Economic and Socio-Environmental Evaluation of Predator Control Alternatives

Russell L. Gum and William E. Martin

A simulation model containing both economic (monetary) and socio-environmental (value index) components is developed in a case study of predator control alternatives. Particular emphasis is given to the description and justification of the socio-economic model. The economic model is estimated in terms of producers' and consumers' surpluses. The empirical tradeoff function developed suggests that alternatives to recent predator control programs exist that would be "better" for both general public and producer interests. The general approach can serve as a prototype for policy evaluations involving multiple objectives.

Predator control is a complex, controversial, and to a few groups in our society, a very emotional issue. At present there is a debate among livestock producers, environmentalists, animal protection groups, and government agencies over both the appropriate level of predator control and the appropriate control methods. The coyote is the major predator harmful to agricultural production in the western United States where annual losses have been estimated at 8 percent of lambs born and more than 2 percent of the sheep inventory [Gee, et al.].

This paper presents and reports results of a simulation model designed to generate a multiple objective analysis of the level and methods of coyote control in protecting sheep herds. Specific attention is given to the development of an environmental quality index generally relevant to predator control and specifically related to coyote control, and to measuring net economic costs and benefits of coyote control in terms of producers' and consumers' surpluses. The economic and environmental measures are used to develop a production possibilities frontier for economic efficiency and environmental quality relevant to coyote control. The biological response portion of the model, based on input from biological scientists involved with predator control, is only treated cursorily here. For those and other details of the model see Gum et al. (1978).

The simulation model is a mathematical approximation of the real life biological, economic, and social systems which are either affected by coyote control or influence its impacts. The general structure of the model is shown in Figure 1. Dollar expenditure information for each control method is fed to the appropriate submodels of the system, which in turn provide information for other parts of the system. The various impacts of the control input are estimated and condensed into two final outputs: the socio-environmental index and the net change in economic benefits relative to actual 1974 control. Each submodel is briefly described below, followed by a discussion of procedures for estimating the economic and socio-environmental impacts.

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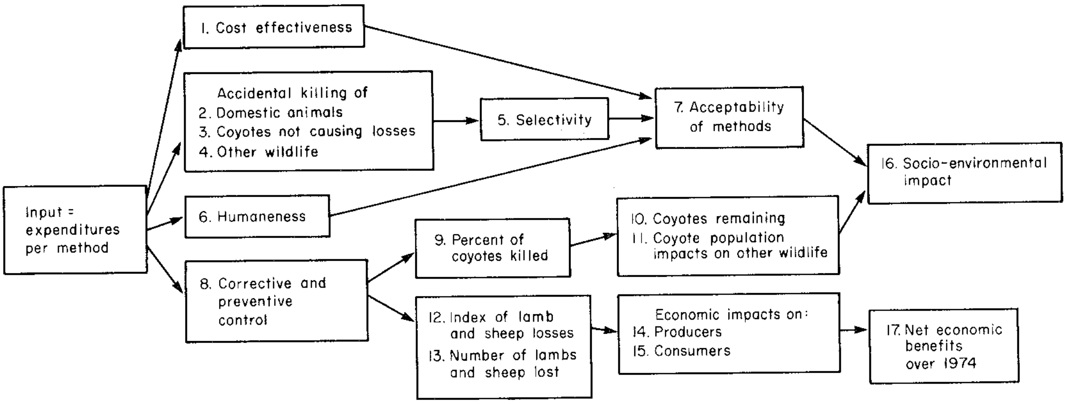

Figure 1. Simulation model structure.

Components of the Simulation Model

Submodel 1 calculates an index of cost effectiveness for the control input by dividing the control cost by the minimum control cost for the same level of sheep loss.

Submodels 2, 3, and 4 estimate the relative numbers of domestic animals, coyotes other than those in the immediate area where lambs or sheep have been killed, and other wild animals that might be accidentally killed by the control measures.

Submodel 5 combines information on accidental killings received from Submodels 2, 3, and 4 into a composite estimate of the relative selectivity of the control input. Selectivity refers to the degree to which the control input affects only coyotes in the immediate area where lambs and sheep have been killed.

Submodel 6 estimates a humaneness index for the control input by weighting the publicly perceived humaneness of each control method by the expenditures on that method.

Submodel 7 combines the cost effectiveness, selectivity, and humaneness indices from submodels 1, and 5, and 6 into an index reflecting the general social acceptability of the control input.

Submodel 8 divides the original control input into corrective and preventive components to account for their differential effects on coyote populations and lamb and sheep losses.

Submodel 9 uses the corrective and preventive information to estimate the relative impact of the control input on the coyote population.

Submodel 10 then iterates through a coyote population model to determine the proportion of the coyote population remaining after the control input has been consistently applied for several years and the initial shock effects are dissipated.

Submodel 11 uses the estimated proportion of coyotes remaining to determine the probable impacts of the coyote population on other wildlife such as deer and antelope.

Submodel 12 uses the corrective and preventive allocation of submodel 8 to estimate the probable relative change in lamb and sheep losses compared with losses in 1974.

Submodel 13 applies the estimate of relative change in losses to actual numbers of lambs and sheep lost in 1974 to estimate the new number lost.

Submodels 14 and 15 use the number of

lambs and sheep lost to determine the quantity of lambs marketed, then estimate through use of a demand equation the retail and farm prices, and finally calculate the economic impacts on producers (net change in total sales proceeds) and on consumers (net change in consumers' surplus).

Submodel 16 compiles and condenses the information on social acceptability of methods, number of coyotes remaining, and coyote impacts on other wildlife into a composite index reflecting both social and environmental factors — hereafter called the socio-environmental index. The weights used in combining the three items are based on public perception of the relative importance of each item.

Submodel 17 calculates the net change in economic benefits of the particular control input relative to 1974 conditions, by summing the positive or negative change in economic impacts on producers and consumers and then deducting the positive or negative change in control costs relative to 1974 costs.

The simulation model is a prototype systems approach to a comprehensive evaluation of the coyote control issue. Relationships which determine the economic and socio-environmental impacts of control measures are explicitly identified and quantified. The quantified relationships are based upon the best data and judgment available during the 1975-77 time period of the study. While neither the basic data nor the functional relationships can be represented as "absolutely true," the model provides a useful first approximation for policy discussion. As Boulding comments on economic measurement of cost-benefit analysis in *Economics as a Science*,

> . . . it is a useful first approximation and when it comes to evaluating difficult choices it is extremely useful to have a first approximation that we can modify. Without some guidelines, indeed, all evaluation is random selection by wild hunches. (p. 129)

The purpose of the model is not to discover a single answer, but rather to provide a structure for use in analyzing the predator control issue. In terms of data quality, economic data (costs and demands) are readily available, public attitudes and perceptions are obtained by survey techniques, but there are arguments among wildlife biologists as to the exact relationships among predator control, coyotes, and other species. As improved knowledge of the biological relationships is generated, further analysis of the coyote control issue may be done using this structure.

Conceptual Framework

The two major goals of interest are socio-environmental and economic. The two goals, being measured in different dimensions, are not aggregated; instead, data on each are presented in a trade-off function.

The economic component is handled traditionally in terms of consumers' and producers' surplus. The conceptual framework underlying the socio-environmental portion of the simulation model (all those data leading to submodel 16) is based on the multiple objective planning system variously known as "Strawman" [Technical Committee 1971], TECHOM [Technical Committee 1974; Gum et al., 1976], or "S.Q.P.I.: System for Quantified Planning Inquiry" [Arthur et al., 1976]. The planning system consists of a hierarchical structure of goals and subgoals where information about the achievement of lower level goals, weighted by their relative importance, is aggregated to form the information about achievement of the higher levels of the hierarchy. While goal hierarchies can be defined for any major societal goal, including economic goals, only a socio-environmental goal hierarchy related to coyote control is defined here.

Economists have long agreed that while there are goals other than economic efficiency in the decision-making process, it is not for them to make decisions about the relative weights of these objectives. As Beattie et al. argue in a summary of economic opinion, "Rather than attempting to estimate the weighting scheme of the political process by observing its actions, it would seem more logical and less conducive to error to provide information concerning the consequences to alternative actions and leave the weighting of these consequences to the political process" (p. 7). The System for Quantified Planning Inquiry (S.Q.P.I.), when combined with separate economic analysis, offers information on alternative actions for both economic consequences and socio-environmental preferences for the decision-makers' consideration. As formulated here, S.Q.P.I. provides a cardinal measure of the major goal of socio-environmental quality, although any particular value can only be compared to an alternative value produced from an alternative action. For the group of people expressing their preferences, one action is better or worse than the other by a given percent. Naturally, a different, relatively homogeneous group could have a different socio-environmental quality index. Thus, for any given policy action and a given group of people, the trade-off information will show a gain or loss in economic benefits and a gain or loss in socio-environmental quality relative to an alternative action. No optimum is specified. Such trade-off information would be equally useful if the socio-environmental index were only ordinal rather than cardinal.

The concept of a hierarchical structure for measuring "fuzzy" goals such as environmental quality, and providing a clearer, more concrete analysis of what kind of results environmental action should be producing, goes back to the "Administrative Behavior" concepts of Herbert Simon. At higher levels, goals are harder to describe operationally and criteria for success are harder to agree upon. However, the higher goals may be broken into sublevel goals until, at the bottom of the structure, the goals may be directly perceived and operationally measured. Further, where there is more than one goal on a given level, each should be assigned its relative weight.

Socio-Environmental Structure for Coyote Control

Figure 2 illustrates the socio-environmental goal hierarchy for coyote control policies. The goals are displayed graphically as a tree structure with the more general measures at the top and the component-specific measures at the bottom. The procedure for the socio-environmental analysis involves a four step process building on this hierarchical structure: 1) Identification of areas of concern (social goals); 2) Development of measures of technical results of alternative actions (technical indicators); 3) Development of relationships of technical indicators to social goals; and 4) Weighting and aggregation of specific social goals to yield measures of more general social goals.

Three areas of concern are identified for the evaluation of coyote control alternatives in step 1: 1) Perceived acceptability of the control methods; 2) The amount of change in coyote population levels; and 3) Secondary impacts on other wildlife of changes in coyote populations.

These three concerns are shown as leading to the major goal of socio-environmental quality in Figure 2. Two of these three concerns are directly measurable. However, the third, the acceptability of predator control methods is, in turn, dependent upon: 1) Humaneness, which is the amount of suffering inflicted on the victims of control; 2) Specificity, relating to the accidental killing of nontarget animals; and 3) Cost-effectiveness, as reflected by the control cost divided by the minimum control cost for the same level of sheep loss.

The specificity measure branches into domestic animals, wild animals other than coyotes, and coyotes that are not in the immediate area where losses to sheep and lambs have been occurring.

The aggregation process of step 4 relates the technical measures of the specific social goals to the general goal of environmental quality. First, the three measures of specificity are aggregated into a general measure of specificity. Then, humaneness, specificity and cost-effectiveness are aggregated into a general measure of control-method acceptability. Finally, secondary impacts of

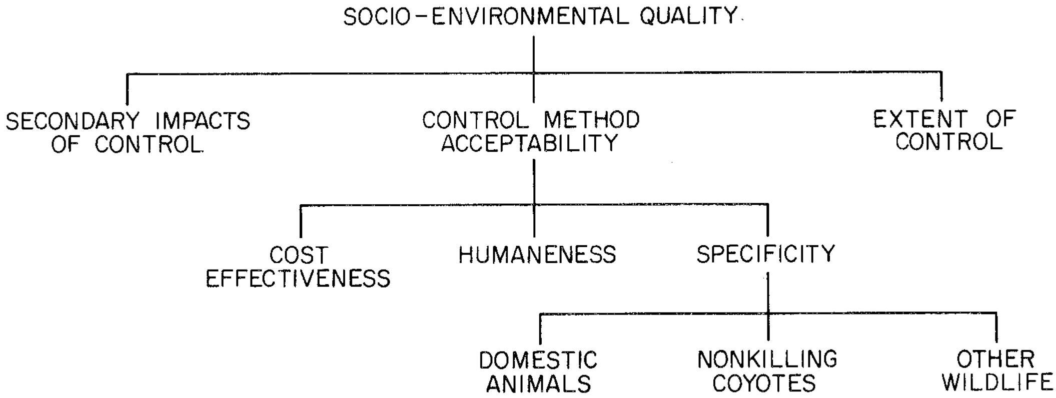

Figure 2. Goal hierarchy.

control-method acceptability, and extent of control of coyote populations are aggregated to form the socio-environmental quality index.

The goal aggregation process is based upon the following assumptions: 1) Individuals have preference for socio-environmental quality; 2) This preference can be described by a utility function; 3) The form of the utility function is a power function with the sum of the coefficients equal to one; and 4) All individuals are of equal importance in defining a societal measure of socio-environmental quality.

Thus,

$$(1) \qquad Us = DA^{a}NC^{b}OW^{c}$$

where, with 0 being the worst possible impact and 100 being no negative impact, for a particular control alternative: Us is the utility index for specificity; DA is an index measuring the potential impact of the control method on domestic animals; NC is an index measuring the potential impact of the control method on nonkilling coyotes; OW is an index measuring the potential impact of the control method on other wildlife and; a, b and c are peoples' preference weights, summing to one, and indicating their relative concern for the three specificity components. In this study, a = .42; b = .20; c = .38.

Then,

$$(2) \qquad Ucma = CE^{d}H^{e}S^{f}$$

where Ucma is the utility index for control-method acceptability; CE is the cost effectiveness index; H is a humaneness index as defined by public survey; S is specificity as estimated from equation (1); and d, e and f are peoples' preference weights for the three components of control method acceptability. Results show d = .16; e = .52; f = .32.

Finally,

$$(3) \qquad Useq = SIC^{g}CMA^{h}EC^{i}$$

where Useq is the utility index for socio-environmental quality, and the right hand side of the equation is taken from the top branch of Figure 2 and defined in manner similar to equations (1) and (2). Coefficient values are g = .46; h = .30; i = .24.

Throughout, the "independent" variables are derived from experts' judgments of technical indices, public judgments of perceptual indices, or the estimated index number from the branch below.

In order to estimate the preference weights and perceptual indices, a random nationwide sample of 2,400 people was interviewed by telephone. By use of a computer-assisted phone interview system and professional interviewers, a response rate of 78 percent was achieved using a sample design that assured random selection by both sex and age.

The questions were of a "rank and distribute" form, where respondents were first asked to rank a set of concerns reflecting one level of the tree in Figure 2 and then to distribute 100 points among the items to reflect their relative importance. For a discussion of the statistical properties of this form of question see Carpenter and Blackwood.

The results from this "allocate 100 point" type of question are directly interpreted as the coefficients of the utility function. The interpretation depends upon the assumption of a utility function with the form of a power function that is homogenous of degree one. Although for the specific stimuli related to coyote control this interpretation is just an assumption, other researchers have found the power function to describe empirically a wide range of value-related stimulus response phenomena [Stevens, Hamblin and Smith, Dawson and Brinkler, Gregson and Russell, Hamblin, Judge, and Maskowitz]. For further discussion of the rationale, assumptions, and validity of this approach, see Gum et al. (1976) and Roefs.

There are several alternative methods of aggregating individual utility functions to produce a single environmental quality index. The simplest approach, on which the results presented in this paper are based, is to use the average responses as a representative utility function. Other approaches are discussed in Gum et al. (1976). They include aggregating individual functions before computing an average function, and grouping individuals by interest group, by homogenous values, or by homogenous characteristics such as income or geographic area. In this study of coyote control the results were not sensitive to the method by which individual utility functions were aggregated (Arthur et al., 1977).

Economic Structure and Estimates

To reflect the total economic impact of coyote predation on sheep and lambs, changes in producers' surplus and consumers' surplus resulting from a change in the level of control expenditure and mix of control methods from those of 1974 must be estimated. Both surplus measures are short term specifically for 1974 conditions, and do not reflect producers going out of business, consumers substituting other products for lamb, or other long term adjustments.

A demand function for lamb was estimated to serve as the basis for calculating the consumers' and producers' surpluses. The data for the demand analysis consist of quarterly observations for 1958 through 1974 for the U.S. for the following variables: P = Seasonal average retail price of lamb; QL = Seasonal average per capita consumption of lamb and mutton; QB = Seasonal average per capita consumption of beef; QP = Seasonal average per capita consumption of pork; I = Per capita personal disposable income; and T = Time.

The regression equation selected was:

$$(4) \quad P = 65.5 \underset{(3.1)}{-20.80QL} \underset{(2.4)}{-1.20QB} \underset{(3.2)}{-0.71QP} \underset{(29.3)}{+0.12I} \underset{(4.7)}{-0.50T(QL)}$$

with a coefficient of determinaton of .99 and an F ratio (for the test that all coefficients equal zero) of 1170. T-tests for all variables included in the model (in parentheses) were significant at the .95 confidence level. The significance of the T(QL) variable indicates that the slope of the demand function is changing over time.

To estimate the 1974 demand for lamb, the average 1974 values for QB, QP, I, and T for 1974 were substituted into the demand equation. The resulting estimate of the demand function was

$$(5) \quad P = 169 - 54QL.$$

At the average 1974 quantity, price flexibility was −.17; that is, a one percent increase in the quantity of lamb produced would have resulted in a .17 percent decrease in the retail price of lamb.

If, for example, the coyote control alternative resulted in less sheep and lamb losses than observed in 1974, lamb production would increase and prices would fall. The resulting change in consumers' surplus is calculated directly from the demand curve as area A B C D in Figure 3.[1] The change in consumers' surplus has been shown by Willig (1976) to be a reasonable approximation of the theoretically more correct welfare measure of compensation variation.

To calculate the change in producers' surplus of the western sheep producers the following assumptions were made: 1) The marginal cost of raising to market a lamb saved from coyote predation is zero. Since most costs to sheep ranchers are either fixed or related to raising and feeding the ewes, this is a reasonable assumption. Detail on costs of sheep production can be found in Gee (1977). 2) A constant farm to retail margin exists for all alternative quantities of lamb marketed.

Given these assumptions, the change in producers' surplus due to reduced sheep and lamb losses to coyotes is the difference between the gross returns under the original condition and the control alternative. In Figure 3 this change is indicated by the difference between rectangles F G H I and J K L H.[2]

The net economic benefits of a control alternative are calculated as the sum of the changes from 1974 conditions of consumers' surplus and western sheep ranchers producers' surplus, minus the change in costs of control. Thus, control costs were not allocated to producers or consumers, but were subtracted from total benefits to yield a realistic representation of net societal benefits.

Results

To evaluate the predator control alternatives, systematic variations in the levels of trapping, aerial gunning, 1080 toxicant, and M-44 were made using the 1974 levels of all other methods as a base. 1080 toxicant is a relatively slow acting poison. M-44 is a springloaded sodium cyanide injector which shoots cyanide into the coyote's mouth when he tugs on the scented bait. The other, much less efficient alternatives, are snaring, denning (digging coyote pups out of the den), and shooting from the ground.

The level of each method was varied in steps of $2 million from $0 to $8 million of expenditures. All possible combinations of expenditures and methods were investigated, resulting in 625 combinations. A scatter plot of the results in terms of the tradeoffs between the environmental index as calculated by the average utility function and net economic benefits is presented in Figure 4. The 1974 base is at zero net economic benefits with a socio-environmental index of 64.

With some exceptions, control alternatives with lower values than any other alternative for both the socio-environmental index and for net economic benefits were judged inefficient and eliminated from further analyses. The exceptions included for analysis were those alternatives which were the most efficient of those which do not include either 1080 or M-44. Of the resulting set of efficient alternatives, presented in Table 1 and Figure

[1]Under the assumptions of a constant marketing margin, the change in consumers' surplus is identical at the retail and farm level. Thus, ABCD equals MGKN. Since retail demand was estimated and a constant marketing margin is an assumption, our estimate is at the retail level.

[2]Schmalensee argues that under conditions of pure competition, Marshallian surplus, that is the sum of producers' and consumers' surplus, may be measured at either the retail or derived demand level. The distribution between producers and consumers will change, however, if the marketing margin is not constant. Under our assumption of a constant margin, the change in consumers' surplus at the retail level plus the change in producers' surplus at the producer level equals the total change in economic benefits.

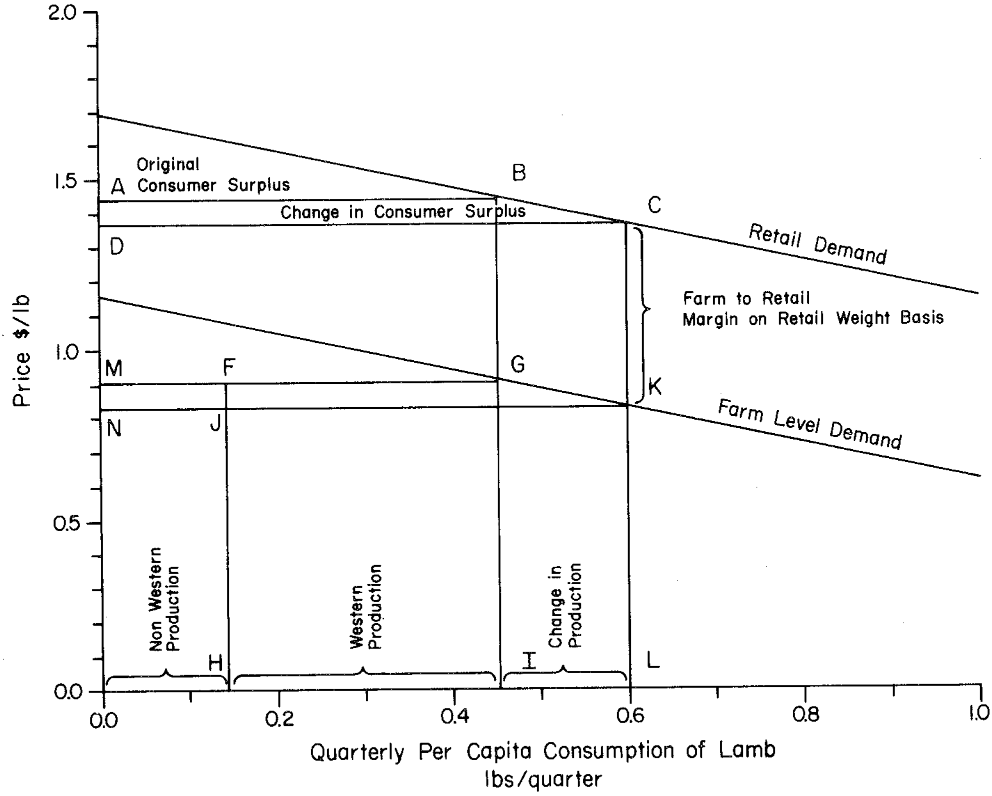

Figure 3. Producers' and consumers' surpluses related to the production and consumption of lamb.

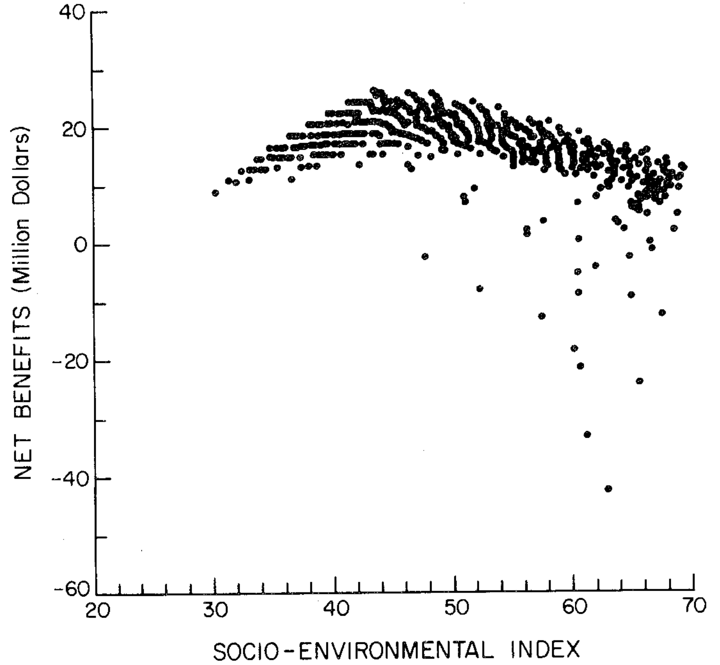

Figure 4. Economic environmental trade-offs, 625 alternatives.

5, only three included expenditures for trapping, while all included use of M-44. The predominance of 1080 and M-44 in the set of efficient solutions is based on the assumption of proper use of toxicants and M-44 by trained professionals. Unregulated use of these methods would not result in the level of socio-environmental quality or net economic benefits predicted by the model.

Efficient alternatives range from a socio-environmental index of 69 with net benefits of $12.9 million to a socio-environmental index of 44 with $25.9 million of net economic benefits. These estimates imply an average trade-off of $520,000 of net economic benefits for an average of one socio-environmental index unit. Note that five of the efficient alternatives have both higher socio-environmental indices and higher net economic benefits than the 1974 level of control and mix of methods. Of the alternatives listed in Table 1 that do not include either 1080 or M-44, three exceed the 1974 conditions for both the environmental index and economic benefits, even though these alternatives are not the most efficient available. These estimates suggest that alternatives to the 1974 control levels exist which would be

TABLE 1. Economic Trade-offs for Efficient Alternatives

Alternative number	Socio-Environmental index	Net benefits	Control Expenditures: Trapping	Aerial gunning	1080 toxicants	M-44	Total[a] expenditures
		million dollars					
1	69	12.9	0	4	0	4	10
2	69	13.4	0	0	0	6	8
3	68	13.4	2	0	0	6	10
4	68	14.5	0	2	0	6	10
5	66	16.0	0	0	0	8	10
6	64	16.8	0	2	0	8	12
7	63	17.2	0	4	0	8	14
8	62	17.9	0	2	2	4	10
9	61	19.2	0	0	2	6	10
10	59	19.8	0	2	2	6	12
11	58	21.0	0	0	2	8	12
12	56	21.2	0	2	2	8	14
13	54	21.5	2	0	4	4	12
14	54	22.2	0	2	4	4	12
15	54	23.3	0	0	4	6	12
16	52	23.5	0	2	4	6	14
17	52	24.4	0	0	4	8	14
18	49	24.7	2	0	6	4	14
19	49	25.2	0	2	6	4	14
20	48	25.9	0	0	6	6	14
21	44	25.9	0	2	8	4	16
22[b]	64	0	3.3	1.4	0	0	6.9
23[c]	68	10.4	0	10	0	0	12
24[c]	67	11.3	0	12	0	0	14
25[c]	65	11.9	0	14	0	0	16
26[c]	63	12.3	0	16	0	0	18
27[c]	61	12.5	0	18	0	0	20

[a]The following expenditures were held constant: Denning $601,000; Ground shooting $1,128,000; and Snaring $289,000.

[b]Actual, 1974.

[c]These are the most efficient alternatives which do not include either 1080 or M-44.

Source: Results from simulation model.

acceptable to both the general public and producer interests.

Recommendations

It is clear from the analysis of the control mix alternatives that 1080, M-44, and aerial gunning are (in that order) the best methods of control from an economic point of view. If chemical methods of control remain legally restricted, then the next best alternative is aerial control.

M-44 and aerial methods are also superior to other methods from a socio-environmental point of view. Therefore, an economically and environmentally balanced strategy would be to increase the proportion of aerial and M-44 expenditures and/or increase the absolute levels of expenditures for aerial and M-44 control. These recommendations assume that the risk of M-44 to humans is very low. If M-44 is proven to be unsafe to humans, then only aerial gunning is both an economically and environmentally reasonable means of control.

Conclusions

Specification of the simulation model and its quantitative results are based on hypotheses about relationships among coyote control methods, coyotes, sheep and lamb losses, and other environmental effects. These hypotheses are based on the available data and on judgments of "experts" in coyote control, but they remain testable and tentative hypotheses. It is hoped that as more data become available, the hypotheses will be tested and revised to describe the control situation more precisely. Meanwhile, the au-

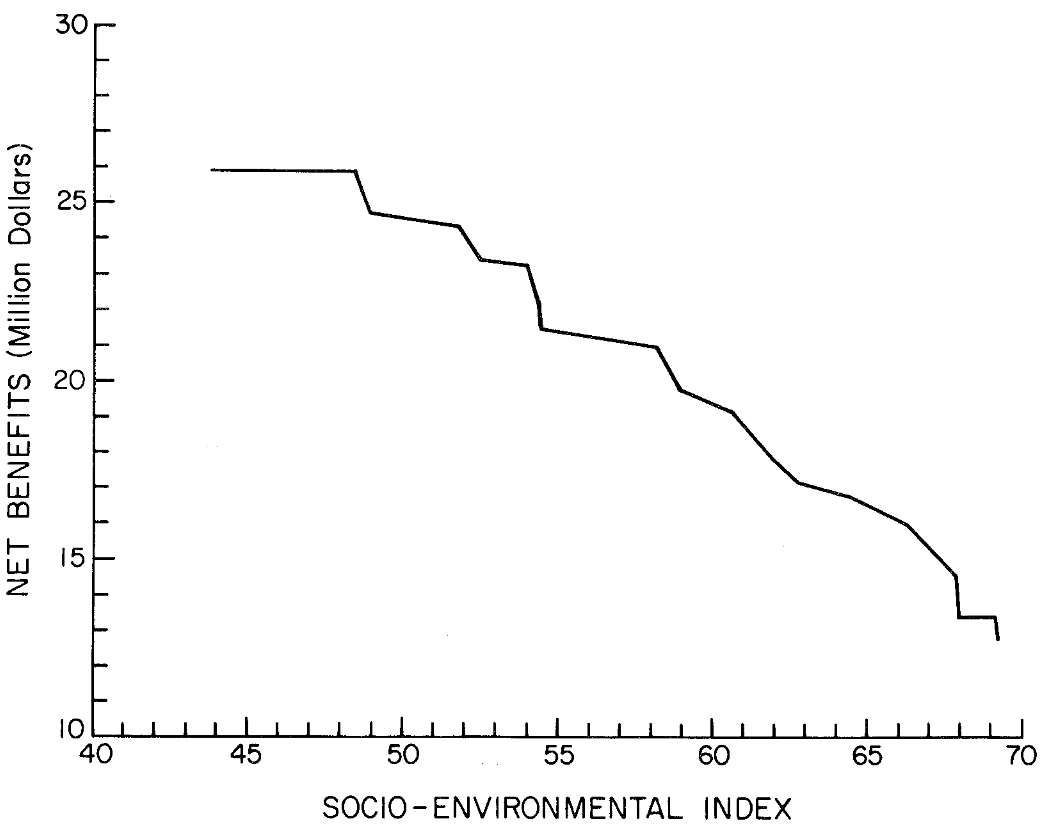

Figure 5. Trade-offs for efficient alternatives.

thors believe this simulation is a reasonable approximation of reality which can provide valuable information to decision makers. In addition, the general approach can serve as a prototype for future policy evaluations involving multiple objectives.

Epilogue

Subsequent to the development of the simulation model, the authors became involved with the policy process as a member (and alternate member) of the Secretary of Interior's "Animal Damage Control Policy Study Advisory Committee." Representation on the committee came from the sheep and cattle industries, environmental organizations, and state and federal agencies as well as from academia.

The model was offered for use as a learning tool, where the committee members could suggest various changes in the assumptions about the technical relationships and observe the sensitivity of the results to those changes. The committee as a group could use the structure for a discussion of the issues.

With several exceptions, the members declined the opportunity, preferring instead to examine the data in unintegrated bits and pieces. There was a tendency to emphasize the data and results that supported their preconceived positions and attacking as "unscientific" the portions of the model with which they did not agree. The first draft of the study report, even stated that "Controversial, political issues in general are not amenable to solution by orderly, rational analysis, irrespective of whether or not the analyses are run through a computer." [U.S. Fish and Wildlife Service, p. C-7, 1978].

It appears that rational policy analysis still faces a long uphill climb.

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