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# Multiple use management of California's hardwood rangelands

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## Abstract

**The importance of evaluating multiple resource values on rangelands is demonstrated in this study of California's 3.0 million hectares of oak-covered (*Quercus* spp.) hardwood rangelands. Production functions are derived for oak tree growth on rangelands for stands with at least 50% of the total tree cover in blue oak (*Quercus douglasii* Hook. & Arn.) based on oak volume per acre and site index. Forage production is estimated based on oak cover, weather variables, growing period, and site factors from data reported in the literature. Hunting revenue and cost functions are derived from a survey of commercial hunting clubs, and are based on oak cover, hunter success variables, hunter demographics, advertising, livestock density, and club size. The interrelationship of these resource values is shown in output from an optimal control model that incorporates these production functions. Oak trees are gradually cleared for situations where cattle are the only economic product, whereas a residual tree canopy is maintained for cases where firewood and hunting enterprises are considered. In addition, cattle stocking is higher and net profitability is lower for the cattle only management scenario when compared with a multiple use management scenario. The development of these multiple use production functions allows the full range of resource management options to be considered.**

**Key Words: range economics**

Rangelands provide a variety of valuable resources such as wildlife habitat, aesthetics, recreation, forage, and watershed protection. Increasingly, economic and policy analysis of rangelands requires that all of these resources are adequately assessed in order to evaluate likely acceptable management practices and long-term resource values. However, production functions for these diverse resource values often do not exist, nor are the interrelationships among different resources known.

California's oak woodlands, also known as hardwood rangelands, are an example of a rangeland system where a variety of resource values are important and where there has been little analysis of the multiple resource values. This absence of detailed information has not prevented multiple resource values from being advocated. These rangeland areas occupy an estimated 3.0 million hectares in the state (Bolsiner 1988). Hardwood rangeland areas have at least a 10% canopy of hardwood tree species, predominantly in the oak genus (*Quercus* spp.), with an understory of annual grasses. Griffin (1978), Bartolome (1987), and Holmes (1990) provide good descriptions of these areas. Historically, these areas have been managed primarily for livestock production. In addition, hardwood rangelands are important in providing critical habitat for many game and nongame wildlife species (Verner 1980, Barrett 1980). Other public values obtained from hardwood rangelands include high quality water supply, outdoor recreation, and aesthetic values. Hardwood rangelands are somewhat unique for western wildlands, with over 80% in private ownership (Bolsinger 1988). Management concerns which impact supply of public values on private rangelands are different from those on publicly owned rangelands because of the need to generate pecuniary returns to maintain the operation.

Policy concerns about the economic and ecological sustainability of California's hardwood rangelands formed the rationale for this study of multiple use values. Hardwood rangelands have decreased by about 485,000 ha in the period from 1945 to 1973 (Bolsinger 1988). There is concern about the lack of regeneration for some oak species in certain geographical areas of the state (Muick and Bartolome 1987, Bolsinger 1988). Low profitability from traditional range livestock operations on hardwood rangelands and increasing population pressure have accelerated loss of these open space areas to subdivisions (Doak and Stewart 1986). These factors make it important to evaluate trends for optimal oak canopy levels, especially since public regulation of oak harvesting on private lands has been proposed (State Board of Forestry 1982. California's hardwood regulation in California hardwood types. Unpublished report of the Study Committee to the State Board of Forestry, Sacramento, Calif.)

Two of the major economic forces affecting oaks on hardwood rangelands are tree removal for firewood and range improvement. Firewood prices increased dramatically in the mid-1970's but remained relatively constant in real dollars through the mid-1980's (Doak and Stewart 1986). Oak clearing for range improvement reached a peak in the 1950 to 1960 era (George 1987). Recent increases in the demand for recreational hunting, with hunters willing to pay landowners for trespass rights, have created new market opportunities. Since the principal upland game species in the state, namely deer, quail, turkey, and feral pig, are all enhanced by oak stands (Barrett 1980), landowners who market hunting rights may be able to capture private economic benefits from oak retention.

## Study Objectives

The objective of this study is to develop models of hardwood rangeland resource dynamics and interrelationships. Firewood production, livestock production, and commercial hunting are 3 enterprises chosen for this study. Not evaluated were other forms of recreation, water supply, or aesthetics. Rangelands are dynamic systems in that decisions made about tree or brush removal, range improvements, and cattle stocking influence the state of the system in all subsequent years. These systems are also subject to seasonal and yearly variability due to climatic and economic factors. These models will also incorporate these uncertainty factors.

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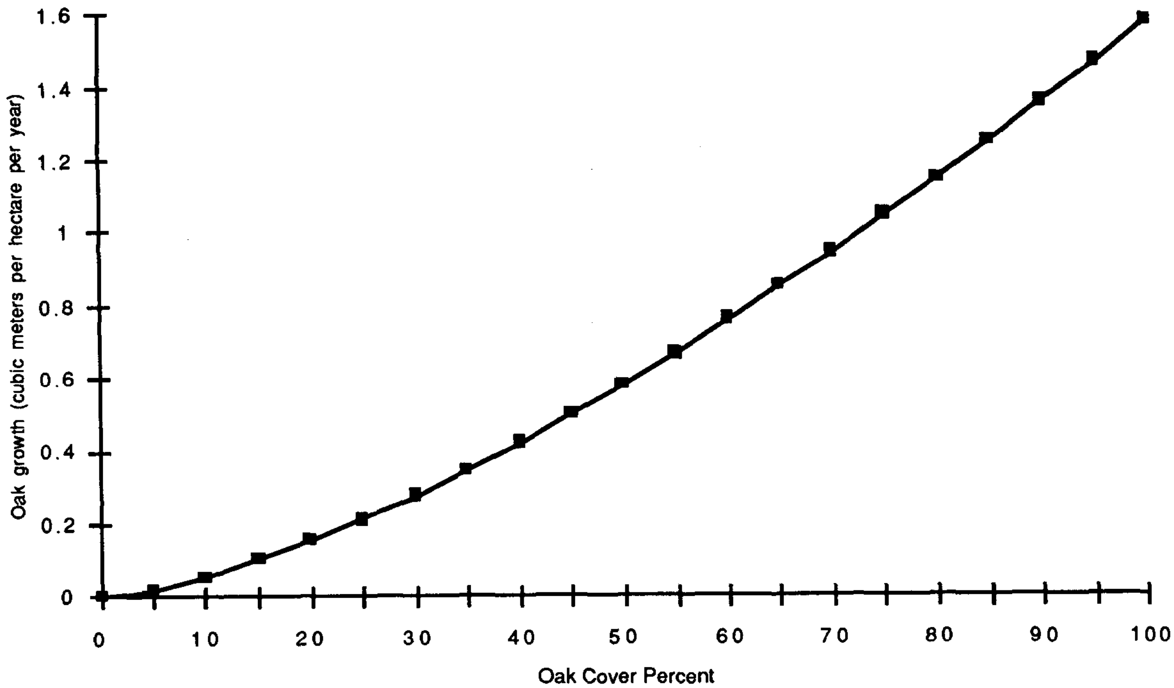


**Fig. 1. Periodic annual oak growth in cubic meters per hectare per year by oak crown cover percent for oak site index 12 m.**

## Previous Studies on Hardwood Rangeland Production Processes

### Hardwood Tree Growth

The only study conducted on oak tree growth on California's hardwood rangelands had static yield relationships (N.H. Pillsbury and M.J. DeLasaux 1985. Site index, height and yield prediction equations for blue oak and coast live oak in Monterey and San Luis Obispo Counties. Unpublished report of the Nat. Res. Management Dept., California Polytechnic State University, San Luis Obispo). This did not allow dynamic updating of the hardwood tree stock as a result of partial tree harvesting.

A wide variety of methods have been used to investigate stand growth. Models of whole stand growth as a function of tree density and site characteristics can usually be developed for fairly low costs (Clutter 1963), which appeared to be the most useful starting point for this study.

### Interaction of Tree Overstory and Forage

The impact of oak cover on forage yield has been well-documented in a variety of studies in California. Kay (1987) reports on 22 years of comparisons between forage production on dense oak woodland and open annual grassland range. This study, conducted on an area receiving 50 to 75 cm of annual rainfall, indicated that forage production in cleared areas was consistently higher than areas with a relatively dense blue oak overstory (*Quercus douglasii* Hook. & Arn.). This can be compared with the results obtained by Holland (1980) and Frost and McDougald (1989) working in areas with less than 50 cm of annual rainfall, showing that range forage production was higher in areas with scattered blue oaks than in open grassland areas. McClaran and Bartolome (1989) reported that forage yield comparisons between areas with 50% canopy and open areas depend upon annual precipitation. On areas with less than 50 cm of seasonal rainfall, forage yield was higher under blue oak canopies, whereas on higher rainfall areas this pattern was reversed. Jensen (1987) reported forage yields for 3 differing crown cover percents of blue oak compared with open range. Forage productivity decreased as oak overstory density increased. In general, oak effects on annual grassland production vary with canopy density and rainfall.

### Annual Range Productivity

Annual fluctuations in forage yield due to weather variability cause uncertainty for hardwood range managers in California. Five studies of hardwood rangeland forage production over 3 to 34 years reported maximum peak standing crop 1.5 to 5 times greater than lowest reported peak standing crop (George et al. 1989, Murphy et al. 1986, Pitt and Heady 1978, George et al. 1989, Duncan and Woodmansee 1975).

Different studies have evaluated various climatic variables to explain this variation in yields. Duncan and Woodmansee (1975) were largely unsuccessful in utilizing early season precipitation to predict forage yields. Pitt and Heady (1978) used temperature and precipitation to explain 73% of yearly standing crop fluctuation. Murphy (1970) found that early season rainfall was a good predictor of fall germination but not of peak standing crop. Sully (1980) used in-season precipitation and growing-degree days to explain forage variability. George et al. (1989) also utilized both early season precipitation and temperature to develop good predictions of both seasonal and peak range forage production and livestock weight gain.

These studies suggest that forage production relationships should include crown cover, rainfall, an interaction of rainfall and crown cover, and growing-degree days.

### Wildlife Values

Although a variety of methodologies have been used to estimate on-site and off-site wildlife values, this study used hedonic regression to estimate on-site wildlife values (Rosen 1974). This involves observation of actual market transactions for goods such as hunting leases and decomposing the price into its component parts using econometric techniques. This method assumes that a good receives values from its bundle of characteristics that contribute to a consumer's utility. Livengood (1983) and Pipe and Stoll (1985) used hedonic regression to assess deer hunting value in Texas based on hunt club location, hunting quality, and services and facilities provided.

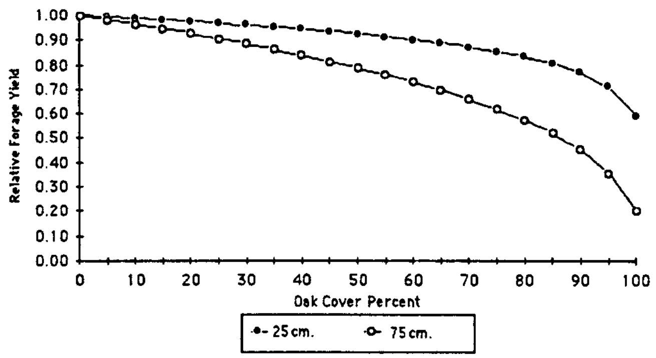


**Fig. 2. Relative forage yield, expressed as a fraction of open crown yield for varying oak crown cover percent, and different average annual rainfall zones.**

## Empirical Estimation of Production Processes

### Oak Tree Growth

To develop oak growth functions, 81 study sites were selected throughout California's hardwood range area in stands of pure blue oak, mixed blue oak and interior live oak (*Quercus wislizenii* A. DC.) stands in the Sierra Nevada foothills, and mixed blue oak and coast live oak (*Quercus agrifolia* Nee) stands in the coastal foothills. Study sites were confined to areas that had a basal area of at least 50% blue oak.

Individual tree diameter at breast height (DBH), basal area, total tree height, crown diameter, and radial growth over the last 5-and 10-year periods were collected at each plot. There were 972 individual trees measured in this study. Relationships for site index, periodic oak tree growth, and crown cover-volume relationships are developed below to be used to simulate the impact of thinning on oak growth on hardwood rangelands with at least 50% blue oak basal area.

Oak site index functions were developed to assess potential tree productivity by integrating the various elements contributing to tree growth into 1 single index number. The standard method for constructing site index curves utilizes height and age of the dominant trees in a stand as a proxy for site productivity. However, since total tree age was extremely difficult to collect on rangeland oaks, the relationship between tree height and diameter was used. Site index under this concept is defined as the height attained by dominant trees at a standard DBH. The standard DBH used in this study was 25 cm. The means that the dominant trees on a stand with a site index of 12 m would average 12 m in height when the average DBH of these dominant trees was 25 cm. The taller the dominant trees for a given DBH, the higher the site index.

Using the method described by Chojnacky (1986) on the 204 dominant trees on the study sites, the regression analysis of the height-diameter relationship was transformed to give equation (1) below.[1]

$$\ln(\mathrm{SITE}_{meters}) = \ln(\mathrm{HT}_{meters}) + 7.882(1/\mathrm{DBH}_{cm}) - 0.3103 \qquad \textbf{(1)}$$

Site index for the 81 samples sites ranged from a low of 7.3 meters to a high of 17.1 meters.

Cubic meter volume for the 81 different study sites ranged from 5 cubic meters per hectare (.8 cords per acre) to 378 cubic meters per hectare (64 cords per acre), with an average annual growth ranging from .14 cubic meters per hectare per year (0.02 cords per acre per year) to 3.6 cubic meters per hectare per year (0.6 cords per acre per year). Equation (2) below shows the results of the regression analysis of cubic foot growth[2].

$$\underset{(-11.49)^{***}}{\ln(\mathrm{PAI}) = -5.8368} + \underset{(12.54)^{***}}{0.60934[\ln(\mathrm{VOL})} + \underset{(5.34)^{***}}{1.2139[\ln(\mathrm{SITE})]} \qquad \textbf{(2)}$$
$$R^2 = .78$$

| Variable | Description |
|---|---|
| PAI | Periodic annual increment ($m^3$/ha/year) |
| VOL | Total volume ($m^3$/ha) |
| SITE | Site index |

[1]Note: The height-diameter equation followed the form –
$\ln(HT) = a_0 + a_1 * (1/DBH)$
where HT = total height; DBH = diameter at breast height; $a_0$ and $a_1$ significant at .05 level.

[2]Note: Numbers in parentheses below coefficients are t-values; ***means significant at <0.01 level; **significant at 0.05 level; *significant at 0.10 level.

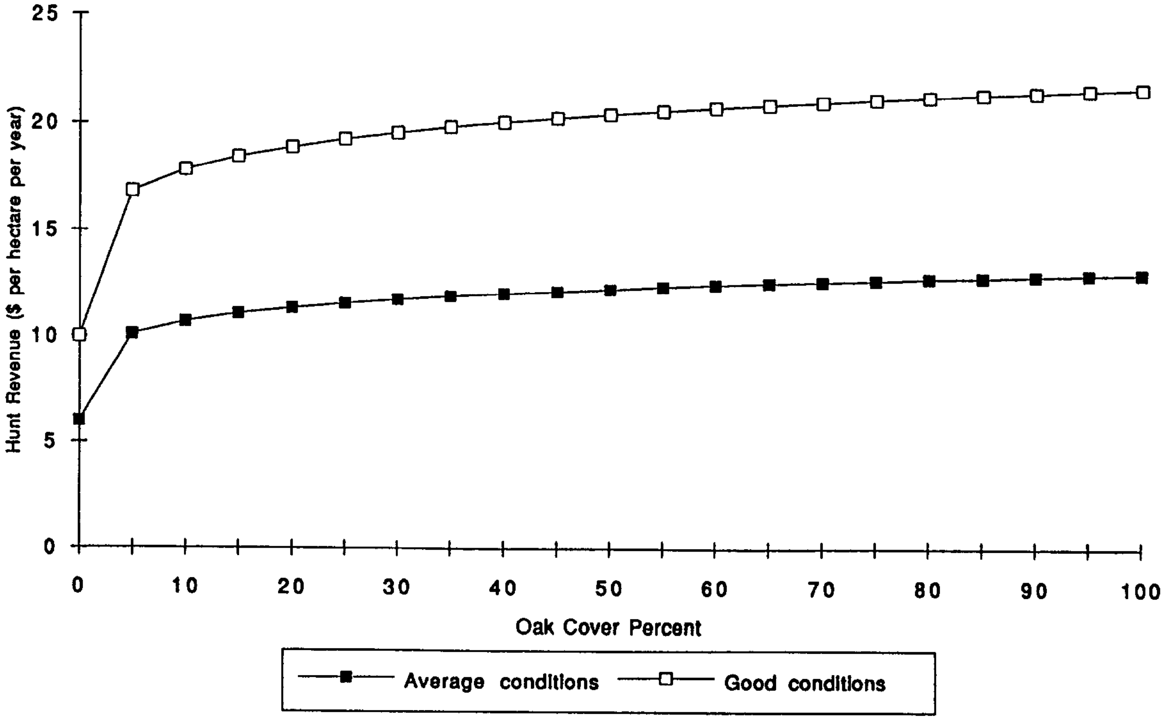


**Fig. 3. Annual hunting revenue per hectare for average and good conditions by oak cover percent.**

### Volume - Crown Cover Relationship

Crown cover is the most commonly used tree measure in range management and is highly correlated with wildlife habitat suitability and range forage production. Oak crown cover on the 81 study sites ranged from 8% to 100%. Equation (3) below shows this relationship between volume and crown cover.

$$\begin{array}{l} \ln(CC) = -4.359 + 0.4268[\ln(VOL)] + 0.8322[\ln(SITE)] \qquad (2) \\ \quad (-8.41)^{***} \quad (8.58)^{***} \quad (3.59)^{***} \\ \quad R^2 = .62 \end{array}$$

| Variable | Description |
|---|---|
| CC | Oak crown canopy percent |
| VOL | total volume ($m^3$/hectare) |
| SITE | Site index |

### Forage Production

A data set of 142 forage production observations in the open and under several different oak canopy densities was collected from 4 different studies on 6 different sample sites representing time series ranging from 2 to 22 years (Jensen 1987, McClaran and Bartolome 1989, Kay 1987, Heady and Pitt 1979). The data set includes forage yield in kg per ha for that year at that location, and crown cover percentage. Since the literature shows the overstory effects vary by climatic regions, seasonal rainfall and accumulated annual degree days were added to the data set.

A combined cross-section time series analysis was carried out for the 6 sample sites to predict forage yield as a function of overstory density and climatic variables. Accumulated seasonal rainfall was shown to be a much more significant weather variable than accumulated degree days for forage yield under different crown covers. A nonnested hypothesis test was carried out for 2 hypothesized functional forms for the forage/tree cover relationship (Davidson and MacKinnon 1981). The selected functional form is shown below in equation (4).

$$\begin{array}{l} \ln(FOR_{i,j}) = -4.2505 - 2.8807s_1 - 2.2442s_2 + 0.2563s_3 - 1.6785s_4 \\ \quad (13.29)^{**} \quad (-5.53)^{***} \quad (-6.74)^{***} \quad (0.40) \quad (-2.62)^{**} \\ -2.0225s_5 - 0.0566[\ln(100-CC_i)] + 0.0074[\ln(100-CC_i)RAIN_{i,j} \qquad (4) \\ (-3.20)^{***} \quad (-0.73) \quad (6.23)^{***} \\ -0.000029[\ln(100-CC_i)RAIN_{i,j}^2 + 0.0162s_1Day_{i,j} + 0.0162s_2DAY_{i,j} \\ (-4.74)^{***} \quad (8.00)^{***} \quad (14.98)^{***} \\ + 0.0126s_3DAY_{i,j} + 0.0187s_4DAY_{i,j} + 0.0208s_5DAY_{i,j} \\ (4.39)^{***} \quad (6.41)^{***} \quad (7.33)^{***} \\ \quad R^2 = .85 \end{array}$$

| Variable | Description |
|---|---|
| $FOR_{i,j}$ | forage yield for year i, day j (kg/ha) |
| $S_1$ | Dummy variable (range site 1) |
| $S_2$ | Dummy variable (range site 2) |
| $S_3$ | Dummy variable (range site 3) |
| $S_4$ | Dummy variable (range site 4) |
| $S_5$ | Dummy variable (range site 5) |
| $CC_i$ | Oak cover percent in year i |
| $RAIN_{i,j}$ | Accumulated cm. of rain in year i, day j (rain-canopy interaction) |
| $DAY_{i,j}$ | Julian day (Sept. 1 = day 1) |

These results show that canopy has a greater effect in depressing forage yield on higher rainfall areas, consistent with the results in the literature. The monotonic increase in forage yield with the number of days since the beginning of a typical season (1 September) in California's annual grassland is consistent with the biology of this range type.

### Hunting Production

A random sample of 60 ranches with recreational hunting programs on hardwood rangelands was surveyed by personal interviews. Each interviewee provided data on type of hunting lease, hunting lease price, number of hunters, hunter success, club location, wildlife habitat at the club, and detailed cost summaries. The major game species of interest in these surveys were deer, wild turkeys, and wild pigs. There were 55 usable surveys.

Total revenue and cost per hectare functions were estimated using hedonic regression techniques (Rosen 1974) to decompose costs and revenues to various physical and biological attributes of the hunting club. Since deer hunting was found on 49 of the 55 ranches, analysis was restricted to areas with deer hunting. The added value from pig and turkey hunting on areas with deer hunting was evaluated.

Average hunting revenue for surveyed ranches was $10.28 per ha. Preliminary analyses showed that distance from the ranch to several large cities such as Los Angeles, Sacramento, and San Francisco was insignificant in explaining variability in price structure. This was surprising at first since higher travel cost associated with clubs further from major cities would leave less surplus for hunting payments. However, a hunting fee study in Texas (Pope and Stoll 1985) showed that fees increased as distance from major cities increased. This indicates hunters may value isolation more highly than the cost associated with obtaining isolation. The tradeoff between isolation value and travel cost must be the reason that distance from major cities was nonsignificant in this study.

Information on various services and improvements provided by clubs was analyzed. Availability of cabins, guide services, camping, hunting dogs, or vehicle use were not significant. This was apparently due to the great diversity in services provided by ranches and the high variability in hunter demand for these services.

A Davidson-MacKinnon nonnested hypothesis test was carried out to evaluate a logarithmic revenue function (equation 5) against a linear form. The logarithmic form of the hunting revenue function was selected by this procedure.

$$\begin{array}{l} \ln(HR) = 3.364 + 0.084[\ln(CC)] + 0.726[\ln(SCEN)] + 0.126[\ln(HINC)] + \\ \quad (3.74)^{***}(2.11)^{**} \quad (2.55)^{**} \quad (2.22)^{**} \qquad (5) \\ 0.046[\ln(DRTRP)] + 0.131[\ln(DRAUM)] + 0.138[\ln(PPIG)] \\ (1.24) \quad (1.99)^{*} \quad (3.06)^{***} \\ - 0.234[\ln(HECT) + 0.108[\ln(ADV)] \\ (-2.80)^{***} \quad (1.92)^{*} \\ \quad \overline{R}^2 = .62 \end{array}$$

| Variable | Description | |
|---|---|---|
| HR | Hunting revenue per hectare | CC |
| SCEN | Subjective scenery rating supplied by interviewee | |
| HINC | Percent high income clientele | |
| DRTRP | Percent harvest deer trophy size | |
| DRAUM | Difference in animal unit months (AUMs) per hectare with and without hunting | |
| PPIG | Percent deer area with pig hunting | |
| HECT | Total hectares hunted | |
| ADV | Advertising dollars per hectare | |

Positive coefficients for scenery, percent of high income hunters, percent of trophy deer, allocation of forage to the hunt club, percent of the hunt club where pig hunting is also allowed, and expenditure for advertising show that as hunt quality or appeal to a higher paying clientele increases, revenue per hectare also increases. The positive coefficient for oak crown cover shows that since oak cover enhances habitat for game species, revenue from hunting also increases. The negative sign on hectare hunted shows that large ranches have lower net revenues per hectare than smaller ranches due to the more dispersed, extensive type of hunting operation on larger ranches.

Average hunting costs in the survey were $7.54 per hectare. Preliminary regression analysis of the hunting cost function showed low significance for care of game, hunt club acreage, transportation services, availability of cabins and percent of high income hunters, possibly due to the high variability in the provision of the bundle of these services between ranches.

A linear hunting cost function is shown below. A logarithmic form was also evaluated and rejected using the Davidson-MacKinnon nonnested hypothesis test.

$$HC = 1.7191 + 2.2912\ ADV - 0.9259\ GUIDE + 1.698\ TAG \quad (6)$$
$$(3.17)^{**}\quad (21.89)^{***}\quad (1.81)^{*}$$
$$R = .91$$

| Variable | Description |
|---|---|
| HC | Hunting cost per hectare |
| ADV | Advertising dollars per hectare |
| GUIDE | Dummy variable for guide services |
| TAG | Dummy variable for deer tags |

The negative coefficient for guide services shows that total cost per hectare of the hunting club decreases for ranches where guides assume management for part of the hunting operation. These guides, who are actually subcontractors, bear some of the hunt club operating costs, reducing costs paid by the rancher. This analysis shows the high significance of advertising on the total cost function. It serves as a good index for other hunting club costs. Ranchers who spend money to advertise may also spend more money per hectare to operate the club. The positive sign of the variable for deer tags shows that these direct costs are borne by the rancher.

## Implications of Evaluating Multiple Use Management

The significant variables in the oak growth, hunting revenue, and forage production functions demonstrate linkages between resource values. For example, oak crown canopy affects forage yield, hunting revenue, and tree growth. Decisions about oak tree harvest levels therefore modify revenue from livestock production, hunting, and wood products in all subsequent time periods. Figures 1 through 3 are generated by simulating equations 2, 3, 4, and 5. These show that as oak canopy increases, tree growth and hunting revenue increase while forage production decreases.

This study also developed a model to assess likely behavior of range managers and the impacts on interrelated hardwood rangeland resources over time. Because of the complexities of the hardwood range system and interest in long term trends for oak stands, an optimal control approach was used.

Optimal control theory is based on derivation of decision rules that determine the optimum trajectory of capital stocks over time. The trajectory is "controlled" by the manager through decision variables, or control variables, that are linked with the capital stock in the system.

The general framework for the optimal control model is shown in equation (7). The purpose of this paper is not to elaborate on the complete specification of the optimal control methodology, which is described in detail in a companion paper (Standiford and Howitt in press), but to discuss the implications of the multiple product functions on rangeland management decisions based on the empirical results of this model.

$$\text{Maximize } NPV = \sum_{t=1}^{T} DF_t \bullet \{WR_t(WDSEL_t, PWD_t) + HR_t(CC_t(VOL_t), HRD_t, DRAUM_t, exog.) + LR_t(HRD_t, CS_t, PCOW_t, PFEED_t, FED_t, REP_t, FOR_t(CC_t(VOL_t), exog.))\} + TV_T \quad (7)$$

Such that:

| | |
|---|---|
| $VOL_{1+t} = F(VOL_t, exog.) - WDSEL_t$ | [Equation of motion for oaks] |
| $HRD_{1+t} = G(HRD_t, REP_t, exog.) - CS_t$ | [Equation of motion for livestock] |
| $E(TR_t(LR_t, WR_t, HR_t) - z_{1-\gamma} \bullet cov(TR_t)^{.5} \geq 0$ | [Chance constraint risk factor] |
| $WD_0 = INITWD$ | [Initial stock of wood] |
| $HRD_0 = INITHRD$ | [Initial stock of livestock] |

where:

| | | |
|---|---|---|
| $CC_t(VOL_t)$ | = | Oak cover percent as function of oak stock [derived from equation 3] |
| $cov(TR_t)$ | = | Variance-covariance matrix for total revenue |
| $CS_t$ | = | Vector of different classes of livestock sold **(control variable)** |
| $DF_t$ | = | Discount factor at time t |
| $DRAUM_t$ | = | Allocation of forage to hunting enterprise in time t **(control variable)** |
| $FED_t$ | = | Supplemental feed purchased at time **(control variable)** |

$FOR_t(CC_t(VOL_t), exog.)$ = Forage yield as function of tree canopy and exogenous range productivity factors [derived from equation 4]

$F(VOL_t, exog.)$ = Tree growth as function of oak volume and exogenous site factors [derived from equation 2]

$G(HRD_t, REP_t, exog.)$ = Livestock growth as function of livestock numbers including replacement heifers, and exogenous factors (i.e. cattle breed)

$HR_t(CC_t, HRD_t, DRAUM_t, exog.)$ = Net hunting revenue as a function of oak cover, livestock, allocation of forage to hunting and exogenous variables (i.e., hunting clientele, guide services, etc.) [derived from equations 5 and 6]

$HRD_t$ = Livestock herd size at time t **(state variable)**

$LR_t(HRD_t, CS_t PCOW_t, PFEED_t, FED_t, REP_t, FOR_t(WD_t, exog.))$ = Net livestock revenue at time t as function of livestock herd, cattle and feed prices, supplemental feed purchased, range forage production, and number of livestock sold.

NPV = Net present value

$PCOW_t$ = Vector of prices for different classes of cattle at time t

$PFEED_t$ = Price of supplemental feed at time t

$PWD_t$ = Price of firewood at time t

REP = Replacement heifers added to the herd at time **(control variable)**

TR = Total revenue at time t as function of firewood, hunting, and livestock revenue

$TV_T$ = Terminal value of capital stocks at time T

$VOL_t$ = Volume of oak trees at time t **(state variable)**

$WDSEL_t$ = Volume of firewood cut in time t **(control variable)**

$WR_t(WDSEL_t, PWD_t)$ = Firewood revenue as function of firewood harvest price in time t

$z_{1-\gamma}$ = Standardized normal variable set for probability **g** that total revenue is nonnegative

The rancher's objective function is to maximize net present value from firewood harvesting, livestock production, and commercial hunting. The 2 state variables for which the trajectories are determined are the stocks of oak trees and livestock. The amount of oak firewood cut, livestock sold, replacement heifers added to the herd, amount of supplemental feed purchased and allocation of forage to the hunting enterprise are the 5 control variables in the optimal control maximization for which the ranch manager makes annual decisions. These were determined for different range sites and initial oak volumes throughout the state. Risk was considered using a chance constrained approach that allowed negative cash flows only 1 year out of 10 (Charnes and Cooper 1959). Solution techniques for the nonlinear optimization are described in Standiford and Howitt (1992).

Figure 4 shows how optimum oak canopy varies depending upon the resource values considered. These figures are for initial conditions of 52 cubic meters of oak volume per hectare (corresponding to about 55% crown canopy), site index of 12 m, 150 cow-calf pairs per 400 ha, and a relatively productive range site. When firewood value and hunting revenue are not considered and only livestock production is evaluated (the Livestock Only option on Fig. 4), the model indicates that rational economic behavior is to gradually clear the oaks because of resulting additional forage. Immediate tree clearing does not take place because of the annual budget constraint imposed in the risk specification. However, when tree value for selective firewood harvesting is considered, a light harvest takes place. All trees are not harvested because of the terminal value the trees represent for the future firewood produc-

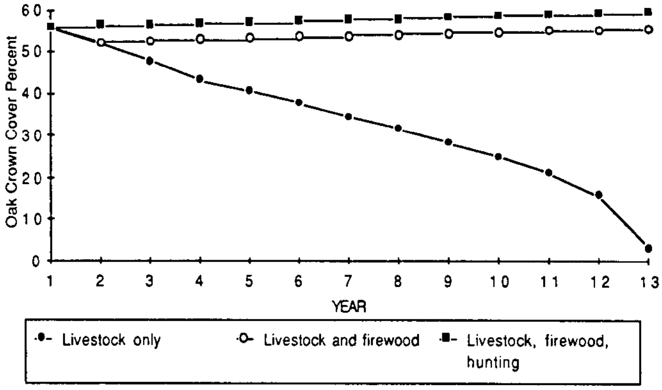


**Fig. 4. Optimal oak canopy level estimated by different levels of management diversification.**

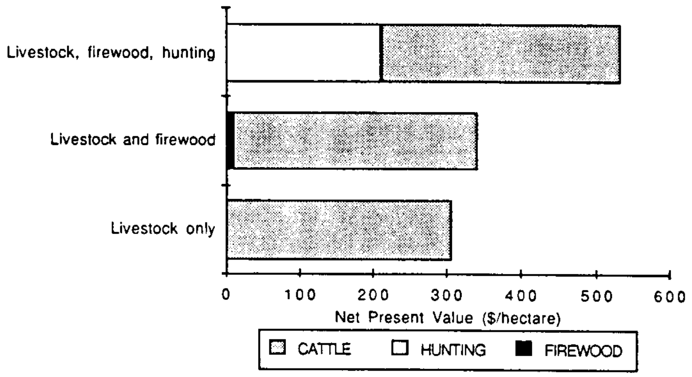


**Fig. 6. Net present value by resource enterprise for different multiple use scenarios.**

tion and the "true" costs of tree harvest determined in a calibration procedure which considers actual producer behavior (Standiford and Howitt 1992). When hunting revenue is received, no firewood harvesting occurs. The marginal value of oak canopy for wildlife habitat exceeds the marginal value of extra forage and firewood volume. To summarize, when tree growth and value are considered for wildlife habitat and wood products, cutting is decreased from the scenario where livestock is the sole revenue source.

Cattle stocking rates are also modified when considering multiple values. Figure 5 shows the assessment of optimum cow-calf pairs for the same set of conditions described above. For the livestock only scenario, optimum cow-calf pairs are higher than for the cases where firewood and hunting value are considered. Failure to include multiple resources in the analysis would lead to a conclusion about optimum cattle stocking that would be too high to optimize net ranch revenue from all sources.

The model showed that hunting revenues can be a significant component of total ranch income. Figure 6 compares the magnitude of economic value from cattle, hunting, and firewood enterprises for a 4% real discount rate. Inclusion of hunting value contributes 40% to total net present value. The value of the firewood enterprise in the livestock and firewood scenario accounts for only about 3% of the total net present value. However, this small contribution provides sufficient value for a conservation incentive for rangeland oaks. Development of production functions for these resources was important in being able to adequately assess the full range of resource management options open to landowners.

## Conclusions

These results indicate that production functions for diverse resource values found on hardwood rangelands can be developed from a combination of field research and data collected from studies reported in the literature. Relationships were developed for range productivity considering site factors, weather variables, and competition from oak tree overstory. Tree growth functions were developed based on an oak site index and tree volume per hectare.

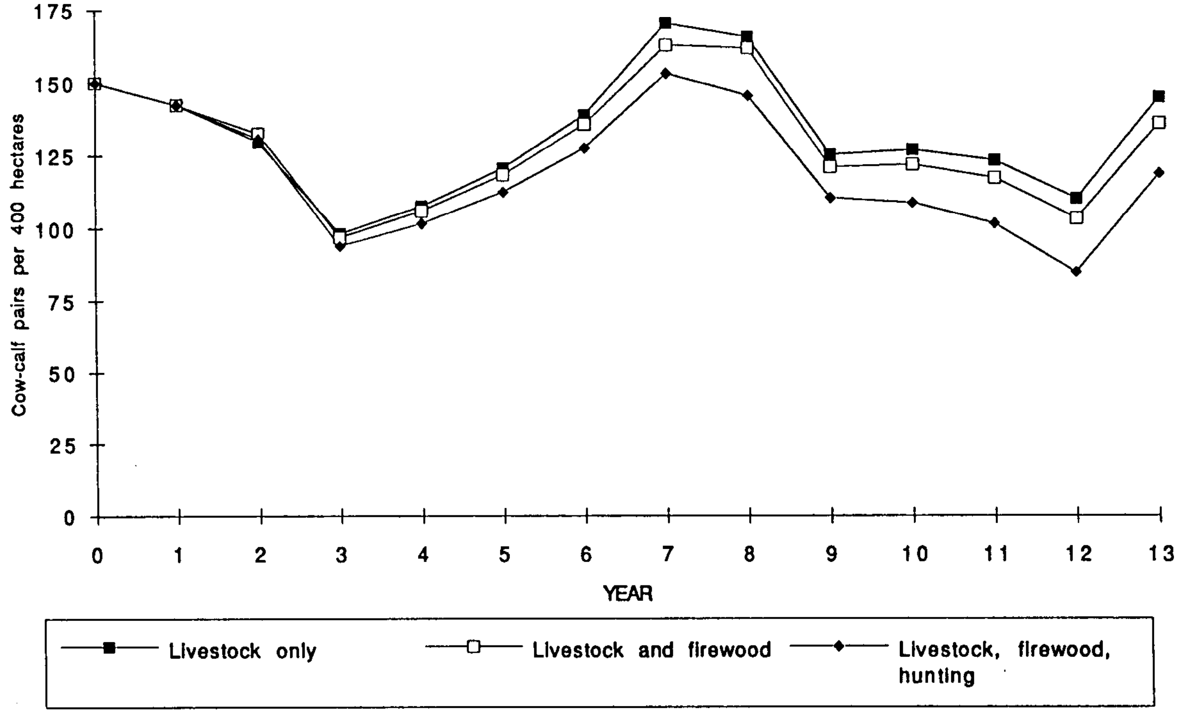


**Fig. 5. Optimal cow-calf pairs per 400 ha for different multiple use scenarios.**

Revenue functions for fee hunting were derived from habitat characteristics of the ranch as well as demographic characteristics of the hunter clientele.

The use of these multiple resource production functions and the interrelationship between these factors is of great importance in assessing likely range management practices. If hunting and firewood values were ignored, for example, then complete oak clearing, higher cattle stocking, and lower profitability would be predicted on hardwood rangelands. With the increasing demands being placed upon rangelands, studies that look at multiple use management will be increasingly important.

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