Transplanted Live Coast Oaks (*Quercus agrifolia*) in Southern California

by Rosi Dagit, Conservation Biologist
Resource Conservation District of the Santa Monica Mountains
Topanga, California, USA
and
Jim Downer, Farm Advisor
University of California Cooperative Extension
Ventura, California, USA

During the late 1980's it became increasingly common to transplant large coast live oaks (*Quercus agrifolia*) to mitigate for the loss of oak woodland due to development. Developers loved the idea of being able to "save" the trees and incorporate them into their new landscapes. Tree moving companies became expert at the extremely difficult technique of moving a boxed tree weighing many tons. New homeowners paid as much as 30 percent more for lots having a mature transplanted tree. The decision makers felt that they had required adequate mitigation for the loss of native oak woodlands and required two to five year monitoring for survival. The long term survival rates (over 5 years) of transplanted trees has not been documented.

To date, few studies have focused on the success of transplantation, the physiological responses of the trees to drastic root loss, or the cost effectiveness of moving trees in light of their long term maintenance and survival. Roberts and Smith (1980) did a one year study of water potential and stomatal conductances of oak trees impacted by root injury from trenching. Scott and Pratini (unpublished data) followed the health and vigor of 593 transplanted coast live oaks in Orange County, CA for more than 4 years. Neither of these studies evaluated quantitative responses. Our study combined both quantitative and qualitative observations over 5-6 years in an effort to better understand the response of the trees to transplantation.

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One of the oldest documented transplantation in California of coast live oaks took place from 1938-1941 at Hearst Castle in Cambria, CA where 6 trees were boxed in concrete. While no formal study of these trees took place, review of the gardener's notes and inspection of the 2 trees partially remaining in 1995 indicated that the trees slowly declined over the years, required continuing maintenance and were barely alive.

As part of an effort by the City of Calabasas to discourage oak tree transplantation, the City required that any transplanted oak trees be monitored for 5 years. Three sites in the City had a total of 25 mature coast live oaks which were moved. Starting in January 1992, monitoring of 10 transplanted trees began at Site 1, followed by the addition of eight trees at Site 2 and seven transplants at Site 3 in April 1993, either as the trees were being boxed or shortly thereafter. Monitoring concluded in October 1997.

Transplantation methodology

All portions of the sites to which trees were moved experienced extensive grading and drainage changes before replanting. Sites 1 and 2 were originally north-facing hillside drainages with intermittent streams, clay soil, and mixed chap-

Table 1. Vigor rating scale.

Vigor rating	Description	Criteria for evaluation
1	Dead	No living canopy, severe root and trunk defects, severe infestation or disease
2	Nearly dead	Less than 25% growing canopy, major root and trunk defects, severe pest infestation or disease
3	Decline	25-50 % growing canopy, some root and trunk defects, moderate pest infestation or disease
4	Stable	Greater than 50 % growing canopy, few root or trunk defects, minor infestation or disease
5	Improving	Greater than 75 % growing Fairly healthy canopy, no root or trunk defects, minimal pest infestation or disease
6	Very healthy	Well balanced, symmetrical canopy, no root or trunk defects, very little pest

Table 2. Vigor Rating of 25 Transplanted Oaks
5 years post-transplanting
(October 1997)

Vigor Rating	Site 1	Site 2	Site 3	Percentage
1 Dead	4	3	0	28%
2 Nearly Dead	1	1	4	24%
3 Decline	3	4	1	32%
4 Stable	2	0	2	16%
5 Improving	0	0	0	0%
6 Very healthy	0	0	0	0%

arral vegetation. Following grading, they were 95 percent compacted cut and fill pads which maximized development opportunities. Site 3 was initially a level riparian area that was transformed into a freeway interchange.

Trees from hillside areas were selected for transplanting by the tree-moving company and their associated arborists. Trees selected ranged in size from 15 to 100 cm Diameter Breast Height (DBH). Some were single trunk, but most were multi-stemmed. Height ranged from 4 - 15 meters. Crown diameter varied as well, from 4 to 25 meters. Concurrent with root pruning and side boxing, the canopies of the selected trees were pruned, removing 30 to 70 percent of living tissues. Deadwood, inner foliage, and terminal buds were trimmed, leaving a thin shell of foliage on the perimeter of the canopy.

A backhoe was used to trench all four sides at once around each tree. Plywood box sizes ranged from 1.5 to 8.5 meters wide, and 1 to 2.5 meters deep. Bottom boxing was completed 3 to 6 months later. After boxing, trees were irrigated weekly by water trucks, as directed by the tree-moving company. All trees were planted in holes dug by backhoes, usually 1 to 2 meters wider than the box and approximately the same depth as the root ball. The plywood box bottoms were left in place, the sides removed, and backfilling done by backhoe and hand tools. Sprinklers were installed at Site 2 and irrigation was modified seasonally. The other two sites continued to be watered by truck from one to three times weekly. By coincidence, a total of 3 trees were planted in the same orientation as they had originally grown.

Monitoring

The monitoring protocol included quantitative and qualitative observations of both transplanted and control trees on a quarterly, then on a semi-annual basis. At each site, 1-8 control trees were selected from undisturbed areas on the development parcel having soil type, orientation, slope conditions, and sizes comparable to the transplanted trees. Every time the trees were observed, each tree was given a vigor rating from 1 (dead) to 6 (very healthy). The rating was modified from the International Society of Arboriculture standard condition evaluation for landscape trees which includes evaluation of canopy, foliage, trunk, and root condition (table 1).

Water potential was measured to monitor tree water stress quarterly, then semi-annually. On each tree, mid-day readings of five sample twigs (5 to 13 cm long) taken from four cardinal directions in full sun were followed by five predawn samples, using either a PMS Scholander Pressure Chamber (PMS Instrument Company, Corvallis, Oreg.), or Model 3005 Plant Water

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Status Console (SoilMoisture Equipment Co., Santa Barbara, Calif.).

Soil probing to examine roots down to 30 cm depth started one meter from the trunk of both control and transplanted trees. Probes were also done at mid-canopy, at the dripline, at the perimeter of root ball, just outside the box edge, and 1.5 meters farther out. Samples were qualitatively examined in the field, noting presence, size (mm), and density of roots (number per cm). At Site 2, non-woody root samples (less than 5 mm width, 5 cm length) were taken from the top 15 cm of soil at four cardinal points around the mid-dripline of the trees in October 1997 and plated to identify any infection by *Armillaria sp.* and *Phythopthora sp.*

Each spring and summer, shoot length, number of leaves and shoots per terminal bud were measured from 5 randomly selected samples within reach of the ground on each tree. Presence of flowers and acorns was also recorded.

Results

Control trees at all sites maintained a stable, healthy condition during the study. Despite several stretches of drought, some exceeding 200 days (Tietje, 1993), the 15 control trees had vigorous shoot growth and full canopies. However, by October 1997, transplanted tree condition had declined severely (figure 1 and table 2).

Control trees maintained a dense canopy and normal branching structure, with few epicormic sprouts. Transplanted trees had little apical growth and their canopies remained characteristically thin, open, and often chlorotic. Trees showing improvement had epicormic growth clustered densely in the center of the tree, thinning out towards the dripline. Transplanted trees chronically suffered from twig girdlers (*Agrilus angelicus*) and whitefly (*Aleuroplatus coronatus*) infestations.

The control trees typically had 2-4 new shoots per sample that ranged in length from 5-30 cm, while transplants had fewer new shoots (1-3 per sample) which did not exceed 12 cm. The number of leaves per shoot (6-18) was consistently higher than that found on the transplants (5-10). Most notable was the difference in distribution of shoots. While the control trees grew in a normal branch pattern, the transplants produced primarily epicormic sprouts from the scaffold branches and trunk, with few shoots emerging from terminal buds.

Most control trees had visible growth cracks in the trunk bark, indicating active radial growth. Such cracks on the transplants, if present at all, were smaller and fewer in number. From 1992 - 1997, the diameter of 10 control trees increased, while 3 remained the same. Transplanted trees had 7 trees showing slight expansion, 9 remained the same size and 9 shrunk (table 3). In the case of one large, declining tree, the diameter lost 18 cm in 5 years.

Soil probe observations indicated that only 2 transplanted trees had roots extending outside the planting hole. Most transplanted tree roots were sparse. By contrast, the control trees had dense mats of roots at all areas probed. *Phytophthora cinnamomi* was isolated from the roots of 6 transplanted trees at Site 2, but not from the 4 control trees sampled.

Water potentials of transplanted trees were not correlated with final vigor ratings (r^2= 0.0008). However, a few trends were apparent. Variability in readings was greater in the transplants, with control trees remaining more consistent at any given time (figure 2). No statistical comparisons were made for individual data from same dates. Control trees (receiving no irrigation) did show lower summer/fall water potential (July and October), but they rarely dropped below a pre-dawn potential of -2.5 MPa. By contrast, declining transplanted trees routinely exceeded that limit. In nearly-dead trees, pre-dawn water potentials exceeded those at midday.

Discussion

After 5 years, only 16 percent of transplanted trees in this study showed signs of establishment. The remaining 84 percent were declining or dead. All continued to require extensive maintenance. Thus it appears that long-term survival for these transplants would be no more than 20 percent, and perhaps considerably less.

This is consistent with trends documented by Scott and Pratini (unpublished data) for an oak transplant project in Orange County, CA. Two methods of moving trees were used at that site in 1989. Some trees were dug up by a bulldozer, with 100% mortality resulting within 6 months. Of the additional trees that were boxed, 50% had also died within the first 6 months. Mortality among those that survived the first 6 months had reached 71percent by 1996, 6 years following transplantation. This initial mortality of trees immediately following boxing is frequently ignored when tree moving companies quote statistics about tree survival. Most important to note is that once the trees began to decline, they were not able to recover.

We observed steady tree decline resulting from transplantation. Impacts from removing the majority of the root system and canopy were manifested in disrupted water relations (Tyree, et al. 1994), loss of internal hormone relationships (Coder, 1994), carbohydrate balance (Hollinger, 1992), and stress-induced pest/disease problems (Hagen, 1989) found in the transplants. Regeneration of root and canopy tissue is related to tree size and maintenance conditions (Watson, 1994). Even with improvements to the transplanting procedure, such as boxing one side at a time over 12 months (Himelick, 1991), it may be that the highest attainable level of care would not be sufficient to overcome the trauma of transplantation for mature coast live oak trees. While transplanted trees remained alive, they were no longer self-sustaining natives, but rather high-care exotics that required intensive, long-term maintenance.

Table 3. Average trunk growth of *Quercus agrifolia* after boxing
(1992/93 - Oct. 1997)
Change in surface area diameter at breast height (cm^2)

Treatment	Site 1	Site 2	Site 3
Transplants	-0.25	0.541	-1.325
Controls (not moved)	0.45	0.1	2.6

The cost of boxing each tree in this study varied from $1,000 to over $100,000, totaling $450,000 for all 25 trees. Given the high cost of moving, maintenance and monitoring (approximately $40,000 per year), it appears that a low 5-year survival rate fails to justify the expense. After 5 years, 28 percent of these trees are already dead, the rest are in decline.

If the goal of mitigation is to replace lost resources, then the cost-effectiveness of transplanting oaks needs to be carefully examined. The impetus for moving large oaks comes from the increased property value associated with mature landscapes and the desire of developers to appear to be environmentally conscious. However, isolated trees distributed throughout a suburban development do not have the same eco-

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logical value as a grove of undisturbed trees with the associated complex suite of organisms found with them. Use of transplantation funds for purchasing existing oak woodlands and dedicating them to the public trust would provide a more realistic mitigation. While there may be a few instances where moving an individual tree is warranted, all involved should be aware of the high long term costs involved in supporting a severely damaged tree.

Another consideration should be the placement of the tree in the landscape. By definition, transplanted oaks are considered to have high hazard potential associated with the drastic root loss. Placement of trees in open space areas away from possible "targets" (such as picnic benches, walkways, buildings and roads) should be required. Oaks are also highly susceptible to infection with *Phytophthora cinnamomi,* a common landscape pathogen. Severely stressed transplants needing continued summer watering provide ideal hosts for the pathogen.

The results of this study indicate that transplanting success is minimal, the physiological response of the trees to the trauma is extreme, recovery is limited, and the costs are high. Transplanting coast live oaks does not appear to be an effective mitigation practice to replace lost oak woodlands.

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