Modeling the Effectiveness of Tree Planting to Mitigate Habitat Loss in Blue Oak Woodlands[1]

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Abstract
Many local conservation policies have attempted to mitigate the loss of oak woodland habitat resulting from conversion to urban or intensive agricultural land uses through tree planting. This paper models the development of blue oak (*Quercus douglasii*) stand structure attributes over 50 years after planting. The model uses a single tree, distance independent growth model, calibrated to data derived from a blue oak plantation. The results vary based on initial planting density and plantation management intensity. Data on crown cover, basal area, and average tree diameter and height are presented. For the range of modeled conditions, canopy cover after 50 years is projected to range from 7 to 33 percent, with an average DBH after 50 years ranging from 3.4 to 4.1 inches (8.6 to 10.4 cm). The cost of these tree replacement strategies is evaluated, and the effectiveness of tree planting as a mitigation tool, especially as it relates to the creation of wildlife habitat, is discussed.

Introduction
California has one of the most rapidly growing human populations in the world. The state's population has grown from less than 100,000 people in 1850, to over 31 million people today (an average annual rate of growth of 3.4 percent) to a projected 63 million people in the next 50 years (Medvitz and Sokolow 1995). This population growth is having an impact on oak woodlands. Although California's oak woodlands cover 7.4 percent of the state (Bolsinger 1988), and are the most biologically diverse broad habitat in the state (Pavlik and others 1991), they are also one of the most rapidly urbanizing areas in California (Duane 1999). A survey of oak woodland owners showed that the majority of all owners now live less than 5 miles (8 km) from a subdivision (Huntsinger and Fortmann 1990, Huntsinger and others 1997). This also showed that approximately one-third of the properties changed owners between 1985 and 1992, and 5 percent were subdivided for residential development.

Over the past 40 years, California's oak woodlands have decreased by over one million acres (405,000 ha) on a statewide scale (Bolsinger 1988) due to human-induced factors. Major losses from 1945 through 1973 were from rangeland clearing for forage production enhancement. Major losses since 1973 were from conversions to residential and industrial developments. Regionally, some oak woodlands have

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decreased from urban expansion (Doak 1989), firewood harvesting (Standiford and others 1996), range improvement (Bolsinger 1988), and conversion to intensive agriculture (Brooks and others 1999). Habitat fragmentation, increased conflicts between people with different value systems, predator problems, and soil and water erosion, have resulted. Blue oak woodlands (*Quercus douglasii* Hook. and Arn.), covering 23 percent of the state's woodlands (Bolsinger 1988), are one of the areas with the largest concerns about conversion.

Concerns about conserving the environmental values of oak woodland resources in the face of conversions to other land uses from rapid urbanization and changing agricultural markets, has led planners to develop strategies to mitigate these effects. Tree planting technologies for blue oak have improved tremendously in the past 15 years, and widespread success from planting is possible (McCreary 1990, McCreary 1995b, McCreary and Lippit 1996, McCreary and Tecklin 1993). Tree planting is often proposed as part of mitigation strategies to replace habitat losses (Giusti and Tinnin 1993, Bernhardt and Swiecki 1991, Fulton 1999). Many mitigation plans regularly call for tree planting on a replacement basis (1:1 to as high as 20:1) for trees lost. However, since there is little experience with growth rates of planted native oaks beyond 10 to 15 years, there has not been an opportunity to assess how oak woodland habitats will develop over time from areas planted, and whether this mitigation approach on overall habitat quality is effective.

The purpose of this study was to evaluate blue oak tree planting as a mitigation strategy for habitat loss. The results should help assess the long-term impacts of tree planting on oak woodland habitat development.

There have been a number of studies evaluating growth of blue oak seedlings, and reporting on height, diameter, and canopy development with various management strategies (McCreary 1990, 1995a, 1995b; McCreary and Lippit 1996; McCreary and Tecklin 1993). There is no information on stand structure development extending beyond 10 to 15 years. There have been several long term whole stand growth models of blue oak woodlands developed by Pillsbury and DeLasaux (1985), and Standiford and Howitt (1988, 1993). However, these do not provide detailed information on stand structure development, but only general volume and basal area growth. A single tree, distance independent growth model has been developed for blue oak natural stands (Standiford 1997) which offers some promise for a more detailed assessment of stand development.

Methods

This study utilized a modeling approach to evaluate blue oak plantation development. *Figure 1* depicts the model used to predict the attributes of a planted stand over time. The individual tree size data (height, diameter, crown spread) 10 years after planting provided the input variables for the model. Individual tree basal area growth was modeled as a function of tree size, competition of each tree with adjacent trees, and site quality (Standiford 1997). Individual tree height growth and canopy development were correlated with basal area increment. The summation of the individual trees provided the stand totals for the first 10 years (basal area per acre, average DBH, average height, crown cover percent). The tree list and stand attributes were updated for every 10-year interval by a growth model that was based on actual blue oak stand age and structure data (Standiford 1997). Woodland productivity was assessed with a height-diameter site index relationship developed for blue oak sites

(Standiford and Howitt 1988). This was derived to give an index number for the height of a dominant tree in a stand when it averages 10 inches (25 cm) diameter at breast height (DBH). A site index of 50 feet (15 m) was assumed for the models presented below, which means that when the dominant trees average 10 inches (25 cm) DBH, they will average 50 feet (15 m) in height.

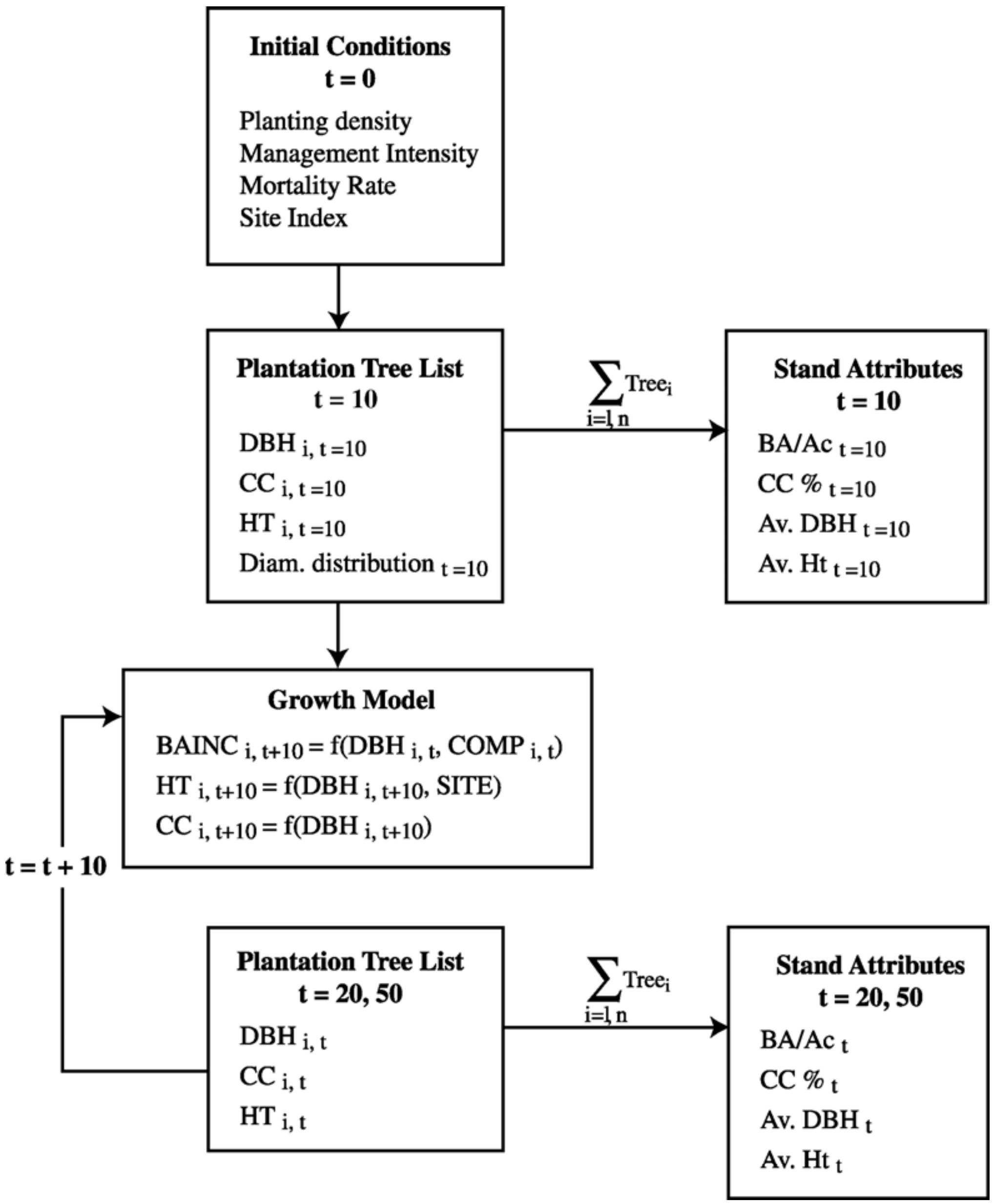

Figure 1—Modeling schematic to evaluate individual tree growth and stand characteristics of planted blue oaks over time. Where: DBH $_{i,t}$ is diameter at breast ht. (4.5 ft) of tree i at time t, CC $_{i,t}$ is canopy cover in sq. ft. of tree i at time t, HT $_{i,t}$ = total height of tree i at time t; BAINC $_{i,t+10}$ is basal area increment model for tree i for ten year period after time t, COMP $_{i,t}$ = competition index (Standiford 1997) for tree i at time t, BA/Ac $_{t}$ = stand basal area in square feet per acre at time t.

Data was collected from 55 sample blue oak trees in a ten-year old blue oak plantation at the Sierra Foothill Research and Extension Center (SFREC) in Yuba County, California, approximately 40 miles (64 km) northeast of Sacramento. The correlation between individual tree basal area and height and crown surface area was evaluated.

Based on the yield table of modeled stand attributes, a general assessment of wildlife habitat relationships was made using the Version 7.0 California Wildlife Habitat Relationships (CWHR) model (Giles and others 1999). The modeled stand is referred to as a "mitigated stand" since it represents tree planting designed to mitigate expected environmental impacts from tree removal in a particular project. The CWHR habitat types were evaluated based on the attributes of the mitigated stand, and applying the classification rules for CWHR (Mayer and Laudenslayer 1988). The list of vertebrate species generated by CWHR for the mitigated stand at different time periods was compared to a natural mature blue oak stand. These differences in vertebrate species were evaluated to see how the mitigated stand compared to the habitat lost in the mature stand.

Results

A regression equation was developed to predict the height and crown canopy area of the individual trees on the basis of the basal area of the individual tree at breast height (derived from DBH). This relationship helped to assess height and crown changes of the planted trees over time, for which there were no existing growth models. Equations 1 and 2 show the results of the regression of blue oak plantation tree height and crown surface area with individual tree basal area. A logarithmic form was utilized to represent the curvilinear shape of the relationship.

$$\ln(HT_i) = 3.164 + 0.213 \times \ln(BA_i) \qquad (1)$$

$$(^{**}) \quad (^{**}) \quad R2 = .67$$

$$\ln(CC_i) = 5.018 + 0.427 \times \ln(BA_i) \qquad (2)$$

$$(^{**}) \quad (^{**}) \quad R2 = .60$$

where: CC_i is canopy cover of tree i in square feet per tree, HT_i is total height of tree i in feet, BA_i is basal area of tree i at breast height (4.5 feet) in square feet per tree, ln is natural logarithm, and ** is significant at 0.01 level

These equations were applied to individual tree basal area, and basal area after growth projections, to develop tree height and crown cover for each tree. The initial tree list was based on diameter distribution data for a plantation that was monitored for 10 years after planting. Two different management regimes were assumed. A high management intensity scenario assumed that complete weed control was maintained for a 3-year period, and that best management strategies for planting seedlings were followed (McCreary 1995a). The assumption is that these stands would average 2 inches (5 cm) DBH after 10 years, and there would be a 90 percent seedling survival. The moderate management scenario assumed that weed control was for the first year only, resulting in stands averaging 1.5 inches (3.8 cm) DBH, with an 85 percent seedling survival. These assumptions are based on actual plantation growth

(McCreary 1990, 1995a, 1995b; McCreary and Lippit 1996; McCreary and Tecklin 1993) and observations of operational restoration projects.

Table 1 shows the results of the simulation of the blue oak mitigation planting. Initial planting densities were evaluated from 100 to 400 trees per acre (247 to 988 trees per hectare) for both the high and moderate management intensities. These results show that for both the high and moderate intensity category, planting only 100 trees per acre (247 trees per hectare) does not result in a stand with over 10 percent canopy cover after 50 years. Mature blue oak stands may only have 40 to 50 trees per acre (99 to 124 trees per hectare) (Bolsinger 1988), so planting 100 trees per acre (247 trees per hectare) would represent a 2:1 replacement strategy. After 50 years, these planted stands would still be classed as annual grasslands by the CWHR classification system since tree canopy cover is less than 10 percent.

Table 1 also shows the CWHR habitat seral stages for the mitigated stand over the 50-year simulation period. The two habitat stages projected to occur in the planted stands 50 years from establishment (Blue oak 2S and Blue oak 2P) were evaluated with the CWHR model. Since the purpose of the modeling was to evaluate the impacts on wildlife species associated with the hardwood tree component of blue oak woodlands, the list of species was reduced by eliminating species primarily associated with aquatic or conifer habitats, and species with an average habitat quality less than "medium." The area chosen for study was the central Sierra Nevada foothills. The results of the vertebrate wildlife projected to occur in these stands showed that 73 species would have medium or high quality habitat values in the two habitat stages projected to exist in planted stands in 50 years (1 amphibian, 40 bird, 19 mammal, and 13 reptile species).

The mitigated stand species list was compared to a natural blue oak stand, averaging 10 inches (25 cm) DBH, with a 30 percent canopy cover (Blue Oak 3P seral stage). The natural stand is assumed to have small and medium size downed wood, snags, acorns and trees with cavities. A natural stand with this habitat condition is projected to have 102 vertebrate wildlife species with medium or good habitat. The impacts were compared by evaluating the percent change in habitat quality between the natural and mitigated stand, using equation 3 below:

$$\left(\frac{H_{nat} - H_{mit}}{H_{nat}}\right) \times 100 = \text{Percent change} \qquad (3)$$

where: H_{nat} is habitat quality for natural stand, H_{mit} is habitat quality for mitigated/planted stand.

Garrison (1994) points out the difficulties in determining the biological significance of CWHR predictions. Garrison and Standiford (1997) address the tenuous nature of these predictions by utilizing a 50 percent change as the significant impact threshold. This is considered a relatively conservative threshold, representing an average habitat suitability change of at least one rating class.

Table 1—*Modeled blue oak stand characteristics after planting*

Planting density	Management intensity[1]	Age yrs.	Crown cover pct.	Basal area sq. ft/ac (sq. m/ha)	Av. diam. breast ht. in. (cm)	Av. height ft. (m)	CWHR seral stage[2]
100 trees per acre (247 trees per hectare)	High	10	6	2.0 (0.5)	2.0 (5.1)	11 (3.4)	AG 1D
		20	7	3.0 (0.7)	2.6 (6.6)	14 (4.3)	AG 1D
		30	7	4.2 (1.0)	3.1 (7.9)	15 (4.6)	AG 1D
		40	8	5.4 (1.2)	3.6 (9.1)	18 (5.5)	AG 1M
		50	9	6.7 (1.5)	4.1 (10.4)	21 (6.4)	AG 1M
	Moderate	10	4	1.1 (0.3)	1.5 (3.8)	10 (3.0)	AG 1D
		20	5	1.9 (0.4)	2.1 (5.3)	12 (3.7)	AG 1D
		30	6	2.8 (0.6)	2.6 (6.6)	14 (4.3)	AG 1D
		40	7	3.8 (0.9)	3.1 (7.9)	15 (4.6)	AG 1D
		50	7	4.9 (1.1)	3.6 (9.1)	18 (5.5)	AG 1D
200 trees per acre (494 trees per hectare)	High	10	12	4.1 (0.9)	2.0 (5.1)	11 (3.4)	BO 2S
		20	13	6.0 (1.3)	2.5 (6.4)	14 (4.3)	BO 2S
		30	15	8.1 (1.9)	3.0 (7.6)	15 (4.6)	BO 2S
		40	16	10.4 (2.4)	3.5 (8.9)	18 (5.5)	BO 2S
		50	17	12.8 (2.9)	4.0 (10.2)	20 (6.1)	BO 2S
	Moderate	10	9	2.2 (0.5)	1.5 (3.8)	10 (3.0)	AG 1M
		20	11	3.6 (0.8)	2.0 (5.1)	12 (3.7)	BO 2S
		30	12	5.3 (1.2)	2.5 (6.4)	13 (4.0)	BO 2S
		40	13	7.3 (1.7)	3.0 (7.6)	15 (4.6)	BO 2S
		50	14	9.3 (2.1)	3.5 (8.9)	17 (5.2)	BO 2S
300 trees per acre (741 trees per hectare)	High	10	18	6.1 (1.4)	2.0 (5.1)	11 (3.4)	BO 2S
		20	20	8.9 (2.0)	2.5 (6.4)	14 (4.3)	BO 2S
		30	22	11.9 (2.7)	3.0 (7.6)	15 (4.6)	BO 2S
		40	24	15.3 (3.5)	3.5 (8.9)	17 (5.2)	BO 2S
		50	25	18.8 (4.3)	3.9 (9.9)	20 (6.1)	BO 2P
	Moderate	10	13	3.3 (0.8)	1.5 (3.8)	10 (3.0)	BO 2S
		20	16	5.4 (1.2)	2.0 (5.1)	12 (3.7)	BO 2S
		30	18	7.9 (1.8)	2.5 (6.4)	13 (4.0)	BO 2S
		40	20	10.6 (2.4)	3.0 (7.6)	14 (4.3)	BO 2S
		50	21	13.6 (3.1)	3.5 (8.9)	17 (5.2)	BO 2S
400 trees per acre (988 trees per hectare)	High	10	24	8.2 (1.9)	2.0 (5.1)	11 (3.4)	BO 2S
		20	27	11.8 (2.7)	2.5 (6.4)	14 (4.3)	BO 2P
		30	29	15.8 (3.1)	3.0 (7.6)	15 (4.6)	BO 2P
		40	31	20.1 (4.6)	3.4 (8.6)	17 (5.2)	BO 2P
		50	33	24.6 (5.1)	3.9 (9.9)	20 (6.1)	BO 2P
	Moderate	10	18	4.3 (1.0)	1.5 (3.8)	10 (3.0)	BO 2S
		20	21	7.1 (1.6)	2.0 (5.1)	12 (3.7)	BO 2S
		30	24	10.3 (2.4)	2.5 (6.4)	13 (4.0)	BO 2S
		40	26	13.9 (3.2)	3.0 (7.6)	14 (4.3)	BO 2P
		50	28	17.8 (4.1)	3.4 (8.6)	17 (5.2)	BO 2P

[1] Management Intensity Assumptions—10 years after Planting—High–average 2 inches (5 cm) DBH with 90 percent survival; Moderate–1.5 inches (3.8 cm) DBH with 85 percent survival.

[2] CWHR Seral Stages—AG 1D is annual grassland, grass height less than 12 inches (0.3 m), over 60 pct. cover; AG 1M is annual grassland, grass height less than 12 inches (0.3 m), 40 to 59 pct. cover; BO 2S is blue oak woodland, 1-6 in. (2.5 to 15.2 cm) DBH, 10-24 pct. cover; BO 2P is blue oak woodland, 1-6 in. (2.5 to 15.2 cm) DBH, 25-39 pct. cover.

The mature blue oak (3P) was compared to planted blue oak stands (2P and 2S). The mitigation resulted in 17 species that showed significant decreases in habitat compared to the natural stand. For the 2S seral stage (projected to occur with planting densities of 200 trees per acre), 18 species had a significant increase in habitat quality after the mitigation. There were 10 species with a significant increase in habitat quality for the 2P seral stage (projected to occur with planting of 300 to 400 trees per acre [740 to 988 trees per hectare]). Seventy-five species had no significant change in quality for the 2S stage, and 67 had no change for the 2P stage.

The species that were projected to have significant decreases in habitat suitability were acorn and cavity dependent species such as various woodpecker species, the western bluebird, and the western gray squirrel. Species with significant increases in habitat suitability were wildlife that prefer meadows and open stand types, including the California pocket mouse, the California vole, the horned lark, and the Western meadowlark.

Discussion

This approach provides planners, developers and the restoration community with a tool to evaluate how important characteristics of the stand will develop over time. The projected structure of planted blue oak stands over a 50 year period from this study can be compared directly to actual stand data for areas that will possibly be lost in a conversion project that will need mitigation.

The general results of this study raise questions as to whether the structure of planted stands adequately mitigate the loss of mature stands. As these results show, average tree size after 50 years under fairly aggressive restoration efforts, is still quite small. The largest mean diameter of the stand is only 3.9 inches (9.9 cm), with a canopy cover of 33 percent.

Using CWHR as a tool to evaluate the wildlife habitat quality of the planted stand showed that in general, the overall biodiversity figures are not greatly affected from the mature stand chosen for comparison in this paper. However, the species composition shifts from wildlife species that utilize cavities, acorns, and downed wood, to species that utilize open meadows and grasslands.

Another factor to be considered is the cost of tree planting as a mitigation strategy. Although planting technology has advanced tremendously, restoration costs may range from $210 (moderate intensity) to $280 (high intensity) per acre for 100 trees per acre ($519 to $692 per hectare for 247 trees per hectare), up to $470 (moderate intensity) to $765 (high intensity) per acre for 400 trees per acre ($1161 to $1890 per hectare for 988 trees per hectare) (Standiford and Appleton 1993). These costs were updated to 2001 dollars using the producer price index. In some cases, it may be more cost effective to utilize the mitigation funds to ensure that existing mature habitat is conserved, through the purchase of conservation easements, the set aside of large blocks of commonly-owned land and density credits, or the establishment of public open space.

Conclusion

The results suggest that it is important to evaluate if tree planting is a viable method of mitigation. It appears to be a very costly, long-term effort, to restore an area. Many important habitat elements, such as cavities, acorns, snags, and woody debris may not be mitigated - at least in the 50-year interval evaluated in this study - through a tree planting strategy alone. Although procedures for discounting habitat decreases for woodland species and habitat increases for meadow species are not established, the results can be used as part of discussions about appropriate mitigation strategies.

These results rely on modeling extrapolated from relatively young tree plantations and natural stand growing conditions. It will be important to consider if the long-term growth of planted stands follows these preliminary projections. Actual height and crown growth models are needed, rather than relying on the correlation with basal area growth. Continued evaluation of planted stands is required to develop these improved models. It is also important to conduct on-site wildlife evaluations to determine the reliability of CWHR projections.

Although the results of this work point out that blue oak plantations develop habitat conditions slowly, and it may take in excess of 50 years to replace mature habitat that is lost in a particular project, tree planting is still an important conservation tool. The great strides that have been made in oak planting on hardwood rangelands should still be encouraged as part of an overall restoration strategy. Effective mitigation, however, may well require a more diverse array of tools to address the impacts of various woodland conversion projects.

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