Status of Transplanted Coast Live Oaks (*Quercus agrifolia*) in Southern California[1]

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Abstract: *Twenty-five coast live oaks (*Quercus agrifolia*) ranging in size from 15 to 100 cm (diameter at breast height), transplanted to accommodate housing developments at three different sites in Calabasas, Calif., were studied for 3 to 4 years after boxing. Transplanted trees, plus 15 native control trees, were monitored quarterly. Water potential, shoot and root growth, and visual condition were measured. Although all 15 controls remained healthy, 16 percent of the transplanted trees died, 20 percent were nearly dead, 24 percent were in decline, 32 percent were stable, and 8 percent were improving. If declining transplants fail to stabilize, then the projected long-term survival rate would be approximately 10 to 40 percent.*

Transplantation of mature coast live oak trees (*Quercus agrifolia*) as mitigation for loss due to development has become increasingly controversial as the extent of oak woodlands in Southern California decreases. In addition to concern over the protection of one species while ignoring the complex associated community, there are also questions of cost effectiveness and long-term tree survival. The cost of moving an oak tree varies with box size and site accessibility, ranging from around $1,000 to more than $100,000.

To date, few studies have examined transplantation or the physiological consequences of root injury. Roberts and Smith (1980) did a one-year study of water potential and stomatal conductances of oak trees impacted by root removal due to trenching and terracing associated with development. Scott and Pratini (1992) followed 593 transplanted trees in Orange County, Calif., for more than 4 years. However, their observations did not include quantitative physiological evaluation. Our study used both quantitative and qualitative evaluation to assess establishment of transplanted oaks in landscaped settings.

Calabasas Transplant Study

The City of Calabasas (Los Angeles County), California, Oak Tree Protection Ordinance discourages transplanting and requires mitigation for tree removal. In addition, monitoring of trees that are moved was required for 5 years. In January 1992, monitoring of transplanted trees began at Site 1, followed by the addition of two more sites in April 1993, either as the trees were being boxed, or immediately afterward. 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 chaparral vegetation. Site 3 was a level riparian area. The perimeter of all three sites had been affected by previous development. Trees were selected for transplanting by the tree-moving company and their associated arborists. 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 around each tree at once. Box sizes ranged from 1.5 × 1.5 × 1 m to 8.5 × 8 × 2.5 m. Bottom boxing was completed 3 to 6 months later. Irrigation while trees were boxed was carried out weekly or

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more often by water trucks, as determined by the tree-moving company. All trees were planted in holes dug by backhoes, usually 1 to 2 m wider than the box and approximately the same depth as the root ball. The box bottoms were left in place, the sides removed, and backfilling done by backhoe and hand labor. Irrigation was installed at Site 2 and modified seasonally. The other two sites continued to be watered by truck once or more weekly.

Monitoring Methods

The protocol included quantitative and qualitative observations of both transplanted and control trees on a quarterly, then on a semi-annual basis. Every time the trees were observed, each tree was given a vigor rating using the International Society of Arboriculture standard condition evaluation for landscape trees which is based on canopy, foliage, trunk, and root condition (*table 1*). Trees were categorized as very healthy (6), improving/fairly healthy (5), stable/no change (4), declining (3), nearly dead (2), dead (1).

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 percent growing canopy, major root and trunk defects, severe infestation or disease
3	Decline	25-50 percent growing canopy, some root and trunk defects, moderate infestation or disease
4	Stable	Greater than 50 percent growing canopy, few active root or trunk defects, minor infestation or disease
5	Improving	Greater than 75 percent growing canopy, fairly healthy, no root or trunk defects, minimal infestation or disease
6	Very healthy	Well balanced, symmetrical canopy, no root or trunk defects, minimal infestation or disease

Water potential was measured to monitor water stress. On each tree, mid-day readings of five sample twigs (5 to 13 cm long) taken from four compass points in full sun were followed by five pre-dawn samples, using either a PMS Scholander Pressure Chamber (PMS Instrument Company, Corvallis, Oreg.), or Model 3005 Plant Water Status Consule (SoilMoisture Equipment Co., Santa Barbara, Calif.).

Soil probing (30-cm depth) for roots started 1 m from the trunk of transplanted trees. Probes were also taken halfway out to the crown, at the dripline, at the perimeter of root ball, just outside the box edge, and 1.5 m farther out. Control trees were probed halfway out to the crown, at the dripline and 1.5 m outside. Samples were examined in the field, noting presence, size, and density of roots.

Results

Control trees maintained a stable, healthy condition during the 4-year study while transplanted trees declined steadily (*fig. 1*). By October 1995 four transplanted trees had died, five were nearly dead, six were in decline, eight were stable, and only two were improving.

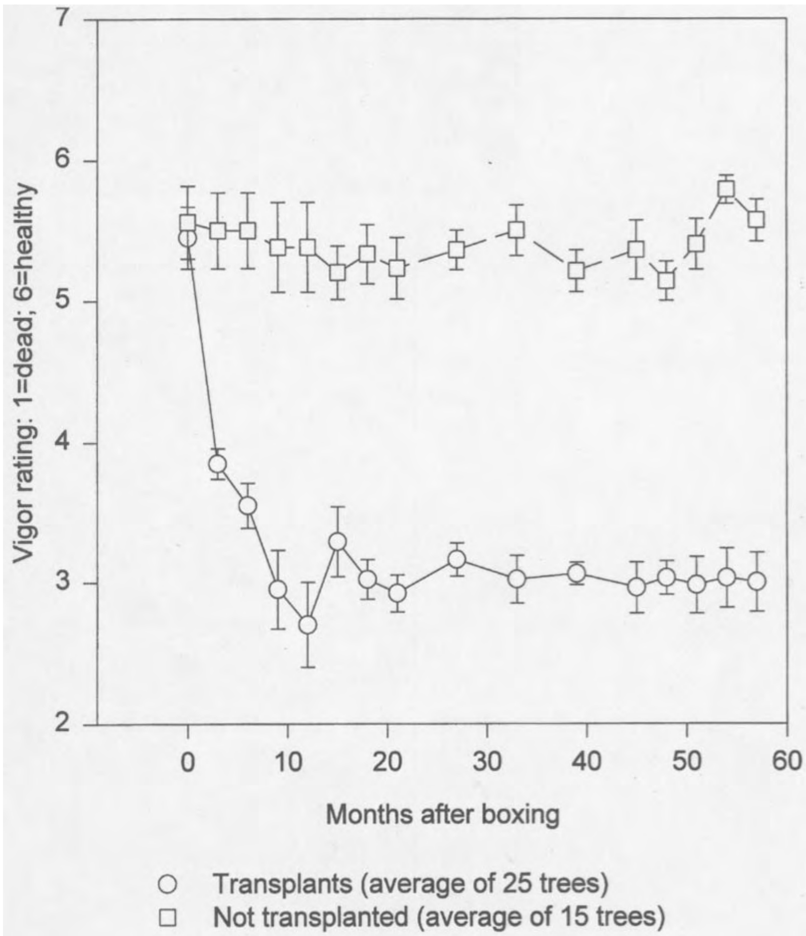

Figure 1—Effect of transplanting on vigor of *Quercus agrifolia*. *Bar is standard error of the mean.

We found canopy condition and vigor to be closely related. Control trees maintained a dense canopy and normal branching structure, with few epicormic sprouts. Transplanted trees, on the other hand, had little apical growth. Instead, epicormic sprouts emerged from the trunk, scaffold branches, and all branches close to the tree interior (*fig. 2*). Transplanted tree canopies remained characteristically thin, open, and often chlorotic. Trees showing improvement had expanded epicormic growth from the center of the tree out toward the edge, and slowly increased their interior density.

The majority of control trees had visible growth cracks in the trunk bark, indicating active radial growth. Such cracks on the transplants were smaller and fewer in number. The diameter of eight control trees increased over 2-3 years, five remained the same, and only one tree became smaller. Conversely, only three transplanted trees expanded, 13 remained the same, and nine decreased (*table 2*).

On the basis of the soil probe observations, only the two transplanted trees showing signs of improvement had roots extending outside the planting hole. Most transplanted tree roots were sparse and limited by the box size. By contrast, the control trees had dense mats of roots at all areas probed.

Figure 2—Trees indicating vigor and canopy condition: (a) Transplanted tree, vigor rating 1 (dead), (b) Transplanted tree, vigor rating 2 (nearly dead), (c) Transplanted tree, vigor rating 3 (declining), (d) Transplanted tree, vigor rating 4 (stable/ no change), (e) Transplanted tree, vigor rating 5 (improving/ fairly healthy), and (f) Control tree, vigor rating 6 (very healthy).

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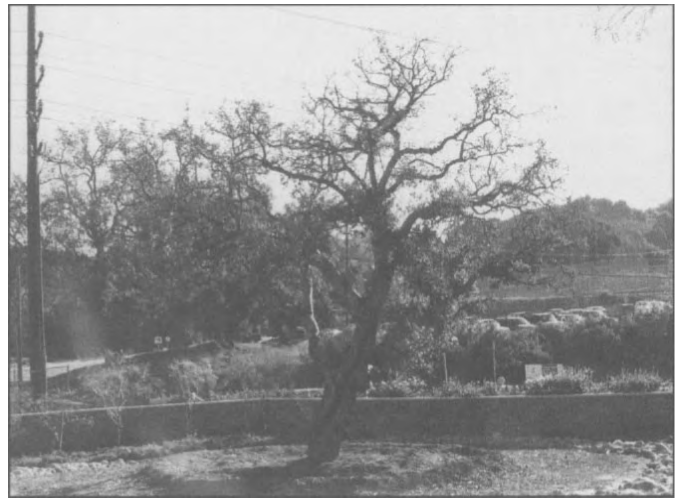

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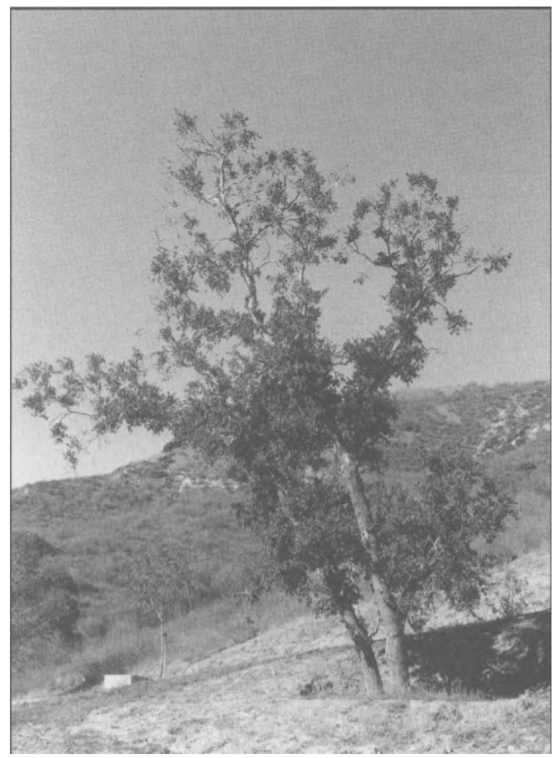

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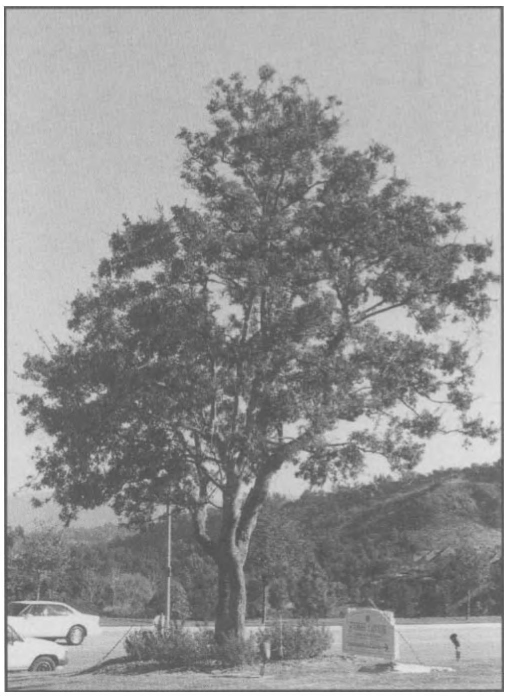

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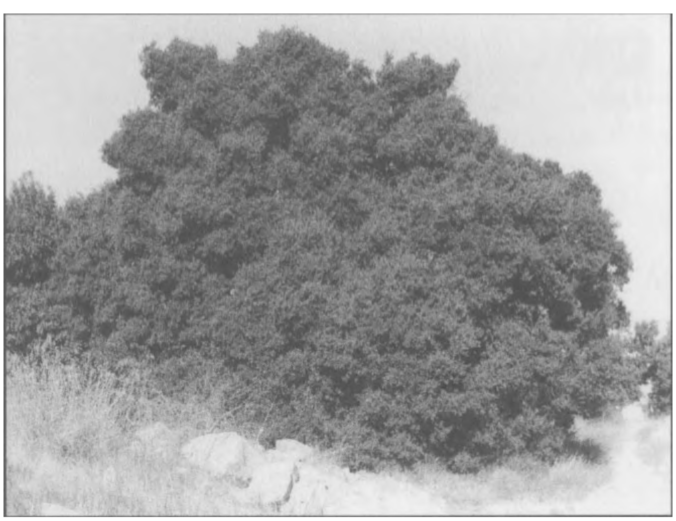

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Water potentials of control trees did not correlate with final vigor ratings ($r^2 = 0.0008$). However, a few trends were apparent. The data indicated a higher degree of

Table 2—Growth of **Quercus agrifolia** *after boxing, 1992/93–Oct. 1995*

Treatment	Change in dbh (cm²)		
	Site 1	Site 2	Site 3
Boxed	-0.59	0.39	-0.2[a]
Controls (not boxed)	2.19	0.12	1.0[a]

[a] Means are significantly different according to t-test at $\alpha = 0.05$.

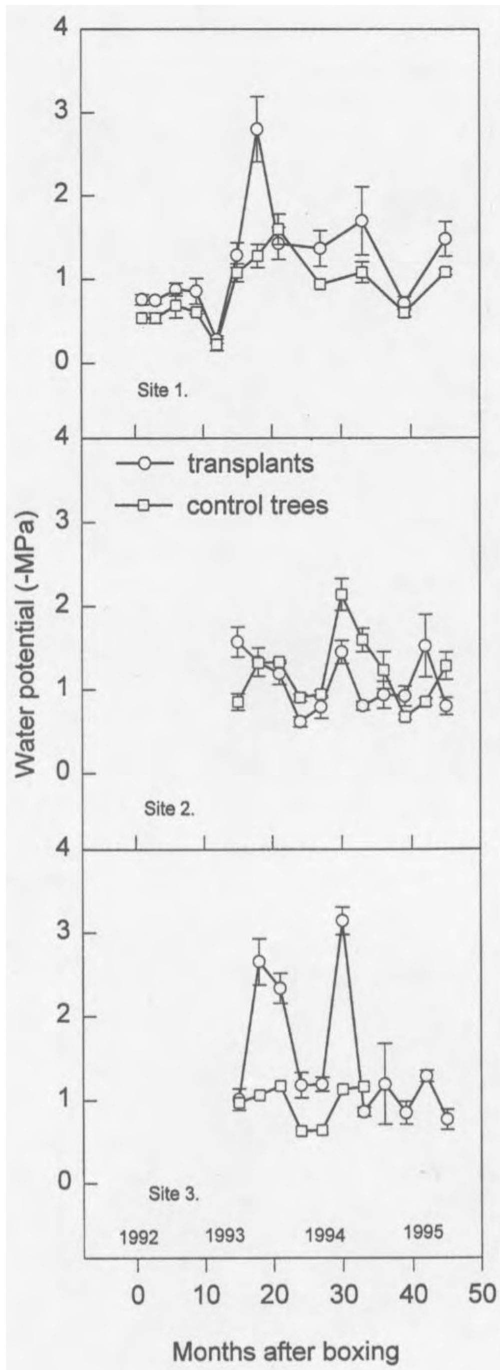

Figure 3—Predawn stem xylem potentials. *Bar is standard error of the mean.

variability among the transplants, with control trees remaining more consistent at any given time (*fig. 3*). Control trees did show more negative 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 and had much more negative water potential at mid-day. In nearly dead trees, pre-dawn water potentials exceeded those at mid-day.

Discussion

Distributed throughout the coastal regions of the state, coast live oaks can be found in a wide variety of locations, from sea level to 1525 m. Despite tremendous adaptability, there appear to be physiological limiting factors that were difficult for the trees to exceed. In order to understand the response of this species to the impacts of transplantation, it was important to review relevant aspects of oak tree biology.

Adapted to the Mediterranean climate, coast live oaks are nonetheless greatly affected by the availability of water. Despite the worst statewide drought of this century, which has had severe impacts on native trees since 1986 (Tietje and others 1993), the control trees were able to utilize available water resources and thrive. Local rainfall patterns during this study have been above average. Torrential storms in 1991-92 deposited more than 130 cm of rainfall in the Calabasas area. The winter of 1992-93 was slightly above average at 40 cm. The rainy season for 1994-95 was heavy again, with more than 155 cm recorded in the area.

Vigor ratings were strikingly different between the control and transplanted trees. We observed steady tree decline associated with the large canopy and root mass loss resulting from transplantation. Neither root nor canopy recovery has occurred for the majority of transplanted trees. However, control trees remained vigorous.

Watson (1985, 1994) found that root recovery was related to stem diameter. For each 2.54 cm of trunk diameter, root replacement following removal took approximately one year in the Midwest. Given a longer growing season in southern California, optimal conditions may allow slightly faster recovery. However, our study found that only two trees (dbh = 44 cm, 64 cm) had evidence of roots extending outside the planting hole. The inability to extend rooting area could be due to the differences in boxed storage time, soil compaction, as well as delayed ability to regenerate lost roots and shoots following traumatic loss.

Hagen (1989) documented that root-related impacts are extremely damaging to most trees, including oaks. A study of coast live oak root pruning at North Ranch, Thousand Oaks (Ventura County), Calif., indicated that while initial water stress was not devastating, accumulation of stress could precipitate decline. "Drastic" root pruning immediately disrupted stem xylem tension, indicating that there were limitations to the amount of root damage that could be sustained before the tree died (Roberts and Smith 1980). In undamaged trees, absorbing roots can extend more than 30.5 m from the trunk (Gilman 1988, Perry 1982). Root-related impacts in southern California can cause stress in trees up to 300 feet away (Kelley 1995). Boxing was done in late summer and fall to take advantage of root growth at this time, stimulated by the auxins produced in the less active terminal buds.

In spring, the roots produce hormones stimulating shoot growth in the terminal buds (Coder 1994). Between three and five shoots erupt from each bud, reaching lengths of 30 to 60 cm if rain is plentiful. Griffin (1973) found that a typical response of oaks to water stress was failure of buds to mature. Transplanted trees in our study had limited apical growth (data not shown), supporting this observation.

Impacts on photosynthate production and resultant canopy condition have been shown to be important in maintaining overall vigor. It has been found that as new leaves photosynthesize, carbohydrate reserves were stored in the roots and trunk during wet years to help sustain the oaks through dry periods (Rundel 1980). Oaks moderated transpirational loss by stomatal regulation according to environmental stress (Roberts and Smith 1980). As summer progressed and soil moisture was limited, photosynthesis on the perimeter of the canopy was reduced while it continued in the humid interior. The photosynthetic activity of the larger, inner canopy leaves produced the extra carbohydrates needed to exceed the baseline metabolic requirements of the tree and provided reserves for storage (Hollinger 1992).

Other studies have used water potential as an indication of stress (Shackel 1993), which varied according to available soil moisture, as well as the ability of the tree to access that water. Low root density has been associated with high internal resistance of water moving through the xylem, even if the soil reached field capacity (Cowan 1965).

In this study, similar water potentials in both control and transplanted trees were noted. Until the transplants were nearly dead, it was not possible to accurately predict their survival using only water potential as an indicator.

While the seasonal trends of water potential between controls and transplants appeared close, the effect on tree vigor was dramatically different. Control trees periodically hit limits of –2.5 MPa and still maintained overall health and vigor. It has been previously documented that water potentials more negative than –2.5 MPa resulted in catastrophic emboli (air bubbles in the xylem water columns reducing conductance) causing more than 50 percent loss of conductance (Tyree and others 1994). When these limits were repeatedly exceeded, tree mortality resulted (Griffin 1973). In our study, however, control trees apparently had sufficient energy reserves to replace damaged tissue, and xylem function continued (Davis 1996). By contrast, transplanted trees in decline routinely had a water potential more negative than –2.5 MPa and showed no signs of recovery, despite irrigation. If embolized tissues cannot be replaced, then continued dieback occurs. Our vigor ratings suggested that the transplants were not able to replace lost conducting vessels as easily, resulting in cumulative decline.

The transplanting techniques commonly used for oaks in southern California (simultaneous trenching on all 4 sides with extensive canopy reduction, followed by relocation within 3-6 months) do not appear to be conducive to long term survival. Transplanting techniques used in other areas (Himelick 1981) may offer some alternatives to improve establishment. Root preparation by trenching one side at a time more than 6-9 months may allow greater root recovery before relocation. Allowing the canopy to die back naturally to that which can be supported by the root mass may not disrupt photosynthesis and hormonal balance as much and may permit terminal buds to expand. Removal of deadwood and any severely injured branches should be sufficient canopy reduction. Careful storage of boxed trees until planting and placement in a suitable new location sharing soil, drainage, and exposure characteristics of the original site may also improve survival.

Conclusion

Only 8 percent of the transplanted trees in this study showed signs of establishment. An additional 32 percent were stable, while the rest were declining. All continued to require extensive maintenance. Thus it appears that long-term survival for these transplants would be no more than 40 percent, and perhaps considerably less.

Our data were consistent with trends documented by Scott and Pratini (1992). They observed that between 40 and 60 percent of transplanted trees died soon after boxing, approaching 100 percent when root preparation was poorly done. This initial mortality was frequently ignored when statistics about tree survival were quoted.

Observations of vigor and canopy condition were valuable indicators of overall tree condition. Water potential measurements allowed irrigation modification and indicated tree recovery over time, but alone were not sufficient to predict survivability. Combined with vigor ratings and evaluation of canopy condition, a more complete assessment of tree status was obtained.

Even with improvements to the transplanting procedure, 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 the transplanted trees remained alive, they were no longer self-sustaining natives, but rather high-care exotics that required intensive, long-term maintenance.

Given the high cost of moving (over $450,000 for 25 trees) and maintenance and monitoring (approximately $40,000 per year), it appears that a low long-term survival rate fails to justify the expense. If the goal of mitigation is to replace lost resources, then the cost-effectiveness of transplanting oaks needs to be carefully examined.

Acknowledgments

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