A Multiattribute Utility Function for Management of a Recreational Resource

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A Multiattribute Utility Function For Management of a Recreational Resource[1]

Abstract— An outdoor recreational experience has several attributes. Keeney's methodology of multiattribute utility functions was used to discover tradeoffs between attributes and the importance of increments in each attribute for management of a small rural sport fishery. The utility function describes the preference orderings of a hypothetical decisionmaker such as a regional manager. Using the methodology, the objective function for management of a recreational stream fishery was expressed as a function of species of fish caught, average size of fish caught, average number of fish caught, and average number of anglers on the stream per day. Alternative sets of parameters for the utility function were tested in a simulation-optimization model to show sensitivities of the parameters in terms of the optimal management strategy.

Introduction

Rational management of a recreational natural resource by a public agency requires maximization of an objective function which reflects benefits to the user as well as to society as a whole. The objective most often used by public agencies is user-day maximization (McFadden 1969) primarily because it is easily quantifiable. However, many attributes may enter into the recreational experience (Moeller and Engelken 1972). In the example of a recreational fishery, important attributes of an individual's fishing experience may include water quality, scenic beauty of the area, size, number, and species of fish caught, privacy, support facilities, and access to the fishing area. Moeller and Engelken (1972) found in their sample that anglers consistently ranked privacy higher than either number or size of fish in the catch. Such results lead us to conclude that user-days is a measure of benefit to the agency rather than to the individual user.

An alternative procedure for developing an objective function is for the decision-maker to specify certain measures of effectiveness and then develop a utility function governing explicit measures or attributes. Given such a utility function, the expected utility may be calculated, and this would be the objective function; the decision-maker would prefer the alternative with the greatest expected utility (Halter and Dean 1971, Raiffa 1970, Von Neumann and Morgenstern 1947). Such a utility function is an expression of preference and sufficient conditions for its existence may be verified (see, e.g., Henderson and Quandt 1971:13).

The present study derives a utility function of several attributes for the management of a sport fishery in a small rural stream (Rich Creek, Monroe County, West Virginia) using the model and procedures of Keeney (1974). The utility function describes the preference orderings of a hypothetical decision-maker, such as a regional manager employed by the West Virginia Department of Natural Resources. This utility function was used in a simulation-optimization model in which maximization of the sum of utility over a year was the objective. This presentation will focus on (1) measurement procedures of the utility function; (2) tradeoffs between the attributes of utility function; an (3) ramifications of the choice of utility parameters in terms of optimal management strategy for the stream.

Study Area

Rich Creek begins as a spring rising in Monroe County, West Virginia, and runs 17.7 km south, passing through Peterstown, West Virginia, and the town of Rich Creek, Virginia, and draining into the New River. The Rich Creek watershed has an area of 85 km^2, the majority of which is pasture land, although some of it is planted in corn. The stream is characterized at average flow by water depths of 0.5 to 0.8 m and an average width of 4.7 m.

The stream is classified as a marginal trout stream by the West Virginia Department of Natural Resources. Trout are available from two sources: (1) the State of West Virginia regularly stocks the stream with trout of catchable size in the later winter months, and (2) a few trout escape during high water from a private hatchery located at the headwaters. No natural reproduction of trout occurs in the stream.

Recreational fisheries in the stream include heavy angling (300–500 angler hrs/ac/yr) for trout and a small amount of fishing for bluegill and smallmouth bass, which have reproducing populations in the stream.

Field studies (Brandt and Schreck 1975) were designed to mimic commercial harvest of bait species by licensed bait fishermen common in the area. These

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fishermen used seines and traps to capture live bait which was sold to recreational fishermen.

Simulation Model

The simulation model and optimization procedures are considered in detail by Powers (1975), but a summary will be presented here. The simulation model consists of a set of nonlinear, time-dependent difference equations which were updated at 24 stages of simulated time with each stage being 15 days in length. Thus, the time was approximately 1 year (January to December). At each updating, fish population abundance, natural mortality, natality, ration size, growth, average weight, and biomass were calculated for each age-class of each fish species. Catch of each fish age-class by each of the five angler categories (trout, bluegill, and bass anglers, seine-users, and trap-users) was also calculated, as well as the concentration of fishermen using the stream.

The following decision variables governed the rate of exploitation of fish populations by commercial and recreational fishermen: minimum and maximum size limits for bluegill and smallmouth bass; possession number limits for trout, bluegill, smallmouth bass, and baitfish; stocking rate of trout; number of commercial fishermen; length of seines; seine and trap mesh size; and proportion of the stream open to fishing. These variables were time-dependent and were integrated into appropriate portions of the simulator.

The objective of the optimization problem was to find the combination of decision variables which maximizes the time-stream of utility over the year; i.e., maximizes the sum of utility over the 24 time stages, where the utility function represented the recreation fishing criterion in the decision problem. In conjunction with this objective, three terminal (year-end) constraints were considered: (1) a limit was placed on the yearly expenditures (costs of stocking trout in the stream); (2) a minimum level of catch by commercial baitfishermen was specified (minimum level of the time-stream of catch/seine/day); and (3) to avoid overexploitation a minimum level for the yearend value of an ecological diversity index was specified.

The optimization algorithm used was a heuristic procedure which combined aspects of search by regression (Schmidt and Taylor 1972) and the discrete maximum principle (Wilde and Beightler 1967:425–444). The algorithm involved fitting transition functions to simulation data, and then solving for the approximate optimal policy by the discrete maximum principle. With the newly derived policy, a new simulation was performed and new transition functions were fit. The interative procedure was continued until convergence occurred. A more detailed account of this algorithm is given by Powers (1975).

The Utility Attributes

Several measures of effectivness or attributes were chosen to reflect the recreational fishing experience in the utility function. These were:

X_1 = fish species appearing in the catch/angler/day
X_2 = average size of fish in the catch/angler/day
X_3 = average number of fish caught/angler/day
X_4 = number of anglers/day

The species attribute, X_1, was defined to be a vector $(X_1^{TR}, X_1^{SMB}, X_1^{BG})$ corresponding to trout, smallmouth bass, and bluegill, respectively. For example, a member of X_1^{TR}, called x_1^{TR}, could only take on the value zero if no trout were caught, or one if some trout were caught (regardless of number), and similarly for x_1^{SMB} and x_1^{BG} (Table 1). Thus, by definition the most preferred outcome of X_1, was $x_1 = (1,1,1)$ corresponding to all three species appearing in the catch.

X_3 was the attribute of number scaled from zero to one. The scaled value of x_3 (a member of X_3) was calculated in the following fashion: let us say the average angler caught 13 trout, 1 smallmouth bass, and 3 bluegill. From Table 1, it can be seen that the maximum number he could have caught would be 20 trout, 20 smallmouth bass, and 30 bluegill. When each of these is expressed as a percentage of the maximum and then averaged, we have $x_3 = (13/20 + 1/20 + 3/30)/3 = (0.80)/3 = 0.267$.

Similarly, x_2 (a member of X_2) was calculated by a weighted average. Assume the average angler caught 3 trout, each 10 inches long, 4 smallmouth bass, each 11 inches long, and 5 bluegill, each 7 inches long. A 10-inch trout, when expressed as a percentage of the possible range, is equivalent to (10-8)/(14-8) or 0.333 (Table 1). Likewise, an 11-inch smallmouth equals (11-9)/(16-9) or 0.286 and a 7-inch bluegill is (7-5)/(12-5) = 0.286. The mean scaled length for all fish caught is $x_2 = [3(0.333) + 4(0.286) + 5(0.286)](3+4+5)$; i.e., $x_2 = 0.295$. Attributes X_2 and X_3 were scaled from zero to one to eliminate their dependence on the species attribute.

The attribute x_4 was a measure of crowding (or conversely, privacy) and it also was converted to a

TABLE 1
Utility attributes and their ranges

Attribute	Least desirable amount	Most desirable amount
Species in catch (Yes = 1, No = 0)		
X_1^{TR}: trout	0	1
X_1^{SMB}: smallmouth bass	0	1
X_1^{BG}: bluegill	0	1
X_1: scaled	0	1
Average length of fish caught (inches) /angler/day		
trout	8	14
smallmouth	9	16
bluegill	5	12
X_2: scaled	0	1
Average number fish caught/angler/day		
trout	0	20
smallmouth bass	0	20
bluegill	0	30
X_3: scaled	0	1
Number of anglers/day (No./500 yd²/day)	50	0
X_4: scaled	0	1

scale of zero to one (Table 1). For example, 15 anglers/500yd²/day was expressed as $x_4 = (50\text{-}15)/50 = 0.7$, because 15 is 70% of the range for X_4.

Given the four attributes which contribute to our "quality of recreational fishing" criterion, we desired to construct a utility function $u(x_1, x_2, x_3, x_4) \equiv u(x)$ reflecting all of these measures. Experience by other investigators (Keeney 1973) has indicated that varying more than two attributes simultaneously makes utility assessments extremely difficult for decision-makers. Therefore, we wished to identify and verify assumptions that would allow us to find a function f such that

$$u(x) = f[u_1(x_1), u_2(x_2), u_3(x_3), u_4(x_4)], \quad (1)$$

where $u_i(x_i)$ is a utility function over attribute X_i. With the assumptions verified, then (1) could be defined by measuring the $u_i(x_i)$ and scaling factors which indicate tradeoffs between atttributes. The model, assumptions, and assessment procedures which we used were developed by Keeney (1973, 1974).

Assumptions

Let $X \equiv X_1 \times X_2 \times X_3 \times X_4$, $X_{ij} \equiv X_i \times X_j$, and $X_{2\bar{4}} \equiv X_1 \times X_3$ (read as "ex not two four"). Let x be a member of X and $x_{2\bar{4}}$ a member of $X_{2\bar{4}}$. $X_{\bar{i}}$ is the Cartesian product of all attributes except X_i with $x_{\bar{i}}$ being a member of $X_{\bar{i}}$. Designate x_i^0 as the least preferred outcome of X_i and x_i^* as the most preferred outcome with $u_i(x_i^0) = 0$ and $u_i(x_i^*) = 1$. Also, $u(x_1^0, x_2^0, x_3^0, x_4^0) = 0$ and $u(x_1^*, x_2^*, x_3^*, x_4^*) = 1$.

The assumptions which allow the development of (1) are preferential independence and utility independence. Preferential independence implies that if an outcome $(x_i, x_j, x_{\bar{ij}})$ is preferred to some other outcome $(x_i', x_j', x_{\bar{ij}})$ for a specific $x_{\bar{ij}}$, then it is preferred for any $x_{\bar{ij}}$. Utility independence implies that preferences for lotteries held over x_i with $x_{\bar{i}}$ held fixed do not depend on $x_{\bar{i}}$, i.e., the conditional utility functions over X_i are positive linear transformations of each other (Keeney 1974),

$$u(x_i, x_{\bar{i}}) = g(x_{\bar{i}}) + h(x_{\bar{i}})u_i(x_i) \quad (2)$$

where g and h are positive scalar functions.

The assumptions were verified by discussions with several members of our Department who took the role of decision-maker during these interviews. As an example, consider whether X_2 (size of fish) and X_3 (number of fish) are preferentially independent of $X_1 \times X_4$. First, we fixed X_{14} at a fairly desirable level (x_1 = trout, only; x_4 = 5 anglers/500 yd²/day). Then, we questioned the decision-maker to find an x_3 such that (x_3;11) was indifferent to (15;9); i.e., x_3 fish caught, average size of 11 inches was indifferent to 15 fish caught, average size of 9 inches. Let us say the amount of x_3 chosen was eight fish. The exact number was not important for verification, only its change with changes in the other attributes. Next, we set x_{14} at trout, only, and 30 anglers/500 yd²/day and repeated the above procedure. Once again, the amount of x_3 chosen was eight fish. Then, we changed x_{14} again and got an equivalent answer on the X_3 scale. At this point we could ask if the value of x_3 would hold for any $x_{\bar{23}}$. The affirmative answer implied preferential independence of X_2 and X_3

Similarly, the utility independence of X_i with $X_{\bar{i}}$ was verified. Let us examine the utility independence of X_4 (privacy) with $X_{\bar{4}}$, as an example. First x_1 was set at trout, only; x_2 at 9 inches; and x_3 at 3 fish. Then the decision-maker was asked for an x_4 which would make him indifferent to x_4 anglers for certain or a 50-50 lottery yielding zero anglers or 50 anglers. Let us say x_4 = five anglers was chosen. Next, x_1 was set at bluegill, only; x_2 at 10 inches; and x_3 at 20 fish. The decision-maker was again asked for the number of anglers for certain that would make him indifferent to the 50-50 lottery. Five anglers were chosen again. In general the decision-maker agreed that his response did not depend on fixed amounts of $X_{\bar{4}}$. This result plus testing of other lotteries verified that X_4 was utility independent of $X_{\bar{4}}$.

Given the validity of the two assumptions, Keeney (1974) proved that the utility function took the form

$$u(x) = \sum_{i=1}^{4} k_i u_i(x_i) + K \sum_{i=1}^{4} \sum_{j>i} k_i k_j u_i(x_i) u_j(x_j)$$
$$+ K^2 \sum_{i=1}^{4} \sum_{j>i} \sum_{n>j} k_i k_j k_n u_i(x_i) u_j(x_j) u_n(x_n)$$
$$+ \cdots + K^3 k_1 k_2 k_3 k_4 u_1(x_1) u_2(x_2) u_3(x_3) u_4(x_4), \quad (3)$$

where the k_i are scaling factors ($0 < k_i < 1$) and K is another scaling factor ($-1 < K$). When $x_i = x_i^*$ and $x_{\bar{i}} = x_{\bar{i}}^0$, i.e., when attribute i is at its most preferred amount and all other attributes are at their least preferred amounts, then $u(x) = k_i$. If $\sum k_i = 1$, then $K = 0$ and (3) reduces to

$$u(x) = \sum_{i=1}^{4} k_i u_i(x_i). \quad (4)$$

otherwise, when $\sum k_i \neq 1$ then $K \neq 0$ and (3) can be algebraically manipulated to yield

$$1 + Ku(x) = \prod_{i=1}^{4} [1 + Kk_i u_i(x_i)]. \quad (5)$$

The species attribute X_1, was defined to be a vector $(X_1^{TR}, X_1^{SMB}, X_1^{BG})$. Therefore, once the three elements of X_1 were shown to be preferentially and utility independent, $u_1(x_1)$ could be expressed as

$$u_1(x_1) = \sum_{j=TR,SMB,BG} c_j u_1(x_1^j), \quad (6)$$

or

$$1 + Cu_1(x_1) = \prod_{j=TR,SMB,BG} [1 + Cc_j u_1(x_1^j)], \quad (7)$$

where the c_j and C are scaling constants equivalent to k_i and K in (4) and (5). The utility over attribute x_1^j is denoted by $u_1(x_1^j)$. Since x_1^j can only take on the values one or zero, corresponding to species i appearing in the catch or not, then $u_1(x_1^j)$ will also only equal one or zero. Therefore, $u_1(x_1)$ was completely defined when the scaling constants c_j and C were determined.

Method of Evaluating Scaling Factors

As was mentioned previously, $k_i = u(x_i^*, x_{i-}^0)$. Therefore, each k_i could be evaluated by finding the probability p at which the decision-maker was indifferent to $u(x_i^*, x_{i-})$ for certain and a lottery offering $u(x^*)$ with a probability p or $u(x^0)$ with a probability $1 - p$. The results yield

$$u(x_i^*, x_{i-}) = p[u(x^*)] + (1 - p)[u(x^0)]. \quad (8)$$

Since $u(x^*) = 1$ and $u(x^0) = 0$, then (8) reduces to

$$u(x_i^*, x_{i-}^0) = p, \quad (9)$$

and the scaling factor k_i is equal to p. Similar procedures are used to find the scaling factors c_j.

If $\sum_i k_i \neq 1$, then $K \neq 0$ and must be evaluated. The scaling factor K may be found numerically by solving

$$1 + K = \prod_{i=1}^{4} (1 + Kk_i) \quad (10)$$

for K. Equation (10) is derived from (5) when all attributes are offered at their most preferred amounts; i.e., $x = x^*$. If $\sum_i k_i > 1$, then $-1 < K < 0$; and if $\sum_i k_i < 1$, then $K > 0$. Thus, (10) may be easily solved by trial and error. The scaling factor C may be found in an analagous fashion.

Utility of Each Attribute

The utility of each attribute $u_i(x_i)$ had to be determined as well. Since $u_1(x_1)$ was completely defined by the scaling factors, utility assessment was only needed for $\bar{X}_2$, $\bar{X}_3$, and $\bar{X}_4$. The model chosen to express this was

$$u_i(x_i) = x_i^{b_i}, \qquad (i = 2, 3, 4), \quad (11)$$

where b_i are constants. The form of (11) was chosen because we desired a simple smooth function which fit the boundary conditions for x_i and $u_i(x_i)$ and for which estimates of the parameters could be easily made. Since part of the study was to determine ramifications of the choice of parameters, the restrictive form of (11) was acceptable.

The utilities could be assessed by asking the decision-maker:

(1) What certainty equivalent of length of trout (in inches) would make you indifferent to the lottery offering a 14-inch trout and an 8-inch trout, each with equal probability?

(2) What certainty equivalent of numbers of bluegill/angler/day will make you indifferent to a lottery offering 30 bluegill/angler/day and 0 bluegill/angler/day, each with equal probability?

(3) What certainty equivalent of number of other fishermen/500 yd²/day will make you indifferent to a lottery offering 50 other fishermen/500 yd²/day and 0 other fishermen/500 yd²/day, each with equal probability?

The responses to the three questions when scaled from zero to one may be termed x_2, x_3, and x_4, respectively. Then $u_i(x_i)$ may be expressed as

$$u_i(x_i) = 0.5[u_i(x_i^*)] + 0.5[u_i(x_i^0)]$$
$$= 0.5 \qquad i = 2, 3, 4.$$

Therefore, using (11)

$$u_i(x_i) = 0.5 = x_i^{b_i},$$

and may be found by

$$b_i = \ln [0.5]/\ln [x].$$

Parameterization of the Utility Function

A utility function represents the decision-maker's personal preferences, and there is no "right" or "wrong" associated with it. However, by the very nature of his position a decision-maker employed by a public agency is required to make value judgements about benefits to the public whom the agency serves. In all likelihood, preference orderings by the users will not be consistent. Even if they were, it is unlikely that the decision-maker's utility responses would completely coincide with those of the public. Therefore, by definition the decision-maker must decide on the utility responses himself.

However, the decision-maker may have no *a priori* judgments of marginal utilities and tradeoffs which will affect public benefits. In such a case public input may be desirable. Sinden (1974) used utility measurements of members of the public to valuate recreational experiences. Morris (1974) notes that preferences of a panel of experts should be viewed as *information* by the decision-maker. Therefore, a sample of the public's (panel of experts') preferences may provide input to the decision-maker before he makes his utility responses.

Using this argument, we wished to have some public input into the utility function. Therefore, we sent 225 questionnaires to residents of Monroe County, West Virginia, who had purchased fishing licenses. Responses to the questionnaires provided initial estimates of the scaling factors and the $u_i(x_i)$. In order to simplify the questionnaires, the technique for calculating the k_i and K was modified (see Appendix). However, the response rate to the questionnaires was still low (11%), indicating the difficulty of obtaining utility information from questionnaires. Interviews might have given the respondents a better understanding. Also, although we had no way of knowing if the respondents were representative of the fishing public, the questionnaires did give initial indications of feasible parameter values. Use of these initial parameters and subsequent perturbations in the simulation model were designed to determine if physical and biological characteristics of the stream fishery would show some of the utility parameters to be less sensitive than the others in terms of the optimal management strategy.

TABLE 2
Parameter values for the utility function

Parameter	Value	Parameter	Value	Parameter	Value
k_1	0.384	c_{TR}	0.800	b_2	1.710
k_2	0.473	c_{SMB}	0.750	b_3	0.387
k_3	0.449	c_{BG}	0.600	b_4	34.314
k_4	0.424	C	−0.976		
K	−0.833				

From the median of the responses to the questionnaires, initial estimates of the parameter values were made (Table 2). The utility of attribute size $[u_2(x_2)]$, number $[u_3(x_3)]$, and privacy $[u_4(x_4)]$ showed increasing, decreasing, and increasing marginal utilities, respectively (Figure 1). The marginal utility of privacy was highly increasing, indicating that reductions in crowding will not significantly increase utility for the median respondent unless crowding is already low. The utility for the outcomes of the species attribute $[u_1(x_1)]$ showed that trout was the most preferred species, then smallmouth bass, then bluegill; and combinations of the three reflected this initial preference (Table 3).

The rank order of the k_i derived from the median questionnaire response showed that $k_2 > k_3 > k_4$, indicating privacy was less important than numbers or size of fish. This rank order and the highly increasing marginal utility of privacy found from the median response were corroborated by observations of rather high crowding conditions in Rich Creek when trout were recently stocked. Tradeoffs between attributes and indifference curves are established in Figure 2.

The parameter values derived from public input (Table 2) completely specify the form of the utility function. It was assumed that our hypothetical decision-maker would first test these parameter values in the simulation model, and next test alternative values to determine the sensitivity of the parameters. Since $\sum c_j \neq 1$ and $\sum k_i \neq 1$, the proper forms of the utility functions are multiplicative over x and over x_1; i.e., equations (5) and (7). Thus, the objective was to maximize the sum of (5) over all 24 time stages; i.e.,

$$\max \mathrm{UT} = \sum_{t=1}^{24} u(x_1, x_2, x_3, x_4). \tag{12}$$

The cumulative sum objective (12) carries several

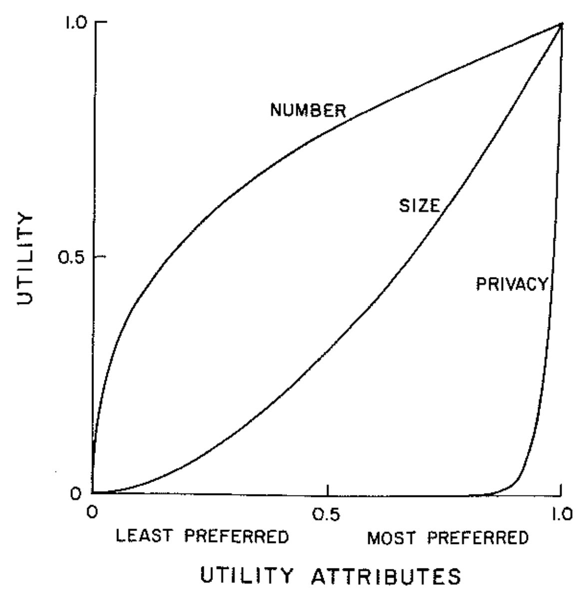

FIG. 1—Utility derived from X_2 (Size), X_3 (Number), and X_4 (Privacy) as found from the median questionnaire response.

TABLE 3
Utility for the eight outcomes of $u_1(x_1)$

Species in catch				
trout	smallmouth bass	bluegill	x_1	$u_1(x_1)$
No	No	No	(0,0,0)	0.000
No	No	Yes	(0,0,1)	0.600
No	Yes	No	(0,1,0)	0.750
Yes	No	No	(1,0,0)	0.800
No	Yes	Yes	(0,1,1)	0.911
Yes	No	Yes	(1,0,1)	0.932
Yes	Yes	No	(1,1,0)	0.964
Yes	Yes	Yes	(1,1,1)	1.000

implicit assumptions. First, since time is not an attribute in the utility function, no discounting takes place. For a 1-year time-horizon this assumption seems reasonable. Secondly, the sum assumes that a time series of utility of (0.5, 0.5, 0.5) is equally desirable as one of (1.0, 0, 0.5); i.e., no disutilities are associated with fluctuations. This may not be valid in many instances.

Simulation Results

We tested 14 sets of utility parameters (Table 4) in the simulation-optimization model, including the original set specified in Table 2. Two basic management strategies evolved from these optimization experiments. These two strategies will be termed the Multispecies Strategy (MS) found to be applicable to Programs VII and XIII (Table 4) and the Trout Strategy (TS) found for all other programs. These terms are not meant to be totally descriptive, but rather they are used to establish nomenclature. The time sequence of x_i (i = 1, 2, 3, 4) was found by optimization and these sequences for TS and MS (exemplified by Programs I and VII, respectively) are presented in Figure 3.

Trout was the primary exploited species in TS except for a short period when bluegill were also harvested. The numbers harvested gradually increased over the year due to an increased stocking rate. Increased angling pressure (time stages 10–14) caused all of the trout that were stocked within a time period to be caught within that same time period. The fishery became a "put and take" trout fishery. Therefore, the trout had no opportunity to grow in size while they were in the stream. The result was that the size attribute (X_2) decreased over time. After time stage 12 all of the fish that were harvested were trout and all were at the least preferable size, i.e. the size at which they were stocked. The attributes of privacy (X_4) and numbers (X_3) increased later in the year to compensate for the small fish being caught.

Programs VII and XII produced the other strategy (MS) due to a high tradeoff associated with size of fish (k_2) and due to an increasing marginal utility for numbers ($b_3 > 1$) respectively (Table 4). When $b_3 > 1$, more fish/angler are harvested early in the fishing season because a unit increment in X_3 will produce a more than 1-unit increment in utility. To allow increases in X_3, all species were harvested during stages

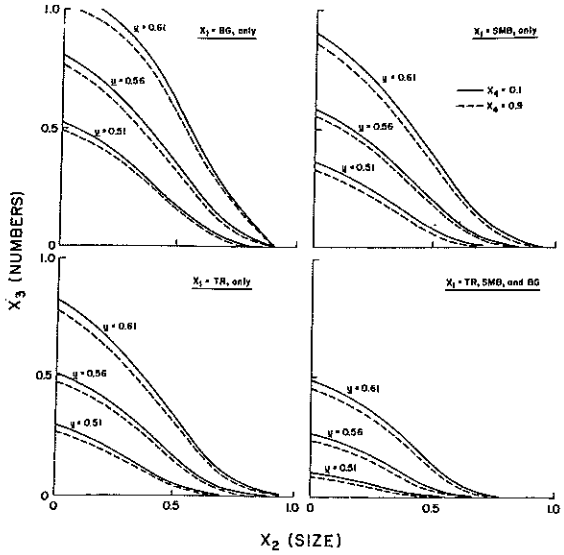

FIG. 2—Tradeoffs between the four utility attributes and the indifference maps, derived from median questionnaire response.

9 and 10. The bluegill and smallmouth bass being caught at this time were large, thus X_2 was high as well.

Conversely, when k_2 is high, larger fish must be harvested. The strategy to allow this (Figure 3) was to induce exploitation of all species. Since the bluegill and smallmouth bass were in abundance during stages 9 and 10, the result was large values for X_3. This argument is the rationale for two seemingly different programs. (VII and XIII) producing the same management strategy (MS).

The Multispecies Strategy resulted when k_2 was very large in relation to the other k_i and when the marginal utility of numbers was changed from decreasing to increasing. The Trout Management strategy was less sensitive to changes in other utility parameters. Recognizing these sensitivities, the decision-maker could use the median utility parameters of the public sample as his own utility parameters in which case the TS would be expected to result. If the decision-maker chose to modify his parameters according to Programs VII and XIII, then the MS would be expected.

Conclusion

An outdoor recreational experience such as sport fishing will have several attributes. These attributes should enter into the objective function in the management of such a recreational system. Even if the uses of the recreational resource by people preferring different attributes are separated "in space or time," the manager of the system will ultimately have to make tradeoffs between attributes when allocating his management effort. Keeney's methodology (1974) of multiattribute utility functions described herein appears to be a good way of discovering the relative magnitude of these tradeoffs and the importance of increments in each attribute.

We have described the use of this methodology in conjunction with a simulation-optimization procedure for determining management strategies for a stream fishery. We also introduced a rational basis for including public input into this process. Although the utility function reflected only one criterion (angler benefits) in this particular example, other criteria such as conservation, commercial fishermen benefits, and agency benefits could be included, as well. Also, if independence can be shown, these criteria could be arranged in hierarchies with one utility function being an attribute of another. If several attributes are included in the management objectives, the public is more likely to obtain the quality outdoor recreational experiences that are desired.

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TABLE 4

Optimal cumulative utility (UT) found by using alternative sets of utility parameters in the simulation model*

Program	c_{TR}	c_{SMB}	c_{BG}	k_1	k_2	k_3	k_4	b_2	b_3	b_4	UT*
I	0.80	0.75	0.60	0.384	0.473	0.449	0.424	1.710	0.387	34.314	7.668
II	0.50	—[a]	—	0.544	0.331	0.307	0.282	—	—	—	6.860
III	0.50	—	—	0.486	0.313	0.283	0.499	—	—	—	7.412
IV	—	0.50	—	—	—	—	—	—	—	—	7.728
V	—	—	0.90	0.748	0.116	0.113	0.109	—	—	—	7.143
VI	—	—	—	0.679	0.237	0.215	0.194	—	—	—	7.386
VII	—	—	—	0.467	0.575	0.272	0.238	—	—	—	7.769
VIII	—	—	—	0.470	0.307	0.540	0.240	—	—	—	7.034
IX	—	—	—	0.556	0.331	0.209	0.282	—	—	—	7.367
X	—	—	—	0.473	0.307	0.274	0.506	—	—	—	8.375
XI	—	—	—		—	—	—	3.000	—	—	7.667
XII	—	—	—	—	—	—	—	—	0.100	—	9.099
XIII	—	—	—	—	—	—	—	—	1.500	—	8.001
XIV	—	—	—	—	—	—	—	—	—	5.000	8.024

[a] Dash denotes the same numerical value as in Program I.

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Appendix

Respondents to the utility questions had difficulty in interpreting the scaled attributes X_2 and X_3; e.g., they did not understand that 15 bluegill and 10 smallmouth bass were the same value in X_3 (Table I). Therefore, the questions were modified to avoid this confusion.

Remember that $x_1 = (x_1^{TR}, x_1^{SMB}, x_1^{BG})$, thus the notation $x_1 = (0, 1, 0)$ denotes smallmouth bass, only, are appearing in the catch. Also remember $X_{34} = X_3 \times X_4$, $X_{34-} = X_1 \times X_2$, x_3^* is the most preferred amount of X_3, and x_3^0 is the least preferred amount of X_3.

If a respondent is indifferent to x for certain, and a lottery of x' with a probability p and x'' with a probability $1 - p$, then

$$u(x) = p[u(x')] + (1 - p)[u(x'')]. \qquad \text{(A-1)}$$

The values of k_i (i = 1, 2, 3, 4) and K were found from the following four questions:

1. Find p_1 such that the respondent was indifferent to $[x_1 = (1, 0, 0), x_{1-}^0]$ for certain, or a lottery offering $[x_1 = (1, 0, 0), x_{1-}^*]$ with a probability p_1 and $[x_1 = (0, 0, 1), x_{1-}^0]$ with a probability $1 - p_1$.
2. Find p_2 such that the respondent was indifferent to $[x_1 = (0, 0, 1), x_2^*, x_{34}^0]$ for certain, or a lottery offering $[x_1 = (1, 0, 0), x_{1-}^*]$ with a probability p_2 and $[x_1 = (0, 0, 1), x_{1-}^*]$ with a probability $1 - p_2$.
3. Find p_3 such that the respondent was indifferent to $[x_1 = (0, 0, 1), x_3^*, x_{24}^0]$ for certain, or a lottery offering $[x_1 = (1, 0, 0), x_{1-}^*]$ with a probability p_3 and $[x_1(0, 0, 1), x_{1-}^0]$ with a probability $1 - p_3$.
4. Find p_4 such that the respondent was indifferent to $[x_1 = (0, 0, 1)\ x_4^*, x_{23}^0]$ for certain, or a lottery offering $[x_1 = (1, 0, 0), x_{1-}^*]$ with a probability p_4 and $[x_1 = (0, 0, 1), x_{1-}^0]$ with a probability $1 - p_4$.

Because there was never more than one non-zero element in x_1, the respondent did not have to convert number and length scales from one species to another.

From the first question and using (A-1), we obtain:

$$u[x_1 = (1, 0, 0), x_{1-}^0] = p_1(1 + Kk_1c_{TR}) \quad (1 + Kk_2)(1 + Kk_3)$$
$$(1 + Kk_4) + (1 - p_1)(1 + Kk_1c_{BG}) \qquad \text{(A-2)}$$

From (5) and (7) in the body of the paper it can be stated that

$$1 + Ku[x_1 = (1, 0, 0), x_{1-}^0] = 1 + Kk_1c_{TR}$$

or

$$u[x_1 = (1, 0, 0), x_{1-}^0] = k_1c_{TR} \qquad \text{(A-3)}$$

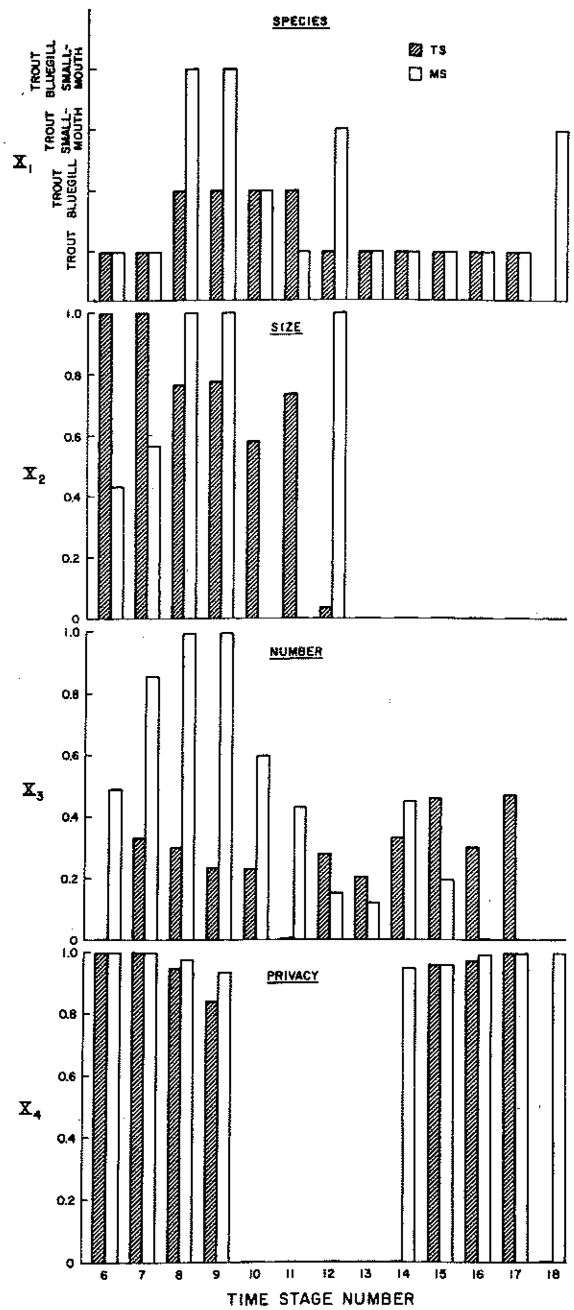

FIG. 3—Time sequence of optimal attributes found by the simulation model. TS is the Trout Strategy. MS is in the Multispecies Strategy. Time stage six corresponds to late March and stage 18 corresponds to late September.

When (A-3) and (A-2) are equated, we get:

$$k_1c_{TR} = p_1(1 + Kk_1c_{TR})(1 + Kk_2)$$
$$(1 + Kk_3)(1 + Kk_4) + (1 - p_1)(1 + Kk_1c_{BG}) \qquad \text{(A-4)}$$

Similarly, responses to questions 2, 3, and 4 produce probabilities p_2, p_3, and p_4; therefore,

$$u[x_1 = (0, 0, 1), x_i^*, x_{ii-}] = p_i(1 + Kk_1c_{TR})(1 + Kk_2)(1 + Kk_3)(1 + Kk_4) + (1 - p_i)(1 + Kk_1c_{BG}) \quad \text{(A-5)}$$

for $i = 2, 3, 4$. We know from (5) and (7) that

$$1 + Ku[x_1 = (0, 0, 1), x_i^*, x_{ii-}^0] = (1 + Kk_1c_{BG})(1 + Kk_i)$$

or

$$u[x_1 = (0, 0, 1), x_i^*, x_{ii-}^0] = k_1c_{BG} + k_i + k_1k_ic_{BG}K \quad \text{(A-6)}$$

for $i = 2, 3, 4$. Equating (A-5) and (A-6) gives

$$k_1c_{BG} + k_i + k_1k_ic_{BG} = p_i(1 + Kk_1c_{TR})(1 + Kk_2)(1 + Kk_3)(1 + Kk_4) + (1 - p_i)(1 + Kk_1c_{BG}) \quad \text{(A-7)}$$

for $i = 2, 3, 4$. We also know that

$$1 + K = (1 + Kk_1)(1 + Kk_2)(1 + Kk_3)(1 + Kk_4). \quad \text{(A-8)}$$

Equations (A-4), (A-7), and (A-8) are five equations in the five unknowns k_i ($i = 1, 2, 3, 4$) and K. These may be solved by an appropriate numerical technique, such as fixed point iteration (Conte 1965:43). This does not guarantee a unique solution. However, in practice several choices of the initial k_i and K in the solution technique produced the same solution. Also, the bounds on k_i and K are rather closely defined ($0 < k_i < 1$, $-1 < K$). Therefore, with some justification it was assumed that the solution obtained was unique.