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Title: ECONOMIC CONSIDERATIONS IN MANAGING OREGON ROCKY MOUNTAIN ELK

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Wilson E. Schmisseur

The size of elk herds in Eastern Oregon has become a controversial issue. Trade-offs exist between the numbers of elk and domestic livestock on a given area of land, and also between elk and commercial timber harvesting policies. Disputes arise from differing views as to proper use of the natural resource base, specifically, public forested and grazing lands. Economic comparisons between elk and alternative uses of the land are complicated by the non-market nature of the elk resource, as this necessitates using a method to value the resource which may not be familiar to many decision makers.

The objectives of this thesis were: (1) to analyze the demand for antlerless elk tags in eastern Oregon and to use the analysis to examine alternative pricing policies for allocating these antlerless tags, (2) to evaluate alternative elk management strategies from an economic perspective, and (3) to optimize societal benefits from the land base over time.

Objective (1) was met by using the travel cost method. Results indicate that state hunting revenues would rise substantially if tag prices were increased so as to equilibrate quantities demanded and supplied. Objective (2) was met by using a computer simulation model to ascertain the impacts of harvesting and management policies upon the herd's stability and productivity. The results, placing emphasis on the antlerless animals, indicate that a slight reduction in current herd levels is economically desirable. This result is caused in part by the decreasing returns to scale from the elk herd as measured by total harvest per 1000 summer adult elk. Limitations of these conclusions with respect to bull elk demand are documented.

Finally, objective (3) is met by formulating the dynamic relationships between elk, domestic livestock, and timber as a system of dynamic Lagrangian multipliers. This allows optimal inter-temporal allocation of resources by discounting future returns from these resources and equating marginal benefits of present and future use. The decision rules are examined, and economic implications of the multipliers are discussed. Although a theoretical model, some data is discussed, as are directions for future research.

ECONOMIC CONSIDERATIONS
IN MANAGING OREGON ROCKY MOUNTAIN ELK

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ECONOMIC CONSIDERATIONS IN MANAGING OREGON ROCKY MOUNTAIN ELK

Introduction

With the settlement of the state and unrestricted hunting, the Oregon Rocky Mountain Elk herds decreased to very low levels by the turn of this century. In an effort to preserve these herds, elk hunting was prohibited in eastern Oregon from 1905 to 1933, and two transplants were made in 1912 and 1913. From these levels, the herds have expanded to an estimated 55,000 summer adult Rocky Mountain elk in eastern Oregon in 1981. Numbers of hunters have increased, until the 1981 season, during which around 78,000 hunters harvested over 15,000 Rocky Mountain elk in Oregon.

The size of the elk herd has become a controversial issue, as elk compete with alternative uses for the land resource base. Livestock and timber interests are the major competitors in Oregon, and tradeoffs between these often conflicting uses have become a concern of land managers. The major purpose of this research is directed towards an operational statement to assist decision makers in evaluating these tradeoffs from an economic perspective.

Inherent in an economic analysis of the elk herd is the question of market versus non-market valuation of different resources. Livestock and timber products have a market valuation associated with them, while most aspects of wildlife valuation are non-market. Little research has been conducted in Oregon in recent years to ascertain values of the elk resource, thus an initial section of the research is directed towards estimating a demand curve for antlerless elk tags and investigating alternative pricing policies for these tags.

Antlerless tags were chosen specifically because of the considerable excess demand for these hunting permits existing in Oregon and elsewhere. This issue is developed in Manuscript 1.

Before a meaningful optimization model of the economic tradeoffs between elk and alternative land uses can be developed, some knowledge of sensitivity of elk herds to alternative harvest strategies and population levels must be known. Thus, Manuscript 2 reports on a computer simulation approach to modeling an elk herd, and combining the results developed to previously estimated demand curves for elk hunting experience. The resulting data is then used to compare cattle grazing and elk hunting from an economic perspective, and to estimate a recruitment function for an elk herd under alternative herd sizes.

Manuscript 3 outlines the necessary conditions for societal economic optimization of the land base. This is accomplished by formulating the bio-economic model within a dynamic Langrangian multiplier framework. Elk population dynamics and alternative land use conflicts are modeled as transition equations, and a suggested benefit function and terminal value function are introduced. Decision rules are developed, and the implications of these decision rules to policy makers are discussed, along with economic interpretation of the Langrangian multipliers. Finally, some of the results derived from earlier analyses are presented within the conceptual framework of the model, and directions for future research suggested.

Manuscript 1

Pricing Policies
for Antlerless Elk Hunting Permits

PRICING POLICIES FOR ANTLERLESS ELK HUNTING PERMITS

One of the effects of increasing emphasis on leisure time in the U.S. has been a growth in demand for hunting privileges. An example of such growth is the rapidly increasing demand for the opportunity to hunt elk in various western states (Potter, 1982). From 1960 to 1979, the number of licensed elk hunters more than doubled in North America, while average elk hunter success steadily declined from 25 to 14 percent over the same period. Even though total elk harvests are increasing, elk populations are not growing at a rate anywhere near that of current demand growth. Thus, state fish and wildlife departments must utilize methods to allocate elk resources. Such allocation procedures include split seasons, waiting lines, drawings, and fee increases, each with distinct efficiency and equity implications (Meyer, 1979; Peek, Pederson and Thomas, 1982).

The problem of allocating Rocky Mountain antlerless elk hunting privileges in eastern Oregon is instructive in this regard. Oregon's Department of Fish and Wildlife controls the hunt of antlerless (cow and calf) elk by controlling the numbers of hunting tags annually issued for each designated geographic area. The numbers of tags issued are determined by estimating the quantity of hunters needed to achieve the target harvest level of antlerless elk in each area. For a one dollar processing fee, prospective hunters may indicate a first and a second choice hunting area from among the 25 areas designated. If applications exceed the number of tags available in the area, a drawing is conducted to determine the winners for that area. Winners who are Oregon residents (over 99 percent of winners) must pay a $22 tag and license fee and give up their bull hunting privilege for the season. Furthermore, winners in the nine most popular hunting areas surrender the right to compete in antlerless tag drawings for the succeeding two years. The Department thus uses a combination of waiting lines, drawings, and fees to allocate antlerless elk hunting permits.

Nevertheless, there are signs the allocation methods could be improved. In 1979, 11,210 applications were considered for the 9,350 controlled antlerless tags available. By 1981, the excess demand had escalated to 31,503 applications for 15,620 tags available.[1/] This excess excludes recent drawing winners who were not permitted to reapply for a two-year period, and about 10 percent of tag applications which were invalidated due to incompleteness or error.[2/] Such figures suggest that tag fees are falling increasingly below levels that would equilibrate the vertical supply of harvestable elk with the demand for hunting it. As a result, state revenues from elk hunting are probably well below levels that could be earned under more competitive prices. Although in the past, most fish and wildlife departments have sought to limit sharply the cost of hunting and fishing privileges, emphasis on low cost may need to be altered if the departments are to achieve a greater measure of self-support. For example, the Oregon Department of Fish and Wildlife received 52 percent of its support from federal and state treasuries in the 1979-1931 budget (*Oregon Wildlife*, 1981).

In the present paper, we report results of an analysis of demand for controlled antlerless tags in Oregon. The analysis is used to evaluate elk tag pricing strategies which alternatively would (a) continue the present system, (b) equate tag quantities supplied with those demanded, (c) maximize state elk hunting revenues, or (d) discriminate between drawing and non-drawing participants. We consider the pricing, allocative, and revenue implications of these policies.

Model Specifications

The quantity of antlerless elk annually available for harvest in each hunting area currently is determined by wildlife biologists on the basis of "available habitat" and is not responsive to individuals' willingness to pay for hunting. Consequently, the annual supply of elk and elk tags by area is considered predetermined for our purposes and demand may be estimated independently of supply considerations. The number of controlled Rocky Mountain elk tags demanded for a given hunting area by individuals in a given population zone may be hypothesized to depend on the price of those tags, on other elk hunting expenses, on income, on the quality of hunting in the area, and on some measure of the relative desirability of competing hunting opportunities.

System of Equations

At least two approaches are available for modelling this situation. The first, following Burt and Brewer (1971) and Cicchetti, Fisher, and Smith (1976), is to specify a separate demand relation for each hunting area. In each such relation, the expected quantity of tags demanded depends upon the cost of travelling to the area in question and upon the costs of travelling to other Rocky Mountain elk hunting areas in Oregon. Letting i refer to population zone, j to Rocky Mountain elk hunting area, and t to year, this is expressed as

$$Q_{ijt} = f_j(P_{i1t}, P_{i2t}, \cdots, P_{ijt}, \cdots, P_{iMt}, Y_{it}) \quad (1)$$

$$j = 1, 2, \cdots, M$$

$$i = 1, 2, \cdots, N$$

$$t = 1, 2, \cdots, T.$$

where

$Q_{ijt} \equiv$ number of individuals from population zone i submitting a first-choice tag application to hunt Rocky Mountain antlerless elk in area j in year t, expressed per unit of population in zone i.

$P_{ijt} \equiv$ cost of access from zone i to area j in year t (including Rocky Mountain tag price);

and $Y_{it} \equiv$ per capita income of the ith population zone in year t;

Bowes and Loomis (1980) have shown that demand response to recreation entry permit prices is the same as the response to travel and other recreation costs if each person travelling to the recreation site proceeds to enter it. Because that is a reasonable proposition in the present instance, tag price and travel cost are combined in P_{ijt}, which is expected to be negatively related to the volume of tags demanded (Brown, Nawas, and Stevens, 1973). The system of (generally linear) equations in (1) permits the substitutability between hunting areas to be expressed through the negative cross-cost terms $\partial Q_{ijt}/\partial P_{ijt}$ ($j \neq j$). If, under the assumption of small budget shares for hunting, these effects are constrained to be symmetric, the equations can be used to generate consistent indicators of consumer surplus under the multi-area demand equations.

In the above approach, coefficients of own-cost and substitution terms reflect average hunter perception of the relative desirability of competing hunting areas. Estimation of (1) would, however, be impracticable if the exogenous cost factors were high correlated across the N population zones utilized. This would, for example, arise if most population zones were grouped together at a distance, and in the same general direction, from most hunting areas. In such circumstances, it is necessary to collapse the M equations and cost terms into a single equation and to reflect the variation in demands among hunting areas by way of shift operators.

Single Equation

To illustrate this second approach, consider the specification:

$$Q_{ijt} = f(P_{ijt}, ROOS_{it}, DEER_{it}, DEN_{jt}, CITY_i, Y_{it}) \qquad (2)$$

where

Q_{ijt}, P_{ijt}, and Y_{it} are defined as previously and

$ROOS_{it} \equiv$ average cost of access from zone i to nearest Roosevelt elk hunting area in year t (including Roosevelt tag price);

$DEER_{it}$ ≡ average cost of access from zone i to nearest deer hunting area in year t (including deer license fee);

DEN_{jt} ≡ number of Rocky Mountain antlerless tags offered per square mile of the jth hunting area in year t;

$CITY_{i}$ ≡ 1 if the ith population zone contains a city of over 20,000 persons; 0 otherwise.

Depending on the functional form of (2), the marginal effect of cost on demand quantity, and associated cost elasticities, may vary by hunting area because the means of shift variables generally differ by area.

Besides facilitating estimation of a curvilinear function, specification (2) encourages examination of factors other than Rocky Mountain elk costs which affect the demand for Rocky Mountain elk. Although such examination is possible in (1), proliferation of explantory variables might strain the degrees of freedom available or exacerbate problems of multicollinearity. For example, costs of hunting Roosevelt elk and deer are included in (2) as assumed substitutes for Rocky Mountain elk. These variables represent the costs of travelling from population zones to the nearest hunting area for the respective species, plus tag or license fees. Each should positively affect demand for Rocky Mountain elk tags. Demand for hunting also should vary directly with the probability of an elk sighting or kill, which in turn would depend on the number of tags offered for sale per square mile of effective habitat (DEN_{jt}). Brown and Mendelsohn (1981) showed that fish density is a powerful predictor of demand for steelhead fishing in Washington State;

and Schulze, d'Arge, and Brookshire (1981) report an average willingness to pay equivalent surplus of $54 per year to increase expected elk sightings from one to five per day. (See also Brookshire, Randall, and Stoll, 1980).

A usual assumption in travel cost analysis is that there is homogeneity of taste among population zones. Hammack and Brown (1974) point out, however, that omission of a taste variable may be a source of serious estimation bias. We suspect taste heterogeneity in the present instance because Potter (1982) shows that on a per capita basis there are more elk hunters living in rural than in urban zones. To test for significantly greater demand in rural than in urban counties, we have included the zero-one variable $CITY_i$. Finally, as in specification (1), the expected effect of income (Y_{it}) on demand is ambiguous; it may, for example, be negative at low income levels (because some low income individuals may hunt to supplement their diet) and positive at higher income levels.

Estimation

We attempted to estimate both specifications (1) and (2) of the demand relations, recognizing that each provides information not feasibly obtained from the other. The Oregon Department of Fish and Wildlife provided the numbers of successful 1980 and 1981 applicants from each postal zip code to each of the nine most popular Rocky Mountain elk hunting areas. These data involved over 16,000 observations, from which 1,640 were randomly drawn for analysis.

Following Brown, *et al.* (1982), we aggregated the zip codes into a relatively large number of population zones (152 for 1980 and 178 for 1981), then divided annual numbers of successful applications by population in each aggregated zone. In order to obtain a sample reflecting total applications, numbers of successful applicants were multiplied by the average ratios of total to successful applications in each hunting area (Loomis, 1982).[3/]

Rocky Mountain elk hunting expenses were determined by calculating the shortest distance from the major town of each population zone to the nearest edge of each hunting area. The round-trip per-mile charge used was $0.20 for each sample year. Entry fees of $23 per hunter, including tags, license, and application fees, were added. Cost data for Roosevelt elk and deer hunting access were developed similarly, although for these species each hunter was assumed to consider only the nearest available hunting area. Income data by population zone were obtained from the Bureau of Economic Analysis, Department of Commerce. Real income variation between 1980 and 1981 was negligible and ignored.[4/]

Procedures Attempted

First, the nine-equation demand system (1) was estimated using an unrestricted seemingly unrelated regressions estimator (Cicchetti, Fisher, and Smith, p. 1266-67). P_{ij} terms in this model were severely multicollinear, with many of the simple correlations above 0.95. Coefficient standard errors accordingly also were large and the coefficients themselves erratic in sign and magnitude. Aggregating the nine hunting areas into four alleviated this problem to some extent, but not sufficiently to warrant further analysis. It appears that much of the correlation among cost terms in (1) arises from the relative isolation of the Rocky Mountain elk hunting areas in eastern Oregon, combined with the concentration of most hunters in the Willamette Valley area to the west. The result is that travel costs to any hunting area from a given population zone are very similar.

As a consequence, we next investigated specification (2), utilizing three alternative functional forms: double-log, exponential (logged dependent variable only) and linear. Application of Glejser tests to the linear OLS model indicated it contained mixed heteroskedasticity; specifically, absolute values of estimated residuals were negatively and linearly related to population levels (Pindyck and Rubinfeld, pp. 150-152). All variables accordingly were weighted by the population effect in a subsequent GLS estimation.[5/]

Results

Estimates of (2) employing the three functional forms are shown in Table 1.1. Deer hunting cost factors ($DEER_{it}$) were removed because of high estimated standard errors, a result of inadequate variation across population zones in travel costs to deer hunting areas. Whereas Rocky Mountain and Roosevelt elk herds are concentrated in specific sectors of Oregon, few areas in the state are situated far from quality deer hunting. Own-cost (P_{ij}) and cross-cost ($ROOS_i$) effects and the tag density factor (DEN_{jt}) are strongly significant in all models and have the expected signs. At sample means,

Table 1.1. Demand for Oregon Rocky Mountain Antlerless Elk Tags, 1980-81. a/

Variable	Designation	Linear GLS	Exponential	Double Log
Intercept		0.005	-5.129	-7.924
		(5.80)	(-7.96)	(-10.76)
Rocky Mountain Elk Cost	P_{ij}	-0.037	-14.375	-1.248
		(-12.14)	(-10.76)	(-13.22)
Roosevelt Elk Cost	$ROOS_i$	0.015	6.432	0.547
		(5.83)	(3.12)	(2.95)
Tag Density	DEN_{jt}	0.00082	0.254	0.297
		(3.82)	(4.13)	(3.18)
Rural/Urban Intercept Shift	$CITY_i$	-0.0011	-0.506	-0.549
		(-4.99)	(-4.41)	(-5.08)
Income	Y_i	-0.00011	-0.104	-0.164
		(-2.11)	(-2.22)	(-0.52)
$\bar{R}^2$		0.40 b/	0.72	0.74
Own-Cost (P_{ij}) Elasticity c/		-2.768	-1.485	-1.248
Cross-cost ($ROOS_i$) Elasticity c/		0.973	0.664	0.547

Footnotes on following page.

a/ The dependent variable (Q_{ijt}) is the per capita number of first-choice applications from a given zone to hunt Rocky Mountain antlerless elk in a given area in a given year (sample mean: 0.0043905 when in original units, -8.78057 when in logs.) Sample size was 330, representing 1640 observations. t-values are shown in parentheses. All money variables are denominated in thousands of dollars. Sample means of explanatory variables, in the order listed in the table, were: 0.1032, 0.1033, 2.10, 0.35, 8.492.

b/ R^2 of corresponding OLS model.

c/ Elasticities are for total cost including tag price. Those for tag prices alone are discussed later. Elasticities for linear GLS and exponential models shown here are calculated at the sample means of P_{ij} and $ROOS_i$.

own-cost elasticities range from -1.248 to -2.768, and cross-cost elasticities from 0.547 to 0.973. "Taste" ($CITY_i$) and income (Y_i) factors are both negative, with significance levels differing among functional forms.6/ Taken together, these negative signs imply that demand for antlerless elk hunting is greatest in rural areas and among low income individuals. Those with low incomes may have a relative preference for antlerless (compared to bull) hunting because the high kill success rate among antlerless makes it desirable for purposes of diet maintenance.

To select a model for subsequent policy analysis, we relied both on goodness-of-fit tests and on theoretical considerations. Following Rao and Miller (1971, pp. 107-111), the sum of squared residuals of the linear fit was multiplied by the squared inverse of the geometric mean of Q_{ijt} in order to express the squared residuals of all models on a comparable basis. Significant differences between the corrected sums were then tested using the statistic $d = (n/2) \mid \ln(\Sigma e_a^2/\Sigma e_b^2) \mid$, where a, b indicate two alternative functional forms. Statistic d has a chi-square distribution with one degree of freedom. In this case, the double-log fit had significantly smaller residual variance than the exponential, which in turn had a significantly smaller error variance than the linear form.7/ The double-log and exponential models were not much different in explanatory power.

Apart from the goodness of fit criterion, we found the exponential formulation conceptually preferable for our purposes. In in the first place, the linear model has questionable behavioral implications: it implies that the rate at which new hunters are enticed to apply for a tag when costs fall is the same at high and low cost levels. This in turn implies that there are as many potential hunters in the relatively high willingness-to-pay group as in the relatively low group. Because there probably exists a small group of especially avid hunters and a larger group of more casual hunters, the implications of a convex shape are more appealing. Although between the two convex forms fitted, the double-log had slightly better explanatory power, its constant demand elasticity makes it inappropriate for identifying a maximum-revenue price. We accordingly emphasize the exponential formulation in the following.[8/]

Pricing Policies

Estimated 1980-1981 demand for Rocky Mountain antlerless tags in the more popular hunting areas of Oregon is depicted in Figure 1.1. This curve is drawn by multiplying exponential model coefficients by mean sample values, summing the products, then varying cost term P_{ij}. Demand (in anti-logs) are multiplied by mean zonal population (111,433) and by the average annual number of zones (165) to reflect total demand in the nine hunting areas. The result is

$$Q_{ijt} = 124{,}745 \exp(-14.375\ P_{ij}). \qquad (3)$$

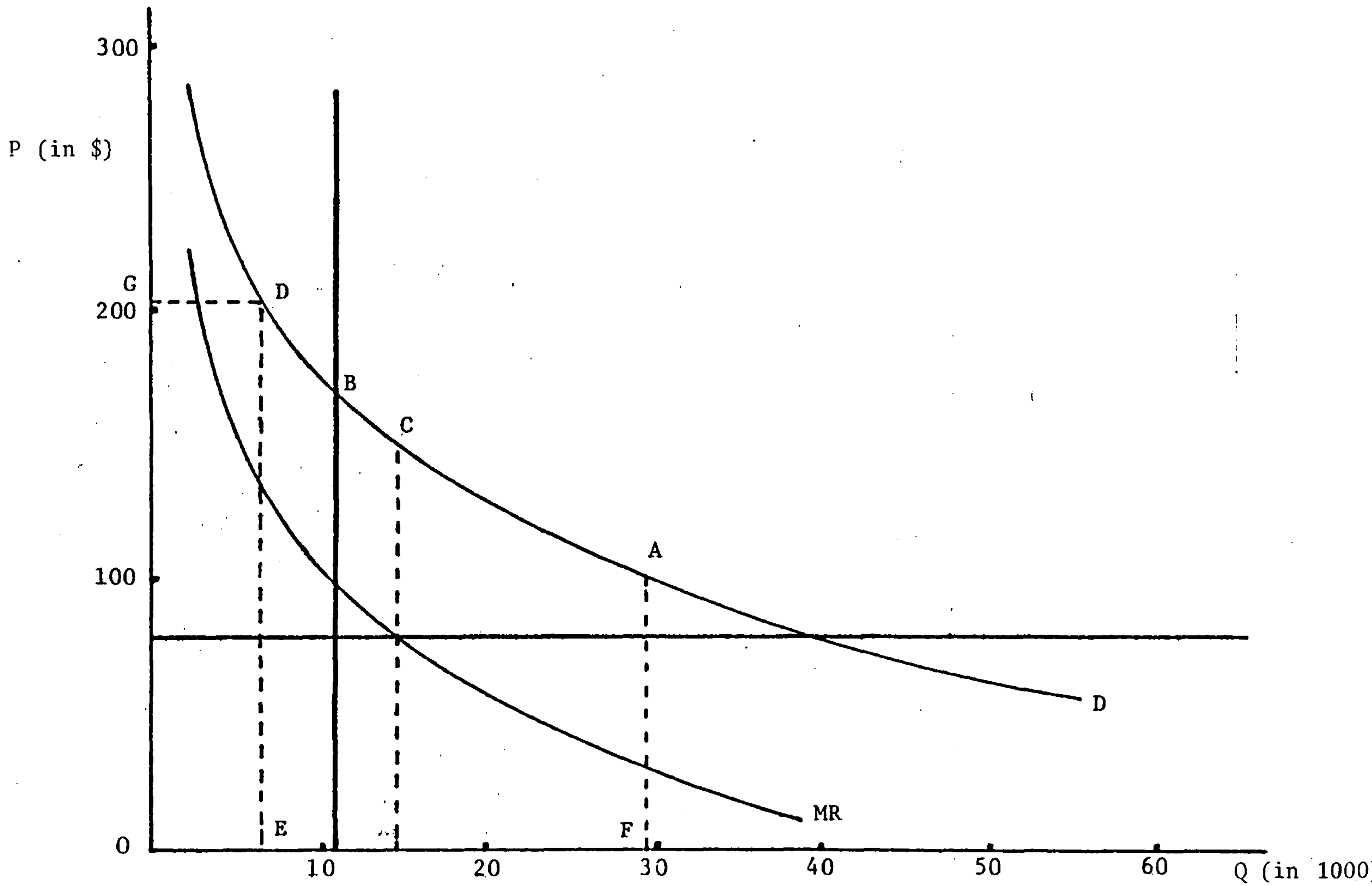

Figure 1.1. Demand for Antlerless Rocky Mountain Elk Tags in Selected Areas of Oregon.

The corresponding marginal revenue curve,

$$MR = 0.7467 - 0.0696 \ln(Q_{ijt}), \tag{4}$$

is also given in the figure.

Recall that a large percentage of the costs represented on the vertical axis of Figure 1.1 consists of travel costs, not tag fees; hence, the marginal "revenues" indicated include payments for travel services as well as for a tag. Fish and wildlife departments have little or no control over travel costs, and such costs are independent of tag price levels. Thus, travel costs should be considered fixed when calculating the departments' returns from alternative tag price policies.

Let total cost P_{ij} be decomposed into travel cost C_{ij} and tag price S such that $P_{ij} = C_{ij} + S$. Equation (3) then can be rewritten as

$$Q_{ijt} = 124{,}745 \exp(-14.375\ C_{ij}) \exp(-14.375\ S). \tag{3'}$$

At the estimated 1980-81 mean travel cost of \$80.28 (0.08028 in \$1000 units), (3') reduces to a function of tag price only:

$$Q_{ijt} = 39{,}340 \exp(-14.375\ S). \tag{5}$$

Associated marginal tag revenue is

$$MR_S = 0.6664 - 0.0696 \ln(Q_{ijt}). \tag{6}$$

The vertical axis of Figure 1.1 may be converted to represent just tag demand price and marginal tag revenue by shifting the origin upward in an amount equal to estimated mean travel expense. This mean ($80.28) is indicated by the solid horizontal line in the figure.[9/]

Present Policy

The effects of four alternative tag pricing policies are shown in Figure 1.1. One policy would be to continue the present practice of charging $23 per tag. The expected response would be 28,264 first-choice applications for a tag, necessitating area-wide lotteries for the 10,854 tags annually available in the 1980-81 period. An applicant's average chance of receiving a tag under this policy would be about 38 percent. Tag revenues accruing to the Department from successful applicants would be exactly $249,642.

The demand elasticity with respect to total hunting cost at this point, A in Figure 1.1, is found by multiplying mean total costs (.10328 in $1000 units) by the coefficient of P_{ij} (-14.375), giving -1.485. Since this elasticity is greater in absolute value than unity, we infer that total hunting expenditures (including those for travel and a tag) would increase if the total cost per hunting trip were to decrease from present levels. However, revenues earned by the Department actually would fall if the cost reduction were to come solely from tag price reductions. At the current $23 price level, the tag price elasticity of demand is (.023)(-14.375) or

-0.331, considerably less in absolute value than unity. Clearly, tag revenues would rise if tag prices were boosted.

Market Clearing Policy

Another feasible policy would be to seek a tag price which would just clear the market of the number of tags annually available. This price is determined by calculating the total cost level ($169.90 at point B in Figure 1.1) at which the vertical supply function intersects the demand curve, then subtracting mean non-tag costs ($80.28) to give $89.62 per tag. Such a figure, of course, merely represents the average of market clearing prices that would be obtained if the indicated procedure were repeated for each of the nine hunting areas. Vertical supplies differ by area and demand schedules differ as well, because each area has a distinct tag density level (DEN_{jt}). Thus, there is generally a unique market clearing price for each hunting area that can be derived directly from Table 1.1 once area tag supply is known. Note that market clearing prices would fall if non-tag costs were to rise, for example in response to gasoline price increases, because the horizontal line in Figure 1.1 would shift upward.

An advantage of a market clearing price policy is that it results in about as many applications as there are tags available, eliminating the need for a lottery. Department revenues accruing from this policy would be about (89.62)(10,854), or $972,735 per annum, nearly four times greater than under the present policy.

On the other hand, at an average $89.62 price, tag price elasticity of demand in a typical area would be -1.288, somewhat greater than unity. Hence, prices which would clear the market would on average be too high to maximize Department revenues. This is indicated by the excess of marginal revenue over the horizontal, mean non-tag expense line just below point B in Figure 1.1.

Revenue Maximizing Policy

A third alternative would be to charge prices designed to maximize Department revenues. Marginal tag revenue is equated with zero, and tag price elasticity of demand becomes -1.00, at the quantity for which the marginal revenue curve intersects the horizontal non-tag expense line in Figure 1.1. The associated revenue-maximizing price is the vertical distance between demand and marginal revenue at this quantity. Marginal revenue corresponding to the exponential demand in Figure 1.1 is $0.746713 - 0.069565 \ln (Q_{ijt})$. Equating the latter with the mean non-tag cost (.08028) gives a total of 14,472 tags demanded, at which point the vertical difference between demand and marginal revenue is $69.60 (point C in Figure 1.1).

If a price of $69.60 per tag were indeed charged, the estimated 14,472 annual applicants would exceed the 10,854 tags currently available per annum. In order for the price actually to maximize Department revenues (at $1,007,251), each of these applicants would need to be allowed to purchase a tag. Thus, under a revenue-maximum policy, the Department would, at least in the short run, have to give up its practice of fixing the supply of tags *ex ante*. The desirability of such practice depends upon the marginal costs associated with increasing elk harvest levels which, in the longer run, would require increasing elk population levels. It should be observed that moving from a market clearing to a revenue maximizing price policy would increase tag revenues by only 3.5 percent, or $34,516.

Unlike under the market-clearing price policy, revenue-maximizing prices would not vary with non-tag cost levels provided demand is exponential. This is so because the revenue-maximizing price is invariably the vertical distance between demand and marginal revenue curves, which is itself invariant. That is, given exponential demand

$$Q = \exp(A - \beta_p P) \quad ,$$

we have price-dependent form

$$p = \frac{A}{\beta_p} - \frac{1}{\beta_p} \ln(Q) \qquad (7)$$

and marginal revenue

$$MR = \frac{A-1}{\beta_p} - \frac{1}{\beta_p} \ln(Q) \qquad (8)$$

where A is the regression intercept for fixed levels of variables other than P. Because the difference between (8) and (7) is just $^1/\beta_p$, the price maximizing tag revenues is always the reciprocal of the regression price coefficient.

Two-Tier Pricing Policy

Some sports event box offices charge two admission prices, a higher one for reserved seats and a lower one for unreserved seats. It would be possible, similarly, to set two tag prices, one for tags purchased outright and another for tags awarded on the basis of a drawing. If, for example, a tag were first offered to any individual willing to pay $125 for one, about 6,523 tags would be sold on this basis (point D in Figure 1.1), leaving 4,331 to be sold on another basis. If the price asked for each of the latter were $23, the current charge for Oregon residents, approximately 21,741 (distance EF in Figure 1.1) would apply, necessitating a drawing for the 4,331 available. Only 20 percent of drawing participants would win, somewhat less than under the present flat-rate policy. Tag revenues under such a two-tier plan would be $914,988, which is $665,346 greater than under the present plan. The difference results from extracting the consumer surplus represented by area OEDG in Figure 1.1. A comparison of results for all four pricing policies discussed is given in Table 1.2.

Conclusions

We have attempted to identify the primary factors influencing demand for antlerless elk hunting tags, and to show how demand analysis can be used to estimate effects of alternative tag pricing policies. The analysis makes clear that current tag prices are, on average, below prices that would equilibrate demand with the

Table 1.2. Summary of Pricing Policy Results.[a/]

Estimates	Policy: Present	Market Clearing	Revenue-Maximizing	Two-Tier
Tag Price ($)	23.00	89.62	69.60	125.00 23.00
Quantity Demanded	28,164	10,854	14,472	6,523 21,741
Quantity Supplied	10,854	10,854	14,472	10,854
Chance of Winning a Tag	0.38	1.00	1.00	1.00 0.20
Revenue ($)	249,642	972,735	1,007,251	914,988
Tag Price Elasticity	-0.331	-1.288	-1.00	-1.797 -0.331

a/ These results are obtained using the exponential functional form in Table 1.1.

Department's exogenously-determined tag supplies. Increasing prices to approximately equilibrating levels would result in significant increases in revenues for the Department of Fish and Wildlife, enabling it to reduce its dependence on taxpayer support. Prices that would clear the market, thus eliminating the need for drawings, are close to those which would maximize tag revenues. A compromise between employing such prices and employing current rates would be to enact a two-tier pricing system.

One must be careful, in assessing implications of pricing policies, of the substitution effects engendered by price changes. In the present study, we were unable to detect substitution effects among the nine Rocky Mountain elk hunting areas considered because travel costs from a given population zone to each hunting area were nearly equal. Similarly, the effect of deer hunting costs on elk demand was indetectable because of the close proximity of deer hunting areas to all population zones in Oregon. It has been shown, however, that Rocky Mountain elk tags are (somewhat imperfect) substitutes for Roosevelt elk tags, and increasing prices of the latter would alter results described above. For example, if the $89.62 market clearing price initially where charged and the price of Roosevelt tags was raised by $10 over the current $23 level, about 714 additional individuals would apply for Rocky Mountain tags. This would require a price increase of $4.43 to continue clearing the market of the 10,854 Rocky Mountain tags available.

The effect of tag density on demand implies that the excess demand for hunting is greater in some elk areas than in others.

If the current practice is continued of charging prices well below market-clearing prices, differences by area in excess demand are of little consequence because excess demand is usually positive nad buyers can be identified by lottery. If market clearing prices are instead charged, such prices will differ somewhat by area. There would be some cost associated with the discovery of these prices (such as the cost of updating, refining, and utilizing the present model) and with the inevitable pricing errors that would occur on some occasions. But costs of conducting area-wide lotteries would be saved.

The primary losers from higher tag prices would be hunters with relatively low willingness to pay who currently manage to be lottery winners but who would refuse to hunt under higher tag prices. The primary beneficiaries would be those with greater demand who currently are denied access to hunting privileges at prices they are more than willing to pay. Whether on balance it is desirable to charge higher prices depends partly upon (a) the extent to which differences in willingness to pay are related to differences in income as opposed to differences in utility for hunting, and (b) the state government's desire to redistribute income among hunters. If willingness-to-pay discrepancies are related largely to differences in utility, the principal reward for taxpayer support is that less eager but luckier hunters often supplant more eager but less lucky ones.

Use of below-market tag prices also effects a wealth redistribution from nonhunting to hunting taxpayers. The desirability of such practice again hinges on the relative income of nonhunters and on the social utility of income redistribution. It is instructive to note that Brown, Nawas, and Stevens (1973) reported, on the basis of 1968 data, an approximate equivalence between average big game hunter income and overall average Oregon income. Potter (1982) showed that the average income of Washington elk hunters was considerably greater than the average for all U.S. residents. Furthermore, hunter incomes were much more strongly skewed toward higher levels than were those of the general population. Fish and wildlife departments may wish to re-evaluate their tag pricing policies in light of such evidence.

ENDNOTES

1/ High demand for controlled elk hunting tags is not confined to Oregon. For the 1980 Montana elk harvest, a total of 35,982 applications were received for 7,360 permits, while in Washington 23,758 applications were received for 3,315 special Rocky Mountain elk tags.

2/ Personal communication from Mary Potter, Oregon Department of Fish and Wildlife, March 1982.

3/ The assumption behind this procedure is that the sample of unsuccessful applicants utilized approximately represents the preferences of unsuccessful applicants. Complete randomness of the elk tag drawing procedure and of our sample selection, plus the size of our sample, justify this assumption.

4/ Virtual time invarince of real cost and income terms in the present case implies that the t-subscripts on P_{ijt}, $ROOS_{it}$, and Y_{it} may be ignored for our purposes. Consequently, these variables are expressed without t-subscripts in the following.

5/ Glejser tests involve regressing absolute values of estimated residuals against variable(s) considered to influence residual variance. Here we used several alternative functional forms to regress residuals on population levels and found $|\hat{e}_{ijt}| = .0049 - .000014(POP_i)$ to be the best fit (where $\hat{e}_{ijt}$ is estimated residual and POP_i is zonal population). Coefficient t-values in this equation were 13.69 and -6.27 respectively, suggesting mixed heteroskedasticity. Expression $.0049 - .000014\ (POP_i)$ thus was divided into all variables and the linear model re-estimated.

6/ Correlations near 0.75 between $CITY_i$ and Y_{it} may partially account for their generally low statistical significance.

7/ Calculated d between double-log and exponential was 12.75, between the exponential and linear was 543.29, and between the double-log and linear was 556.04. (The critical value at the 5 percent significance level is 3.841).

ENDNOTES cont.

8/ Strong showed that an exponential transformation corrected heteroskedastic residuals in a linear model better than did a GLS transformation. This conclusion is confirmed by Vaughan, Russell, and Hazilla (1982) and by our own research. Applying the Glejser test (footnote 5) to the exponential model, we found a calculated t-value of only -0.43 associated with the POP_i variable, implying our exponential model is homoskedastic.

9/ Another way to compute the total demand function across all distance zones would be to compute the predicted quantity per capita for each zone at the observed values of the explanatory variables for each zone. Each value would then be multiplied by the corresponding zonal population to obtain the total predicted quantity for each zone, the sum of which would be an estimate of multiplier A in $\hat{Q}_{ijt} = A \exp(-\beta_p P_{ij})$. Assuming that the summed predicted quantities approximately equal the summed observed quantities, we obtained $Q_{ijt} = 28{,}264 \exp(-14.375 P_{ij})$ for the average hunting zone. Converting to a function of elk tag prices (S) only gives $Q_{ijt} = 39{,}338.9 \exp(-14.375 S)$, which is very close to the result provided in equation (5).

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Manuscript 2

A Computer Simulation of an Eastern Oregon Rocky Mountain Elk Herd

A COMPUTER SIMULATION
OF AN EASTERN OREGON ROCKY MOUNTAIN ELK HERD

Since the early 1960's, North America has witnessed an increasing demand for the opportunity to hunt elk in various western states, with the number of licensed elk hunters more than doubling from 1960 to 1979. Although total elk numbers harvested have increased, this increase is less than the number of hunters over the same period (Potter, 1982). Hunting pressure in Oregon has exhibited these same patterns (Starkey et al., 1982). Since the 1979 hunt, Oregon has required hunters to choose between Roosevelt and Rocky Mountain elk seasons, and between a shorter first period hunt or a longer second period hunt for bull animals. In addition, random drawings are held to allocate anterless elk tags in Oregon, and successful applicants are not permitted to hunt during the general bull season. Consequently, hunters would like to increase herd numbers, or at least maintain current populations.

Many ranchers are convinced that herd sizes are already too large. The 1980 and 1981 Rocky Mountain elk herds were above the Oregon Department of Fish and Wildlife (ODFW) management objective levels (ODFW, 1982). Elk numbers have become an extremely controversial issue in Oregon; an excellent review of this situation is contained in Peek et al. (1982). In some cases, private costs in the form of forage consumed, fences damaged, and hunter access are borne by ranchers in supporting a public elk herd. This problem is accentuated during late winter and early spring grazing periods. This issue is not confined to Oregon, as Peek et.al (1982) contains a survey of professional wildlife managers listing livestock grazing, logging, and energy development affecting most of the western states and provinces supporting an elk herd.

Before a meaningful optimization model of the economic tradeoffs between elk and alternative land uses can be developed, some knowledge of the sensitivity of elk herds to alternative harvest strategies and population levels must be known. This paper reports on a computer simulation approach to modeling an elk herd in eastern Oregon. Results from the population dynamics model developed herein are combined with demand curves for elk hunting estimated from other research (Helfrich, 1981, and Sandrey et.al, 1982) to allow for an economic interpretation of the biological changes resulting from alternative management strategies. This data can then be compared to cattle grazing to evaluate biological tradeoffs from an economic viewpoint.

Objectives

The specific objectives of the report are (1) to simulate a hypothetical elk herd utilizing population parameters governing a herd in eastern Oregon; (2) to derive a recruitment function and harvest projections, based upon simulation runs of alternative herd sizes and management strategies; (3) to evaluate these alternative herd sizes and management strategies from an economic perspective by combining the population dynamics section of the model with previously estimated demand curves for elk hunting; and (4) to evaluate elk hunting and cattle grazing tradeoffs from an economic viewpoint.

Initial simulations hold adult female numbers to an annual level of approximately 1,200 head. This herd size was initially chosen to represent the Bridge Creek herd in eastern Oregon. A constant harvest rate of 85 percent is applied to adult males of all age classes, as this percentage seems to represent the actual harvest rate of males in most Oregon herds. Attention is focused on the antlerless animals to control herd sizes, and these rates are adjusted annually.

Proposed management objectives for Oregon's Rocky Mountain elk herds are published in ODFW (1982), and these objectives include desired calf:cow ratios, minimum bull escapements per 100 cows, desired bull harvest per unit, and adult population levels per unit, for late winter and summer seasons. These population parameters are modelled as closely as possible to simulate an Oregon elk herd over a 40-year period. Once the initial herd level of 1,200 post-harvest adult females has been modelled, the model is used to report effects of increasing and decreasing herd sizes.

Description of the Simulation Model

Numerous assumptions are made in the model and will be justified later. Use is made of the GASP IV simulation package (Pritsker, 1974) and a flow chart of the organization is given in Appendix 2.1. The annual population cycle is simulated in three steps: births, harvest mobility, and winter mortality. An annual population updating subroutine is included, and economic data are calculated in a separate subroutine. Fecundity rates are considered to be the net survival rates of the elk offspring, as no mortality occurs in the model until the following winter except for the antlerless harvest, thus recruitment to the herd is births less harvest and natural winter mortality.

Three stocahstic variables are used in the model:

(1) the severity of the winter,

(2) female population numbers. These are not known with certainty in a real-world situation, so a distribution for the relative error in female levels estimated is used. Harvest levels are then applied to the actual numbers.

(3) Range condition, a proxy for quantity and quality of feed, which is assumed to follow a random normal distribution. No attempt is made to derive the covariance between feed conditions and winter severity, if a covariance does exist. Range conditions are calculated once a year during the summer, and considered as representing forage for that year.

Biological Bases of the Model

1. Breeding Routine

A flow diagram of subroutine BREED is shown in Appendix 2.2. The major biological relationship is the cumulative effect of population density, range conditions, and winter severity on birth rate. In addition, a lagged effect from the previous winter alters potential breeding performance. This lagged effect is casued by a severe winter placing additional stress upon the female animals slightly reducing chances of becoming pregnant the following season.

Wide fluctuations of calf:cow ratios and breeding performances are reported in the literature from studies in Oregon and other states. This literature includes Taber et. al (1982), Crompton (1975), Thorne et. al (1976), Kimball and Wolfe (1974, 1979), Buechner and Swanson (1955), Gross (1969), Walters and Gross (1972), and Peek (1965). Analysis of results reported from these sources, plus available data from ODFW (1982) reports provided insight into possible mean calf:cow ratios, as well as standard deviations. Oregon's Blue Mountain elk herds are extensively hunted and exhibit higher calf:cow ratios than many other units in other states. One possible reason for this is that 2-year old animals appear to be more productive in Oregon than in some other areas.

Range conditions and elk density are deemed to affect calving potential via two alternative linear equations. Because no summer mortality takes place in the model, calves are assumed to survive until the fall harvest and winter mortality periods. Thus, the equations used to calculate calving ratios are effectively calculating survival of 6 to 7 month old calves, when the fall harvest occurs. These two equations, for good and poor range conditions, respectively, were considered to be:

$$Y_{GOOD} = 0.83 - 0.0001\ X \qquad (1)$$

and

$$Y_{POOR} = 0.81 - 0.000125\ X \qquad (2)$$

where

Y = the so-called "potential" constant for calving to to be adjusted for winter severity and age class of female,

and

X = the adult population calculated during the late summer breeding season (prior to harvest).

The "potential" constant found after considering range conditions and density relationships is then adjusted once more for age classes. Four separate age classes are considered, with the following adjustment factors for each class.

(1) Age 2 years ° X 0.60 for good range condition,
° X 0.45 for poor range condition, i.e., younger females are affected by range conditions to a greater extent than mature females,

(2) Age 3 years ° X 0.90,

(3) Age 4-9 years ° X 1.10,

(4) Age 10-14 years ° X 1.0.

Over the relative range of herd sizes we are considering, a summer adult population of approximately 1,800 adult animals is needed to sustain a post-harvest female herd of around 1,200 animals. Once adjusted for age class, the calving equations might need adjustments for winter severity. These figures, with summer adult elk at 1,800 head in good years, and before winter severity adjustment, are as follows:

Age 4-9 years	° 65.0 calves per 100 cows,
Age 10-14 years	° 71.5 calves per 100 cows,
Age 3 years	° 58.5 calves per 100 cows,
Age 2 years, good range	° 39.0 calves per 100 cows.

Values for winter severity are shown later in the paper, but range from 0.78 to 1.00, with 1.00 having no impact upon the breeding routine. In addition, winter severity has a greater impact upon 2-year old animals than mature females. Graph 2.1 shows the density effect upon potential breeding of female animals over the range of summer adults considered in the paper.

2. Mortality Subroutine

All natural mortality is assumed to take place in the winter, after hunting. This assumption is used in many simulation models. A flow

Graph 2.1. Potential Breeding in Relation to Herd Size, Summer Adults.

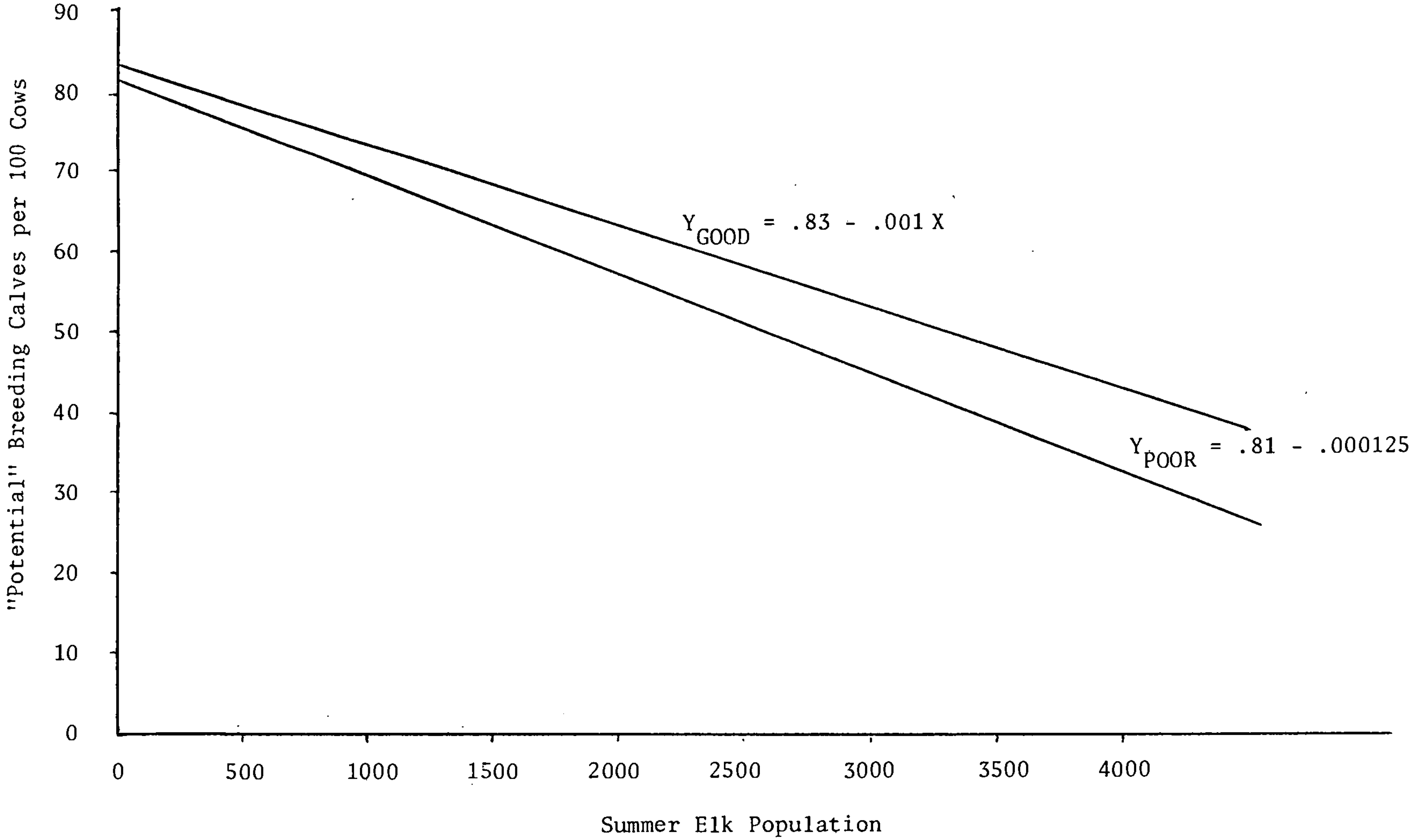


chart of the subroutine is shown in Appendix 2.3. Mortality is dependent upon herd size, winter severity, and range conditions, with each variable being assessed independently. Effect of all three variables is accumulative in calculating mortality, and if a high population level, poor range conditions, and a severe winter coincide, mortality can be very high. A severe winter covers up much of the available forage, forcing the animals to alternatives, usually lower elevation, winter pastures with increasing crowding effects. Calves are affected to a greater degree by adverse winter conditions, as occur in nature. No mortality other than harvesting is assumed for adult bull elk, although this could be incorporated.

3. The Harvesting Subroutine

Male adult harvest is kept at a constant 85 percent of the adult male population. This figure is rather arbitrary, but it is set at 85 percent to ensure an acceptable escapement of mature bulls for breeding purposes. Unless bull escapement drops below three mature bulls per 100 cows, males can be deemed harvestable surplus with little impact upon herd performance. Females, on the other hand, can be regarded as having a dual role from an economic perspective -- harvest for immediate benefit or production of income-generating progeny in future years. Elk calves are harvested at an assumed 50 percent of the rate applied to adult females, thus female (antlerless) harvest actually contains some male animals in the form of male calves.

4. The Economics Subroutine

After harvest levels of bull an anterless animals are set for the year, this subroutine calculates anticipated revenue from the sale of elk permit tags for that year. Hunting success rates are kept constant at 13.223 percent and 47.9 percent for bull and anterless animals, respectively[1/] during the simulation, and the numbers of tags are calculated from this information. The marketing strategy used is a system of "market clearing" tag prices each season, and to assume these market clearing prices are charged.

Market clearing strategy establishes a price, estimated from a demand curve, that will enable authorities to sell all available tags at the highest price. An example of this is given in Figure 2.1, with a hypothetical price and quantity relationship. If the number of tags available is at position A, then a price of "a" can be charged to sell all these tags, or "clear the market." However, if the number of tags available is at B, then a lower price of "b" must be charged to sell all the tags. This introduces the concept of marginal revenues and shows how an increase in the quantity supplied effected the price charged and, consequently, total revenue. Total revenue for "A" tags is the area OaαA, while this area is ObβB for "B" tags. The "elasticity" of demand enables an economist to calculate whether the quantity of tags should be increased or decreased to maximize total revenues, or to compare the "A" area with the "B" area under the demand curve.

More specific information on demand curves is as follows:

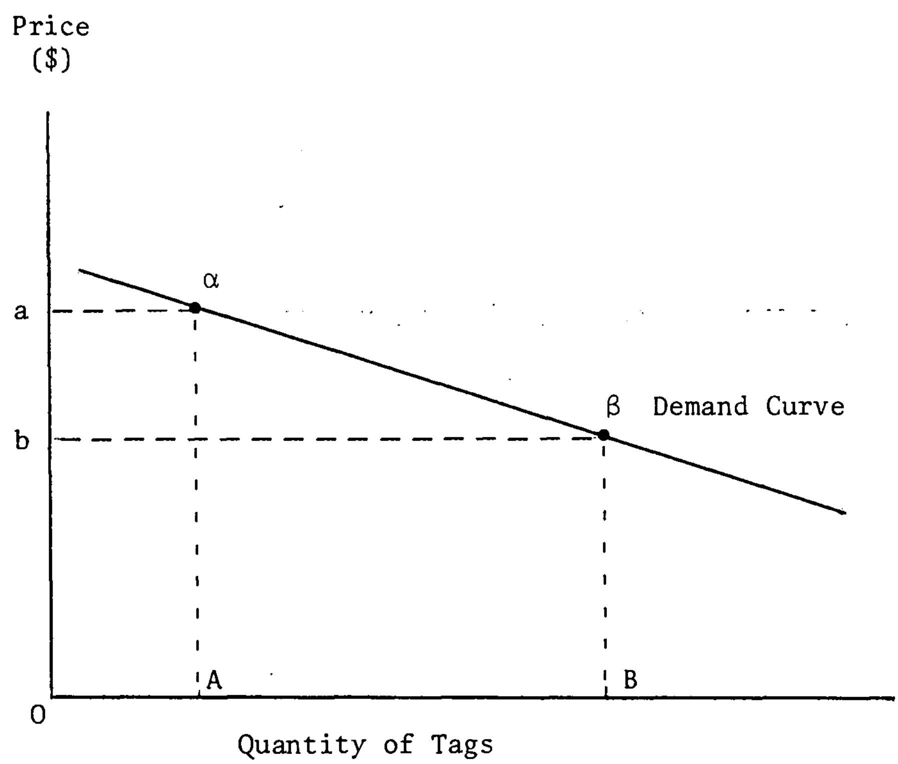


Figure 2.1 Hypothetical Demand Curve for Elk Tags

(a) Bull Elk

Using a Willingness-to-Pay survey, Helfrich (1981) has estimated a demand curve for bull elk in the Apache-Sitgreaves National Forest in Arizona. While Oregon's elk herd is significantly larger than Arizona's, it is felt that this demand curve would be a reasonable approximation to Oregon conditions. Helfrich's equation is

$$Y = 2{,}206\ X^{-0.09} - 17.72 \qquad R^2 = .97 \quad (3)$$

where

Y = demand for permits, expressed as percent of tags sold,

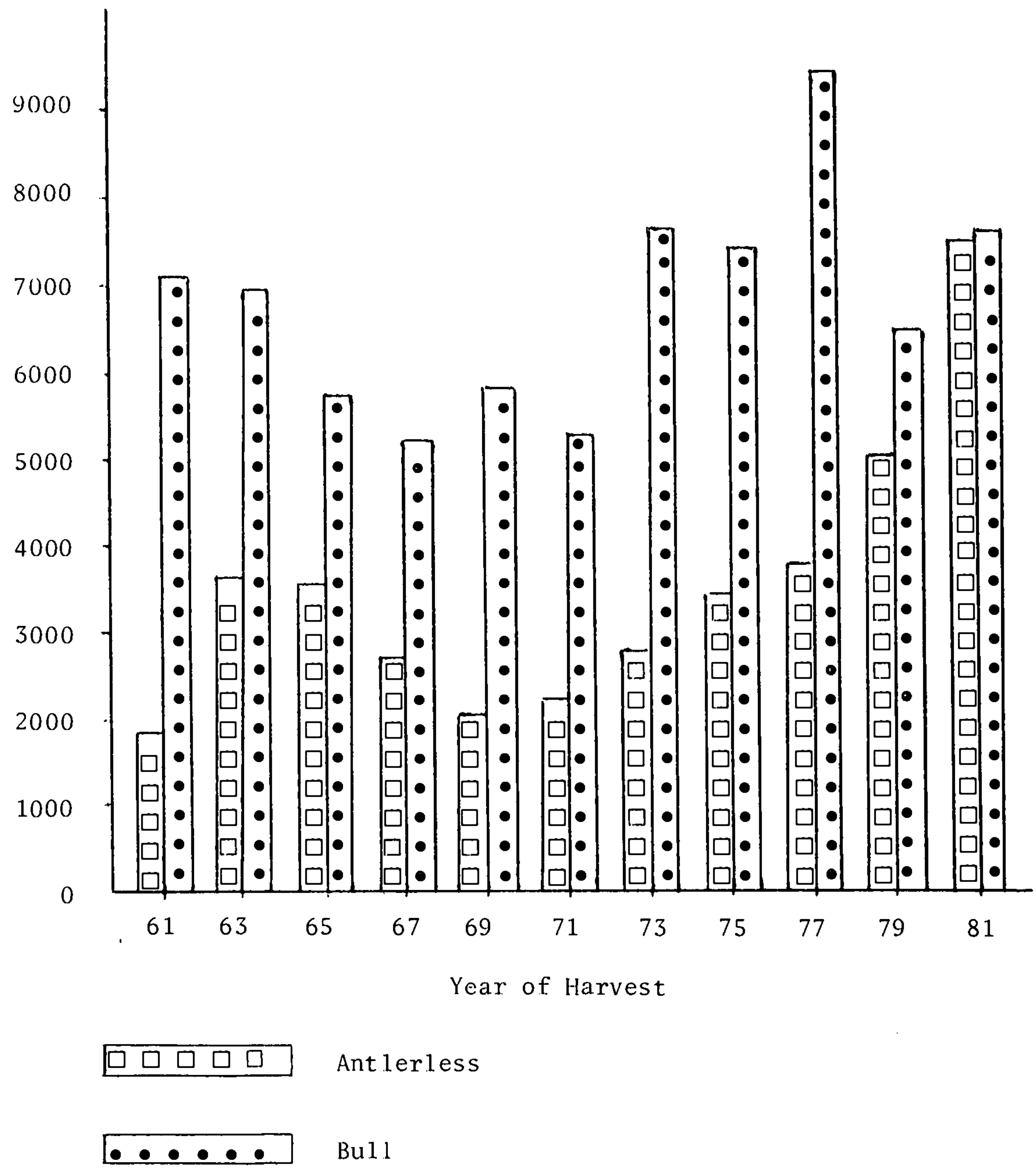
X = individual's willingness to pay for the bull hunting privilege.

Current Oregon fees are $22 (resident), and the model is adapted to use this value as the mean tag value.

(b) Antlerless Elk

Since 1961, the annual harvest of antlerless elk has tended to move upwards until the 1981 harvest when antlerless harvests almost matched the bull harvest (Figure 2.2). Hunter access to antlerless tag permits has been restricted in the first instance by a random drawing, and secondly by a two year wait before successful applicants can reapply in some units. This excess demand for the antlerless tags has been analyzed in Sandrey et.al (1982) using the so-called "travel cost" method. This travel cost method uses the distance recreationists travel to an area as a proxy for the amount of money they are willing to pay for the

Figure 2.2. Oregon's Rocky Mountain Elk Harvest Trends 1961-1981



Source: Oregon Wildlife, May 1982.

hunting experience. Using a system of concentric travel zones, the analysis is able to trace out a demand curve for the tag permits similar to that shown in Figure 2.1.

The following exponential function was developed to model demand for antlerless tags in selected hunt units of Oregon:

$$Q_{ijt} = 124{,}745 \exp(-14.375 \text{ Cost}) \qquad R^2 = .74 \qquad (4)$$

where

Q_{ijt} = number of individuals from population zone i, submitting a first-choice tag application to hunt Rocky Mountain antlerless elk in area j, in year t, expressed per unit of population in zone i.

Cost = tag price and travel cost used as a proxy for total cost.

This model was estimated using 1980 and 1981 data and shows a price of $89.60 was needed to reach a situation where the number of tags issued for those years was equated to the number of tags applied for, or the "market clearing" pricing strategy outlined earlier. This represents an increase of $66.60 on current prices, and the equation was adjusted to reflect annual changes in the number of tags issued, based on a 47.9 percent hunting success rate. Once these tag prices are known, average values per animal are calculated, along with total revenues. Average values per animal are simply the revenue per animal derived from sale of hunting permits.

One limitation of this approach is that no values are assigned to the elk herd for nonconsumptive value. These values include elk viewing, photography, and just the value people derive from knowing a viable elk herd exists in eastern Oregon. If these were of major concern, provision could easily be made to incorporate these values into the simulation results. Another limitation may be that complete independence is assumed between antlerless and bull hunting. This may be unrealistic insofar as many hunters may hunt antlerless animals if they are successful in drawing a tag or hunt bulls if they do not draw an antlerless tag under the present situation in Oregon. The only other approach may be to keep hunting numbers constant and vary success rate of the harvest, but this would require further information on hunters' willingness to pay for success in the hunt. However, the antlerless elk tag demand curve does reflect the considerable excess demand for antlerless tags currently observed in Oregon and other western states.

5. Population Update Subroutine

The subroutine is used to update the age structure prior to the breeding season and also to gather statistics on the herd's performance, both biological and economic.

Simulation Results

Under the management strategy employed in the so-called "base" model, antlerless elk tags are issued for estimated surplus female animals above 1,200 head post-harvest. Mean summer population of adult animals over the simulation period was 1,819 head, with a standard deviation (S.D.) of 90. Late winter populations averaged 1,850; with 1,240 adult females, 58 mature bulls, and 556 calves. Additional details are given in Table 2.1.

Harvest

Using an 85 percent harvest rate on all age classes of adult bulls, the average harvest was 276 bulls. This left an average of over 4 percent mature bulls per 100 cows in the herd for breeding, as well as spike bulls. Oregon Department of Fish and Wildlife (ODFW) management objectives for minimum escapement of adult bulls per 100 cows range as low as 3 percent, so the simulation average should be acceptable. Further comparisons between the simulation model and Oregon's Blue Mountain elk herds are shown in Table 2.2. Over a 3-year period, from 1979 to 1981 harvests, an aggregate of 9 herds in Oregon[2/] sustained an average of 260 animals harvested per 1,000 summer adults, compared to the simulation average of 283. From a less productive herd (average calf/cow ratio of 30-31 per 100) Wyoming's Jackson herd sustains an average of 220 animals per 1,000 summer elk.[3/]

Antlerless harvest averaged 237 animals, including 44.7 calves. This means the antlerless harvest averages 86 percent of the bull harvest, compared to the biological potential of matching the antlerless harvest with the bull harvest (ODFW, 1982) and the actual over a 3-year period in the 9 Oregon units of 77.4 percent. Greater instability is shown in the antlerless harvest than the bull harvest (S.D. of 59 and 25, respectively), with antlerless totals exceeding bull totals in 8 of

Table 2.1. Summary of Simulation Results (simulated over a 40-year period)

	Average	Minimum	Maximum
Summer Adults	1819	1470	1932
Winter Females (pre-calving)	1240	1170	1300
Young (late winter)	556	428	676
Calf Ratio	44.9	35.4	54.9
Male Harvest	275	216	322
Antlerless Harvest (including young)	237	138	332
2-year Old Bulls	47	40	58
Calf Mortality (non-harvest)	55	13	146
Adult Cow Mortality (non-harvest)	62	18	154
Percent Natural Mortality Females	4.7	1.5	10.6
Percent Natural Mortality Young	8.9	2.4	22.9
Percentage Replacement of Females	18.3	15.5	21.6

Table 2.2 Comparison Between Selected Areas and Simulation Model, 1979 to 1981.[a]

	Actual				
	1979	1980	1981	Average 1979-81	Simulation
Bull Harvest per 1000 Summer Adults[b]	137.2	167	134	146.6	157
Antlerless Harvest per 1000 Summer Adults	89	107	144	113.5	135
Total Harvest per 1000 Summer Adults	226	274	279	260	283
Ratio Antlerless per 100 Bulls Harvested	65	65	108	77	86
Estimated Summer Adults (1000)[c]	3.94	4.38	4.01	4.11	1.81

[a] The 9 units used are the units used to analyze excess demand for antlerless elk in Sandrey et.al, 1982. They are the Chesmimnus, Starkey, Whenaha, Sled Springs, Walla Walla, Mt. Emily, Heppner, Desolation, and Ukiah herds.

[b] O.D.F.W. Management Objectives are for 132 bulls per 1000 summer elk in the same units.

[c] O.D.F.W. Management Objective is for 3,628 summer elk per unit in these units. Numbers are shown as an average value for each of the 9 units.

the 40 years. A mean percentage of 12.38 of females are harvested annually.

Following Pindyck and Rubinfeld (1981, p. 90-91), the regression technique of standardized regression coefficients was applied to the simulation output. This technique allows the researcher to make statements about the relative importance of the independent variables in a multiple regression. Each variable is normalized by the subtraction of its mean and dividing through by its standard deviation. Applying this approach, female population numbers from the summer 18 months previous (i.e., the population growing the current cohort group) was shown to have the greatest impact on bull harvest. Relative importance of each variable can be judged directly from the rankings, in absolute value, of the coefficients associated with each variable. These coefficients are:

LAGSUMFSQU	=	35.71
LAGSUMF	=	-34.01
LAGCALF:COW	=	21.89
SUMFSQU	=	2.88
LAG YOUNG MORT	=	-2.36

where

LAGSUMF and LAGSUMFSQU represent summer female elk from 18 months previous and lagged summer female populations squared, respectively; SUMFSQU is summer female population from the previous year; LAGCALF:COW is the ratio of calves to cows from which the current cohort group was bred; and LAGYOUNGMORT is death rate of young bulls the previous winter as calves. The sign associated with LAGSUMFSQU is positive, indicating increasing total male harvest with increasing female numbers over this range of the data. LAGCALF:COW ratios are positive, indicating increasing harvest of males with increasing calf to cow ratios from the previous season.

Reproductive Performance

A mean calf:cow ratio of 0.45 is recorded for the simulation run. This figure varies from 0.35 to 0.55, and has a standard deviation of 0.05. Simple correlations between the number of young and the number of cows yield r values of 0.97, indicating strongly that actual cow herd size has more impact than stochastic variables upon the number of calves. Ratios of calves to cows are calculated in the late winter period and can be considered recruitment to the herd as yearlings.

Applying the standardized regression techniques to calf numbers recruited into the herd, female numbers from the previous season (SUMF and SUMFSQU) were found to have the largest impact on the numbers of calves. Severity of the winter 12 months previous (LAGWINT) and the current winter (WINT) influence numbers with density (DENTY) also having some impact[4/]. The negative value associated with SUMFSQU indicates decreasing returns to cow numbers over the range of the simulation data.

Average recruitment of females into the breeding herd at one year of age was 18.33 percent of the total females (S.D. of 1.4 percent). This figure may be compared to the 18.36 percent figure given in Taber _et.al_

(1982) as estimates from a hypothetical elk herd with 10 percent of the females harvested annually. Kimball and Wolfe (1979), with average fecundity rates similar to those in this present model (0.47 calf:cow ratios), estimate a female survival rate of 78.5 percent would be necessary to produce a stationary population. Including natural mortality, the present model female survival from cohort to two years old is 79.25 percent.

Mortality

No mortality other than harvest is assumed for bulls past the first winter as calves. Although this may bias harvest upwards, given the low (15 percent) escapement of 1½ year old bulls, this bias is likely to be small.

Calf mortality averages 55 calves per year (winter mortality), with a low of 13 and a high of 146 calves. Expressed as a percentage of calf numbers, the average was 8.9 percent, with low and high percentages of 2.4 and 23.0, resepectively. Severity of the winter had the greatest impact, with density relationships and forage conditions also factors.

Female adult mortality had a mean percentage value of 4.7 percentage of the female herd, with ranges from 1.5 to 10.6 percent. Inherent in the mortality question are the numbers of illegal harvest from the herd. These numbers are difficult to estimate in a real world elk herd but obviously occur to some degree. In the current simulation model, natural mortality can also be broadened to include crippling loss from legal harvest and illegal harvest numbers. From an economic viewpoint, some economic value should be assigned to illegal harvest, just as economic value should be assigned to noncomsumptive benefits from the elk herd. These values are not assigned in the current model.

Stochastic Parameters

(1) Winter severity impacted calving performance and mortality in 18 of the 40 years, although in some years the effect was minor. Relative values of winter severity are given in Table 2.3, with a low of 0.78 being recorded, which accounted for the largest mortality figures. Following this winter of 0.78, harvest of both antlerless and bull animals declined and did not return to an average number until the fourth harvest.

(2) Range conditions were in the lower category for 19 of the 40 years, and in the better category for the remainder. This impacted upon female calving potential, via the linear equations given earlier, and also upon winter mortality.

(3) Errors in estimating the actual population ranged from 71 below to 56 above, as reported earlier.

Sensitivity Analysis

Multiple runs over a 40 year period showed little change from the results presented in Table 2.1. Using a random normal distribution for the stochastic parameters over a 40-year period implies that we would expect the results to converge to a mean, and thus expect little variation to a sensitivity analysis.

Table 2.3 Relative Winter Severity

Value Recorded	Number of Observations
1.00	22
0.95 - 0.999	8
0.90 - 0.949	5
0.85 - 0.899	3
0.80 - 0.849	1
0.75 - 0.799	1

Economic Results

Although the price of a bull tag varies from \$18.84 to \$27.65, little variation exists in total revenues from sale of bull tags. In every instance, revenue was higher when more tags were sold, demonstrating that increasing harvest is the optimal strategy to maximize revenue from bull tags even when facing downward sloping demand curve.

Total revenue from antlerless tag sales was greatest when tag sales were above the mean value of 495 tags.[5/] Revenue varied more with antlerless sales, from \$45,910 high to \$35,920 for a low, with a maximum at tag sales in years 11, 24, and 29 of the simulation run, with sales of 665, 653, and 653, respectively. Market clearing prices of these tags showed a greater variation than those of bull permits, with a low of \$66.68, a high of \$130.30, and mean value of \$90.23 per tag. Thus, given the demand curve used in this model (equation 3), revenues from tag sales of antlerless animals averaged 315, or a 32 percent increase from the present numbers of 237 antlerless tags. However, given the elasticity of the demand curve at the present mean antlerless harvest of 237 animals, total revenues from antlerless tags only increase by \$1,412 in moving from 237 to 315 for antlerless animals harvested. Even though total revenue increases, the increase is only 3.3 percent for an increase of 32 percent in animals harvested. Antlerless tag prices are higher than bull tag prices because of the higher success rate associated with antlerless animals than bull hunting.

Average revenues per animal were also calculated and shown in Table 2.4, along with other data summarized from the ECON subroutine. These average values are obtained from simply multiplying the tag price by the number of tags allocated (7.56 for bulls and 2.09 for antlerless). Although of less interest to an economist than marginal values, these figures do reflect the excess demand that exist for antlerless elk in eastern Oregon.

Marginal values are the addition to total revenues from the increase in harvest of one more animal. At the mean antlerless harvest or 236 animals, the marginal value of an extra antlerless animal is $37.81. The corresponding value for a bull animal is $5.42. However, in interpreting these results the reader must bear in mind that the antlerless demand curve was derived from actual Oregon data, while the bull elk demand curve is from Arizona research.

Alternative Management Strategies

1. Supplementary Winter Feeding

Oregon currently does not provide an active program of supplementary winter forage to the Blue Mountain elk herd. If it is felt that winter forage may be a constraining factor to increase elk harvest, and winter feeding is deemed acceptable, then it is instructive to program the model to reflect this management change. Two basic changes were made in the MORT subroutine--effects of winter severity and density upon the mortality rate were both reduced if either a hard winter or poor forage conditions existed for the year. This is because supplementary forage

Table 2.4. Summary of Economic Results from the Simulation Model ($)

	Average	Minimum	Maximum
Price a a bull tag	22.18	18.84	27.65
Total revenue from bull tags	45,680.00	45,170.00	45,880.00
Average revenue per bull elk	167.70	142.50	209.10
Price of antlerless tag	90.23	66.68	130.30
Total revenue from antlerless	43,180.00	36,600.00	45,910.00
Average revenue per antlerless elk	188.40	133.00	272.00
TOTAL REVENUE ALL TAGS	88,831.00	80,829.00	91,510.00
Revenue from harvested elk, both bull and antlerless	173.50	-	-
Revenue from adult summer elk	48.84	--	--

will compensate for the adverse effects of winter severity or poor forage conditions. No alteration was made to the BREED subroutine, although it is possible that supplementary forage may have impacts on the number of pregnancies carried to term and the body weight of calves at birth, thus increasing calf:cow ratios. This assumption may be heroic, and would require some research to ensure calf:cow ratios did not in fact decrease owing to disease factors resulting from the elk being confined to a smaller wintering area.

Results of this strategy are summarized and compared to the "base" model in Table 2.5. Mortality of both young animals and females are reduced, increasing calf:cow ratios to 0.477. This mortality effect obviously outweighs density effects upon the subsequent calf drop. Harvest of bulls is increased by 20 animals to 295 annually, while antlerless harvest is increased by almost 30 percent to 304 annually. Even though mean price of an antlerless tag decreases, total revenues increase because of the extra tag sales.[6/] Total harvest per 1,000 summer adult elk is increased to 319 animals, as compared to 283 in "base" model. This represents a 12 percent increase in productivity using harvest per 1,000 summer elk as a productivity measure.

Supplementary feeding has been conducted for several years on the National Elk Refuge in Jackson, Wyoming, and the period of supplemental feeding has averaged 75 days per year since 1913. Since 1975 alfalfa pellets, fed at a rate of 7.5 pounds per elk per day, have completely replaced baled hay in the feeding program, at a cost of $0.234 per ani-

Table 2.5. Comparison of Alternative Management Strategies

	(1) Base Model	(2) Sup. Forage	(3) Constant Ant. Harvest
Bull Harvest	275.	296.	271.
Antlerless Harvest	237.	304.	237.
Cow:Calf Ratio	.449	.477	.452
Price of Antlerless Tag ($)	90.23	71.93	88.95
Average Rev. Antler ($)	188.40	150.20	185.70
Price of Bull Tag ($)	22.18	20.64	22.53
Average Rev. Bull ($)	167.70	156.10	170.40
Average Total Revenue ($)	88,830.	90,740.	89,650.
Mortality of Young (%)	5.50	3.37	5.32
Mortality of Females (%)	6.27	3.01	5.93
Percentage of Replacement Females	18.3	19.30	18.40
Average Calf Numbers	557.	599.	549.
Average Female Winter Pop.	1,240.	1,255.	1,214.

mal per day in 1976 (Robbins, et.al, 1982). Using this data to approximate Oregon conditions, the 1916 winter elk in the simulation model would cost $448.34 a day to feed, or $26,900 for a 60-day winter. This is considerably more than the $1,910 increase in revenues, assuming the "market clearing" pricing policies, although supplementary forage was only provided in 25 of the 40 years, thus effectively decreasing the average annual cost to $16,813 over the simulation time period.

To place this cost in perspective, if we assume that these figures would hold for an expanded herd size, the cost of supplementary feeding all the winter elk on the 9 units used in Table 2.2 would be $343,600 annually. Offsetting this cost would be an increase in harvest of 409 bulls and 1,369 antlerless animals annually, for an increase in revenues (using the "market clearing" strategy) of $39,034 annually. Damage to private land owners' hay reserves and early spring grazing may well be reduced by supplementary elk feeding, thus affecting an equity transfer from private to public cost of wintering elk in some instances. These private costs may be substantial, as a survey of Wallowa County ranchers in 1978 indicated a total big game damage estimate to ranchers in that county of $505,279.[7/]

Before deciding to adopt a policy of supplementary winter feeding, decision makers must consider benefits from the increased harvest and possible lower mortality against the financial cost involved in actual direct feeding costs. Possible equity transfers from private to public cost may be substantial and require further research before any definite conclusion can be drawn. The loss in utility to big game hunters from having elk being categorized as "semi domestic" animals may be real and also needs to be considered. An additional cost may be incurred from having an elk herd become dependent upon supplementary forage and not foraging in the traditional winter feeding grounds.

2. Constant Antlerless Harvest Policy

Since the years of antlerless harvest at or above mean values provide the greatest revenue from tag sales, it was decided to run the simulation model with harvest of antlerless animals set at 237, or 495 tags being issued. Total revenues are increased over the base model, even though bull harvest is down by 4 animals. Winter population numbers of adult females are decreased by 26 animals under this strategy and the standard deviation is 77, compared to a more stable standard deviation in the "base" model. Following a severe winter, female numbers drop below 1,200 head to a low of 1,059 and stay at less than 1,200 animals for 13 years. The effect of another severe winter coupled with poor range conditions at these low levels may well mean the herd would not be able to sustain a regular harvest level. Compensating for the lower female herd size is an increased calf:cow ratio and decreased mortality. Comparisons between alternative strategies are shown in Table 2.5.

Alternative Herd Levels

The next stage in the simulation process was to alter the herd size from its projected post-harvest level of 1,200 female adult elk. Herd sizes were decreased to 900 females and increased to 2,400 females, with more changes being made in herd sizes nearer the "base" level of 1,200 females. Selected results of these changes are shown in Table 2.6. As expected from the assumption used in the model, calf:cow ratios declined, mortality increases, and total harvest per 1,000 summer elk decline as the herd level increases. Bull harvest actually increases in each period, although at a decreasing rate. Antlerless harvest decreases, as increased cow mortality and decreased calf:cow ratios mean that more adult cows are required to remain in the herd for reproductive purposes. As the herd size increases, the percentage of two year old replacement females entering the herd gradually decreases, indicating an older female herd structure.

Harvest

Total harvest per 1,000 summer elk decreases as the size of the herd increases, as expected from decreased recruitment to the herd as numbers increase. This measure of productivity has been regressed against summer elk totals to produce the following equation:

$$Y = 162{,}771\ \text{SUMELK}^{-0.853} \qquad R^2 = 0.98 \quad (5)$$

where

Y = total harvest per 1,000 summer elk.

Thus, even though bull elk totals increased in total as the herd level increased, the productivity of the herd decreases. Revenues decline as a result of decreases in the antlerless tag sales, which are greater than can be made up by increases in bull elk tag sales. If more

Table 2.6 Results of Altering Herd Sizes

Post Harvest Levels of Adult Females	900	1050	1125	1200	1275	1350	1500	1800	2100	2400
Total Harvest	456	501	521	512	503	489	480	510	527	529
Male Harvest	228	255	268	275	282	289	304	339	368	390
Antlerless Harvest	228	246	253	237	221	200	176	171	159	139
Calf:Cow Ratio	.48	.47	.46	.45	.44	.43	.41	.39	.37	.35
Percent 2-year Females	19.4	18.9	18.7	18.3	17.9	17.5	16.9	16.2	15.6	15.0
Percent Female Harvest	14.9	14.2	13.8	12.4	11.1	9.7	7.8	6.4	5.2	4.1
Summer Adults	1439	1641	1739	1819	1898	1973	2134	2468	2774	3050
Harvest per 1000 Summer Adults	317	305	300	283	265	248	225	207	190	173

accurate information were available on Oregon conditions with respect to bull elk tag demand, this revenue pattern may alter. Lingering doubts exist over applying Arizona data to an Oregon situation, but no more detailed information is available. Consequently, we will examine antlerless harvest in greater depth in the following section.

Antlerless Harvest

Antlerless harvest increases initially and then declines as the population level increases. Biologists have long been familiar with the Schaefer model as applied to fish populations. This model shows relationships between population levels and yields, as given in the yield-effort curve for the Schaefer model below.

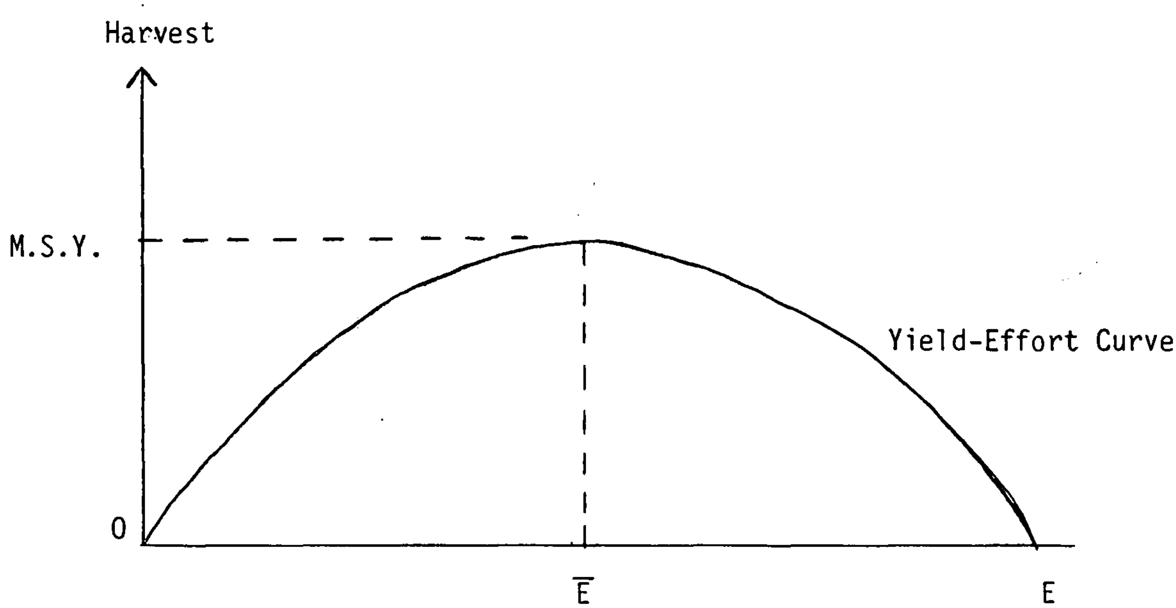


Figure 2.3 Yield Effort Curve for Schaefer Model.

With increasing levels of effort (E), the harvest level rises until reaching a maximum at M.S.Y. (Maximum Sustainable Yield) for an effort of E, and subsequently declines. Following Clark (1976) we can then trace out the optimal herd size from the effort/yield curve to sustain the biologically maximum yield. This relationship is given in Figure 2.4, with X* representing the desirable population level able to sustain maximum harvest.

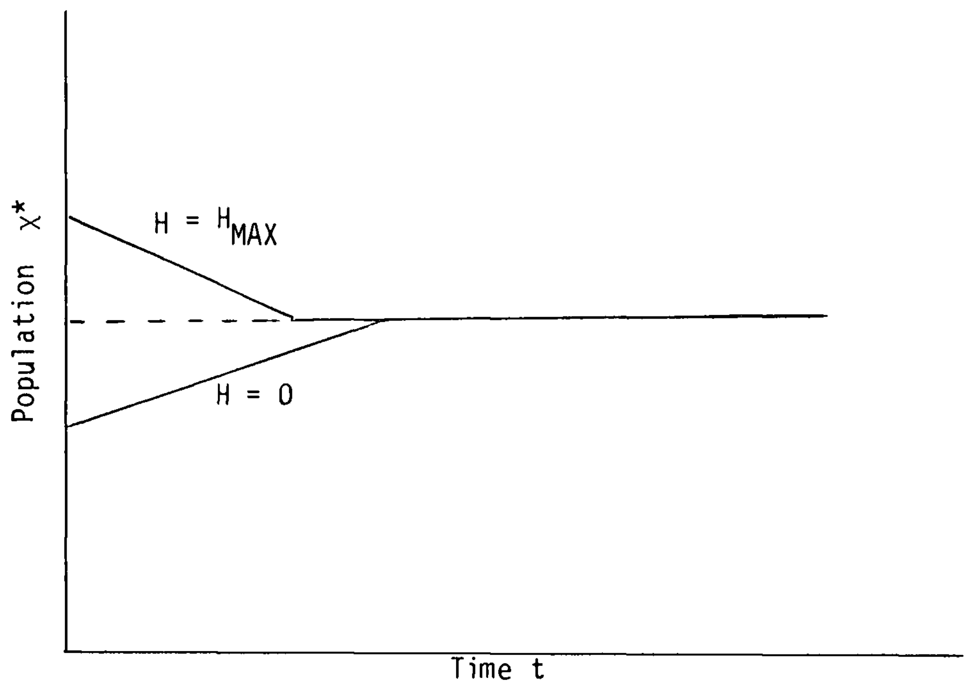


Figure 2.4. Optimal Population, X*.

If population level is above X*, then a harvest of H_{MAX} should be applied to the population to reduce to X*. Similarly, if the level is below X*, then no harvest until X* is reached. Both the yield effort curve and optimal population diagrams shown make no allowances for a downward sloping demand curve for the antlerless tags as used in this paper. If the revenue maximizing level of tag sales is below that of maximum physical yield, a single owner seeking to maximize revenue may reduce yields below M.S.Y. levels.

From the results of the simulation model, we regressed the revenue from antlerless harvest tags on the hunting effort levels, as measured by percentage of females harvested. using the 10 observations from output in Table 2.6, we found the following relationship:

$$ANTREV = 15141.5 + 4215.39\ PER - 158.45\ PERSQ \qquad (6)$$

$$(R^2 = 0.99)$$

where

ANTREV $\equiv$ revenue from antlerless tag sales,

PER $\equiv$ percentage of adult females harvested,

PERSQU $\equiv$ square of the above variable, i.e., in quadratic form.

To find the maximum value of the above equation, we differentiate with respect to PER and set the resulting function to zero and solve the equation. This gives a harvest level of 13.305 percent on adult females as maximizing revenues from antlerless harvests. Corresponding to this harvest effort we would have a population level used in the base model. The actual level of antlerless harvest at this population of adult elk would be 261 animals annually. Marginal revenue of an antlerless animal at this level is $27.55.

Expressed mathematically, we can model elk population dynamics in the form of a difference equation as:

$$E_{t+1} = E_t - H_t + f(E_t) \quad (7)$$

where

E_{t+1} = elk the following season,

E_t = elk in current season,

H_t = harvest level of elk,

f = some function for recruitment.

At a steady-state solution, the value, or expected value of E_{t+1} and E_t are the same, implying that the harvest level H_t should equal the recruitment level, or young cohort entering the herd less natural mortality.

One effect of a downward sloping demand curve on the optimal time needed to reach X^* as shown in Figure 2.4 can be demonstrated from the model. If it is decided to reduce the elk herd from 1,200 post harvest adult females to 900 post harvest females, then a revenue maximizing agency would not apply H_{MAX} as a physical level, but rather an economic level. From a purely biological viewpoint, the population level can be reduced in two seasons by harvests of 559 and 347 antlerless animals in these seasons. However, from the earlier analysis, we know that 315 antlerless animals is our revenue maximizing level. Applying this harvest level takes seven harvests to reach the X^* population level.

Revenues from antlerless tags increase by $19,420, or an average of $2,775 annually over the seven years by restricting output.

Recruitment

As expected, calf:cow ratios decline as the herd size increases. This relationship is expressed in the following form from a regression analysis as:

$$\text{CALF:COW} = 12.65\ \text{SUMELK}^{-0.446} \qquad R^2 = 0.99 \qquad (8)$$

The non-linearity of this equation is the result of increased mortality as well as decreased birth rates, since calf:cow ratios are measured as effective recruitment to the herd of young animals.

One restricting assumption made in the model is linearity in the mortality rate with respect to the density of elk, although three alternative levels of density are used. The winter severity and forage conditions are stochastic, as explained earlier. However, once we pass an adult female post-harvest herd size of 1,500 animals, the mortality figures for calves stay constant at 11.6 percent and for adult cows at 7.4 percent.

This restrictive assumption allows us to expand upon the difference equation expressing population dynamics earlier (equation 5). The recruitment function $f(E_t)$, is the number of young recruited in the herd (REC), less natural mortality of the adult females (FMORT), i.e.,

$$f(E_t) = (\text{REC} - \text{FMORT}) = H_t \qquad (9)$$

for a steady-state harvest level. From the simulation results from varying herd sizes we regressed the recruitment of young elk (REC) on herd sizes (SUM) to obtain:

$$REC = 2.42\ SUM^{0.724} \qquad R^2 = 0.99 \qquad (10)$$

Thus, the harvest H_t, can be expressed as

$$H_t = 2.42\ SUM^{0.724} - FMORT$$

for any given level of summer elk. As shown earlier, the harvest mix changes as the herd size changes. Anterless elk decrease, while bull elk increase as a percentage of the harvest as herd size increases.

<u>Livestock Interactions</u>

Until now, the elk herd has been regarded as existing in isolation from alternative land uses. This assumption is naive, as domestic livestock (cattle) and forestry interests compete to varying degrees for the land resource. Forest resources are difficult to model in conjunction with an elk herd, mainly because of the time dimension involved in a timber harvest routine. Consequently, we will restrict our discussion to livestock interactions, represented by cattle grazing.

Cattle-elk forage relationships have been extensively studied, but little exact data on the mathematical relationship exist. For instance, Lyon and Ward (1982) contains reference to 60 studies in this area, with little concensus of opinion among them. Nelson (1982) considers consumptive equivalence, diet similarity, forage availability and utilization, animal dispersion patterns, numbers of animals and seasonal use patterns, and social interaction are all factors influencing competition. The usual tradeoff equation used is two elk equals one domestic cow, but this equation only incorporates consumptive equivalence and ignores other factors.

Nelson and Burnell (1975) contains a report on extensive research into elk-cattle tradeoffs in the Wenatchee area of central Washington. This area is similar in many respects to Oregon's Blue Mountiains. Using the factors cited from Nelson (1982), this Wenatchee study concludes that for every additional elk placed into the system, 0.21 cattle must be removed. This figure was arrived at after concluding that elk spend 35 percent of their time on slopes greater than 50 percent where cattle do not interact.

Returning to the simulation model, increasing post-harvest adult females from 1,200 to 1,500 increased adult summer populations from 1,819 to 2,134. This increase of 315 adult elk would translate to a decrease in cattle numbers of 66 head of adult cattle to compensate. Using Oregon State University Extension Service Data Sheets for eastern Oregon cattle ranching, it was calculated that for every 100 adult cattle[8/], 65 calves were produced for sale in the fall. This translates to 43 fewer calves to market from our increase in elk numbers. Thus, in making comparisons between alternative land uses, the increase in elk production must be compared with a decrease of marketable calves from cattle production. Since over this range of elk herd increases total harvest of elk declined, a net loss was incurred as a result of increasing elk numbers. If, however, one was unhappy with some of the biological assumptions made in the model, extrapolating from the "base" model harvest levels of 283 elk per 100 summer adults would give an increase of 89 harvestable elk to compare with 43 less domestic cattle calves.

Using 1980 Oregon State University (OSU) Extension Service data sheets, the market value (1980 prices) of these 43 calves would be $18,893. This figure is of course the gross figure and does not take costs of raising the cattle into account, and also does not include some additional revenue from sale of cull cows. Expanding the simulation model to represent the Blue Mountain elk herd in Oregon would result in an increase of 10,437 summer adult elk from the present estimated 58,350 (ODFW, 1982). Using the 0.21 cattle to elk ratio, this translates into 1,425 less calves for the northeastern area of Oregon, or an income decrease of $626,012 from calf sales. Expressed as a percentage, this expansion of elk herds over the whole region resulting in a decrease of 1,425 calves from domestic cattle would decrease domestic cattle output by 1.18 percent. Using a 2 to 1 elk/cattle tradeoff relationship, the increase in elk would result in a decrease of 2.81 percent in domestic cattle output. This decrease in cattle production would not of course be spread evenly across all cattle producers, and some producers could be impacted significantly.

Differences in revenue projections between elk and domestic cattle result in differences in the demand curves for the two resources. As explained earlier, an increase in the quantity supplied of elk tags causes a reduction in the price to sell those tags (Figure 2.1). However, given the very small percentage change in total beef cattle for the entire United States resulting from changes in Oregon elk numbers, not very much change would be expected in the price of beef or domestic calves to result from changes in these elk numbers.

Earlier in the paper, optimal herd size was estimated from an economic perspective using antlerless harvest effort as the criterion of 1,767 summer adults, or a three percent summer adult herd size decrease. This translates to an increase of 235 domestic calves over the entire region, or a percentage increase of 235 domestic calves over the entire region, or a percentage increase of 0.2 percent. Once again, the increases would not be spread evenly across all producers. The dollar value of this increase, using the 1980 OSU figures, would be $103,237.

Discussion and Conclusions

From the downward sloping demand curves used to value both the bull and antlerless harvests, antlerless harvest was found to have a greater impact upon total revenues than does bull harvest, if the "market clearing" approach to tag sales was used. This is a direct result of both the considerable excess demand existing for antlerless tags in Oregon and the higher success rate associated with antlerless harvest. Using the market clearing system to allocate antlerless elk tags involves an equity issue, and the reader is referred to Sandrey et.al (1982) for a discussion on the losers and beneficiaries if such a system was, in fact, adopted.

Given the relationships used in this model, both biological and economic, it was found that antlerless elk revenues would be maximized by increasing harvest effort, as measured by percent of adult females harvested, to 13.305 percent. This would result in a summer adult population decrease of 3 percent from the simulation "base" model. Extending this result to the entire northeastern Oregon elk herd, a 3 percent reduction would decrease summer adult elk numbers from the 1981 estimate of 53,650 to 52,040 summer adults. This figure is still about 5 percent above the ODFW management objective herd size for the Blue Mountains. Thus, using antlerless harvest as the decision criterion, the simulation model results would support the current ODFW policy of reducing herd sizes, although not to the extent of the 8 percent reduction proposed in the Management Objectives.

Marginal revenue of an antlerless animal with a 3 percent decrease in herd sizes would be $27.55, indicating that considering an elk herd in isolation it may still be optimal to increase antlerless harvest. The corresponding marginal revenue from a bull animal is $5.42, suggesting that revenues may be increased by slightly increasing the antlerless harvest at the expense of bull harvest. This could be done by increasing the harvest of male calves, and has not been investigated as a policy alternative.

Obtaining a more accurate demand curve by direct survey of Oregon hunters' willingness-to-pay for bull elk hunting privileges may enable more definitive statements to be made regarding bull elk values. Additional research may result in a demand curve more responsive to price change with respect to total revenues. At present, revenue from bull tags using a constant success rate has a standard deviation of only

$152 in the "base" model. This indicates a demand curve very unresponsive to price changes, and may be a limitation of the present research.

Adopting some policy of winter forage supplements would probably increase harvest by reducing mortality. Decreasing mortality can be translated into increased harvests from two separate sources. Less adult female mortality means a lower recruitment requirement and consequently a larger antlerless harvest, and a lower calf mortality translates directly into increased bull harvest. On a direct comparison between benefits from increased revenues and costs of the supplementary feed, the policy would not be cost effective. However, consideration was given to other factors, such as a equity transfer which may result from private to public support of an elk herd, which need to be taken into account and may alter the above analysis.

Mainly as a result of increased mortality among calves and female adult cows, increasing the herd size decreases productivity as measured by total harvest per 1,000 summer adult elk. A recruitment function (equation 10) was estimated, and this should be of interest to wildlife managers considering alternative herd sizes, assuming that the biological relationships used in the model are accepted.

Introducing the concept of "opportunity cost" into the analysis allows comparison between elk-cattle tradeoffs from an economic perspective. Using the relationships from Nelson (1982) the projected increase in cattle production was shown from a 3 percent decline in elk numbers. Figures were also calculated for the projected decline in cattle production if elk numbers were to be increased. Considerable controversy exists in the literature over the exact physical relationship between elk and cattle, although the research used from Nelson and Burnell was considered the most applicable to Oregon conditions.

Endnotes

1/These percentages are the average for Rocky Mountain elk bull harvests for 1979 to 1981 and antlerless harvests for 1980 to 1981 in Oregon.

2/These are the same 9 units used in estimating the antlerless elk demand curve for tags. Harvest information was obtained from Oregon Wildlife magazine, and herd numbers from ODFW (1982).

3/Garvis Roby, Wyoming Game and Fish Department, 1982, personal communication.

4/Actual coefficient values are as follows:

SUMF = 3298.6,	SUMFSQU = -94.1,	LAGWINT = 31.1,
WINT=5.1,	DENTY=7.8.	

5/Using the demand curve presented as equation (4), elasticity of tag price is -1.0 when antlerless tag sales are 659, or 315 animals are harvested. This value then is the revenue maximimizing value, since revenues are maximized when elasticity is equal to negative one.

6/Elasticity of demand for tags is reduced in absolute value to -1.03, thus explaining the increase in antlerless revenues. Recall revenue is maximized at elasticity of -1.0, when antlerless harvest is at 315 animals annually. Marginal revenue at mean antlerless harvest is reduced to $5.44 per animal. Total revenue is increased by $1,910 annually.

7/Personal communication, Mick Birkmaier, rancher at Enterprise. The survey included both elk and deer damage, and caution must be used in interpreting the results as the survey is unofficial and was not subject to the usual survey criteria. Estimated elk numbers in Wallowa County in 1978 were 20,300 (ODFW, 1982).

8/Using an 85 percent calf drop on 95 percent of the cows which are actually pregnant, 6 bulls per 100 cows and a 20 percent cow replacement requirement.

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Manuscript 3

Economic Management of Elk Concurrent with Grazing and Timber Harvesting

ECONOMIC MANAGEMENT OF ELK CONCURRENT WITH GRAZING AND TIMBER HARVESTING

Herd sizes and harvest levels of Rocky Mountain Elk in the Blue Mountains of eastern Oregon have been increasing steadily since the mid 1960s, and the optimal size of that elk herd has become an emotional issue throughout the State of Oregon. Ranchers and foresters, some of whom bear private costs in supporting a public elk herd, are concerned that levels may be too high. Users of the elk, both of a consumptive and nonconsumptive use, would like to see an increase in herds in many areas.

Economists have long recognized the problem of conflicting land use between big game animals and domestic livestock. Published articles in recent years exploring approaches to determining optimal combinations of land use include works by Pearce (1968, 1969) and Martin, Tinney, and Gum (1978). These works are essentially static in nature, and illustrate how differing values placed on each product influence determination of the economic optimal combination, once a biological production relationship has been derived.

Burt and Cummings (1970) derive the necessary conditions for optimal intertemporal exploitation of a given resource, using transition equations to incorporate the dynamics. The purpose of this paper is to conceptually apply the general framework of Burt and Cummings to a model maximizing the economic benefits from a given area of land providing grazing for both elk and domestic livestock.

Revenue from timber production is important to local communities in eastern Oregon, and interactions between elk and timber production have become controversial. Recognition of the timber-grazing relationships can be incorporated into the model in this dynamic framework. This enables the theoretical conditions for maximizing elk herds, livestock grazing, and timber production over time to be presented from a bioeconomic viewpoint. Areas where data on specific relationships is either nonexistent or contradictory are discussed.

The Bioeconomic Model

In this section a bioeconomic model is presented for alternative uses of the land base. Population and resource stock transition equations are formulated and described, and then extended to include intertemporal changes. This section concludes with a suggested benefit function and a terminal value function.

Elk Population Dynamics

At the beginning of any period t+1, elk resource stocks can be represented by the difference equation:

$$E_{t+1} = E_t - H_t + h(E_t,F_t,T_t),$$

where

E = Elk,

H = Harvest of Elk,

F = Forage,

T = Timber Cover, or Standing Timber,

t = time, and $t = t_0$ to t',

h = some function, representing net additions to the resource stock, Elk, during period t.

Factors which biologists consider to influence herd size from one period to the next are the birth and recruitment rate, natural mortality rate, and harvesting policies.

Recruitment could be expected to be influenced by available forage, timber harvesting policies, and winter severity. Conception rates of elk cows are influenced by the body condition of the animals in the previous summer and fall forage conditions. Severity of the previous winter also appears to have some lagged effect, especially on younger animals. Later winter forage and winter severity both affect survival rates of new-born calves. Calf/cow ratios, as estimated just prior to spring calving provide the measure of recruitment rate. Observed ratios in Oregon's Blue Mountains are in the 40-45 percent range, although little specific data is available. Means, standard deviations, and the specific impact of the different variables are needed to ascertain the recruitment function.

Density dependence must operate as an elk herd nears its habitat carrying capacity, but the economically optimal level of a renewable natural resource (elk herd) is below the biological maximum level (Clark, 1976). Within the range of herd sizes currently existing in eastern Oregon, herd density may have little effect on conception rates or fecundity, although it could affect winter survival of calves and thereby recruitment.[1]

Harvest policies are directly under the control of Oregon Department of Fish and Wildlife by fiat. The actual harvest consists of two

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[1]Personal communication, Warren Aney, O.D.F.W., La Grande.

components, bull and antlerless. Unless the bull ratio is allowed to drop below a critical level (considered to be 3 percent of the cow herd), bulls can be regarded as being harvestable surplus. Hunter congestion and bull escapement can be manipulated somewhat by altering season dates and duration. Antlerless harvest becomes the effective control on herd size, and considerable excess demand exists in Oregon and elsewhere for antlerless elk tags. Potential exists for antlerless harvest to be as large as the bull harvest, and this would have the impact of lowering the average age of elk cows. Information on elk population dynamics is needed to compare alternative harvesting strategies from a purely biological viewpoint, and then marginal values of the elk are needed to economically compare these alternative strategies. Elk herds have the characteristic of being relatively stable through time, especially when compared to deer populations. This implies a steady-state harvest rate concept is a realistic assumption, with a single average expected value for every characteristic of an elk population. This is the underlying assumption made in population dynamic models of elk (Taber, Raedeke and McCaughran, 1982).

Elk preferences for both summer and winter thermal cover are well documented (Thomas, 1979). Winter survival rates of the herd are directly influenced by winter severity, body condition (forage), and thermal cover (timber). Hiding cover and general security of the animal are also considered essential in elk habitat (Lyon, 1980, Lyon and Ward, 1982), and this involves spatial allocation of the timber resource. Habitat effectiveness is considered optimal at a 60/40 ratio of forage areas to cover (USDA, Forest Service, 1979). This ratio is assuming ideal dispersion of the timber, as elk prefer grazing on edge range. Deviations from optimal ratio could be represented by:

$$1/2(\text{Forage/Cover Index})^{1/2}$$

with ideal ratios and dispersion providing a geometric mean for the index. Data is needed both for the specific cover ratio indes, and the probable impact of deviations from optimal or desired index figures.

Peek et al. (1982) conclude that winter thermal cover for elk, while preferred, is required only during extreme winter conditions involving high winds. Similarly, summer habitat is based upon selection of the availability of succulent vegetation, and cover per se is not necessary. This suggests costs of deviation from optimal habitat may not be high in most instances.

Little specific data is available on mortality rates for Oregon's Rocky Mountain Elk. Given the high rate of exploitation of the bull herd, little natural mortality of adult bulls would occur. Illegal harvest, to the extent that it takes place, could for economic considerations be included as harvest, and not mortality. Winter severity adversely affects calves and older animals, although, once again, few old cows would exist in a managed herd. Few natural predators impact elk in Oregon. An average assumed natural mortality rate by age class would be used for modeling purposes, if that average was known.

Timber-elk relationships are complex, and although much research has been conducted on ideal elk habitat for elk, little is known of the consequences of deviations from optimal habitat. At one time, elk were the most widely distributed member of the deer family in North America, and their habitat included grasslands and arid desert (Lyon and Ward, 1982). This suggests the elk is a very adaptable animal. Thermal and hiding cover have been discussed, as has spatial allocation of the timber and forage. Lyon and Ward (1982) consider that forestry has two general effects on elk.

(1) Disturbance of animals and their habitat during logging operations, and

(2) Long-term modification of the habitat.

In addition, elk can impact forest practices by damage to young regenerating trees. Given the time horizon of an eastern Oregon timber life cycle (120 years), these effects are difficult to quantify. Tradeoffs between elk and timber are evaluated by the U.S. Forest Service in terms of M.B.F. cost for each extra elk potential in a given area (USDA Forest Service, 1979). It must not be assumed, however, that elk and timber production are incompatible. Both silviculture and logging may open up areas of old growth to permit extra forage production, thus impacting elk beneficially via the forage equation. Tradeoffs between forage and timber production are contained in Hall (1975).

Forage Equation

Forage is considered to be a state equation in our model, and the control variable in numbers of cattle permitted to graze on public land. We recognize this assumption may have property rights connotations, and imply the traditional access to public land by ranchers is a privilege, not a right. In addition, spatial dispersion of the livestock needs to be considered. Available forage in a given period can be represented by the difference equation,

$$F_{t+1} = F_t + g_t(L_t, E_t, C_t)$$

where

L_t = domestic livestock (cattle)

C_t = cuttings of timber

g_t = some function representing changes to the forage base, and other variables as previously defined.

Time is introduced into the forage equation (g_t) explicitly to denote that range conditions may change over time. We would hope product management would not allow range conditions to deteriorate over time, and this could be imposed as a constraint. Elk are usually light grazers of forage, but can be very destructive during times of critical forage shortage. As earlier outlined, forage does not appear to be constraining elk over most of Oregon's Blue Mountain area. If critical late winter shortages developed, the economic implications of emulating other states and adopting supplementary winter forage needs be studied.

Cattle-elk forage relationships have been extensively studied, but little exact data on the mathematical relationship exists. For instance, Lyon and Ward (1982) contains reference to 60 studies in this area, with little consensus of opinion among them. Nelson (1982) considers consumption equivalence, diet similarity, forage availability and utilization, animal dispersion patterns, number of animals and seasonal use patterns, and social interactions all are factors influencing competition. The usual tradeoff equation used is two elk equals one domestic cow, but this equation only looks at consumptive equivalence, and ignores the other factors. Competition only occurs when we are on an efficiency frontier, and it may be meaningless to model possible tradeoffs until we reach an efficiency frontier. Competition between elk and other herbivores exists in the Blue Mountains, although it would seem reasonable just to model elk-cattle relationships.

Prudent timber management may be beneficial to forage production, especially on summer range. Increased cuttings open up the ground cover and allow more forage to grow, thus $dg_t/dC_t > 0$. Implications of possible disturbance from logging have been discussed earlier.

Relationships between forage in one period to the next may well depend upon the time periods we are considering. Little or no relationships may exist between one year and the next, but carryover may be significant for shorter periods, especially from late fall to late winter. Forage would be measured as dry matter per acre (D.M./acre). Given an area of diverse terrain and timber cover, a composite acre would be used for computational purposes.

Timber Equation

$$T_{t+1} = T_t - C_t + f(T_t)$$

where

f = some function modeling timber growth, and other variables as defined earlier.

Any change in standing timber is simply a function of timber in the previous periods and harvest in the current period. Timber production could be measured in million board feet (M.B.F.) per acre, and deviations of actual from potential production used to measure opportunity cost. Kingma and Sinden (1975) provide a framework for evaluating timber and grazing tradeoffs using a production transformation function. This allows tradeoffs to be modeled, once the data has been specified. Volume of harvested timber may be restricted by spatial constraints imposed by wildlife managers upon timber cuttings, and recognition of these relationships can be incorporated into a model. Elk-timber interactions have been discussed in detail earlier, and need not be repeated. Consideration could be given to the impact of elk on timber production by introducing elk, E_t, into the timber function, $f(T_t)$. The relatively slow growth rate of eastern Oregon's timber resource makes it difficult to evaluate impacts of elk on timber, especially if the young trees will not be harvested for at least a century from planting.

Benefit Function

Benefits to society accrue from elk harvest, livestock, timber production, and numbers of elk over time. This may be specified at time t as

$$B_t(H_t,L_t,C_t,E_t),$$

and is assumed to be concave.

Elk are explicitly included in the benefit function to reflect possible nonconsumptive values of an elk herd. These nonconsumptive benefits may be derived from activity values such as photography and wildlife viewing or existence values. Existence value is the utility gained from knowing a viable elk herd exists. Consumptive benefits would be those accruing to the hunters from H_t, and include the value of elk per se as well as the hunting experience. Harvest levels can be adjusted to incorporate these two possibly conflicting types of benefits.

Normally costs associated with harvesting a natural resource can be expected to rise as the herd level decreases, as increased effort is required to locate the harvestable resource. If this was demonstratably the case with elk, then incorporating elk into the benefit function would enable this to be reflected. However, in the case of hunting, increased effort to locate animals may be considered by some hunters as being a benefit, as long as success rate is not decreased. Conflicts between the public good of an elk herd and private land holders may increase in a nonlinear manner as the elk herd increases, and having elk explicitly in the benfit function would capture this relationship.

The important problem is to determine the harvest sequence $H = (H_t^*)$, livestock numbers $L = (L_t^*)$, and timber cuttings $C = (C_t^*)$ that maximizes benefits from the land resource. This would give us the optimal herd size and composition, E^*, as well as optimal forage and timber cover ratios, F^* and T^*. Elk can be considered as being capital goods which are held by decision makers as long as their capital value in production exceeds their harvest value.

Given we are maximizing over some arbitrary time period of t' years, we have a terminal value function Ψ relating benefits from ending stocks of elk, forage, and timber resources from time t' onwards. This would be represented as

$$\Psi(E_{t'},F_{t'},T_{t'}).$$

We introduce an appropriate discount rate, r, to discount future returns to a present value. Setting $\alpha = 1/(1+r)$ we would then postulate the following equation as our benefit function for the natural resource at any time t as

$$B_t(H_t,L_t,C_t,E_t)\alpha^t + \alpha^{t'}\psi(E_{t'},F_{t'},T_{t'})$$

where

$t \equiv$ time, $t = t_0$ to t'.

The Control Problem

The discrete time control problem of a centralized decision maker may now be stated as

$$\text{Max} \sum_{t=0}^{t'-1} B_t(H_t,L_t,C_t,E_t)\alpha^t + \alpha^{t'}\psi(E_{t'},F_{t'},T_{t'}) \qquad (1)$$

subject to

$$E_{t+1} - E_t + H_t - h(E_t,F_t,T_t) = 0 \qquad (2)$$

$$F_{t+1} - F_t - g(E_t,L_t,C_t) = 0 \qquad (3)$$

$$T_{t+1} - T_t + C_t - f(T_t) = 0 \qquad (4)$$

$$E_t,\ H_t,\ F_t,\ L_t,\ T_t,\ C_t \geq 0 \qquad (5)$$

$$E_0 = \overline{E} \qquad (6)$$

$$F_0 = \overline{F} \quad (7)$$

$$T_0 = \overline{T} \quad (8)$$

Equations (2), (3), and (4) are the difference equations specified earlier. The usual non-negativity constraints for all variables are introduced as equation (5), and equations (6), (7), and (8) represent initial conditions of the elk herd, forage conditions, and timber cover, respectively.

If the constraint qualification is satisfied, multipliers $\lambda(t)$, $\mu(t)$, and $\gamma(t)$ exist for each transition equation (2) to (4). The constraint qualification is satisfied if it is assumed that $B(\cdot)$ is a concave function, $h(\cdot)$, $g(\cdot)$, and $f(\cdot)$ are convex functions, and there is some point in the opportunity set which satisfies all the inequality constraints as strict inequalities (Intrilligator, 1971, p. 57). If the feasible region is a convex set formed by linear constraints only, as in a linear programming model or a non-linear programming model with linear constraint, the constraint qualification is always met (Chaing, 1974, p. 718).

Using the discrete maximum principle, the Hamiltonian function is:

$$^{o}H = B_t(H_t,L_t,C_t,E_t)\alpha^t + \alpha^{t+1}\gamma_{t+1}\,[h(E_t,F_t,T_t) - H_t] + \alpha^{t+1}\mu_{t+1}$$

$$[g(E_t,L_t,C_t)] + \alpha^{t+1}\gamma_{t+1}\,[f(T_t) - C_t] + \alpha^{t'}\Psi(E_{t'},F_{t'},T_{t'}) \quad (9)$$

Taking derivatives of the Hamiltonian function with respect to the control variables and setting these less than or equal to zero results in the decision rules for the control variables at any time t.

$$d^oH/dH_t = \alpha^t dB/dH_t - \alpha^{t+1}\lambda_{t+1} \leq 0,\ d^oH/dH_t * H_t = 0,\ H_t \geq 0 \quad (10)$$

$$d^oH/dL_t = \alpha^t dB/dL_t + \alpha^{t+1}\mu_{t+1} dg_t/dL_t \leq 0,\ d^oH/dL_t * L_t = 0,\ L_t \geq 0 \quad (11)$$

$$d^oH/dC_t = \alpha^t dB/dC_t + \alpha^{t+1}\mu_{t+1} dg_t/dC_t - \alpha^{t+1}\gamma_{t+1} \leq 0,$$

$$d^oH/dC_t * C_t = 0,\ C_t \geq 0 \quad (12)$$

We assume all control variables are greater than or equal to zero, and incorporate this condition and the second equation d^oH/d Controls * Controls = 0, to complete the Kuhn-Tucker conditions for optimality in equations (10) to (12).

Differentiating the Hamiltonian function with respect to each of the state variables, elk, forage, and timber cover leads to the following adjoint equations:

$$d^oH/dE_t = \alpha^t dB/dE_t + \alpha^{t+1}\gamma_{t+1}(1+dh/dE_t) + \alpha^{t+1}\mu_{t+1} dg_t/dE_t - \alpha^t\lambda_t \leq 0 \quad (13)$$

$$d^oH/dF_t = \alpha^{t+1}\lambda_{t+1} dh/dF_t + \alpha^{t+1}\mu_{t+1} - \alpha^t\mu_t \leq 0 \quad (14)$$

$$d^oH/dT_t = \alpha^{t+1}\lambda_{t+1} dh/dT_t + \alpha^{t+1}\gamma_{t+1}(1+df/dT_t) - \alpha^t\gamma_t \leq 0 \quad (15)$$

Furthermore, differentiating the Hamiltonian at time t', terminal time, gives transversality conditions

$$d^oH/dE_{t'} = \alpha^{t'} [d\Psi/dE_{t'} - \lambda_{t'}] = 0 \quad (16)$$

$$d^oH/dF_{t'} = \alpha^{t'} [d\Psi/dF_{t'} - \mu_{t'}] = 0 \quad (17)$$

$$d^oH/dT_{t'} = \alpha^{t'} [d\Psi/dT_{t'} - \gamma_{t'}] = 0 \quad (18)$$

By the envelope theorem, we know at optimality the following interpretation can be given to the values of λ_t, μ_t, and γ_t:

$$\lambda_t = \sum_{j=t}^{t'-1} dB_t/dE_j + d\Psi/dE_t \geq 0 \tag{19}$$

$$\mu_t = \sum_{j=t}^{t'-1} dB_t/dF_j + d\Psi/dF_t \geq 0 \tag{20}$$

$$\Psi_t = \sum_{j=t}^{t'-1} dB_t/dT_j + d\Psi dT_t \geq 0 \tag{21}$$

Economic Interpretation of the Multipliers

The value λ_t is the marginal value resulting from a change in the numbers of elk at any particular time, j. Ramifications of a change in elk will be reflected in that time period, and all subsequent time periods, including possible changes in the residual valuation function, Ψ. Thus, the problem is a truly dynamic one, with changes in any resource level being reflected in that time period and subsequent time periods. The Hamiltonian multipliers provide a sensitivity analysis, showing how sensitive the objective function is to change in the resource levels, and is the dynamic analogue to the Lagrange multipliers of static economizing problems. These multipliers can also be considered as being analogous to a shadow price in a linear programming model.

Equation (13), the derivation of the Hamiltonian with respect to elk for the optimal path may be rearranged as

$$\lambda_t = dB/dE_t + \alpha\lambda_{t+1}(1+dh/dE_t) + \alpha\mu_{t+1}dg_t/dE_t \quad (22)$$

The left hand term is the marginal value of elk at time t, while the right hand side of the equation shows the components of that marginal value. Changes at any time have immediate impacts on the benefit function, and future impacts by altering the marginal value in the next time period ($\alpha^t\lambda_{t+1}$ term). In addition, we have changes in future herds as a result of changing the herd now, and impacts upon the forage in future time periods. Given the specification of the forage equation, these increased or decreased elk numbers will reflect back upon both livestock potential and range conditions. Thus the value of λ_t reflects immediate changes in the benefit function and the so-called "user cost," or the marginal intertemporal opportunity cost of elk for future use. Actual solution of the equation to find λ_t is complicated and involves the multiplier μ_t in a simultaneous relationship.

Less terms are involved with the multiplier μ_t, associated with the forage equation. This is equation (14) and is rearranged here as:

$$\mu_t = \alpha t\lambda_{t+1}dh/dF_t + \alpha^t\mu_{t+1} \quad (23)$$

Forage does not appear directly in the benefit function, so the "value" of changes will be reflected via impacts upon future levels of elk and livestock. Benefits or costs associated with forage changes are shown in equation (23) to equal the marginal benefits of elk times changes induced in the elk herd as well as direct benefits gained from forage reflected by livestock grazing.

Equation (12) is rearranged as follows:

$$\gamma_t = \alpha^t\lambda_{t+1}dh/dT_t + \alpha^t\gamma_{t+1}(1+df/dT_t) \tag{24}$$

Timber cover does not impact directly on either the benefit function or the forage equation but indirectly influences both by the cuttings variable. Solution of the multiplier, γ_t involves three direct terms. Firstly, we have the impact of timber cover on elk populations. The next term, $\alpha^t\gamma_{t+1}$, is the multiplier associated with the timber equation in the next time period and is the marginal value of timber at time t+1. Finally, we have the effects of changes in the growth function of future stocks, times the marginal value of those timber stocks.

Decision Rules

Assuming differentiality of all functions, the discrete maximum and the Kuhn-Tucker Theorem imply that equations (10) and (12) are the decision rules for the control variables or our social maximization problem, i.e., H_t, L_t, and C_t.

Restating the first of the Kuhn-Tucker conditions from equation (10) as

$$d^oH/dH_t^* = \alpha dB/dH_t - \alpha^t\lambda_{t+1} \leq 0, \tag{25}$$

where H_t^* represents the optimal harvest of elk. Thus we are evaluating deviations from the optimal path of the control variable, holding all other variables constant.

The first term, $\alpha dB/dH_t$ is the increment to the benefit function from an increased harvest of elk at time t, while the second term, $-\alpha^t\lambda_{t+1}$, is the marginal value in future time periods of increasing elk herd numbers at time t. Thus, elk will be harvested up to the point where the value of an animal taken is equated with the discounted value of that same animal left in the herd for generating future stock.

Condition number two, $d^oH/dH_t * H_t = 0$, follows directly from the first and means one of two things:

(a) the value of elk is greater left in the herd, in which case d^oH/dH_t is strictly negative, and the harvest level is zero.

(b) $d^oH/dH_t = 0$, in which case harvesting values are equated with stock values, and we have positive levels of harvest.

Either of these conditions means the product is a zero, i.e., either d^oH/dH_t or H_t is zero.

The third condition, $H_t \geq 0$ simply means the level of harvest is positive or zero.

Similar interpretations can be made for equation (11), the change in the Hamiltonian with respect to the change in livestock at any time t. The term $\alpha^t dB/dL_t$ reflects changes in the benefit function from changes in revenue from livestock grazing and has a positive derivative. The term $\alpha^{t+1}\mu_{t+1}dg_t/dL_t$ represents the discounted marginal value of an increase in livestock being transmitted through the forage equation and the resulting impact on future elk numbers indirectly affected by that change in forage. We would have a negative sign associated with dg_t/dL_t, forcing the whole term negative. The same Kuhn-Tucker interpretations as before imply -- we would equate benefits from livestock grazing to the future loss in benefits from reduced elk numbers.

An extra term is involved in equation (12), the timber cutting equation. Changes in direct revenues are reflected as before, with

dB/dC_t, which is positive. Associated with dg_t/dC_t we have the multiplier μ_{t+1}, describing positive marginal benefits from increased "browse" from cutting. Interpretation of the negative term, $-\alpha^{t+1}\gamma_{t+1}$, is a little more complex. In a well managed stand of trees the marginal benefits from cutting trees now is to be equated to discounted future returns from leaving those trees standing for later years, and the multiplier γ_t would give this. Also, solving for γ_t we find λ_t appears as an argument, indicating the benefits to elk of foregoing timber harvests at time t. We then have to equate benefits from cuttings and increased forage with foregone benefits from future cuttings and possible elk impacts.

Empirical Analysis

Expanding upon the elk equation (2) and rearranging, we can show

$$E_{kst+1} = S_k(E_{kst} - H_{kst}) + h(E_{kst}, Fe_t, T_t) \qquad (26)$$

where

$k \equiv$ year class of elk, $k = 0$ to 14 for females

$k = 0$ to 4 for males

$s \equiv$ sex class, Fe = females, M = males

$S_k \equiv$ survival from natural mortality for age class k, $(1 - pMort_k)$

where

$pMort_k$ is probability of natural mortality and other variables as previously defined. From empirical analysis in Oregon's Blue Mountain area, females of breeding age are for $k = 2$ to 14. Age class $k = 0$ are calves, and recruitment into the herd occurs at $k = 1$. Age structures are assumed for $E_{1MT} = E_{1Fet} = 1/2(S_{ot}, E_{ot})$, i.e., a 50-50 sex ratio recruited to the herd at year 1.

Recruitment to the herd at t+1 is represented as $h(E_{kst},F_t,T_t)$. Since the probability of harvest for female age classes 1 to 14 is constant, little is lost in assuming a constant calving potential rate, γ_k, for female age classes 2 to 14. This potential rate is a function of E_t, or density effect upon the birth rate. As outlined earlier, elk-timber relationships are complex and will be deleted from the empirical analyses. Similarly, livestock in the form of domestic cattle will be deleted from initial analysis. Thus, $h(E_{kst},F_t,T_t)$ reduces to $h(E_{kst}, F_t)$ where F_t represents forage for an elk herd in isolation from cattle, and is dependent upon stochastic natural variables and the density factor, E_t.

Setting $pH_t(E_{kst}) = W_{ks}$ we have the probability of harvest at time t of age class k and sex class s equal to W_{ks}. Values for W were assumed constant for adult bulls, or E_{kmt} for k = 1 to 4. Thus effective control variable on herd size is for E_{ot} and E_kFe_t for k = 1 to 14, i.e., calves and females, or antlerless animals. The optimal harvest H_t^* now becomes $H_t^*(E_kFe_t)$ where k = 1 to 14 and for E_{ot}, or calves.

Net revenues, N_{kst}, are the revenues from age class k, sex category s at time t. These revenues, N_{kst}, are considered to be a decreasing function of $H_t(E_{kst})$.

A steady-state solution would imply a constant herd size, $E_{t+1} = E_t$, a constant harvest rate, $H_{kst+1} = H_{kst}$, and a constant shadow price, $\lambda t+1 = \lambda_t$. Natural stochastic variables (winter severity) and forage conditions are set to mean values for a steady-state solution.

Non-consumptive benefits from the elk herd will initially be disregarded owing to the dearth of information on these benefits in Oregon. Assuming these benefits to be positive, we would expect a stock level, E^*_{kst}, to be greater with non-consumptive benefits included than with these benefits excluded. Proof of this is contained in Berck (1981).

Benefit Function

Using a willingness-to-pay survey, Helfrich (1981) estimated the following demand curve for bull elk (E_{kM}, k = 1 to 4):

$$Y = 2{,}206X^{-0.9} - 17.72 \qquad (27)$$

where

$Y \equiv$ demand for permits, expressed as a percentage

$X \equiv$ individual's willingness-to-pay for a tag.

Although Oregon's elk herd is significantly larger than Arizona's, it is felt that this demand curve would be a reasonable approximation to Oregon conditions, and equation (27) is adopted to use the $22 Oregon non-resident license fee as the mean tag value.

From empirical analysis using the travel cost approach, Sandrey, et al. (1982a) estimated a demand curve for antlerless elk, E_{ot} and E_kFe_t, k = 1 to 14, as

$$Q_{ijt} = 124{,}745 \exp(-14.375 \text{ COST}) \qquad (28)$$

where

$Q_{ijt} \equiv$ number of individuals from population zone i submitting a first-choice tag application to hunt Rocky Mountain antlerless elk in area j in year t, expressed per unit of population in zone i.

COST ≡ tag price and travel cost used as a proxy for total cost.

These equations, (27) and (28), could be employed to derive benefits from H_t, and provide net revenues, N_{kst}.

Recruitment Function

Since $E_{t+1} = E_t$ and $H_{t+1} = H_t$ in a steady-state solution, we can show from equation (26) that

$$H_t = h(E_{kst}) = H_{t+1} \tag{29}$$

where

$h(E_{kst})$ recruitment function, holding $h(F_t,T_t)$ constant.

From a computer simulation model, (Sandrey, et al., 1982b) show equation (29) to be

$$H_t = 2.42(E_{kst})^{0.724} - \text{FMORT} \tag{30}$$

where

E_{kst}, k = 1 to 14 for E_{Fe} and k = 1 to 4 for E_M, and

FMORT ≡ female mortality (no non-harvest adult bull mortality is assumed)

Calf:cow ratios are the usual indication of productivity for an elk herd, and the following non-linear function represents recruitment to the herd as measured by calf:cow ratios.

$$\text{CALF:COW} = 12.65(E_{kst})^{-0.446} \tag{31}$$

for E_{kst}, k = 1 to 14 for E_{Fe} and k = 1 to 4 for E_M and

CALF:COW ≡ calves per 100 adult cows recruited to the herd.

Harvest

Total harvest for 1,000 summer adult elk is, as expected, a decreasing function of elk and can be represented as

$$H_t = 162,771(E_{kst})^{-0.853} \qquad (32)$$

where

H_t ≡ harvest per 1,000 summer adults

and

E_{kst} ≡ summer adults, or E_{kFet}, k = 1 to 14 and E_{kMt}, k = 1 to 4 as before.

Using antlerless harvest (E_{kFet} and E_{ot}) as the control variable, and keeping H_{kMt} constant at 0.85 for k = 1 to 4, net revenues from anterless harvest were maximized (using equation 28) when H^*_{kFet} = 0.13305, k = 1 to 14, and H_{ot} = 0.0665, for an elk herd in isolation from alternative land uses. Marginal value of an antlerless animal at H^*_t is $27.55.

Areas of Future Research

Re-estimation of equation (27), the demand curve for bull hunting privileges, using Oregon data would facilitate analysis of the elk resource. This estimation could be either a willingness-to-pay approach, as equation (27), or a travel cost approach, as equation (28), the antlerless elk demand curve. Incorporating the cross substitution effects between equations (27) and (28) would also strengthen the analysis. As previously outlined, the whole question of non-consumptive values of an Oregon elk herd has not been addressed, and these values should also be incorporated into the benefit function. Illegal harvest, to the extent which it occurs, may also constitute an economic "good" with positive valuations.

Several areas of this research which are critical to economic analysis are controversial even as to the biological relationships. Cattle and elk physical tradeoffs are examples of somewhat conflicting research from the physical point of view. This makes it extremely difficult to model from an economic point of view since these relationships are a central theme of the research. Relationships between winter thermal cover and elk-timber tradeoffs are also controversial. It is entirely conceivable that a critical point may exist -- above this point changes in the timber cover may not impact at all on the elk, but below this level the impact may be significant.

Policy Implications and Conclusions

The major objectives of this paper are to make some steps towards an operational statement identifying areas of possible economic tradeoffs between alternative uses of the land and to provide a framework for adjusting resources to account for these tradeoffs. Static optimization requires equating marginal benefits of alternative uses of the land base at any given time period. This is achieved by using each resource to the extent where the marginal cost of using more is equated with the marginal benefits obtained from using that extra unit.

Dynamic optimization extends this principle to intertemporal analysis, introducing a discount rate to find present values. An extra consideration is added as the foregone benefits in the future associated with using the resource now. This is the user cost concept, and is central to optimal economic utilization of a renewable resource. We have shown how alternative resource levels impact both upon other resource usages and upon the dynamic relationships. Ramifications of all changes need to be considered when any change in resource levels are envisioned.

The analysis of an elk herd in isolation was extended to develop a recruitment function, harvest projections, and a possible benefit function for elk harvesting using relationships estimated by Helfrich (1981), Sandrey, et al. (1982a), and Sandrey, et al. (1982b). These relationships would facilitate an operational solution to the control problem of a centralized decision maker as stated in equation (1). Areas which are either deficient in biological data or do not contain a consensus of opinion among biological scientists are identified and discussed.

Providing an operational solution to the optimal allocation of alternative resources would identify an efficient solution. However, changes in present usage patterns may involve an equity issue, and this cannot be handled by a control problem as discussed or any other form of mathematical programming. Much of the controversy surrounding elk management in Northeastern Oregon is based on equity issues as well as efficiency issues, and one may conclude that the emotional issue of elk-livestock-timber relationships will remain in Northeastern Oregon in the foreseeable future. This paper may make a contribution to finding an efficient allocation of resources in wildlife management.

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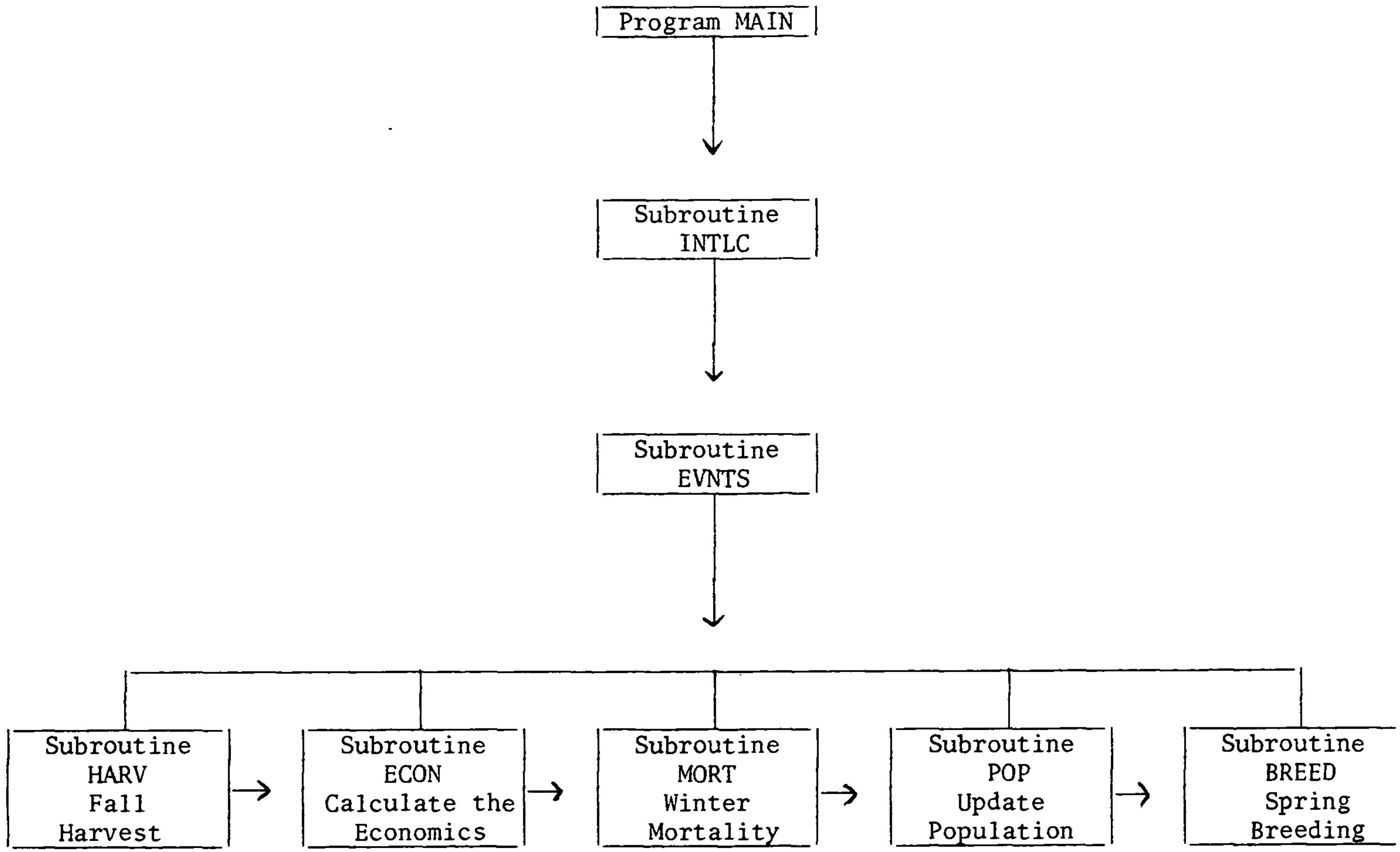
APPENDIX

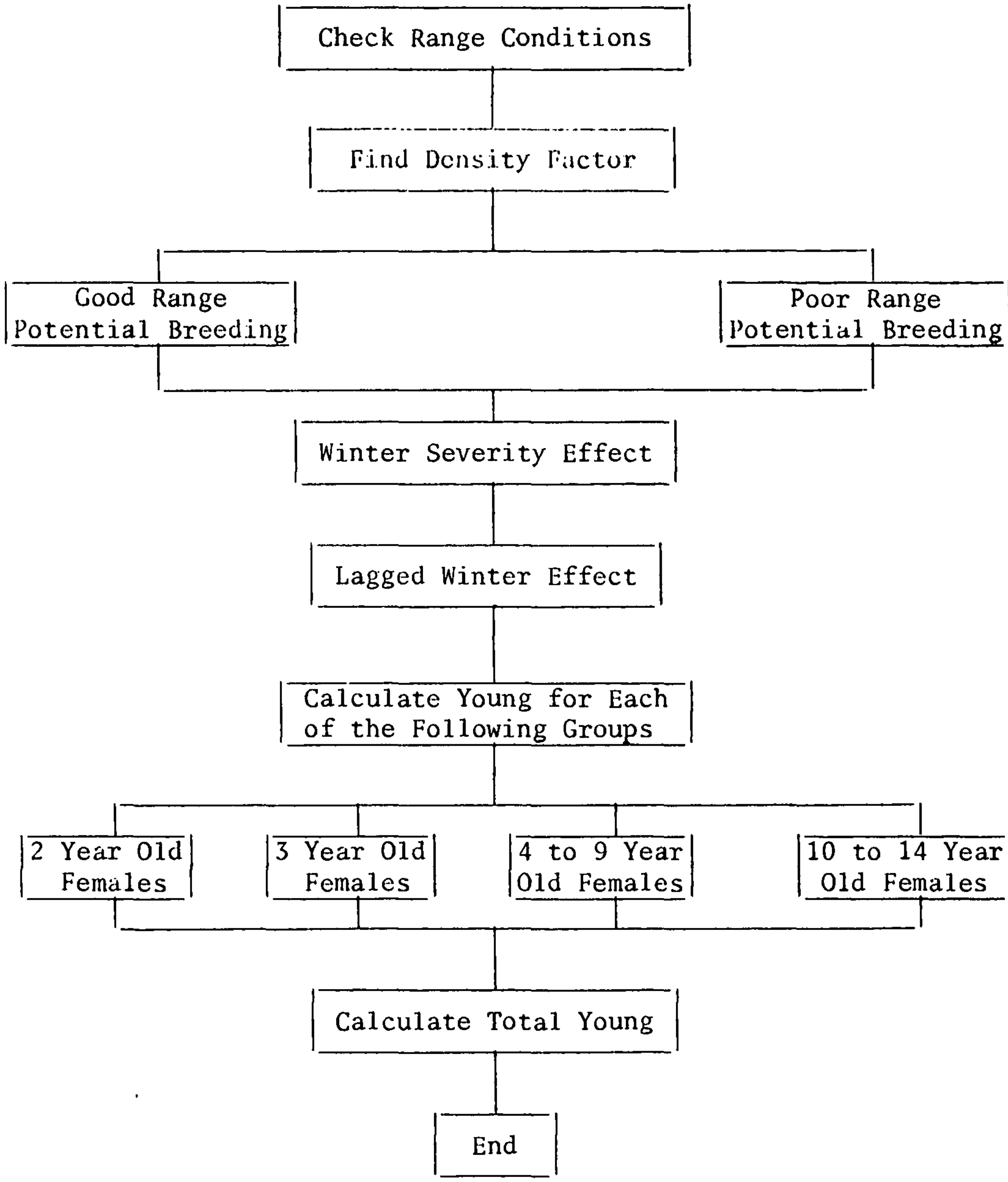
Appendix 2-1

FLOW CHART OF THE MODEL



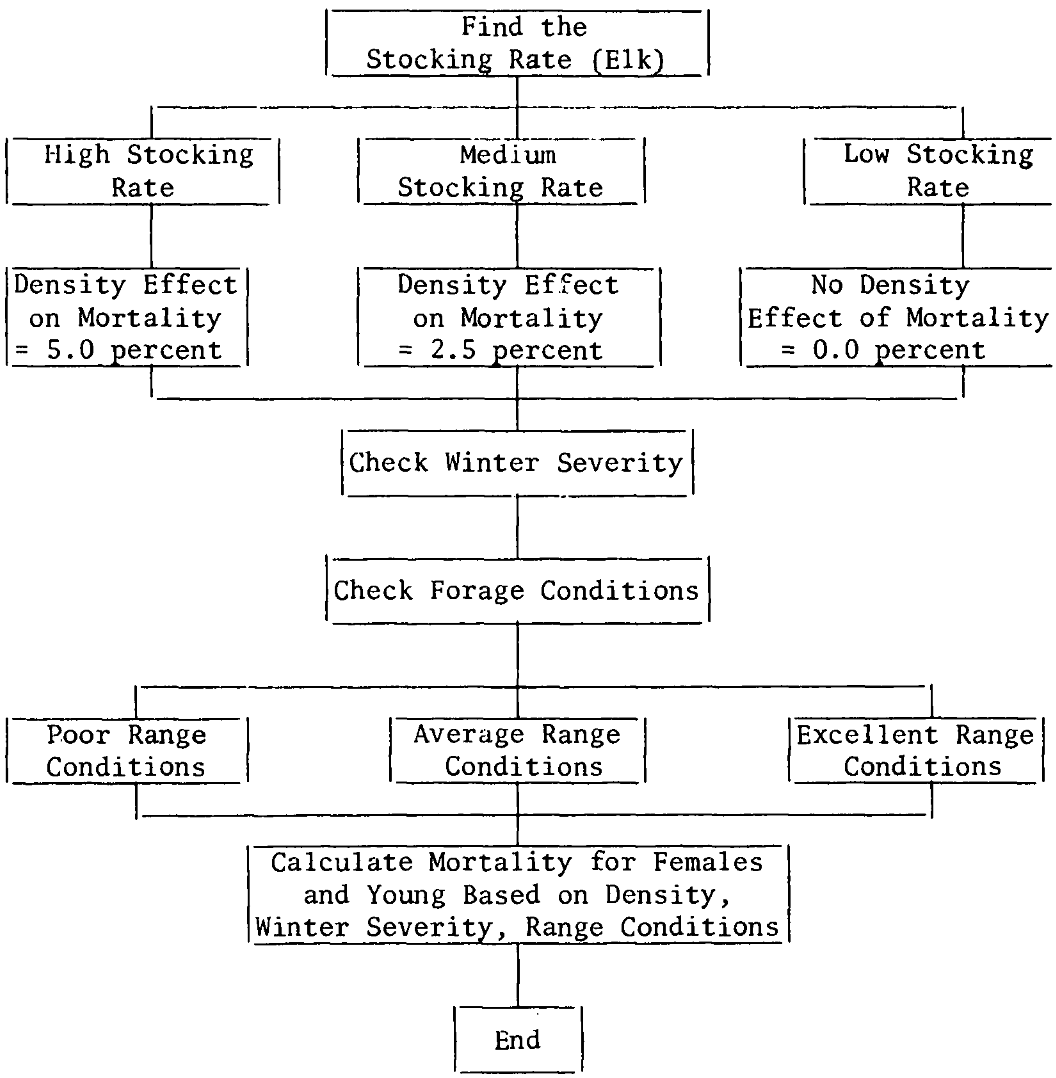
Appendix 2-2

SUBROUTINE BREED



Appendix 2-3

SUBROUTINE MORT.



Appendix 2·4.

Variables Used in the Model

(1)	AVRANT	Average revenue per antlerless animal
(2)	AVRBUL	Average revenue per bull
(3)	BTAG	Number of bull tags sold
(4)	CALF	The annual cow:calf ratio, as calculated in late winter
(5)	DENTY	Shows the effect of density on the mortality rate
(6)	FAG(14)	An array of 14 entries to keep track of the number of female elk in each age group
(7)	FEST	Estimated number of female elk, and used for allocation of antlerless elk tags
(8)	FHARV	Total antlerless harvest, including female elk and calves (same as FTAG)
(9)	FMORT	Annual number of female elk dying of natural causes
(10)	FOLD	Number of female elk age 10 years to 14 years
(11)	FTOT	Total number of adult females
(12)	MAG(4)	An array to keep track of adult males
(13)	MHARV	Annual male harvest, same as XHARV (not including male calves)
(14)	MTOT	Total males in the herd, not including calves. Same as XTOT
(15)	PBTAG	Price of a bull tag
(16)	PBULL	Ratio of adult bulls to cows, calculated during summer
(17)	PERTAG	Percentage from mean value of the number of bull tags issued
(18)	PFHARV	Percentage of antlerless harvest calculated from total females
(19)	PFMORT	Percentage mortality of females

(20)	PFONE	Replacement percentage of rising 2-year females int the herd
(21)	PMHARV	Percentage of males harvested annually — constant 85 percent
(22)	PYHARV	Percentage of calves harvested during the antlerless hunt
(23)	PRICE	Price of an antlerless elk permit
(24)	PYMORT	Calf mortality percentage calculated in late winter
(25)	RANGE	Indicates forage conditions
(26)	TAG	Number of antlerless elk tags
(27)	TRREV	Annual revenues
(28)	TRANT	Antlerless tag revenue, undiscounted
(29)	TRBULL	Bull tag revenues, before discounting
(30)	WINT	Winter severity
(31)	X	Used in recruitment equation for density relationship
(32)	YMORT	Annual mortality of young elk
(33)	YNG	Record of total numbers of young animals
(34)	YHARV	Number of young animals harvested during antlerless hunt