To Prune or Not to Prune: Responses of Coast Live Oaks (*Quercus agrifolia*) to Canopy Retention during Transplanting[1]

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Abstract

A total of 62 coast live oaks (*Quercus agrifolia*) were monitored since they were initially boxed for transplantation in 1993. At that time, only branches injured during the moving process and deadwood were removed, leaving the entire canopy intact. This was a departure from the usual transplanting methodology that traditionally removes up to 70 percent of the canopy in order to compensate for the massive root loss incurred during boxing. To date, survival of non-pruned trees has exceeded that of a cohort of 25 transplanted oaks that received the standard canopy reduction. A discussion of the impacts of pruning and transplanting on diameter growth, canopy condition and overall health and vigor of the transplanted oak trees is provided.

Introduction

Transplantation of mature coast live oak (*Quercus agrifolia*) as mitigation for development of oak woodlands has been a common practice in southern California. Typically, tree canopies are severely pruned (up to 70 percent loss) at the time of root pruning, which usually takes place in the extreme heat of late summer/early fall. The justification for this is to reduce transpirational stress and "balance" the root:shoot ratio.

Since 1992, the City of Calabasas, California, has required monitoring of 4 development sites where coast live oaks were transplanted as part of a mitigation effort to compensate for the loss of oak woodland resources to development. At Sites 1-3, a total of 30 mature coast live oaks with severe root and canopy pruning were monitored following boxing in January 1992 to October 1997. At Site 4, only the roots of 100 mature coast live oaks were pruned, leaving the canopies intact, except for removal of deadwood and any branches damaged during the moving process. Monitoring of the 4th site began in October 1996 and concluded in April 2001.

Comparing the condition and survival rate of the trees that retained their natural canopies to the severely pruned trees provides important data on the effects of extensive canopy loss on mature transplanted coast live oaks. To date, few studies have evaluated the success of transplanting mature coast live oaks, the physiological

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responses of the trees to the extensive root loss, or the cost effectiveness of moving trees considering the need for long-term maintenance and poor survival rates. Roberts and Smith (1980) did a 1-year-study of water potential and stomatal conductance of oak trees impacted by root injury from trenching and found that mortality increased when more than half of the root system was impacted. Scott and Pratini (1992) followed the health and vigor of 593 transplanted coast live oaks in Orange County, California, for more than 4 years and found that following high initial mortality, trees that began to decline were unable to regain lost vigor and subsequently died. Dagit and Downer (1996) reported on the survival status of the 30 pruned trees at Sites 1-3, finding that 16 percent of the trees died immediately following boxing. Of those that survived the initial trauma, 28 percent of the trees were dead, 24 percent were nearly dead, 32 percent were in decline and only 16 percent were stable 5 years after transplanting.

This study compares canopy recovery, leaf tissue conditions, growth and condition of the pruned to the non-pruned transplanted coast live oak trees.

Transplantation Methodology

All portions of the sites from which trees were moved experienced extensive grading and drainage changes before replanting. Sites 1, 2 and 4 were originally north-facing hillside drainages with intermittent streams, clay soil, and mixed chaparral/oak woodland vegetation. Following grading, the sites consisted of 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, with limited area for planting.

Trees were selected for transplanting by the developer's tree-moving company and their arborists. Trees selected ranged in size from 15 to 175 cm DBH and most were multi-stemmed. Tree 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 at Sites 1-3, removing up to 70 percent of foliage bearing branches. Deadwood, nearly all inner foliage, and many terminal buds were trimmed, leaving a thin shell of foliage on the perimeter of the canopy. At Site 4, the tree canopy was left intact, with only dead branches or damaged branches removed *(fig. 1)*.

A backhoe was used to trench all four sides around each tree, resulting in the loss of approximately 90 percent of the root system. 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. The trees were planted in a hole dug by backhoe, 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 Sites 2 and 4, and irrigation was automated and poorly overseen. The other two sites continued to be watered by truck one to three times weekly. By coincidence, 3 of the trees were planted in the same orientation as they had originally grown.

The situation at Site 4 is unusual, in that 31 trees have been planted, while the remainder are still boxed. A wildfire swept through the property in October 1996, burning many of the boxed trees, but none of the planted trees. The 31 burned, boxed trees were thus removed from further consideration in this study. Despite inoculation with mycorrhizae, mulching and irrigation, these boxed trees continue to decline. Those planted in the landscape have been subjected to a variety of irrigation and drainage problems.

The majority of the transplants have been installed in common open space areas, except at Site 4, where they have also been placed on private property, adjacent to driveways and street intersections.

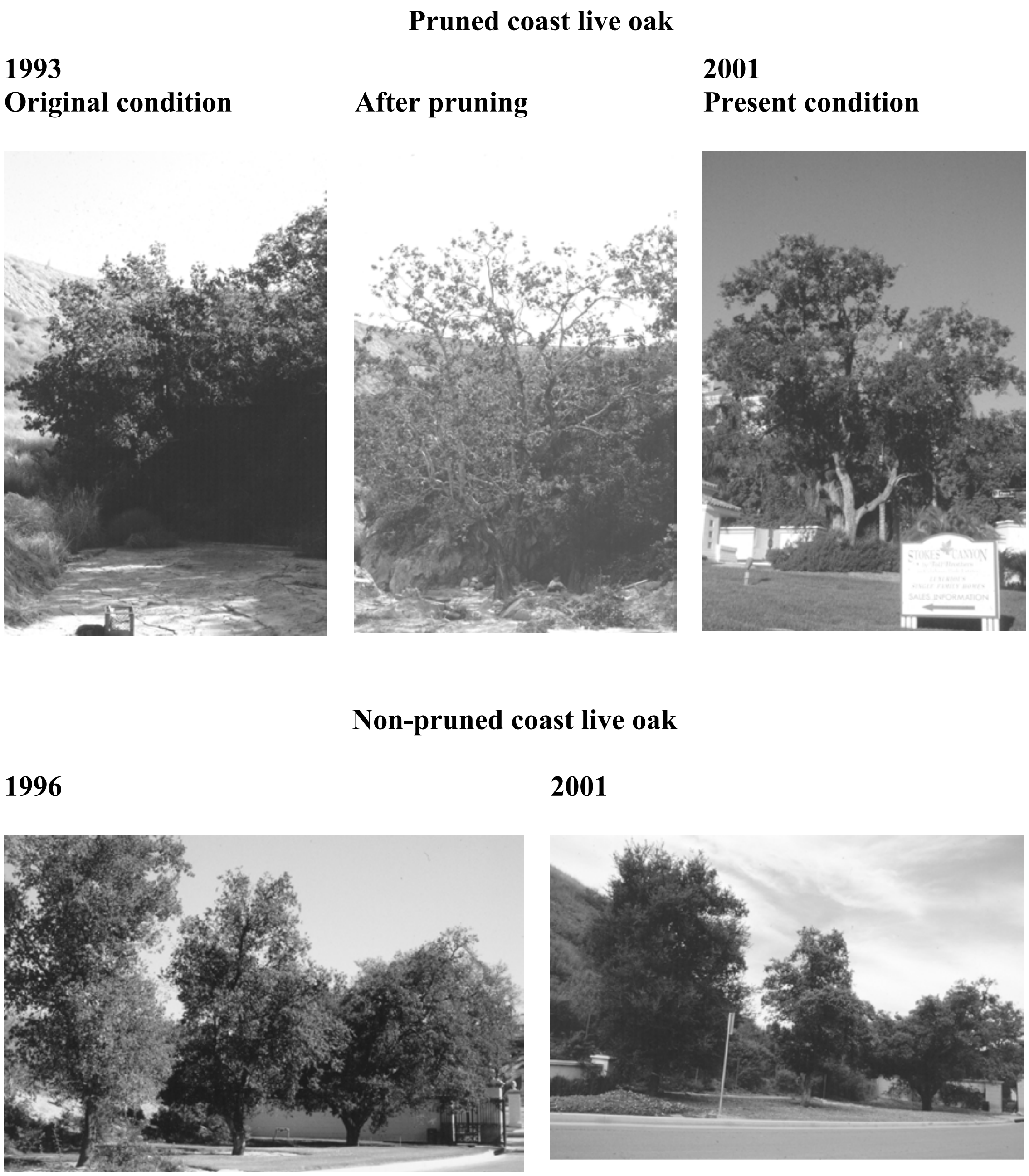

Figure 1—Photographs of pruned and non-pruned transplanted coast live oaks (trees rated as stable).

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, one to eight control trees were selected from undisturbed areas on the development parcel having soil type, orientation, slope conditions, and sizes comparable to the transplanted trees. Unfortunately, several of the control trees have subsequently been impacted by adjacent landscaping changes, and are showing signs of decline. Every time the trees were observed, each tree was given a vigor rating from 1 (dead) to 5 (excellent). The rating was modified from the International Society of Arboriculture standard condition evaluation for landscape trees that includes evaluation of canopy, foliage, trunk, and root condition *(table 1)*.

Table 1—*Vigor rating scale.*

Vigor rating	Description	Criteria for evaluation
1	Dead	No living canopy
2	Decline	Less than 50 percent living canopy, few growth cracks (<1mm), some root and trunk defects, moderate pest infestation or disease.
3	Stable	50 percent or more living canopy, few growth cracks (1-3 mm), some root or trunk defects, minor infestation or disease
4	Good	Greater than 75 percent living canopy, many growth cracks (1-4 mm), few root or trunk defects, minimal pest infestation or disease
5	Excellent	Well balanced, symmetrical canopy, many growth cracks (1-8 mm), few root or trunk defects, healthy tree.

Diameter at breast height (4.5 feet above grade) was measured quarterly, along with visual estimation of canopy density. Data concerning size and number of growth cracks indicating new growth in the trunk and branches were also collected.

Each spring, shoot length, number of leaves and number of shoots per terminal bud were measured from five randomly selected samples within reach of the ground on each tree. Presence of insect pests, diseases, flowers and acorns were also recorded. Leaf tissue samples were collected once a year from four cardinal points within reach around the lower canopy, and sent to the lab for analysis.

Soil probing to examine roots down to a 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 Sites 2 and 4 in October 1997, non-woody root samples (less than 5 mm width, 5 cm length) were taken from the top 15cm of soil at four cardinal points around the mid-dripline of the trees and plated to identify any infection by *Armillaria* sp. and *Phytophthora* sp. Additionally, in May 2001 at Site 4, root samples were collected at four cardinal points within the dripline using a soil probe. Root fragments were sorted from the soil sample to determine root length and dry weight. Soil volume was determined for each sample. All non-pruned trees were inoculated with ectomycorrhizae following treatment for *Phytophthora* sp. with metalaxyl.

Water potential to monitor tree water stress was measured quarterly, then semi-annually for a total of 5 years. On each tree, mid-day readings of five sample twigs (5 to 13 cm long) were taken from four cardinal directions in full sun. That night an additional five pre-dawn samples per tree were measured, using either a PMS Scholander Pressure Chamber (PMS Instrument Company, Corvallis, Oregon), or Model 3005 Plant Water Status Console (Soil Moisture Equipment Co., Santa Barbara, California).

Results

The majority of control trees at all sites maintained a stable, healthy condition during the 10-year-study, with the exception of four trees adjacent to installed landscaping that are showing signs of decline from root rot. Despite several periods of drought, all of the unimpacted control trees had vigorous shoot growth and full canopies. A summary of overall tree survival during the course of the study is provided in *table 2*.

Table 2—*Summary of transplanted oak survival.*

Treatment	Dead	Decline	Stable	Good	Improving	Total number of trees
Pruned – 10 years post planting	7	6	8	4	0	25
Pruned – 5 years post planting	7	14	4	0	0	25
Non pruned – 5 years post planting	3	17	10	1	0	31
Non pruned – 5 years post boxing (burned)	7	21	3	0	0	31
Control trees no impact	0	0	4	15	3	22

Change in vigor from before transplanting to present of the non-pruned planted trees was compared to that of the pruned transplanted trees *(fig. 2)*.

Due to the impacts of the wildfire, the non-pruned trees that remained boxed and were burned are not included in the following results.

It is interesting to note that 5 years post pruning, fewer of the pruned trees were in stable or good condition, and more trees had died as compared to the condition of the non-pruned trees. Even after 10 years, the pruned trees have failed to recover their pre-transplant vigor level. It remains to be seen if the non-pruned trees are able to achieve pre-transplant vigor when they reach the 10-year mark. There was no notable difference between the rate of growth or vigor rating between single trunk and multi-trunk trees.

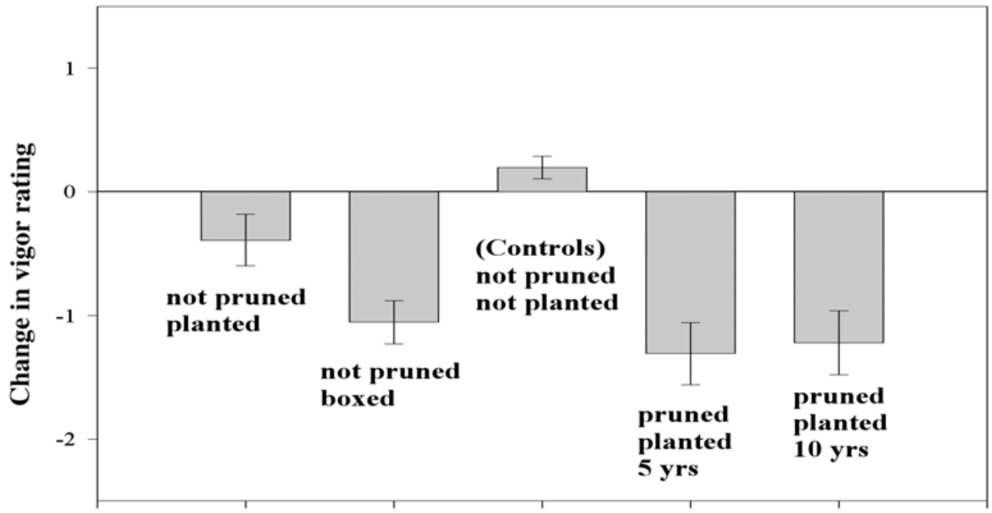

Figure 2—Change in vigor rating of pruned and non-pruned transplanted coast live oaks.

Change in diameter over time reveals additional interesting information. During the first 5 years post planting, the pruned trees did not grow, while the non-pruned trees showed evidence of slow, continuous, growth. However, 5 years post planting, the pruned trees did begin to grow, and by 10 years post planting, they had almost caught up to the rate of growth constantly maintained by the control trees *(fig. 3)*. By contrast, most control trees had visible growth cracks in the trunk bark, indicating continual active radial growth each year. Such cracks on the pruned trees during the first 5 years, if present at all, were smaller and fewer in number. Active radial growth for the non-pruned trees maintained a small, but steady increase.

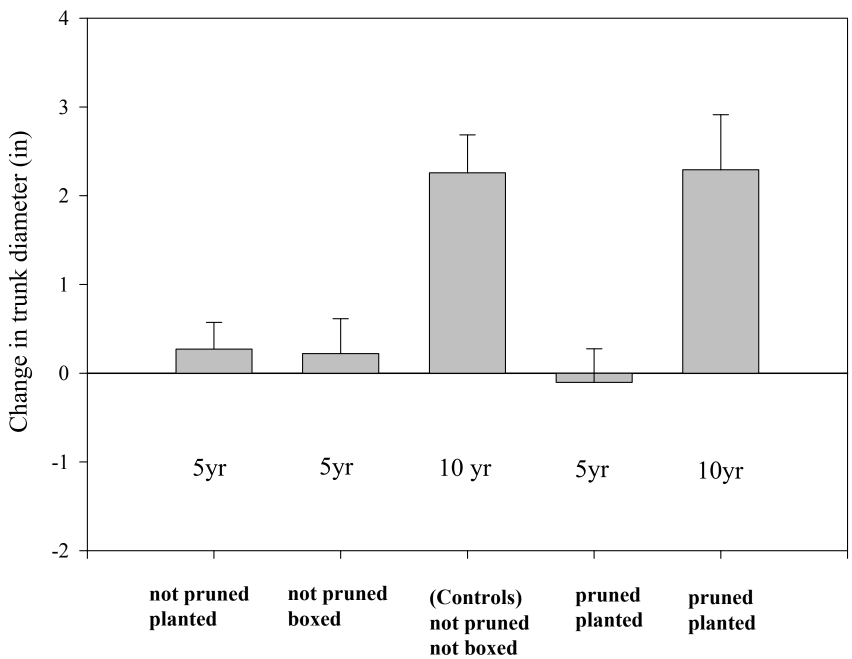

Figure 3—Change in trunk diameter of pruned and non-pruned transplanted coast live oaks.

Control trees maintained a dense canopy and normal branching structure, with few epicormic sprouts. Pruned 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. This pattern was notably different in the non-pruned trees, which maintained a normal terminal growth pattern, with additional epicormic growth appearing after several years. There was no obvious change in the canopy density initially for the non-pruned trees. Canopy loss began after several years, concurrent with overall loss of vigor *(fig. 4)*. Both pruned and non-pruned transplanted trees chronically suffered from twig girdlers (*Agrillus angelicus*) and whitefly (*Aleuroplatus coronatus*) infestations.

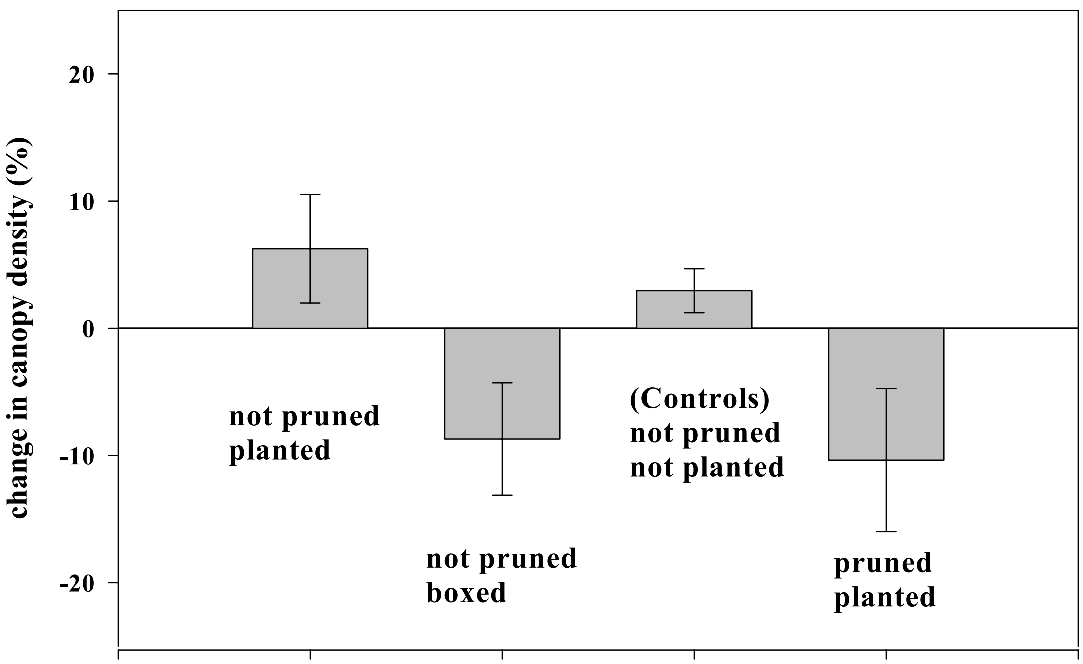

Figure 4—Change in canopy density of pruned and non-pruned transplanted coast live oaks.

There was a marked difference in spring flushing growth patterns between the pruned and the non-pruned trees. Most notable was the difference in distribution of shoots *(table 3)*. While the control and non-pruned trees grew in a normal branch pattern, the pruned trees produced primarily epicormic sprouts from the scaffold branches and trunk, with few shoots emerging from remaining terminal buds.

Table 3—*Comparison of twig growth.*

Treatment (cm)	Avg. no. shoots	Range of shoot length	Range number leaves/shoot
Pruned	2	1-12	5-10
Non-pruned	2	2-18	9-12
Controls	3	5-30	9-18

Analysis of leaf tissues did not indicate any notable differences for the majority of parameters. The optimal range of total nitrogen levels for coast live oaks according to Fruit Growers Laboratory is between 1.15 to 1.21 percent. This is a much narrower range than that for either valley oaks (*Q. lobata*) which extends from 1.2 to 3.5 percent, or for cork oaks (*Q. suber*) which ranges from 1.5 to 2.5 percent (Perry and Hickman 2001). Data from our study found that both the pruned and non-pruned coast live oak transplants had broader ranges from 1.4 to 2.6 percent, while the control trees in the study were between 1.4 to 2.1 percent. However, no statistically significant differences in total nitrogen levels were found according to a paired t-test ($p<0.05$).

There did appear to be a more significant difference between calcium levels. Control trees had levels averaging 1.06 percent. The pruned trees averaged 0.86 percent and the non-pruned trees averaged 1.03 percent *(fig. 5)*.

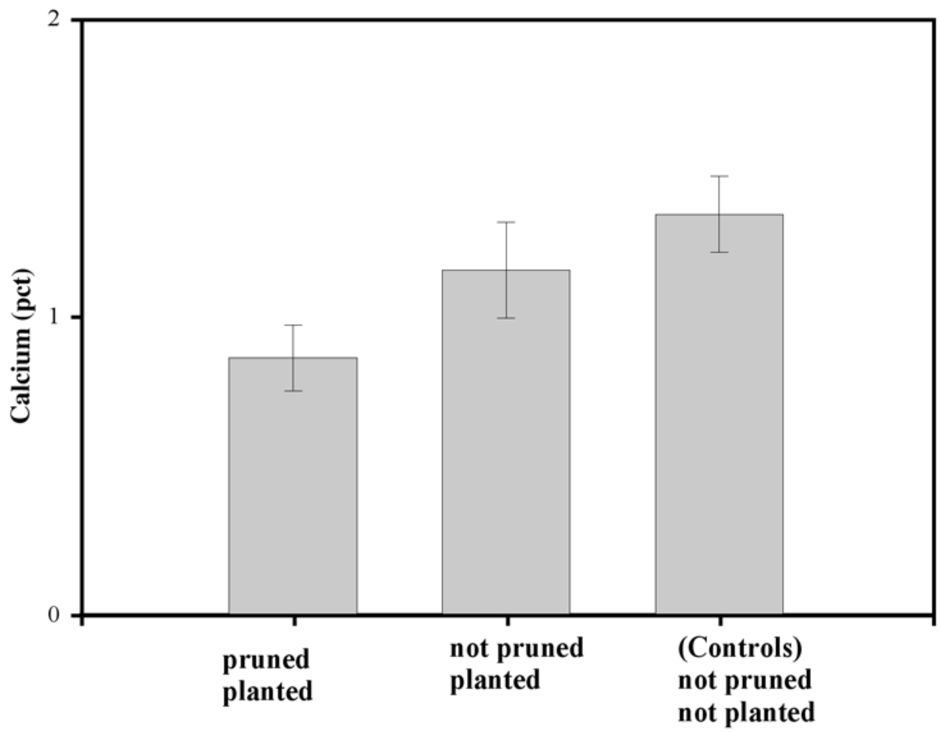

Figure 5—Comparison of average percent calcium levels in leaf tissues of pruned and non-pruned transplanted coast live oaks.

Among the non-pruned transplanted trees at Site 4, root density was not apparently related to tree vigor. As a result of mycorrhizal inoculations and mulching, both the planted and boxed transplants had greater fine root (<5mm) density than the control trees, which received no inoculations or additional mulching. There was no significant difference between root density of planted vs. boxed non-pruned trees. Interestingly, the rate of infection by root pathogens (*Phytophthora* sp.) decreased following the mycorrhizal inoculations, as did the percentage of beneficial fungi and protozoans. It appears that the inoculations and additional mulching were successful in improving the soil foodweb conditions. No comparable data was available for the pruned trees.

A plot of the water potentials of transplanted trees and final vigor rating suggests that there is no statistical relationship. However, a few trends were apparent. Variability in readings between trees was greater in both the pruned and the non-pruned transplants, with control trees remaining more consistent at any given time. No statistical comparisons were made for individual data from the 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 mid-day.

Discussion

We observed steady tree decline resulting from transplantation, although the non-pruned trees initially maintained better vigor, canopy density, and growth than the pruned trees. Impacts reported from removing the majority of the root system and canopy were manifested in the transplants by disrupted water relations (Tyree and others 1994), loss of internal hormone relationships (Coder 1994), changed carbohydrate balance (Holinger 1992), and stress-induced pest/disease problems (Hagen 1989). Irrigation and drainage problems probably added to the stress of all the transplants, but were not significantly different between the non-pruned and the pruned trees.

Regeneration of lost root and canopy tissue is related to tree size and maintenance conditions (Watson 1994). For each 2.54 cm of trunk diameter, root replacement took approximately 1 year in the Midwest (Watson 1985). The pruned trees struggled to regain lost resources, and are just beginning to stabilize 10 years post transplanting, finally exhibiting symptoms of root recovery.

The data indicates that the non-pruned trees are less stressed initially, providing greater opportunity for eventual establishment. Heavily pruned trees are handicapped by disruption of the xylem–phloem system for distributing water, nutrients and photosynthate throughout the trees. For example, severe pruning can effectively "starve" the roots if the foliage on the lower and inner branches is removed, preventing materials from reaching the roots. This leads to less root exudate leaching into the soil and reduces nourishment for symbiotic soil organisms in the rhizosphere. Water is less effectively recycled throughout the tree and the delicate feedback loop between the roots and the canopy is further stressed (Ringgenberg 2001).

Calcium concentrations in leaf tissue are also indicative of the complex impacts to metabolic processes resulting from transplanting. Leaf tissue levels of calcium in the control trees were significantly better than those found in the transplants, although the non-pruned trees were in better condition than the pruned trees. Calcium is essential to both shoot and root growth, and low levels are observed when new growth is stunted (Harris 1992). Although sufficient calcium is generally present in the soil, its uptake is regulated by complex interactions that are clearly disrupted by severe root loss and canopy reduction. The role of the soil foodweb in facilitating nutrient uptake is also critical, and transplanted trees with disturbed and deficient microbial communities are not able to support the nutrient cycling necessary to optimally invigorate the tree (Ingham 2001).

Preliminary results of tests to identify preferred locations of carbohydrate storage in pollarded London Plane trees found that while the tree remained pollarded, carbohydrate storage remained near the heading cuts, with little found at other locations in the tree. Trees that are not pruned store carbohydrates primarily in the woody roots, root crown, branches, and at the base of the trunk (Svihra, personal communication). If this is true of oak species as well, it would further explain why the trees take so long to recover from the loss of 90 percent of their root system, including the majority of woody roots containing stored carbohydrates. Oaks are known for their ability to store extensive energy reserves, and loss due to root pruning clearly has a significant impact on the tree (Rundel 1980). It is clear that 10 years is the minimal monitoring period needed in order to begin to understand the full impacts of transplanting on the physiology of coast live oaks.

It appears that canopy retention and mycorrhizal inoculation make a positive difference on transplanting success. Even with additional improvements, 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 the majority of mature coast live oak trees. While both the pruned and non-pruned transplanted trees remained alive, they were no longer self-sustaining, but rather high-care exotics that require intensive, long-term maintenance.

The cost of boxing each tree in this study varied from $1,000 to over $100,000 dollars, totaling almost a million dollars for all 130 trees. Given the high cost of moving, maintenance and monitoring (approximately $80,000 per year for 10 years, and counting), it appears that a low establishment rate fails to justify the expense.

Conclusions

Initial recovery of coast live oaks from transplantation appears to be enhanced by retaining the natural canopy. After 5 years, only 14 percent of transplanted pruned trees in this study showed signs of establishment, compared to 35 percent of the planted, non-pruned trees. Additionally, 28 percent of the pruned trees were dead, compared with 10 percent of the non-pruned trees. All of the transplanted trees continued to require extensive care and maintenance. Even with the eventual improvement shown by the pruned trees 10 years after transplanting, they have still failed to recover their original level of vigor. While retaining the natural tree canopy appears to reduce initial loss of vigor following transplanting, it remains to be seen if the long-term survival of the non-pruned trees is significantly better than that of the pruned trees.

It is also important to note that the initial mortality of trees immediately following boxing is frequently ignored when tree-moving companies quote statistics about tree survival. Of the 130 oaks boxed for this study, 32 percent died (42 trees: 5 pruned, 37 non-pruned) immediately following boxing, and were not included in the study results. The high initial mortality of the non-pruned trees was a result of a financial crisis, which left the developer unable to maintain the trees once they were boxed. The financial uncertainty involved in the development process needs to be factored in, since loss of funding is a common problem, leaving many transplanted trees without care. Posting of bonds to cover the monitoring and maintenance of transplanted trees should be required.

If the goal of mitigation is to replace lost natural 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 oak trees distributed throughout a suburban development do not have the same ecological value as a grove of trees with their undisturbed habitat. A more pragmatic approach to mitigation would be to use transplantation monies to purchase and dedicate as open space existing oak woodlands. 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 severe 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. Summer irrigation necessary to support transplanted trees creates conditions that foster root diseases. All of the transplanted trees were treated with an appropriate fungicide to inhibit *P. cinnamomi*.

The results of this study indicate that while transplanting success is enhanced initially by retaining the natural canopy of coast live oak trees, the physiological response of the trees to the trauma is still 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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References

Coder, Kim. 1994. **Regulation of tree growth: keeping the green side up.** Arborist News 3: 33-36.

Dagit, Rosi; Downer, A. James. 1999. **Transplanted coast live oaks *(Quercus agrifolia)* in southern California.** Journal of the International Oak Society 9: 145-150.

Hagen, Bruce W. 1989. **Tree roots-major considerations for the developer**. Tree Notes, No. 2, January 1989; 2 p.

Harris, Richard W. 1992. **Arboriculture: integrated management of landscape trees, shrubs and vines.** 2nd ed. Englewood Cliffs, NJ: Prentice Hall; 290.

Himelick, E.B. 1991. **Tree and shrub transplanting manual**. Savoy, IL: International Society of Arboriculture; 78 p.

Holinger, David. Y. 1992. **Leaf and simulated whole canopy photosynthesis in two co-occurring tree species.** Ecology 73:1-14.

Ingham, Elaine. 2001. **Soil foodweb information**. Soil Foodweb, Inc. Corvalis, OR; 4 p.

Ringgenberg, Stefan. 2001. **Flow in the phloem**. Arborist News 10(1): 21-26.

Roberts, Stephen W.; Smith, Robin I. 1980**. Aspects of water relations in coast live oaks and valley oaks subjected to root damage from land development operations**. In: Plumb, T.R. technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-GTR-44. Berkley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 171-175.

Perry, Ed; Hickman, Gary W. 2001**. A survey to determine the leaf nitrogen concentrations of 25 landscape tree species.** Journal of Arboriculture 27(3): 152-158.

Rundel, Philip W. 1980**. Adaptations of Mediterranean-climate oaks to environmental stress.** In: Plumb, T.R. technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-GTR-44. Berkley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 43-54.

Scott, Thomas; Pratini, Nannette. 1992. **Efficiency of transplanting oak trees for woodland habitat restoration.** Unpublished draft supplied by author.

Svihra, Pavel. Farm Advisor, University of California Cooperative Extension, Marin County [Telephone conversation with Rosi Dagit] 2001.

Tyree, Melvin T.; Davis, Stephen D.; Cochard, Herve. 1994. **Biophysical perspectives of xylem evolution: is there a trade-off of hydraulic efficiency for vulnerability to dysfunction?** International Association of Wood Anatomists Journal 15: 335-360.

Watson, Gary W. 1985. **Tree size affects root regeneration and top growth after transplanting**. Journal of Arboriculture 11: 37-40.

Watson, Gary W. 1994. **Root development after transplanting**. In: Watson, G.W; Neely, D. eds. The landscape below ground. Savoy, IL: International Society of Arboriculture; 54-68.