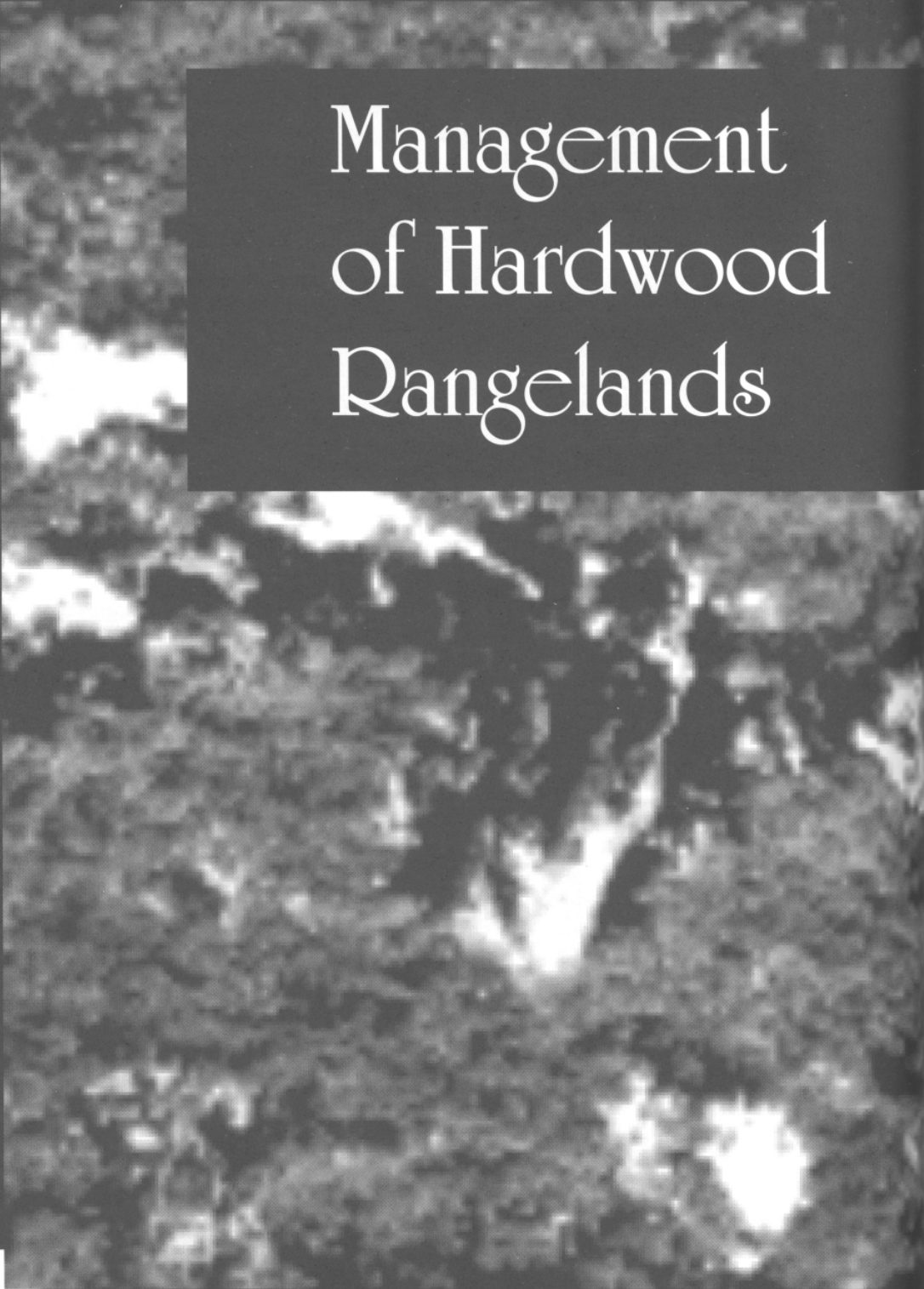
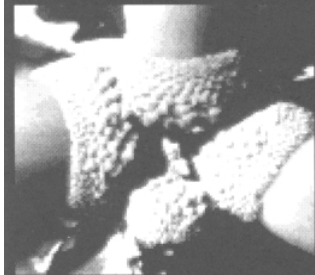




Management of Hardwood Rangelands



A Dynamic Model of California's Hardwood Rangelands¹

Richard B. Standiford Richard E. Howitt²

Abstract: Low profitability of hardwood rangeland management, and oak tree harvesting for firewood markets and forage enhancement has led to concern about the long-term sustainability of the oak resource on rangelands. New markets for recreational hunting may give value to oaks for the habitat they provide for game species, and broaden the economic base for managers. A ranch level optimal control model has been developed to assess optimal oak tree canopy and livestock stocking under different biological and economic conditions. The impact of recreational hunting on management was also assessed. In general, hunting improved the economic return on hardwood rangelands, and resulted in lower oak harvest levels and lower livestock stocking. The policy implication is that public concern over oak tree harvesting may be partially alleviated by new markets for recreational hunting on hardwood rangelands.

California's oak-covered rangelands occupy 7.4 million acres (California Department of Forestry and Fire Protection 1988). Over eighty percent of the area is privately-owned, providing one-third of the forage for the state's livestock industry. The public goods supplied by hardwood rangelands, including wildlife habitat, watershed protection and aesthetics, have led to strong public interest in the management of these private lands. One of the important ecological characteristics of this area is the interconnectedness of large expanses of woodland.

Conversion of hardwood rangelands to urban or intensive agricultural use is one of the leading sources of habitat loss and fragmentation, amounting to around seven percent of the oak woodland acreage between 1950 and 1980 (Bolsinger 1988). Oak clearing for forage enhancement was at one time a major source of habitat loss, however this practice peaked in the 1950's and 60's (George 1987). Rapid increases in firewood prices in the 1970's (Doak and Stewart 1986) suddenly gave value to the oak trees on rangelands, resulting in increased firewood harvest. Poor oak regeneration has also been documented in some areas, leading to some concern about the long-term sustainability of this resource (Muick and Bartolome 1987).

These concerns about the future of this valuable resource have resulted in zoning restrictions and ordinances at the local level, and proposals for statewide regulation of tree removal. However, no empirical estimates have been made of the effect of current and future economic conditions on landowner man-

agement decisions for these large expanses of private land. Private hardwood rangeland profitability directly affects the rate of fragmentation due to subdivision. The forces impacting oak tree harvest, such as income from firewood and increased forage for livestock, affect the structure of the tree canopy and its value for different wildlife species. New markets for fee hunting on private rangelands have recently developed in the state. Since many of the game species demanded by hunters are enhanced by oak cover, this new market may serve to provide a market-based oak conservation incentive for landowners.

STUDY DESIGN

The objective of this study is to assess the likely impacts of different biological and economic conditions on oak stands by developing a multiple resource management model for hardwood rangelands. This requires the development of production functions of the basic processes that impact management decisions on hardwood rangelands and reflect the relationship between these resources. In addition, economic models that represent the behavior of hardwood rangeland owners need to be determined.

Figure 1 shows a schematic flow diagram for multiple resource decision-making. This assumes that ranchers make decisions about their level of oak tree retention and cattle stocking based on cattle and firewood markets, the relationship between oak tree cover and forage production, the rate of growth of these resources, and the potential for alternative economic enterprises such as commercial hunting. As this shows, decisions are made annually based on the biological and economic factors of these resource values.

To evaluate this decision-making framework, an approach which addresses both dynamics and interrelated resource values is needed. Traditional methods of analysis in range economics, which often focus on forage as an annual crop with partial budgeting used to compare the costs of range improvements to livestock gains, were felt to be inadequate for this purpose. Optimal control theory provides a powerful tool which can be used to develop the decision rules to determine the optimum pathway of the stocks of oak trees and cattle over time. The pathway is "controlled" by the manager through decision variables, or control variables, that are linked with the tree and cattle capital stock in the system. The amount of oak firewood cut and livestock sold (or bought) are the control variables. The ranch manager makes annual decisions about the level of these control variables.

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²Forest Management Specialist, Dept. of Forestry and Resource Management, University of California, Berkeley; Professor, Dept. of Agricultural Economics, University of California, Davis.

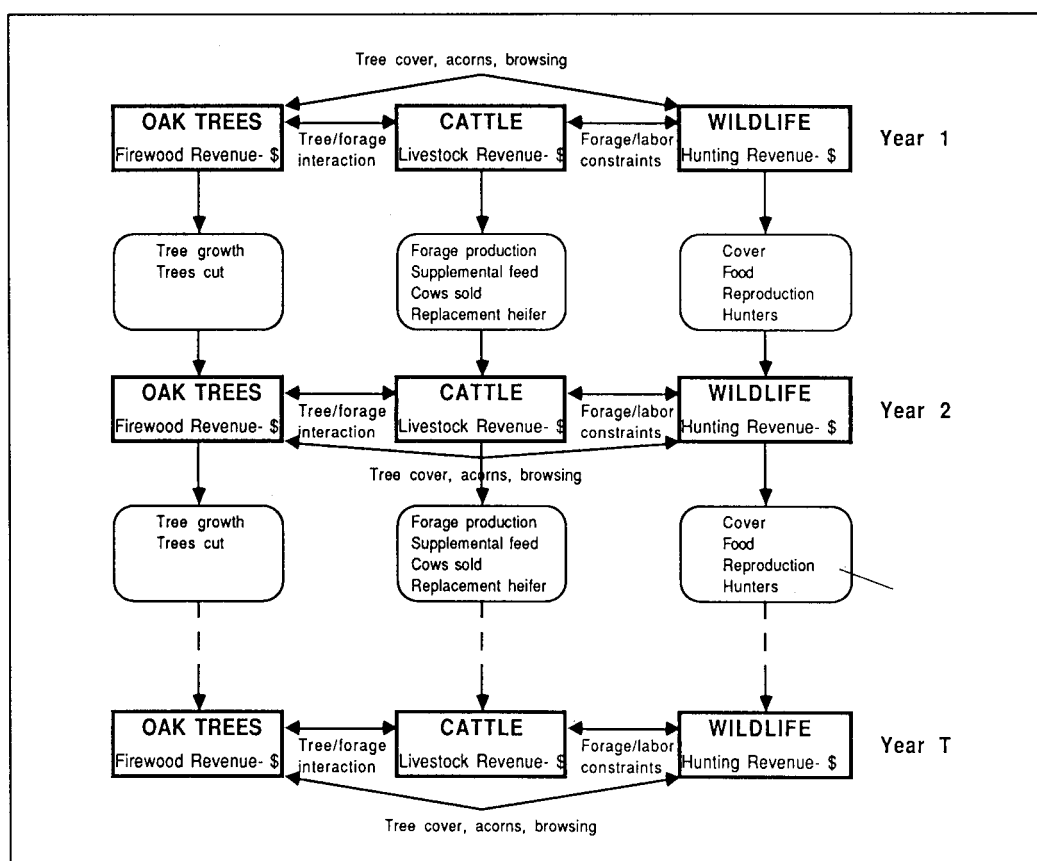


Figure 1—Decision-making flow diagram for hardwood range management.

Equation (1) below shows the general framework used to evaluate management decisions on hardwood rangelands. This is based on a manager maximizing net present value (NPV) over a time period of T years. This shows the decision to be based on firewood revenue, livestock revenue, and hunting revenue. Biological growth functions, known as equations of motion, provide links between years for the capital stocks. The hypothesized interrelationships between the various hardwood range resources are shown below.

(1) Maximize: NPV=

$$\sum_{t=1}^T DF_t^* (WR_t (WSEL_t) + HR_t (WD_t, HRD_t, \text{exog.}) + LR_t (HRD_t, CS_t, FOR_t (WD_t, \text{exog.})))$$

such that:

$$\begin{aligned} WD_{t+1} &= F(WD_t, \text{exog.}) - WSEL_t && \text{[Equation of motion for oaks]} \\ HRD_{t+1} &= G(HRD_t, \text{exog.}) - CS_t && \text{[Equation of motion for livestock]} \\ WD_0 &= \text{INITWD} && \text{[Initial stock of wood]} \\ HRD_0 &= \text{INITHRD} && \text{[Initial stock of livestock]} \\ WSEL_t &\geq 0 && \text{[Wood cutting nonnegativity constraint]} \end{aligned}$$

where:

DF_t = discount factor at time t
 $WSEL_t$ = volume of firewood cut in time t
 $WR_t (WSEL_t)$ = firewood revenue as a function of firewood cut in time t
 WD_t = Stock of oak trees at time t
 HRD_t = stock of livestock at time t
 $HR_t (WD_t, HRD_t, \text{exog.})$ = Hunting revenue at time t as a function of the stock of trees and livestock and exogenous variables (location, wildlife population, etc.)
 CS_t = Vector of different classes of livestock sold
 $LR_t (HRD_t, CS_t, FOR_t (WD_t, \text{exog.}))$ = Livestock revenue at time t as a function of the stock of livestock, forage production, and the number of livestock sold.
 $FOR_t (WD_t, \text{exog.})$ = Forage production expressed as a function of tree canopy and exogenous range productivity factors
 $F(WD_t, \text{exog.})$ = Tree growth during time t as a function of the stock of oaks and exogenous site factors
 $G(HRD_t)$ = Livestock growth during time t as a function of the stock of livestock and exogenous factors (i.e. cattle breed)

ESTIMATION OF PRODUCTION FUNCTIONS

Production functions were determined for the various components of the hardwood range decision-making model. Complete details on the analysis are in Standiford (1989).

Oak Tree Growth

The dynamic optimization process requires that oak growth can be assessed for differing stand densities in order to evaluate the impact of selective oak harvesting on future stand structure and its impacts on livestock, recreation, and firewood enterprises. Eighty-one study sites were selected in seven locations in stands of pure blue oak (*Quercus douglasii*), mixed blue oak and interior live oak (*Q. wislizenii*) stands in the Sierra Nevada foothills, and mixed blue oak and coast live oak (*Q. agrifolia*) stands in the coastal foothills. Individual tree diameter at breast height (DBH), total height, crown diameter, and five- and ten-year radial growth was measured on 972 individual trees. This was used to develop relationships for oak site index, periodic oak tree growth, and crown cover-volume relationships (Standiford and Howitt 1988).

Forage Production

A data set of 142 observations of forage production in the open and under several different densities of oak canopy was collected from four different studies, representing time series ranging from 2 to 22 years (Jensen 1987; McClaren and Bartolome 1989; Kay 1986; Heady and Pitt 1979). Seasonal rainfall and accumulated annual degree days were included for each study site from weather records. Combined cross-section and time series analysis was used to evaluate variability between sites and years. A seasonal forage yield model was estimated based on overstory oak cover, accumulated julian days, and accumulated seasonal rainfall. In this model, oak canopy has a greater effect in depressing yield on higher rainfall areas, which is consistent with the results reported in the literature (McClaren and Bartolome 1989).

Hunting Production

A random sample of 60 ranches identified as operating recreational hunting programs was surveyed, providing data on the type of hunting lease, price of the hunting lease, number of hunters, hunter success, location of the club, 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. Revenue and cost functions were estimated on a per acre basis using hedonic regression (Rosen 1974) to decompose the costs and revenues to the various physical and biological attributes of the hunting club. Since deer hunting was found on 49 of the 55 usable surveys, analysis was restricted to areas with deer hunting, with the value from pig and turkey hunting that operated jointly on deer areas evaluated.

Oak crown cover, a numerical rating for scenery, the percent of high income hunters, percent of trophy deer harvested, the difference in animal unit months (AUMs) with and without hunting, percent of the hunt club where pig hunting is allowed, and the expenditure for advertising were all positive variables in the hunting revenue function. Acreage had a significant negative sign in the hunting revenue function, which shows that as ranch size increases, net revenues per acre decreases due to more dispersed, extensive type of hunting operations. Family labor constraints are also more likely to be binding on large ranches. Distance to several large cities, availability of cabins, guide services, camping, hunting dogs, and vehicles for hunter use were not significant in explaining variability in hunting revenue.

The cost function per acre for hunting clubs was also evaluated. Advertising cost per acre, a dummy variable for guide service, and a dummy variable for whether deer tags are provided, were all highly significant variables. Care of game, hunt club acreage, transportation services, availability of cabins, and percent of high income hunters, had very low significance in the analysis.

Price Expectations

One of the largest factors impacting hardwood range management is the large year-to-year variability in livestock and hay prices. Price data for different classes of cattle was collected (U.S. Department of Agriculture, various years; and California Department of Food and Agriculture, various years). Fair quality alfalfa hay was used as a proxy for hay prices, and collected for the Petaluma and Madera areas of the state from the Federal-State Market News Service (various years). Firewood prices per cord were collected from data in Doak and Stewart (1986) for delivered prices in the San Francisco Bay Area. All prices were deflated to constant 1977 dollars using the Price Receive Index.

Ranchers were hypothesized to base cattle, hay and firewood price expectations on a weighted average of past observations. To model this, a Box-Jenkins analysis of the time series data estimated the coefficients and variances for price expectation models of cattle, hay and firewood prices. A block diagonal matrix of variances, with off-diagonal covariances between livestock classes, was calculated to evaluate risk due to price variability in the optimal control model. Independence was assumed between firewood, hay, and livestock prices. Since hunting revenue is usually based on a long-term lease, zero price variability was assumed for hunting revenue.

Firewood Harvesting Cost

Dammann and Andrews (1979) report on the costs of harvesting, processing, and transporting firewood in hardwood stands in New Hampshire. This engineering data was used to construct a model of firewood harvesting costs based on the volume of wood sold.

THE OPTIMAL CONTROL MODEL

Based on these production functions and the general optimal control framework shown in equation (1), a discrete time optimal control model was set up with three seasons within a year to model annual range forage production, and yearly time increments for hunting and wood volume production. Complete details on the actual formulation of the model are in Standiford (1989).

Preliminary runs of the optimal control model showed the firewood harvest was either at its minimum (i.e., no wood cut) or at its maximum (i.e., all the wood is clearcut). Since actual wood harvest data shows that partial harvest is the typical method for oak tree harvest (Bolsinger 1988), a procedure to determine missing "costs" of harvesting firewood was used. Ranchers value oak trees for the value they add to their ranch for their own personal aesthetics and for game and nongame wildlife species (Huntsinger and Fortmann 1990) even without a commercial hunt club. A firewood adjustment cost was determined to reflect the net value of the wood harvest to the rancher by calibrating the model to actual oak tree harvest data over a thirteen year period for different hardwood range forest types (Bolsinger 1988). Inclusion of this firewood adjustment cost allows policy analysis to be based upon actual behavior.

The livestock enterprise is assumed to be a cow-calf operation, the predominant type on hardwood rangelands in California (California Department of Forestry and Fire Protection 1988). Livestock revenue in time t is composed of the sale of feeder calves (steers and heifers) and the sale of cull cattle. The price expectation models were used to evaluate livestock price uncertainties. Costs of the livestock enterprise include variable costs based on the herd size (Van Riet 1988), and feed costs based on the amount of feed purchased per season, which is a control variable estimated in the optimization. Hay price uncertainty was modelled using the price expectation models developed.

The seasonal forage model assumes that forage growth on the annual grassland range occurs only in the first two seasons (i.e., September 1 through May 31), with the residual forage left in the summer available as low quality dry forage. Forage availability in a season is based on climatic variables, the number of livestock animal unit months (AUMs) in that season and previous seasons, and the quantity of supplemental feed

purchased. Seasonal livestock nutritional requirements in AUMs were determined exogenously using the program COWFLOW (Bell 1988) based on livestock weights, target rates of gain, calving percent, and the percent bulls in the herd.

A terminal value was calculated at the end of the control period to incorporate the value of future earning stream for the firewood, hunting and livestock enterprises.

A chance constrained approach was chosen to incorporate producer price uncertainty into the optimal control model (Charnes and Cooper 1959). Producers incorporate uncertainty into their management decision by setting the probability level that the net cash flow each year is positive based on a combination of indebtedness and interest rate. The higher the probability level, the less a producer is able to take a loss, representing a more risk adverse individual.

SOLUTION TECHNIQUE

The discrete time optimal control model was solved for four control variables, namely forage allocation to hunting, supplemental feed purchased, the number of cattle to hold off the market as replacement heifers, and the quantity of firewood sold. The model was also solved for two state variables, namely the number of cow-calf pairs, and the standing volume of oak trees. Optimal controls were calculated for the situation assuming no price variability (the certainty equivalent case), and for the chance constrained case. Forage variability was considered by including the actual time series of seasonal rainfall for the areas being evaluated.

This system was solved using the GAMS/MINOS system (Brooke and others 1988) for nonlinear optimization on a personal computer. The problem was solved over a thirteen year control period to coincide with the firewood harvest calibration time period.

A low and high quality range site was included in the analysis, as well as poor, medium, and good oak site indexes. Four different initial oak volume levels were evaluated, ranging from 250 to 1000 cubic feet per acre. The effect of hunting was evaluated by solving the optimal control model for average and good quality hunting conditions, and for no hunting. The entire set of policy runs was solved for both the certainty equivalent case, and for the chance constrained case. This range of scenarios resulted in 144 different optimal solutions.

RESULTS

Effect of Hunting on Total Return

The effect of a broadened market base may improve profitability on hardwood rangelands and help reduce conversions. Figure 2 shows the net present value for poor and good quality hardwood range site with 750 cubic feet of oak per acre. On a poor range site, adding hunting as an enterprise increases NPV by 144 percent (from \$50 to \$122 per acre), and makes hunting the dominant economic enterprise. On a good range site, hunting increases the NPV by 50 percent (from \$154 to \$231 per acre), although cattle production is the dominant economic value on

this site. This figure shows the relatively minor contribution that firewood harvesting makes to the total economic value of the operation. On the poor range site with hunting, firewood revenue is only 4 percent of the NPV, while on the good range site with hunting, firewood harvesting is only 1.5 percent of the total NPV. Including risk in the analysis increases the percentage that hunting and firewood revenues occupy in the portfolio, and decreases the percentage from the livestock enterprise.

Optimal Wood Harvest Levels

Table 1 shows the cumulative firewood harvest over the 13 year control period for three oak site indexes, four initial oak volume levels, with and without hunting, and two different range productivity classes. Slightly less oak firewood harvesting occurs when hunting takes place, especially in stands with 750 to

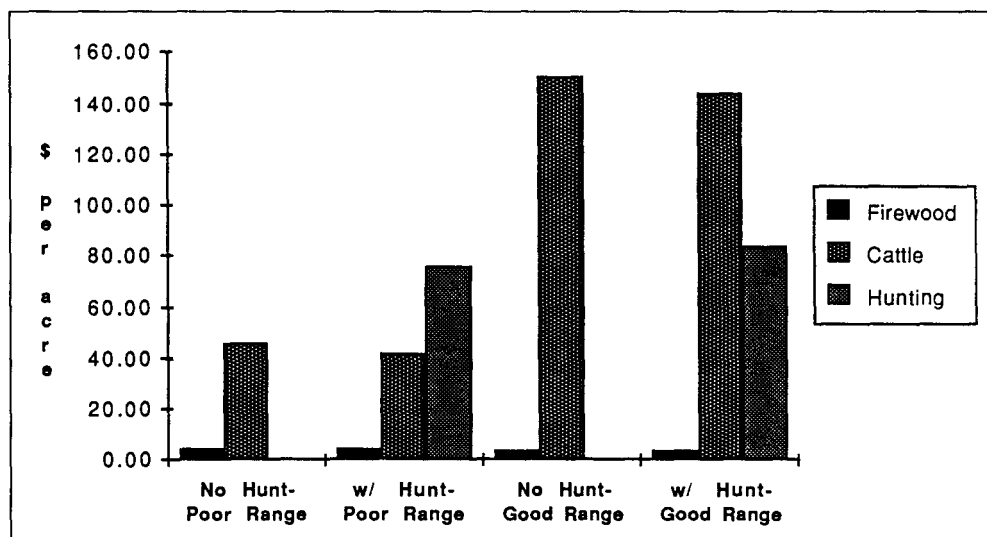


Figure 2—The effect of hunting, firewood harvest, and cattle production on net present value per acre for a medium quality oak site and a poor and good range site, with 750 cubic feet of oak per acre.

Range Production	Initial Oak Volume (cu.ft./ac)	SITE 30		SITE 40		SITE 50	
		No Hunt	Hunt	No Hunt	Hunt	No Hunt	Hunt
Poor Range Site	250	0.00	0.00	0.00	0.00	0.00	0.00
	500	0.00	0.00	71.43	64.88	73.06	67.00
	750	116.42	110.86	117.87	112.62	120.21	115.54
	1000	229.25	222.57	231.48	225.26	235.54	230.29
Good Range Site	250	0.00	0.00	0.00	0.00	0.00	0.00
	500	0.00	0.00	0.00	65.69	0.00	0.00
	750	114.46	104.49	117.62	112.58	123.81	118.43
	1000	225.71	219.19	231.64	224.66	241.33	234.86

Table 1— Cumulative firewood harvest in cubic feet per acre over 13 years for the certainty equivalent case.

1000 cubic feet per acre. This indicates that the marginal decrease in hunting revenue due to oak canopy changes is greater than the marginal revenue from the firewood harvest. Hunting apparently does provide an incentive for hardwood range managers to conserve oak trees. The small difference between ranches with and without hunting may be because the firewood adjustment cost reflects the fact that even without a hunting club, ranchers' utility is enhanced by habitat for game and nongame wildlife, and the aesthetic value of oaks. It is of special interest that no firewood harvesting occurs on areas with only 250 cubic feet per acre. The marginal cost of harvesting firewood exceeds the firewood price at these levels. It is also worth noting that ranchers are not likely to completely clear their ranges for forage enhancement because the marginal revenue of the added forage is less than the marginal cost of cutting trees. Inclusion of the risk term tends to increase the amount of wood cut.

Optimum Livestock Density

Figure 3 shows the optimal trajectory for the number of cow-calf pairs over the 14 year control period on a good range site with initial conditions of 750 cubic feet of oak per acre and 150 cow-calf pairs per 1000 acres. This trajectory shows that livestock density decreases as hunting quality increases. This can be thought of as an allocation of forage to wildlife, and also allocation of management effort to the hunting enterprise. The allocation of AUMs to either the hunting operation or the livestock operation are set so that marginal hunting revenue

from the last AUM added to the hunting enterprise equals the marginal decrease in livestock revenue. When risk is included, livestock numbers do not show the same degree of annual fluctuations as the certainty equivalent case.

Purchase of Supplemental Feed

Given the range of hay prices and price variability included in these scenarios, very little hay is purchased to provide supplemental feeding for cattle. The optimal control model shows that only a small amount of hay is purchased and only in 2 out of 13 years. Somewhat more hay is purchased in the certainty equivalent case which suggests that hay price variability has a larger effect than forage variability due to climatic fluctuations.

GENERAL CONCLUSIONS

This study showed the interrelationship between the stocks of oak trees and cattle, and how management decisions about trees harvested, cows bought or sold, hay bought, and the operation of enterprises such as hunting, all interrelate to affect ranch profitability. Relatively low oak firewood harvests are calculated by the model, indicating the low value of firewood and the fact that ranchers already incorporate nonmarket values

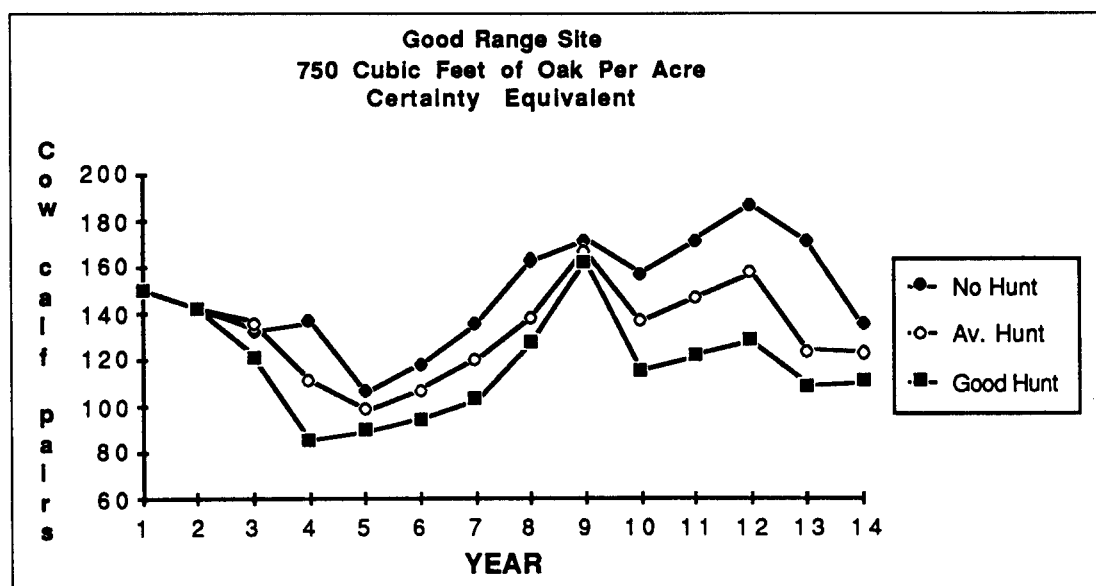


Figure 3—Optimum 13 year trajectory of cow-calf pairs on a good range site with an oak overstory of 750 cubic feet per acre for three hunting levels, and a certainty equivalent and chance constrained approach to risk.

for oaks in their management decisions. Complete oak removal for forage production appears to be an unlikely management practice. This study also showed that operation of a commercial hunting enterprise has a significant effect on ranch profits. In fact, on poor quality range sites, hunting becomes the dominant economic production factor. This suggests that diversification of the ranch portfolio with new economic enterprises may help decrease subdivision pressure by increasing net profits as well as spreading out the risk of production. Operation of hunting enterprises also affects firewood harvest and cattle stocking levels, again demonstrating the importance of evaluating the multiple resources that exist on hardwood rangelands.

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