acres. Future scale up is anticipated.

INTRODUCTION

Nearly all forest tree planting stock is propagated from seed. However, with very high quality and expensive seed now flowing from seed orchard programs worldwide, many attempts are being made to increase (bulk up) the supply of this elite genetic material using vegetative propagation through rooted cuttings (Ritchie 1991, 1993). This paper will present a brief overview of this technology as a prelude to describing a commercial scale Douglas-fir rooted cutting system now under development by Weyerhaeuser Company in western Washington state and Oregon.

REVIEW OF ROOTED-CUTTING PRODUCTION FOR REFORESTATION

Rooted cutting technology is normally employed to capture one of two opportunities. The first is to "bulk up" valuable seed supplies, the second is to "clone" valuable genotypes. In the process of bulking, relatively small numbers of copies are made of a relatively large number of genotypes. For example, 1 lb (0.46 kg) of Douglas-fir seed might produce about 20,000 seedlings under normal nursery practices. That same pound of seed can be bulked into over a million plants in one propagation cycle using rooted cuttings. Cloning, on the other hand, makes a large number of copies of a relatively small number of elite genotypes.

Cloning forest trees is difficult because each individual clone must be field tested prior to its use as planting stock. This requires several years, during which time all clones must be maintained in a juvenile state to await identification, multiplication, and propagation of the elite clones. This is expensive and cumbersome with all species but those relative few that produce juvenile material, such as basal sprouts, as mature trees. Certain species of poplar (*Populus* spp.) willow (*Salix* spp.) and eucalypt (*Eucalyptus* spp.) exhibit this property and are the subject of large-scale cloning programs in Europe, Asia, North America, Brazil, Australia, the Congo, Colombia, and other places (Leakey, 1987; Ritchie, 1993; Zobel, 1993). In Japan, sugi, *Cryptomeria japonica* D. Don, has been cloned on a massive scale for at least 500 years (Ohba, 1993) and the Chinese have cloned Chinese-fir (*Cunninghamia lanceolata* (Lamb.) Hook. f., for a millennium (Li et al., 1990; Ritchie, 1993). Other, much more recent, conifer cloning programs are those with Norway spruce, *Picea abies* L., in Germany, and black spruce, *P. mariana* (Mill.) B.S.P., in Ontario.

Nearly all bulking systems have been developed for use with conifers and nearly all of these for amplifying the supply of genetically improved seed (seed produced in seed orchards). The use of this technique for bulking open pollinated (OP) seed is economically justified only where seed is very scarce and valuable, such as in Scandinavia with Norway spruce (Bentzer, 1993). More often, bulking is used to produce stock from control-pollinated (CP) seed, where genetic gains are higher and seed much more expensive to produce. Sitka spruce, *Picea sitchensis* (Bong.) Carr., a North American conifer that is highly prized in England, Scotland, and Ireland, is propagated by rooted cuttings at a rate of about 6 million annually, most from CP seed (Mason, 1991). Another North American tree, Monterey pine, *Pinus radiata* D. Don, is the principal conifer grown in both Australia and New Zealand. Aggressive breeding programs undertaken during the 1960s and 1970s are now producing commercial quantities of CP seed and much of this is being bulked by rooted cuttings. Australian production in 1992 was about 3.3 million (Ritchie, 1993).

WEYERHAEUSER'S DOUGLAS-FIR BULKING PROGRAM

Weyerhaeuser's Douglas-fir rooted-cutting program is aimed only at bulking CP seed. This seed is produced in grafted seed orchards that were established in western Washington and Oregon during the mid 1960s from phenotypic selections. Seed are from parents whose progeny have been extensively tested over the past 15 years in replicated field trials and whose volume growth and stem-form characteristics are in the upper echelon of the production population. These parents are bred in March from pollen collected the previous year. Crosses are made by hand, using lift trucks, and the cones are bagged following pollination to prevent entry of foreign pollen. Cones are harvested in August to September then after-ripened for several weeks. Seeds are extracted, cleaned, and then stratified for 9 or 10 weeks prior to sowing.

Seeds are sown into cells in "Mini-Plug" trays (cell dimensions = 2 cm × 2 cm × 3 cm deep) and germinated in a greenhouse during early spring. In early May, they are transplanted into gallon (4 liter) plastic cans and arrayed on the floor of a production greenhouse. Cans contain a mix of 1 peat : 1 perlite (v/v) plus Sierra slow-release fertilizer. These stock plants are watered and fed by drip irrigation.

By December, they are about 1 m tall and contain about 50 branches, each of which is harvested and placed into freezer storage (-1C) until late April.

These cuttings are set into Multipot-5 trays in the same type of peat:perlite medium and rooted with high pressure fog and bottom heat. Rooting averages over 90% across the production population. In July, they are weaned and, in August, transplanted into a bare-root nursery using a 7-row Lannen transplanter specially modified for this purpose (Fig. 1). After transplanting, cuttings are watered heavily and continue to produce roots during autumn, but few break bud. In winter they may be frost protected using overhead irrigation if needed. In May, the buds break and the cuttings begin a phase of very rapid growth, culminating in a plant averaging about 7 mm in stem diameter, 45 cm in height, and weighing about 15 g (oven dry) by the following December. During the nursery phase they are fertilized and weeded and often wrenched to stimulate root development. (Wrenching involves first undercutting then drawing a thick blade beneath the nursery bed, which heaves the plants up, loosens the soil, breaks new root tips, and improves root fibrosity). The plants are lifted for field planting between December and February when they are dormant. They are successfully held in frozen storage (-1C) until field planting, which occurs December through April.

Extensive and intensive physiological tests (Ritchie et al., 1992) and field trials (Ritchie et al., 1993) have been carried out with Douglas-fir rooted cuttings to confirm their suitability as forest planting stock. Rooted cuttings tend to cold harden earlier in autumn than genetically similar seedlings and transplants and tend to retain their hardiness later into spring. They have comparable root growth potential (RGP) but exhibit a more intense winter dormancy than the other stock

Figure 1. Seven-row Lannen transplanter specifically modified for planting Douglas-fir rooted-cutting plugs. The machine carries about 30,000 cuttings, enough to plant a 1000-ft-long nursery bed.

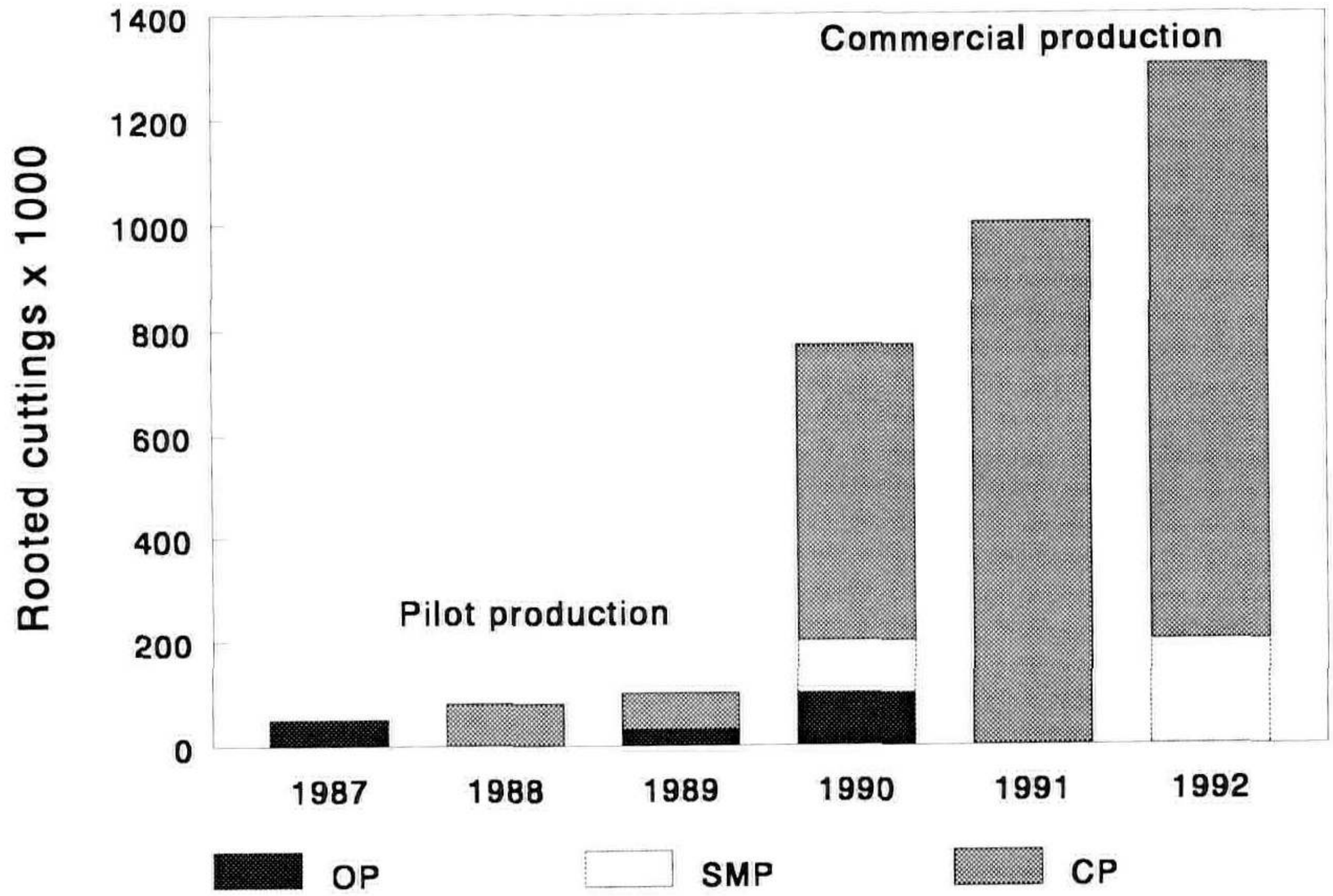

Figure 2. Production history for Douglas-fir rooted cuttings at Weyerhaeuser Company. OP=open pollinated seed, SMP=supplemental mass pollinated seed, CP=control pollinated seed.

types. Rooted cuttings also tend to have a higher ratio of stem diameter to height than seed-origin Douglas-fir.

Field trials with rooted cuttings over a wide range of sites have led to the following conclusions: (1) after 1 year in the field rooted cuttings are visually undistinguishable from seed-origin material, (2) there is no evidence of maladaptation or unusual growth habit (e.g., topophysis) with rooted cuttings, and (3) rooted cuttings exhibit the same survival and height growth as seedlings and transplants of the same stem diameter, root quality, and genetic background.

Weyerhaeuser's production began in 1987 with a pilot scale crop of about 50,000 (Fig. 2). This was followed with two more pilot scale crops. In 1989, production was scaled up from about 80,000 to about 800,000 and then to about 1 million. Early production was with open pollinated (OP) seed. However, propagation success has led to an orchard breeding strategy specifically aimed at providing CP seed for bulking with rooted cuttings. Current crops are fed entirely with seed from controlled crosses or from supplemental mass pollination (SMP).

Current research is focused on bringing production costs down by improving yields and efficiencies at every step in the process. When this is achieved, and as field trials continue to confirm the excellent performance of this material, production levels may increase.

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