Clonal selection of forest trees

W. J. Libby

Three clones of Monterey pine. Z5, left, is the best identified to date. Z4, center, has the same two selected parents as Z5, but not as favorable a recombination of those parents' genes. MM5, right, is a random and fairly typical clone from wild seed collected at Monterey.

Earlier forest plantations in California and elsewhere were commonly established in response to a moral outlook or pressure that replanting was responsible resource husbandry. Later, there were legal requirements to replant inadequately regenerating areas following clearcutting, fire, or other destructive events. Getting trees back on the land was important, but getting *good* trees back was not generally part of the moral or legal mandate. Chances of replacing the forest with poorer trees proved much greater when the forest was artificially regenerated than when it was naturally regenerated. At least three mistakes were commonly made.

1. *Planting seedlings from inappropriate populations.* Only rarely are nursery seedlings raised from seed gathered from the precise site on which they are to be planted. More often, seeds are gathered from other populations, frequently occupying sites with substantially different soils and climates, and their seedlings are not adapted to the new site.

2. *Choosing poor mothers.* The best trees for timber production are tall and straight, have few or small lower branches, and devote little of their photosynthate to cones and pollen. It is safer and cheaper to collect cones from shorter, heavily-branched trees with many cones. The effect of using seeds from poorer mother trees has not been well quantified, but it is surely negative.

3. *Planting the offspring of incestuous matings.* Most native forests are composed of families; nearby trees are frequently at the brother-sister, uncle-niece, or cousin level of relationship. Offspring of matings between such relatives are usually retarded in growth and development, frequently have serious abnormalities and are less able to cope with their environments than are offspring of unrelated parents. (The general phenomenon, when relatives are mated, is called *inbreeding depression.)*

Many seedlings in a naturally-regenerated forest are inbred; they soon die in competition with the herbs, brush, and abundant other tree seedlings that typify successful regeneration. However, when humans intervene, they usually remove herb and brush competition and plant seedlings at wide enough spacing so that early competition is not severe. Under such conditions, many inbred seedlings, that would have died in nature, manage to survive, and the resulting loss in health and vigor of the plantation appears substantial (estimates range from 5 to 30 percent of volume growth).

Early farmers increased the value and usefulness of their crops by picking seed from their most desirable plants before harvesting. This practice is being adopted in forestry. It largely eliminates the poor-mother selection error and (with good records on site) reduces the introduction of inappropriate populations. The problem of inbred seedlings remains as long as wild seed is collected.

The practice of getting forest-tree seed from managed seed-orchards was pioneered 25 years ago in Scandinavia, New Zealand, and the southeastern United States, and many seed-orchards of important forest species were started in California in the last decade. Foresters comb forests, selecting outstanding trees. Normally, only one tree is chosen from any given stand so that relatives cannot mate in the seed-orchard. Branches, cut or shot from the selected trees, are grafted onto seedlings at the orchard site; the mature grafts soon produce cones and pollen, and seeds are produced by open-pollination among these selected grafted branches.

Problems

Problems crop up. The grafted branch is usually rejected by the host seedling, frequently 10 or more years after the graft has been made—at a time when the seed-orchard should begin to produce heavy seed crops. Cone and seed insects, concentrating in the seed-orchards, require aggressive (and sometimes environmentally damaging) pest management. Unwanted pollen blowing in the orchard contaminates the pollen from the select grafted branches; the seeds produced are, at best, below expectation and may be seriously maladapted. These problems, however, seem amenable to technical solutions.

Of most concern to us at Berkeley are the economic problems, and like many economic problems, they seem more unmanageable. Seed-orchards are expensive and subject to economies of scale—a few big seed-orchards produce cheaper seed than a lot of little ones. One should not put two small seed-orchards of the same species next to each other to gain economies of scale; they will cross-pollinate and produce genetic combinations not intended and probably inappropriate. We tend to make our seed-orchards too big, and therefore serve too great a variety of sites, thus risking mistake No. 1.

Because of the high costs of establishing seed-orchards, including research and development, there is a tendency to concentrate on only a few species. Single-species seed-orchards lead to single-species plantations, but replacing, for example, mixed-conifer California forests with single-species plantings may be a bad idea. We have, therefore, begun to explore an alternative technology that would allow effective genetic selection in many species and that would serve accurately many different sites. This work is, namely, the development of a clonal alternative to reforestation with seedlings.

Cloning

Using clones of trees is not novel; most California fruit, nut, and vine crops are clonally propagated. Many of the disadvantages available with orchard clones can be obtained for forest trees, including reliable and predictable performance of well known clones and the capture of the best of the available genetic variation. (Only part of the available genetic variability can be captured by seed-orchards, even less by selected wild seed.) Rejecting the uniformity advantage of single-clone plantings, we plan to mix at least 20 clones in any given plantation to maintain an ecologically-healthy within- and between-species diversity. Cloning, we think, is effective in attaining selected, yet locally diverse, forests.

Because of the cost of grafts and the problem of graft rejection, we deem rooted cuttings or perhaps plantlets from tissue culture more appropriate than grafts to cloning forest trees. In 1962, it seemed likely that Monterey pine could be effectively reproduced as rooted cuttings, but information on California's other timber species was either sketchy or wholly lacking. We began work with Monterey pine, and soon discovered that we needed a greater understanding of the effects of maturation on rooting and subsequent growth.

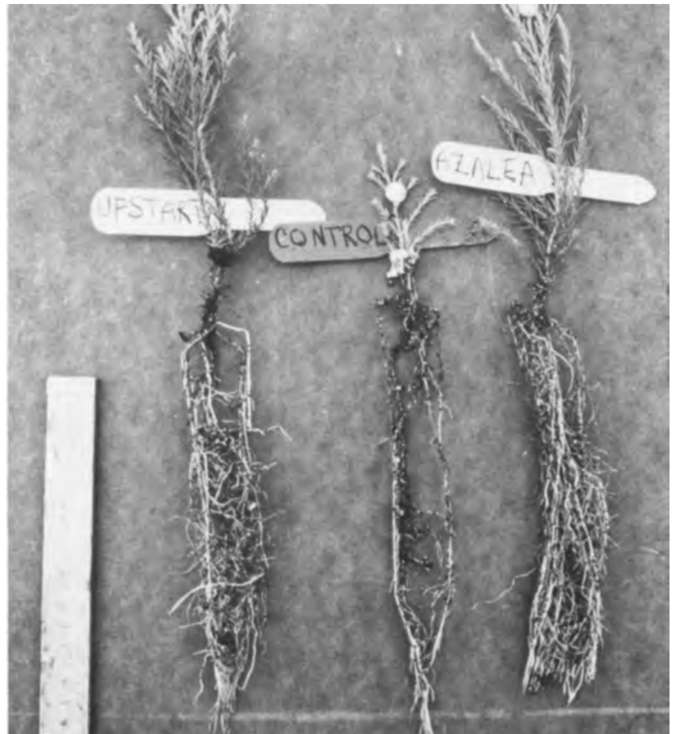
Monterey pine cuttings from seedlings root easily and grow much like seedlings. Cuttings from mature trees are difficult to root; those that are rooted have growth characteristics quite different (and generally poorer) than those of seedlings. Cuttings from adolescent Monterey pines of about 6 to 8 years' maturation have good growth rates, better form than seedlings, and are more resistant to two important diseases. Choosing the appropriate maturation state of the cutting donor is now another form of genetic selection.

Hedging

By 1970, repeated hedging of cutting donors of Monterey pine proved effective in delaying maturation of the clone. We could then evaluate clones produced from such hedges and years later return to the same hedges to recover a similar performance from the selected clones. Since 1974, we have been applying the hedging technique to most of California's other timber species. It is still early to tell how effectively they can be cloned, but we have had some early hints.

High percentages of rooting were achieved (at least in some trials) with the 11 California species we tried. The best success was obtained with juvenile cuttings from seedlings or young hedge donors. Species studied were: blue bishop, ponderosa, Jeffrey, western white and sugar pine; white and red fir, Douglas-fir, incense-cedar, coast redwood, and giant sequoia.

The several trials with coast redwood and giant sequoia indicate that the early form and vigor of juvenile rooted cuttings is essentially the same as for seedlings. (Older cuttings of coast redwood can be rooted in small percentages, maintain their sexual maturity, and for this species are the preferred alternative to grafts in seed-orchards.) Smaller and less advanced trials of juvenile rooted cuttings indicate form and vigor similar to seedlings



Juvenile rooted cuttings of giant sequoia show differences in shoot and root growth associated with different aftercare fertilizer schedules. *Photo by Lauren Fins.*

for incense-cedar and blue bishop, ponderosa, and Jeffrey pine, but white fir and Douglas-fir tend to grow as branches. It is too early for any reasonable conclusions about trials with other species.

Perhaps our greatest difficulty to date is devising appropriate aftercare schedules for rooted cuttings. Such aftercare is necessary to produce plants for successful establishment under California plantation conditions.

At present, Monterey pine, blue bishop pine, coast redwood, giant sequoia, and incense-cedar all can be effectively hedged; the hedges rapidly produce large numbers of cuttings and high percentages of the rooted cuttings have been grown to produce plants that survive well in research outplantings. The stage is set for development of mass-production facilities and operational outplanting.

Some considerations

Clearly, the breeding strategies adopted today will affect future forests. For the past 20 years at Berkeley, and particularly during 1977-1978, we have investigated genetic selection efficiency, mostly using mathematical models and computer simulations. We have become increasingly uncomfortable with the assumptions underlying these models and have tended to rely more on evaluating operational efficiencies and ecological principles.

The points we have considered in some detail include: (1) estimating adaptability of a genotype or population in different environments; (2) estimating genetic interrelations of different selected and unselected characteristics of the tree; (3) mixing diverse genotypes that make complementary rather than competing demands on a site; (4) maintaining long-term genetic variability in the breeding line; (5) reducing or eliminating inbred trees from production plantations; (6) the number of crosses needed per generation; (7) the time that alternative schemes take from selection to testing to large-scale planting; (8) the flexibility and robustness different mating designs allow in subsequent analyses; and (9) the flexibility allowed in field-test designs. Based on these criteria, the clonal option comes out very well compared with other genetic selection schemes, and we remain committed to developing it.

W.J. Libby is Professor, Forestry and Genetics, U.C., Berkeley.