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A UTILITY FUNCTION FOR EXAMINING POLICY AFFECTING SALMON IN THE SKEENA RIVER

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Abstract

The interests of many groups, some with multiple objectives, are important to include in evaluating strategies affecting salmon in the Skeena River. A multiattribute utility model is proposed for addressing these issues. Two first-cut utility functions are assessed using the preferences of two individuals familiar with the problem. These utility functions provide a basis for constructive discussion to arrive at a reasonable utility function for examining alternative policies. Two rather unique features of this study are the explicit focus on value tradeoffs and equity considerations among interest groups, and a comparative examination of the two first-cut multiattribute utility models. This examination indicates the range of fundamental preferences which can be captured using multiattribute utility functions and illustrates the potential of the theory for conflict illumination and resolution.

1. Introduction

The Skeena River, and its tributaries in British Columbia, Canada, is an important salmon fishing area. Salmon fishing, which is the basis of the area economy, currently provides around 5000 jobs. This includes the fishermen themselves, people working in canneries, and individuals earning a living from tourism as a result of the recreational fishermen. Policy decisions indicating, for example,

1. who can fish,
2. what they can fish (types or size of salmon),
3. where they can fish,
4. which methods they can use,
5. when they can fish,

impact directly or indirectly everyone living in the Skeena area. Other options such as the development of artificial spawning grounds are also possible and need to be evaluated. Such possibilities have many parameters (size, construction type, cost). Even if one decides to construct spawning grounds, how should they be designed?

The decision maker for policy problems such as those indicated is the Canadian Department of the Environment. The problem is both very important and very complex. Three crucial aspects of the complexity are:

1. Any decision (or no decision) impacts several groups, and these groups have interests directly in conflict with each other.

2. Some of these groups themselves have multiple conflicting objectives.

3. The uncertainties in the consequences of any decision are large.

Any analysis meant to assist the Canadian Department of the Environment (CDE) in evaluating options should address these complexities.

This report illustrates an approach--multiattribute utility analysis--which allows one to address the three complexities above. Multiattribute utility addresses the preference and value tradeoff aspects of the problem. For instance, it will indicate 'how much' the CDE should be willing to take away from group A in order to give a specified amount to group B. To be used directly in evaluating options, one also needs a model to indicate the impacts on groups A and B of the various options. A simulation model has been developed by the Ecology Project at IIASA to do the latter (see Walters [5]). Here we will concentrate only on the preference model, called a multiattribute utility function or, more simply, just a utility function. A utility function is nothing more than an ordinary objective function (to be maximized) except for one special property: in selecting among alternatives involving uncertainty, the expected utility is an appropriate indicator of the desirability of the alternative. If one accepts a set of reasonable assumptions first postulated by von Neumann and Morgenstern [4], then the decision maker should choose the alternative with the highest expected utility. Raiffa [3] discusses the implications of these assumptions and argues for their reasonableness for selecting among alternatives.

The report is organized as follows. Section 2 structures the preference aspects of the problem. The interests of the various groups are indicated. Section 3 briefly introduces aspects of multiattribute utility theory used in this study. Sections 4 and 5 form one unit. The fourth section indicates one possible first-cut utility function for each of the interested groups. In Section 5, the preferences of these groups are used as inputs to construct a utility function for the CDE. Sections 6 and 7 also form a unit and construct an alternative utility function for the CDE.

All the assessments in this report are based on discussions with Dr. Ray Hilborn (Sections 4 and 5) and Dr. Carl Walters (Sections 6 and 7) of the Ecology Project. Both

Hilborn and Walters are from the University of British Columbia and are working on a model of salmon in the Skeena River. In making the utility assessments, each used his knowledge of the "Skeena Problem" to respond in the way he expected the groups and the CDE to respond. In Section 7 we discuss some of the differences in basic preference attitudes implied by the two utility functions. The final section suggests ways in which a multiattribute utility analysis may help in examining options for the Skeena River. Of course, before any serious evaluation of CDE policy with such a procedure, attempts should be made to get the actual groups' utility functions. It is intended to try to assess utility functions for each group in the course of the overall Skeena study.

One should interpret the results in this paper as preliminary. The utility functions assessed for each of the groups were done quickly and roughly using rather standard methodology (see Section 3) to provide a basis on which to improve and to provide the component utility functions necessary for constructing a first cut of the CDE's preferences. There were two more unique aspects of the study. The first involved synthesizing the utility functions of the separate groups into an overall CDE utility function. This required the explicit consideration of value tradeoffs between groups and of equity among the groups. The second unique feature involved the comparative examination of Dr. Hilborn's and Dr. Walters' utility assessments. This clearly identifies points of agreement and disagreement concerning the preference structure (i.e. objectives) to be used in the study. Similar analyses, done in more detail with more care, could assist in identifying and resolving conflicts in problems with multiple decision makers.

2. The Interest Groups and Their Objectives

There are five main groups whose preferences are important to the CDE. Four of these--the lure fishermen, the net fishermen, the sportfishermen, and the Indians--are directly involved in fishing. The fifth group includes all those individuals whose welfare is tied to fishing, such as the cannery employees and motel operators. Let us just refer to the latter group as the 'regional development' group.

The lure and net fishermen both fish for a livelihood, using lures and nets respectively. The lure fishermen are near the mouth of the Skeena, and the net fishermen are upstream a little in a controlled area. Upstream from them are the sportfishermen and upstream still are the Indians. The latter two groups fish mainly for pleasure and food.

The objectives hierarchy for this problem is illustrated in Figure 1. The CDE, as decision maker, has six major objectives: to satisfy each of the five interest groups as much as possible and to minimize their own (government) expenses. The degree to which the net fishermen are satisfied depends, of course, on how well their own objectives are satisfied. As indicated in the figure, their main interests are to maximize their income per fisherman, optimize their fishing time (i.e. don't work too much or too little), and maximize the diversity of the catch. The last objective is a proxy indicator for their psychological well-being. Knowing the river is healthy (i.e. supporting many species) provides both future flexibility as well as future security. The lure fishermen have the same objectives for themselves as do the net fishermen. The Indians and sportfishermen are interested in maximizing their fish catch. The region wants to maximize economic benefits from employment and recreational sources as well as to have an abundance of fresh fish to eat.

Let us return to the three complexities mentioned in the introduction and elaborate on them in the context of our problem. Suppose the CDE is considering a policy of constructing artificial spawning grounds which cost millions of dollars. One scenario may be that only a few additional fish return from the ocean whereas another scenario may lead to large increases in adult salmon in the Skeena. The uncertainties here are large. If the CDE changes licensing strategies, this may increase administrative (government) costs and simultaneously lead to better harvests for lure and net fishermen. However, they may need to work more to get this increase. Another impact may be there are less fish for the sportfishermen and the Indians. These groups would then be displeased. The overall impact on the region might be more employment in canneries, etc., but less recreational income. What should the CDE do? Somehow they must get a measure of each of the possible impacts, balance these in some fair way, and decide "With all pros and cons considered, should we go ahead with the new licensing strategy or not?".

In Figure 1, the bottom level of the hierarchy lists twelve objectives which affect the CDE's decisions. Table 1 lists a measure, called an attribute, for each of these objectives, as well as ranges of the possible impacts on each attribute. We designate X_i $i = 1,2,\ldots,12$ as the attribute associated with the i^{th} objective.

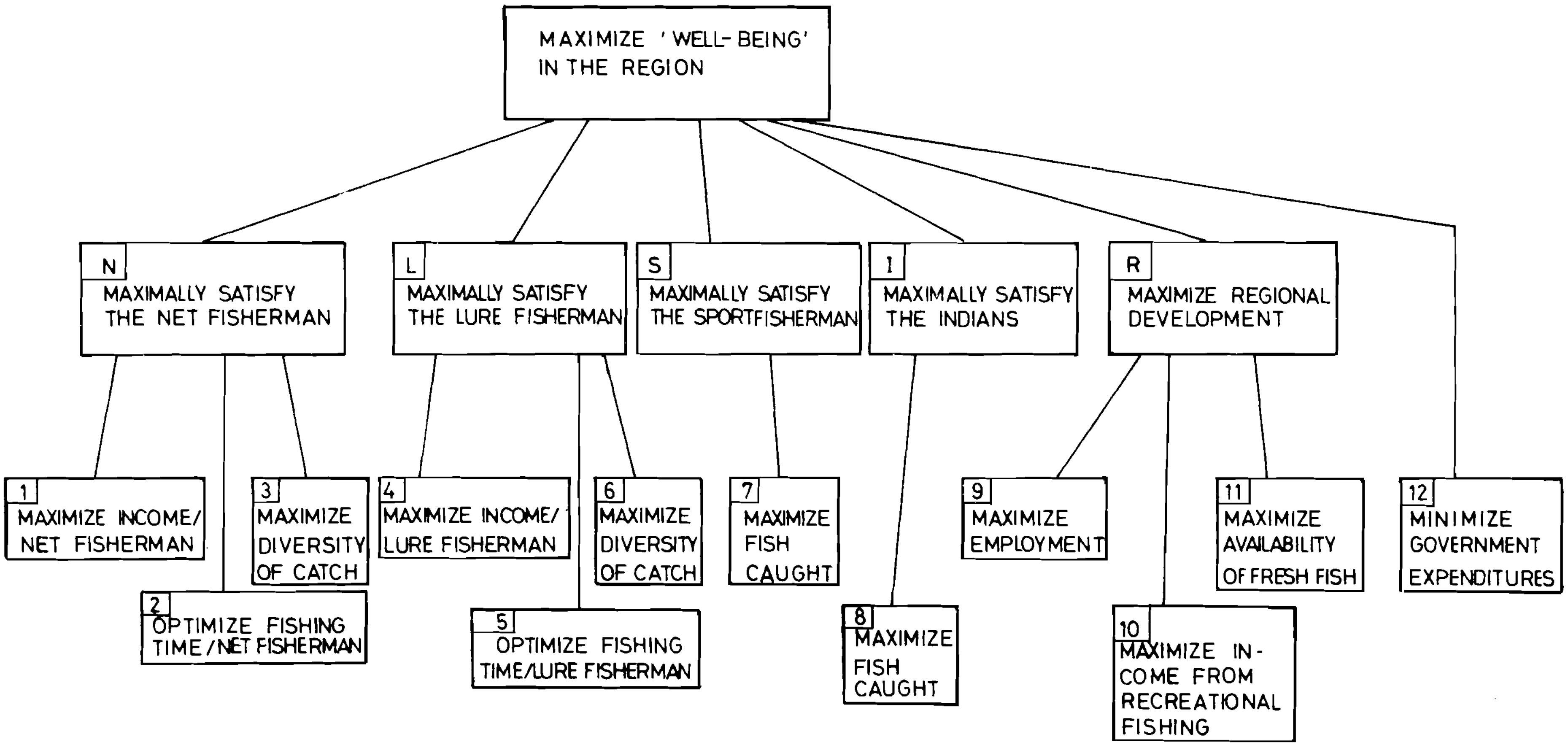

FIGURE 1. THE OBJECTIVES IN THE SKEENA PROBLEM

Table 1. Attributes for the Skeena Problem

	Attribute	Worst Level	Best Level
X_1 ≡	annual income/net fisherman	0	$25,000
X_2 ≡	annual days fishing/net fisherman	100	0
X_3 ≡	species of salmon in the Skeena	1	10
X_4 ≡	annual income/lure fisherman	0	$25,000
X_5 ≡	annual days fishing/lure fisherman	100	0
X_6 ≡	species of salmon in the Skeena	1	10
X_7 ≡	annual sportfisherman catch of salmon	0	1,000,000
X_8 ≡	employment	0	5000
X_9 ≡	annual revenue due to recreation	0	$10,000,000
X_{10} ≡	cost of fresh salmon/lb.	$10.00	$0.20
X_{11} ≡	annual Indian catch of salmon	0	100,000
X_{12} ≡	annual expenditures (millions of dollars)	$10	$0

3. The Methodology

Let us use x_i to designate a specific level of attribute X_i; then the consequence of any decision taken by the CDE can be represented by the twelve-tuple $(x_1,x_2,...,x_{12})$. For decision making, we want to assign a number $u_G(x_1,x_2,...,x_{12})$, referred to as utility, to each consequence. One may think of u_G as the government's CDE utility function. Rather than assess u_G directly, we will break the problem into parts using the structure

$$u_G(x_1,x_2,...,x_{12}) = u\left[u_N(x_1,x_2,x_3),u_L(x_4,x_5,x_6),u_S(x_7),u_R(x_8,x_9,x_{10})u_I(x_{11}),x_{12}\right] \quad (1)$$

where u_N, u_L, u_S, u_R, and u_I are utility functions for the net fishermen, lure fishermen, sportfishermen, region, and Indians, respectively, x_{12} is the CDE's expenditures, and u is itself a utility function over the six attributes U_N, U_L, U_S, U_R, U_I, and X_{12} which take on amounts designated by $u_N,u_L,...,x_{12}$.

The three multiattribute utility functions u_N, u_L, and u_R are also divided into their component parts, so

$$u_N(x_1,x_2,x_3) = f\left[u_1(x_1),u_2(x_2),u_3(x_3)\right] \quad , \quad (2)$$

$$u_L(x_4,x_5,x_6) = g\left[u_4(x_4),u_5(x_5),u_6(x_6)\right] \quad , \quad (3)$$

and

$$u_R(x_8,x_9,x_{10}) = h\left[u_8(x_8),u_9(x_9),u_{10}(x_{10})\right] \quad , \quad (4)$$

where each u_i is a utility function over the attribute X_i.

In order to structure the utility functions as indicated in (1) through (4), one needs to make some assumptions. The two assumptions used in this study are preferential independence and utility independence. Let us briefly define these and state two results following from them which are used in this study.

Assume we have the set of attributes $\{Y_1, Y_2, \ldots, Y_n\}$. If $n \geq 3$, we will say the pair of attributes $\{Y_1, Y_2\}$ is <u>preferentially independent</u> (PI) of the other attributes if the preference ordering of (y_1, y_2) pairs, given the other attributes are held fixed, does not depend on the levels where they are fixed. If $\{Y_1, Y_2\}$ is PI, then the value tradeoffs between Y_1 and Y_2 won't depend on the levels of Y_3 through Y_n.

Whereas preferential independence only concerns preferences for sure consequences, utility independence concerns preferences for lotteries. A lottery indicates which of several consequences may occur and an associated probability of the occurrence of each. We will say Y_1 is <u>utility independent</u> (UI) of the other attributes if the preference order for lotteries over Y_1, given the other attributes are fixed, does not depend on the level where those attributes are fixed.

Given various preferential and utility independence conditions, one can derive various forms of utility functions u consistent with the decompositions (1) - (4). For purposes here, we are interested in two particular results.

<u>Theorem 1</u>. Given $Y_1, Y_2, \ldots, Y_n$, $n \geq 3$, suppose for some Y_i, both $\{Y_i, Y_j\}$ is PI for all $j \neq i$, and Y_i is UI, then either

$$u(y_1, y_2, \ldots, y_n) = \sum_{i=1}^{n} k_i u_i(y_i) \quad , \quad \text{if } \sum k_i = 1, \quad (5)$$

or

$$1 + ku(y_1, y_2, \ldots, y_n) = \prod_{i=1}^{n} \left(1 + kk_i u_i(y_i)\right) \quad , \quad \text{if } \sum k_i \neq 1, \quad (6)$$

where

i) u and the u_i are utility functions scaled 0 to 1, (7)

ii) $0 < k_i < 1 \quad , \quad i = 1, 2, \ldots, n \quad ,$ (8)

and if $\sum k_i \neq 1$, $k > -1$ is the nonzero solution to

iii) $$1 + k = \prod_{i=1}^{n} (1 + kk_i) \quad . \quad (9)$$

Theorem 2. Given Y_1 and Y_2, if Y_1 is UI and Y_2 is UI, then either (5) or (6) holds. With our scaling convention, both cases can be written as

$$u(y_1,y_2) = k_1u_1(y_1) + k_2u_2(y_2) + (1-k_1-k_2)u_1(y_1)u_2(y_2) \quad . \tag{10}$$

Proof of these results as well as more details about preferential independence, utility independence, and related results are found in Keeney and Raiffa [2]. In the sections which follow, we will repeatedly use these theorems in structuring the preferences of the CDE.

4. Hilborn's First-Cut Utility Functions for the Interest Groups

In this section, we illustrate the assessment of the utility functions of the five interest groups. As mentioned earlier, these utility functions were assessed in interviews with Ray Hilborn. Before we began any assessments, the Ecology Project had identified the attributes for the problem. Ray had also done some reading about utility theory before we began.

Our first assessment session consisted of examining the reasonableness of the preferential independence conditions required by the theorem stated in the last section in order to use (2), (3), and (4). At that time a fourth attribute, called freedom measured by the number of boats fishing an area, was included in both the net fisherman and lure fishermen preferences. It turned out that the fishermen would give up more in terms of annual salary to avoid large congestion (many boats) if annual days fishing was high than if it was low. Thus, freedom combined with income, for example, was not preferentially independent of days fishing. However, preliminary analysis indicated that the weight of the freedom attribute, given its possible ranges, would likely have little impact on evaluating policy. Hence, it was decided to drop it. This left us with the three attributes for the two commercial fishermen groups. Given this structure, the preferential independence and utility independence conditions necessary to use Theorem 1 seemed reasonable.

Let us examine preferences of the various groups.

The Net Fishermen's Utility Function

Given our assumptions, we know that either

$$u_N(x_1,x_2,x_3) = k_1u_1(x_1) + k_2u_2(x_2) + k_3u_3(x_3) \tag{11}$$

or

$$1 + k_Nu_N(x_1,x_2,x_3) = \left(1 + k_Nk_1u_1(x_1)\right)\left(1 + k_Nk_2u_2(x_2)\right)\left(1 + k_Nk_3u_3(x_3)\right) , \tag{12}$$

where u_N, u_1, u_2, and u_3 are scaled from zero to one and k_i is defined as the utility measured by u_N of attribute X_i at its best level and the other two attributes at their worst levels for both (11) and (12). The number k_N is calculated directly from k_1, k_2, and k_3 if $k_1 + k_2 + k_3 \neq 1$. If $k_1 + k_2 + k_3 = 1$, then (11) holds. Thus to specify $u_N(x_1,x_2,x_3)$, we needed to assess u_1, u_2, u_3 and k_1, k_2, k_3.

The assessment of u_i, $i = 1,2,3$, followed standard procedures as discussed in Keeney and Raiffa [2]. For instance, concerning X_1, we found that the average of any lottery is preferred to the lottery itself. This implied u_1 was concave. Then the certainty equivalent* for the lottery <$0;$25,000> yielding a 50-50 chance at an annual salary of $0 or $25,000 was found to be $8,000.

Thus, $u_1(8000)$ was assigned from

$$u_1(8000) = .5u_1(25000) + .5u_1(0) = 0.5$$

which together with our scaling convention gives us the three points on the graph in Figure 2A. The utility function u_1 was chosen using an exponential fit through these three points. As a check, we assessed $3000 indifferent to <$0;$8000> which seemed quite consistent.

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*In interpreting certainty equivalents for income, it is important to realize the amounts refer to fishing income. Fishermen have other sources of income including government aid.

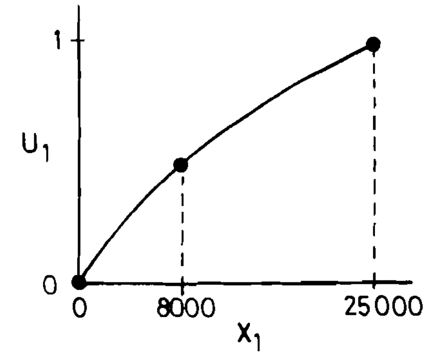

FIG.2A. UTILITY FUNCTION FOR NET FISHERMAN INCOME

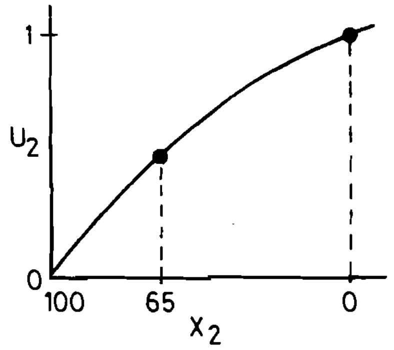

FIG.2.B.UTILITY FUNCTION FOR NET FISHERMAN WORKDAYS

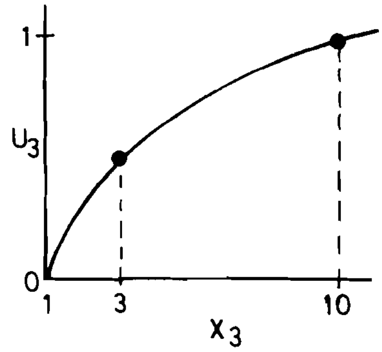

FIG.2C. UTILITY FUNCTION OF NET FISHERMAN FOR VARIETY

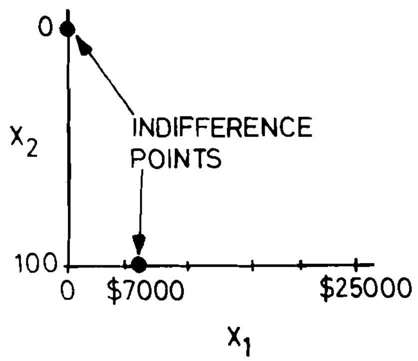

FIG.2D.TRADEOFFS BETWEEN X_1 AND X_2

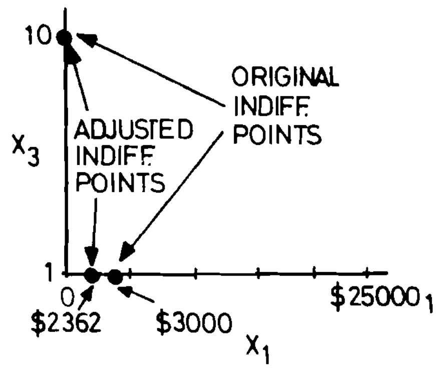

FIG 2E.TRADEOFFS BETWEEN X_1 AND X_3

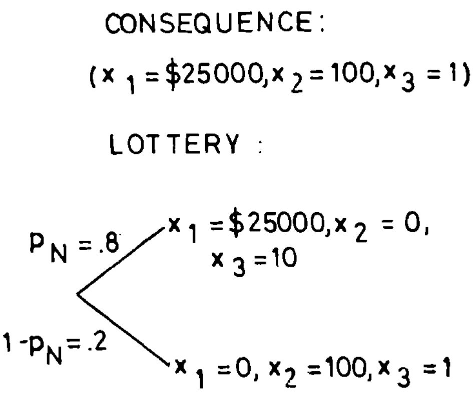

FIG.2F. ASSESSING p_N FOR INDIFFERENCE

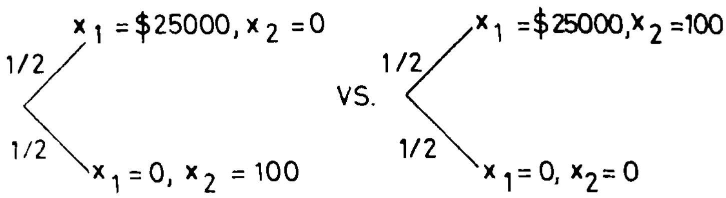

FIG. 2G. COMPARING TWO LOTTERIES (THE SECOND WAS PREFERRED)

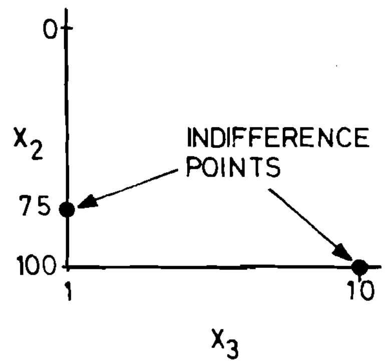

FIG.2H. TRADEOFFS BETWEEN X_2 AND X_3

FIG. 2. ASSESSING HILBORN'S UTILITY FUNCTION FOR NET FISHERMEN

Similar exponential fits were used for attributes X_2 and X_3 through the three points indicated in Figures 2B and 2C. Part of the justification for the use of this simple form is that more sophisticated forms add little additional flexibility in a multiattribute context relative to their additional complexity.

Next we wanted to assess k_1, k_2, and k_3 in as simple a way as possible. This was done with the information in Figures 2D, 2E, and 2F. First, we considered tradeoffs between X_1 and X_2 given X_3 was held fixed. It was found that $(x_1 = 0, x_2 = 0)$ and $(x_1 = \$7000, x_2 = 100)$ indicated in Figure 2D were indifferent. Equating the utility of these two consequences using either (11) or (12) yields

$$k_2 = k_1 u_1(\$7000) \quad . \tag{13}$$

Similarly looking at tradeoffs between X_1 and X_3, we found $(x_1 = \$3000, x_3 = 1)$ and $(x_1 = 0, x_3 = 10)$ indifferent. Thus

$$k_3 = k_1 u_1(\$3000) \quad . \tag{14}$$

Finally, we assessed the probability p_N such that the consequence and the lottery in Figure 2F were indifferent. This was found to be $p_N = .8$. Equating utilities of the consequence and the lottery yields

$$k_1 = 0.8 \quad . \tag{15}$$

Solving the three equations (13), (14), and (15) using u_1 from Figure 2A, we find $k_1 = 0.8$, $k_2 = 0.36$, and $k_3 = 0.17$. Since $k_1 + k_2 + k_3 \neq 0$, the multiplicative utility function (11) is the appropriate one.

We ran two consistency checks on the assessments. The first involved choosing which of the two lotteries in Figure 2G is preferable. In each case there is a 50-50 chance of getting 0 or \$25,000 for the year and a 50-50 chance of working 0 or 100 days. The difference is in how the two attributes are combined. The second lottery was preferred, which implies $k_1 + k_2 + k_3$ must be greater than one. This check was consistent.

The second check involved considering tradeoffs between X_2 and X_3. We found $(x_2 = 75, x_3 = 1)$ and $(x_2 = 100, x_3 = 10)$ to be indifferent as indicated in Figure 2H. Equating utilities implies

$$k_3 = k_2 u_2(75) \quad . \tag{16}$$

Evaluating $u_2(75) = 0.38$ from Figure 2B, and assuming the values k_2 and k_3 which we found to be correct, one obtains the inconsistency $(0.17) = (0.36)(0.38)$.

To correct this, there are several alterations of the responses which could lead to consistency. The simplest involves changing the indifference pairs in one of the Figures 2D, 2E, or 2H. The three possibilities are indicated in Table 2.

Table 2. Tradeoff Changes to Achieve Consistency of u_N

Change	Implications
1. k_3 from 0.17 to 0.14	$(x_1 = 9342; x_3 = 1) \sim (x_1 = 0, x_3 = 10)$ in Fig. 2E
2. k_2 from 0.36 to 0.45	$(x_1 = 2362; x_2 = 100) \sim (x_1 = 0, x_2 = 0)$ in Fig. 2D
3. $u_2(75)$ to $u_2(67.5)$ in (16)	$(x_2 = 100, x_3 = 10) \sim (x_2 = 67.5, x_3 = 1)$ in Fig. 2H

It was decided the first change seemed very reasonable, resulting in $k_1 = 0.8$, $k_2 = 0.36$, and $k_3 = 0.14$. From this the value of k_N was calculated from (9) to be -0.71. Thus from (12), the net fishermen's utility function is

$$u_N(x_1, x_2, x_3) = \frac{1}{-0.71}\left[\left(1 - .568\,u_1(x_1)\right)\left(1 - .256\,u_2(x_2)\right)\left(1 - .1\,u_3(x_3)\right) - 1\right] \tag{17a}$$

where

$$u_1(x_1) = 1.26\left(1 - e^{-.0000633x_1}\right) \quad , \tag{17b}$$

$$u_2(x_2) = 1.385 - 0.385e^{.0128x_2} \quad , \tag{17c}$$

and

$$u_3(x_3) = 1.06 - 1.458e^{-0.319x_3} \quad . \tag{17d}$$

The Lure Fishermen's Utility Function

Hilborn felt that as a first cut, the same utility function could be used for the lure fishermen as for the net fishermen. The only difference is that the income for the year and the workday measures pertain to the lure fishermen. Different policies of the CDE could have very different implications in terms of income, for instance, on the net and lure fishermen. Hence although we have taken their preference structures to be the same, it does not follow that their preferences for options will be in any agreement. The diversity attributes X_3 and X_6 are identical. For reference the lure fishermen's utility function is

$$u_L(x_4, x_5, x_6) = \frac{1}{-0.71}\left[\left(1 - .568\,u_4(x_4)\right)\left(1 - .256\,u_5(x_5)\right)\left(1 - .1\,u_6(x_6)\right) - 1\right] \tag{18a}$$

where

$$u_4(x_4) = 1.26\left(1 - e^{-.0000633x_4}\right), \tag{18b}$$

$$u_5(x_5) = 1.385 - 0.385e^{.0128x_5}, \tag{18c}$$

and

$$u_6(x_6) = 1.06 - 1.458e^{-0.319x_6}. \tag{18d}$$

The Sport Fishermen's Utility Function

Here there was only one attribute, the annual catch of sport fishermen. We assessed 300,000 indifferent to a 50-50 lottery yielding 0 or 1,000,000. Using these three points indicated in Figure 3, we fit the exponential utility function

$$u_S(x_7) = 1.198\left(1 - e^{-.0000018x_7}\right), \tag{19}$$

where x_7 is the number of fish in the annual catch. It was also checked that the utility function was indeed risk averse over the entire range.

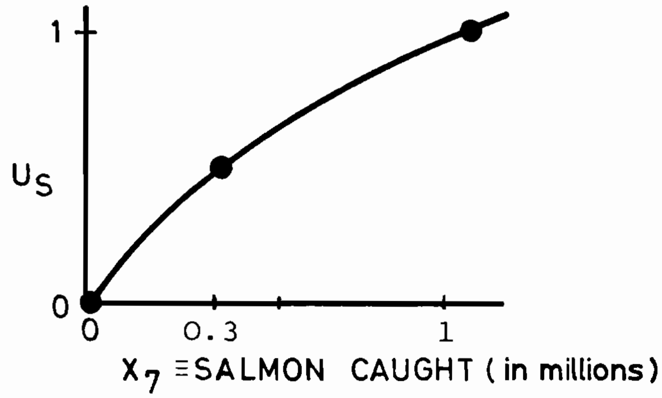

Figure 3. Hilborn's Utility Function for Sport Fishermen

A Utility Function for the Region

The assessments used over the three attributes X_8, X_9, X_{10} to obtain the region's utility function were analogous to those indicated with the net fishermen's preferences. These are all indicated in Figure 4 in the same order as in Figure 2. The individual utility functions were first assessed. The interesting fact is that $u_{10}(x_{10})$ in Figure 4C is risk prone. This is due to the feeling that once salmon prices get above a few dollars a pound, you have eliminated from the market most of the people interested in eating the fish. Thus one would be just willing to risk a one-half chance at $10/lb for a one-half chance at $0.20/lb if the alternative was $2/lb for certain. As can be seen from Figure 4, the consistency check in Figure 4H implied a change must be made in one of the original assessments. This was done in Figure 4E.

The final values of the k_i's were $k_8 = .8$, $k_9 = .43$, and $k_{10} = .125$. Using (9), the additional scaling factor in the multiplicative utility function was evaluated to be -0.76. Thus the regional utility function is

$$u_R(x_8,x_9,x_{10}) = \frac{1}{-0.76}\left[\left(1 - .61\,u_8(x_8)\right)\left(1 - .327\,u_9(x_9)\right)\left(1 - .095\,u_{10}(x_{10})\right) - 1\right] \quad (20a)$$

where

$$u_8(x_8) = 1.44\left(1 - e^{-.000237x_8}\right), \quad (20b)$$

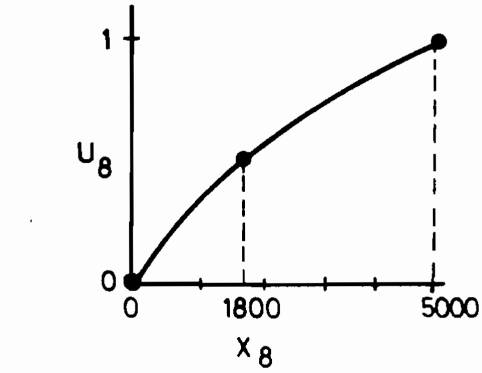

FIG.4A. UTILITY FUNCTION FOR EMPLOYMENT

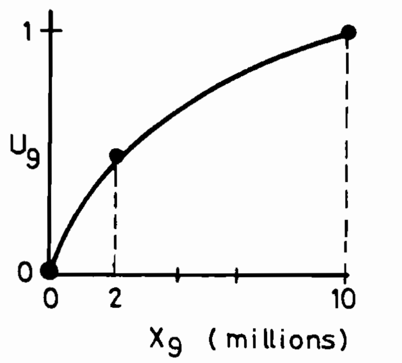

FIG.4B. UTILITY FUNCTION FOR RECREATIONAL INCOME

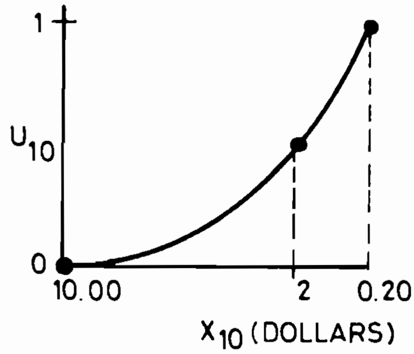

FIG.4C. UTILITY FUNCTION FOR SALMON PRICE

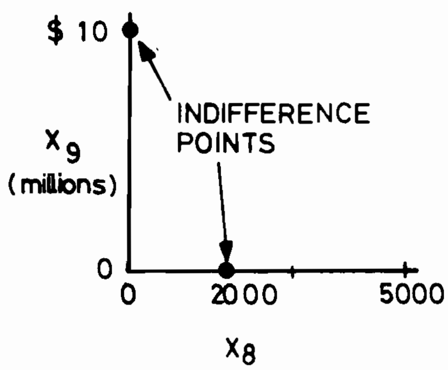

FIG.4D. TRADEOFFS BETWEEN X_8 AND X_9

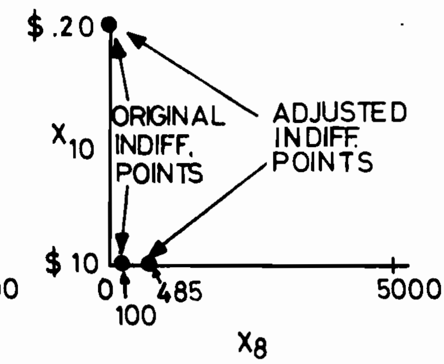

FIG.4E. TRADEOFFS BETWEEN X_8 AND X_{10}

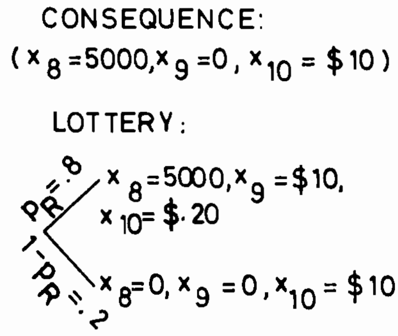

FIG.4F. ASSESS p_R FOR INDIFFERENCE

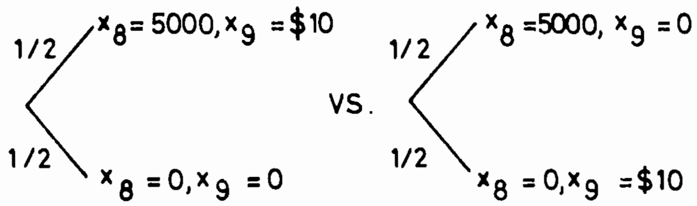

FIG.4G. COMPARING TWO LOTTERIES (THE SECOND WAS PREFERRED)

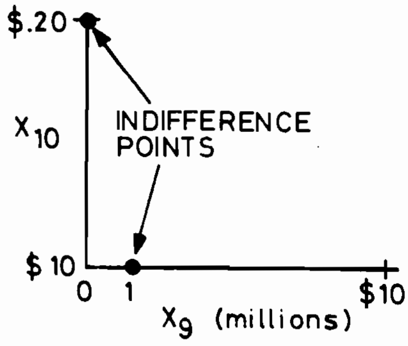

FIG.4H. TRADEOFFS BETWEEN X_9 AND X_{10}

FIG. 4. ASSESSING HILBORN'S UTILITY FUNCTION FOR THE REGION

$$u_9(x_9) = 1.04\left(1 - e^{-.328x_9}\right) \quad , \quad x_9 \text{ in millions,} \qquad (20c)$$

and

$$u_{10}(x_{10}) = -.027 + 1.11e^{-.37x_{10}} \quad . \qquad (20d)$$

The Indians' Utility Function

Again with only one attribute X_{11}, it was a straight forward assessment to find the Indians' utility function. We found 20,000 fish caught in a year was indifferent to the lottery yielding either 0 or 100,000 fish, each with probability one-half. The exponential utility function scaled zero to one implying the indifference is

$$u_I(x_{11}) = 1.04\left(1 - e^{-.0000328x_{11}}\right) \quad . \qquad (21)$$

It is shown in Figure 5.

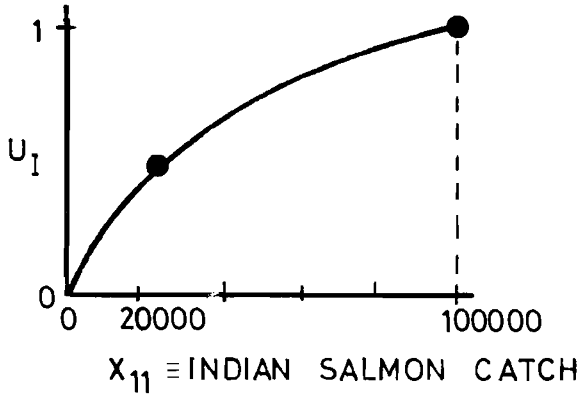

Figure 5. Hilborn's Utility Function for the Indians

5. Hilborn's Overall Utility Function for the Canadian Department of the Environment

Now we can move up to the top level of the objectives hierarchy in Figure 1 and try to assess a utility function u_C for the CDE. Our approach will be in two steps. First, we will integrate the preferences of the five groups into a single indicator of preference u, and then, we will combine this with attribute X_{12}, the cost to the Canadian government, to obtain overall CDE utility function u_C. So our approach is to find $u(u_N, u_L, u_S, u_R, u_I)$ and $u_G(u, x_{12})$.

Integrating the Preferences of the Interest Groups

We want a utility function u with five arguments u_N, u_L, u_S, u_R, and u_I. We can think of an attribute U_j associated with each of these five groups. As a first step, we investigated whether the assumptions necessary for Theorem 1 seemed reasonable.

In this context, the preferential independence conditions imply that tradeoffs between any two of the five groups do not depend on how well satisfied the other three groups are. The utility independence conditions means that if the consequences to only one group are uncertain, we will always choose among alternatives using only the outputs to that group.

After examining the conditions implying Theorem 1, we decided the utility independence conditions seemed reasonable, but the preferential independence assumptions were not completely justified. The main difficulty was that tradeoffs between the net fisherman and the region, for example, depended on the lure fisherman. If the lure fishermen were doing poorly, there was a willingness to give up more in regional development to move net fishermen from a bad to good position (e.g. a 0.2 to a 0.8 utility measured by u_N) than there was if lure fishermen were doing well. That is, there was a premium on having at least one of the commercial fishermen at a good level.

The next possibility investigated concerned first combining u_N and u_L into a commercial fishermen's utility function u_C, with associated attribute U_C. Then if tradeoffs between U_C and U_R are examined, they do seem to be preferentially independent of $\{U_S, U_I\}$. For instance, it seemed reasonable to give up the same amount in regional development to move u_C from 0.2 to 0.4 regardless of what combinations of u_N and u_L lead to the u_C equal to 0.2 and 0.4.

Given the utility independence and the preferential independence assumptions which were verified, we could use Theorem 2 to combine u_N and u_L into u_C and then use Theorem 1 to combine u_C, u_S, u_I, and u_R into u.

There is one additional assumption that seems reasonable in the group context. In terms of our problem, the assumption is that the CDE's utility function for satisfying group j is group j's utility function. If this assumption is not accepted, one can always construct situations where group j prefers option A over option B and all other groups are indifferent, but yet the government prefers B over A. This assumption just says the CDE's utility function for any of the five attributes U_N, U_L, U_S, U_R, and U_I is linear.

Combining this assumption with those previously verified, we find

$$u_C(u_N,u_L) = \lambda_N u_N + \lambda_L u_L + (1 - \lambda_N - \lambda_L)u_N u_L \qquad (22)$$

and

$$u(u_C,u_S,u_R,u_I) = \lambda_C u_C + \lambda_S u_S + \lambda_R u_R + \lambda_I u_I \quad , \qquad (23)$$

or

$$1 + \lambda u(u_C,u_S,u_R,u_I) = (1+\lambda\lambda_C u_C)(1+\lambda\lambda_S u_S)(1+\lambda\lambda_R u_R)(1+\lambda\lambda_I u_I) \quad , \qquad (24)$$

where again the u's are all scaled zero to one and the λ_j's have the same interpretation in (23) and (24).

Given (22) through (24), one needs to assess the u_j's and λ_j's. However, in the last section, we have already assessed the u_j's except for u_C on the scale zero to one which is desired. Hence we only needed to obtain the λ_j, $j = N,L,S,R,I,C$, and u_C.

<u>Assessing u_C</u>

First we considered the two lotteries in Figure 6A and the second one was preferred. This substantiates an attitude found when we investigated the dependence of the preferential independence conditions involving one of the commercial fishermen groups on the other commercial fishermen group. Notice that with the second lottery, at least one of the two groups is doing fine (i.e., its utility is one), whereas with the first lottery there is a one-half chance that both groups do terribly (i.e., utility equal to zero.) It was found that there was a premium on having at least one of the two groups doing well. This implies that the sum of λ_N and λ_L in (22) must be greater than one.

Next we ask whether it would be better, given we started from $u_N = u_L = 0$, to move u_N to 1 or u_L to 1. The response was that it was equivalent, implying $\lambda_N = u_L$. Finally, to get a specific number for λ_N we asked for the indifference probability such that the consequence and lottery in Figure 6B were equally desirable. The indifference probability was 0.6 which, by equating the utilities of the consequence and lottery, implies $\lambda_N = 0.6$. Thus the commercial fishermen's utility function is

$$u_C(u_N,u_L) = 0.6u_N + 0.6u_L - 0.2u_Nu_L \quad . \tag{25}$$

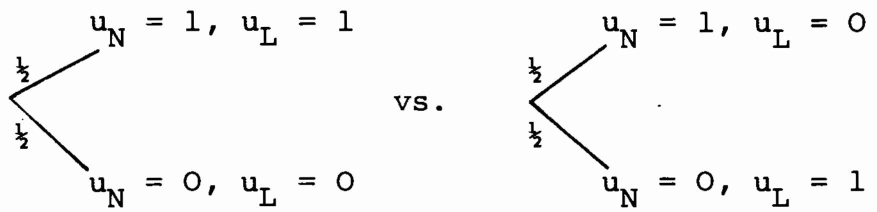

Figure 6A. Comparing two Lotteries (The Second was Preferred)

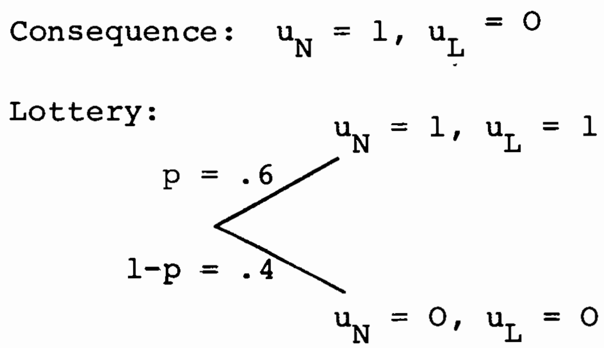

Figure 6B. Assessing p for Indifference

Figure 6. Assessing Hilborn's Utility Function for the Commercial Fishermen

In making evaluations and tradeoffs necessary to assess u_C, we constantly made reference to the original attributes $\{X_1,X_2,X_3\}$ representing the net fisherman and $\{X_4,X_5,X_6\}$ representing the lure fisherman. Thus for instance, to interpret

$u_N = 1$, one should recall $u_N(x_1 = \$25{,}000,\ x_2 = 0,\ x_3 = 10) = 1$ and think about the implications of these amounts of X_1, X_2, and X_3. This will become clearer in what follows.

Assessing u

First we wanted to rank the λ_j's for $j = S,R,I,C$. This was done with the aid of Table 1. I asked "Given all the attributes $X_1,\ldots,X_{11}$ are at their worst level, which one of the four attribute sets: $U_C \equiv \{X_1,X_2,X_3,X_4,X_5,X_6\}$, $U_S \equiv \{X_7\}$, $U_R \equiv \{X_8,X_9,X_{10}\}$ or $U_I \equiv \{X_{11}\}$ would you rather push up to its best level if you could push only one?" To answer this, Ray Hilborn put himself in the position of the CDE. He felt that it would be most desirable to move $\{X_8,X_9,X_{10}\}$ up to their best levels. These are the attributes associated with regional development, so λ_R, the regional development scaling factor, must be the largest λ_j. We then asked "Which of the remaining three attribute sets would you want to move to its best level next?" The answer was the commercial fishermen's attributes. Hence $\lambda_R > \lambda_C$. Continuing in the same manner led to

$$\lambda_R > \lambda_C > \lambda_I > \lambda_S \quad . \tag{26}$$

Now we wanted to get values for those λ_j's. First we looked at tradeoffs between U_R and U_C. However, one cannot answer questions directly in terms of u_R and u_C so we must go back to the basic attributes of each group. It is best to choose the heaviest-weighted attribute of each group and look at the CDE's tradeoffs in this context. The region weighted employment highest in (20), that is k_8 is greater than k_9 or k_{10}, and the commercial fisherman weighted annual income the highest. Thus we looked at the tradeoffs between X_1 and X_8 in Figure 7A. Specifically we found $(x_1 = 0;\ x_8 = 800)$ indifferent to $(x_1 = \$25{,}000;\ x_8 = 0)$. Equating the utilities of these two points using either (23) or (24), while assuming the other attributes are fixed (we can assume at their worst levels because of preferential independence), yields

$$\lambda_R u_R\left(x_8 = 800;\ x_9 = 0;\ x_{10} = \$10\right) = \lambda_C \lambda_N u_N\left(x_1 = \$25{,}000;\ x_2 = 100;\ x_3 = 1\right) \quad . \tag{27}$$

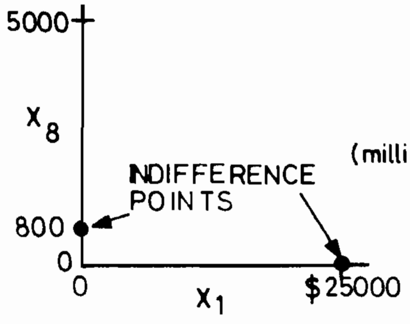

FIG.7 A. TRADEOFFS BETWEEN NET FISHERMEN AND REGIONAL DEVELOPMENT

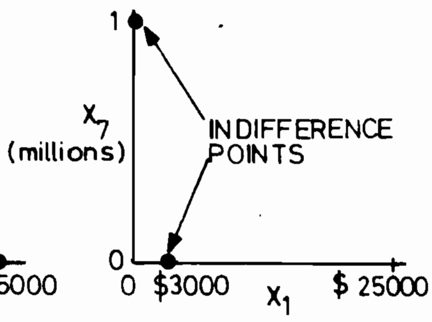

FIG.7 B. TRADEOFFS BETWEEN NET FISHERMEN AND SPORT FISHERMEN

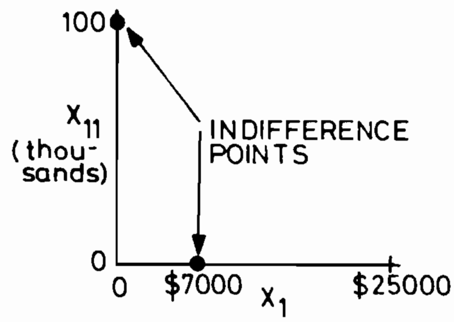

FIG.7C. TRADEOFFS BETWEEN NET FISHERMEN AND INDIANS

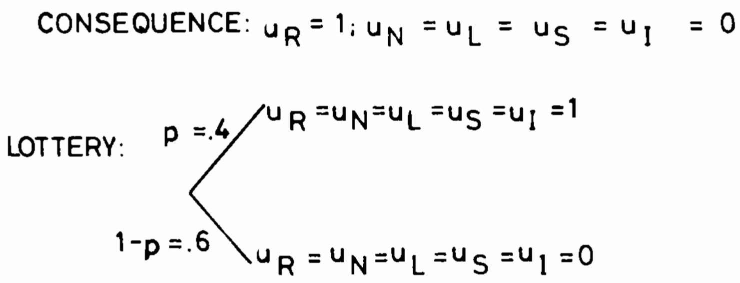

FIG.7 D. ASSESSING p FOR INDIFFERENCE

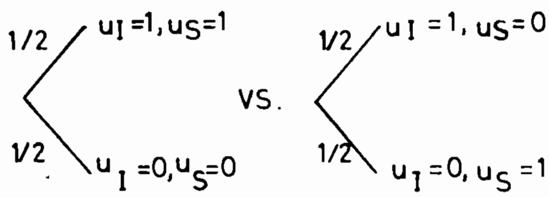

FIG.7 E. COMPARING TWO LOTTERIES (THE FIRST WAS PREFERRED)

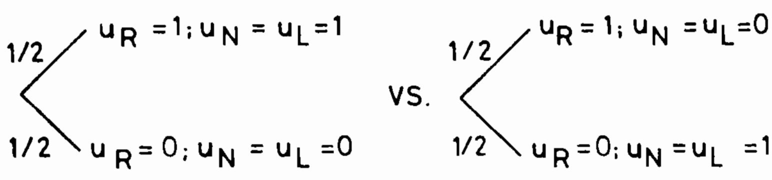

FIG.7 F. COMPARING TWO LOTTERIES (THE FIRST WAS PREFERRED)

FIG.7. ASSESSING HILBORN'S UTILITY FUNCTION FOR THE SKEENA GROUPS

Substituting (20) into the left side and (17) into the right side of (27), we find

$$\lambda_R k_8 u_8(800) = \lambda_C \lambda_N k_1 u_1(\$25{,}000)$$

or

$$\lambda_R(.413) = \lambda_C \quad . \qquad (28)$$

Next we considered tradeoffs between commercial fishermen and sportfishermen by finding the two indifference points involving X_1 and X_7 in Figure 7B. Using the same reasoning as above, we find

$$\lambda_S = \lambda_C \lambda_N k_1 u_1(\$3000) = \lambda_C(.131) \quad . \qquad (29)$$

Thirdly, the CDE's tradeoffs between Indians and commercial fishermen were elaborated by assessing the indifference points in Figure 7C. Equating utilities and using (17) and (21) led to

$$\lambda_I = \lambda_C \lambda_N k_1 u_1(\$7000) = \lambda_C(.270) \quad . \qquad (30)$$

Equations (28) through (30) fixed the relative values of the λ_j's. To get their absolute level, we assessed the probability p where the lottery and consequence in Figure 7D would be indifferent. The sure consequence has the region (i.e. attributes X_8, X_9, and X_{10}) at its best and the attributes of the four fishing groups (i.e. attributes $X_1,\ldots,X_7$ and X_{11}) at their worst. The lottery yields all eleven attributes at their best with probability p or all at their worst otherwise. The indifference probability was found to be 0.4. Equating the utility of the consequence to that of the lottery using either (23) or (24) gives

$$\lambda_R = 0.4 \quad . \qquad (31)$$

The set of equations (28) to (31) was solved to yield

$$\lambda_R = 0.4 \quad , \quad \lambda_C = 0.165 \quad , \quad \lambda_I = 0.045 \quad , \quad \lambda_S = 0.022 \quad . \qquad (32)$$

Since the sum of these four λ_j's is not one, the multiplicative form (24) is appropriate. The parameter λ was calculated to be 3.05 from the λ_j's in (32) and the resulting utility function is

$$u(u_C, u_S, u_R, u_I) = \frac{1}{3.05}[(1+.503u_L)(1+.067u_S)(1+1.22u_R)(1+.137u_I) - 1] \quad (33)$$

where the u_j's are as specified in (19) to (21) and in (25).

Consistency Checks

As a check on the multiplicative form with $\Sigma\lambda_j < 1$, we asked which of the two lotteries in Figure 7E was preferred. One can see that both lotteries give a one-half chance of both the sport fishermen and the Indians having either their best or worst situation. However, the first lottery has both at their best together or both at their worst. The second lottery has one of the two groups at its best level with the other at its worst. For reasons of equity the first lottery was preferred, which is consistent.

As a second check, the two lotteries in Figure 7F were compared. These have the same interpretation as above, only they lump the commercial fishermen together. Here it was also felt that the first lottery was preferred. (Note that in the real world, great fishing conditions correlate to high satisfaction of the regional development. However, our lotteries in 6F are not asking this question, they are concerned with preferences independent of the possible impacts--or said another way, with the impacts specified by the lotteries.) The choice of the first lottery in 7F is consistent with the utility function (33).

Assessing u_G

Now we want to aggregate u and x_{12} to get an overall utility function u_G for the CDE. It seemed reasonable to assume U and X_{12} were utility independent of each other, so from Theorem 2,

$$u_G(u, x_{12}) = hu + h_{12}u_{12}(x_{12}) + (1-h-h_{12})uu_{12}(x_{12}) \quad , \quad (34)$$

where we have used u itself to measure the utility of specific amounts of U.

First we asked which of the lotteries in Figure 8A was preferred and found the first one was. This implied $h + h_{12}$ was greater than one. To get values for h and h_{12}, we assessed the probabilities such that the consequences and lotteries in Figures 8B and 8C were indifferent. These implied that $h = .9$ and $h_{12} = .4$, so

$$u_G(u,x_{12}) = 0.9u + 0.4u_{12}(x_{12}) - 0.3uu_{12}(x_{12}) \quad . \quad (35)$$

Lastly, we needed to assess u_{12}. This was done by finding $x_{12} = \$6$ was indifferent to a lottery yielding either $x_{12} = \$0$ or $x_{12} = \$10$, each with a one-half probability. Fitting a constantly risk averse utility function to this data implies

$$u_{12}(x_{12}) = 1.784 - .784e^{.082x_{12}} \quad , \quad x_{12} \text{ in millions of dollars.} \quad (36)$$

Equations (33), (35), and (36) give us one possible overall utility function u_G for the CDE.

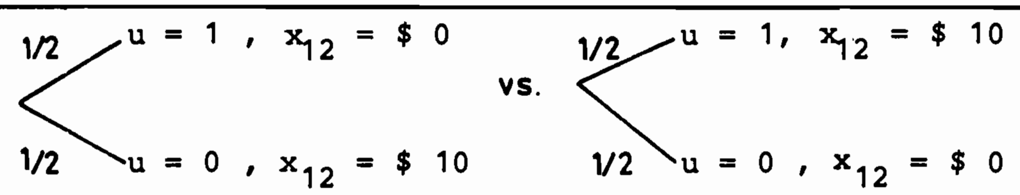

Fig.8A. Comparing Two Lotteries
(The Second was Preferred)

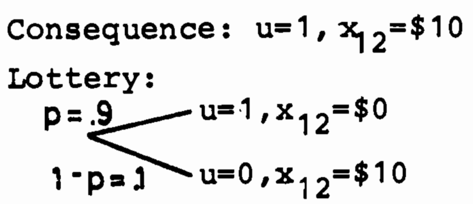

Fig.8B. Assessing p for Indifference

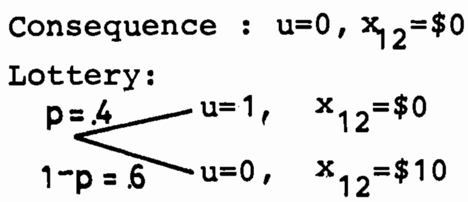

Fig.8C. Assessing p for Indifference

Fig.8. Assessing Hilborn's Utility Function for the Canadian Department of the Environment

6. Walters' First-Cut Utility Functions for the Interest Groups

In this and the next section, another preliminary utility function using Carl Walters' judgments was assessed. In the discussion, we will not spend as much detail as in the previous case since the overall process is very similar. However, the aggregation of Walters' preferences required a slightly different structure and these differences will be illustrated. To avoid interchanging the utility functions of Hilborn and Walters, we will use v as a utility function for Walters, whereas u was used previously.

The Net Fishermen's Utility Function

We first began by assessing the net fishermen's utility function using either the additive form (11) or the multiplicative form (12). The utility functions v_1, v_2, and v_3 for attributes X_1, X_2, and X_3 were first assessed. We found the certainty equivalent for the lottery <\$0;\$25,000> yielding a one-half chance at each of the two consequences was x_1 = \$8000. An exponential fit then resulted in the utility function shown in Figure 9A. A similar exponential fit gave us u_3 in Figure 9C.

Preferences for attribute X_2 were found to be nonmonotonic. They increased from 0 to 50 days fishing and then dropped off to an absolute minimum at 100 days. As a result, two exponential fits were used for v_2. Using 85 indifferent to <50,100>, we specified v_2 for x_2 between 50 and 100, and using 20 indifferent to <0,50> we specified v_2 for x_2 between 0 and 50. To consistently scale these two parts we found 85 days and 0 days were equally desirable. Thus $v_2(0) = v_2(85)$. The final result is shown in Figure 9B.

To evaluate the scaling factors k_1, k_2, and k_3, the indifference pairs in Figures 9D and 9E were assessed along with the indifference probability in Figure 9F. This gave us $k_1 = 0.84$, $k_2 = 0.29$, and $k_3 = 0.49$.

For two checks, we found the preferences between the lotteries of Figure 9G and the indifference pair in Figure 9H. Both of these were consistent. The final utility function is

$$v_N(x_1,x_2,x_3) = \frac{1}{-0.9}\left[\left(1 - .756v_1(x_1)\right)\left(1 - .261v_2(x_2)\right)\left(1 - .441v_3(x_3)\right) - 1\right] \tag{37a}$$

where

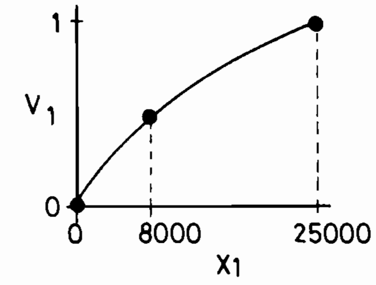

FIG.9A. UTILITY FUNCTION FOR NET FISHERMAN INCOME

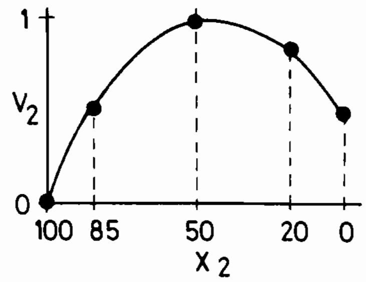

FIG.9B. UTILITY FUNCTION FOR NET FISHERMAN WORKDAYS

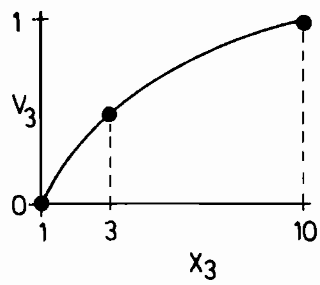

FIG.9C. UTILITY FUNCTION OF NET FISHERMAN FOR VARIETY

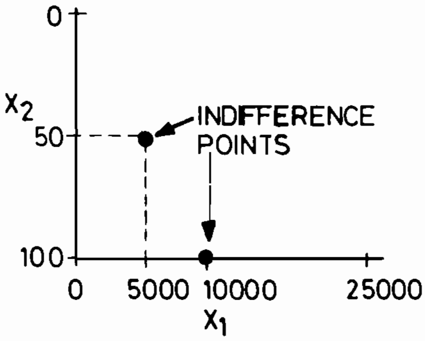

FIG.9 D. TRADEOFFS BETWEEN X_1 AND X_2

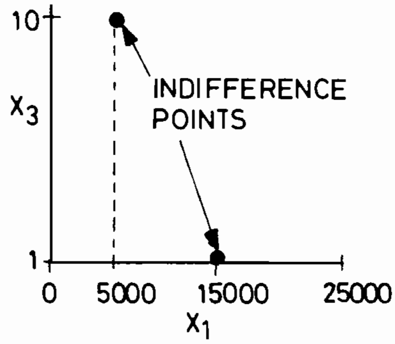

FIG. 9E. TRADEOFFS BETWEEN X_1 AND X_3

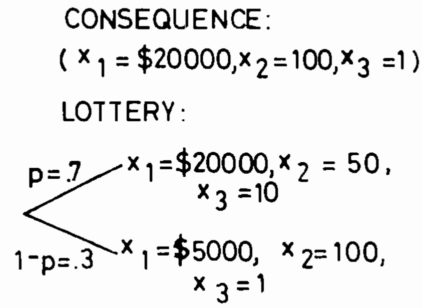

FIG.9F. ASSESS p FOR INDIFFERENCE

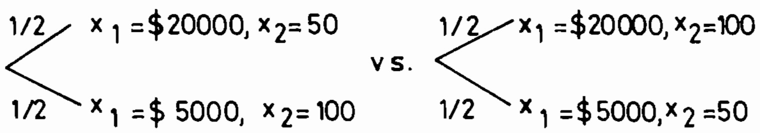

FIG.9. COMPARING TWO LOTTERIES (THE SECOND WAS PREFERRED)

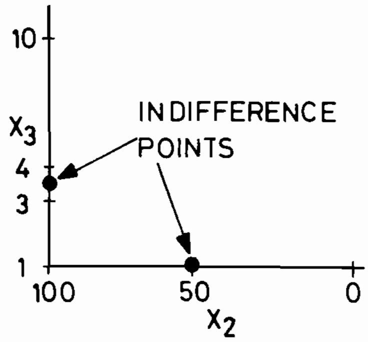

FIG.9H. TRADEOFFS BETWEEN X_2 AND X_3

FIG.9. ASSESSING WALTERS' UTILITY FUNCTION FOR THE NET FISHERMAN

$$v_1(x_1) = 1.26\left(1 - e^{-.0000633x_1}\right) \tag{37b}$$

$$v_2(x_2) = \begin{cases} 1.392 - 0.0892e^{-.0164x_2} , & 0 \le x_2 \le 50, \\ 1.197 - 0.033e^{.036x_2} , & 50 \le x_2 \le 100, \end{cases} \tag{37c}$$

and

$$v_3(x_3) = 1.06 - 1.458e^{-.0.319x_3} . \tag{37d}$$

There is one important difference about the assessment procedures used for u_N and v_N. With v_N, the lowest income used was $5000 whereas $0 was used in assessing u_N. Since $0 is extremely unlikely as well as severe, it is much more difficult to evaluate tradeoffs when possibilities of obtaining $0 exist. The change to use 'more thinkable values' likely leads to better assessments.

<u>The Lure Fishermen's Utility Function</u>

The procedure followed was identical to that for the net fisherman. Using the information in Figure 10, the utility function was found to be

$$v_L(x_4,x_5,x_6) = \frac{1}{-.46}\left[\left(1 - .304v_4(x_4)\right)\left(1 - .147v_5(x_5)\right)\left(1 - .092v_6(x_6)\right) - 1\right] , \tag{38a}$$

where

$$v_4(x_4) = 1.01\left(1 - e^{-0.170x_4}\right) , \tag{38b}$$

$$v_5(x_5) = \begin{cases} 1.234\left(1 - e^{-0.021x_5}\right) , & 0 \le x_5 \le 80 , \\ 1.078 - 0.0029e^{0.041x_5} , & 80 \le x_5 \le 100, \end{cases} \tag{38c}$$

and

$$v_6(x_6) = 1.06 - 1.458e^{-0.319x_6} . \tag{38d}$$

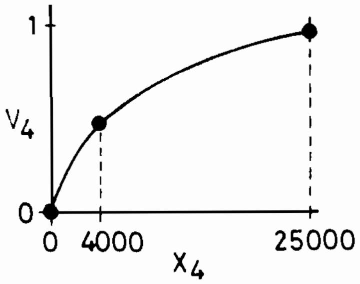

FIG.10A. UTILITY FUNCTION FOR NET FISHERMAN INCOME

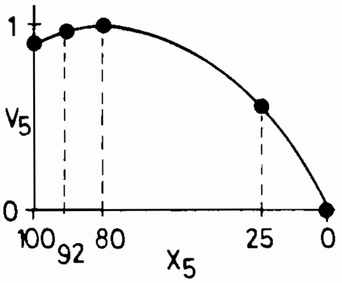

FIG.10B. UTILITY FUNCTION FOR LURE FISHERMAN WORKDAYS

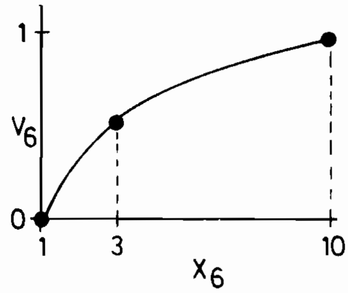

FIG.10C. UTILITY FUNCTION OF LURE FISHERMAN FOR VARIETY

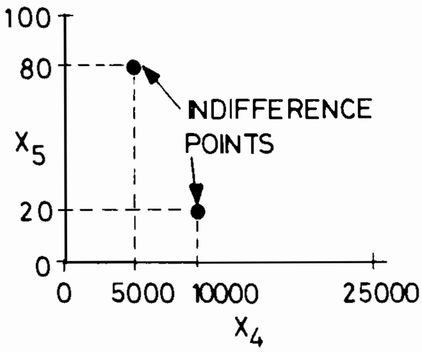

FIG.10D. TRADEOFFS BETWEEN X_4 AND X_5

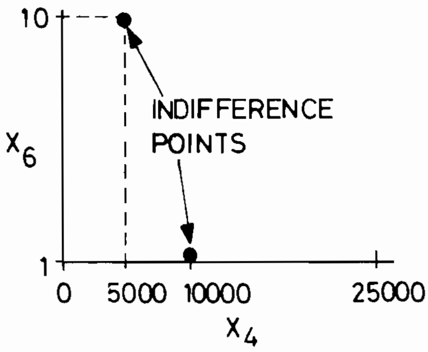

FIG.10E. TRADEOFFS BETWEEN X_4 AND X_5

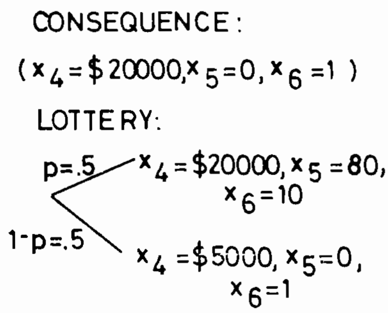

FIG.10F. ASSESS p FOR INDIFFERENCE

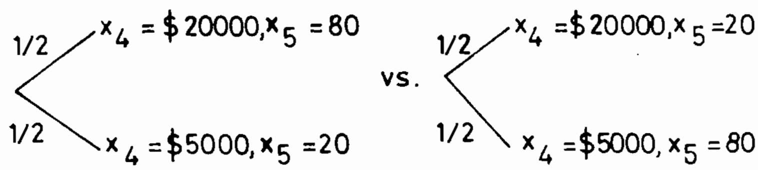

FIG.10G. COMPARING TWO LOTTERIES (THE SECOND WAS PREFERRED)

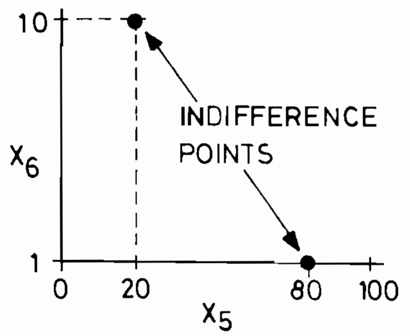

FIG.10H. TRADEOFFS BETWEEN X_5 AND X_6

FIG.10. ASSESSING WALTERS' UTILITY FUNCTION FOR THE LURE FISHERMAN

The scaling factors were $k_4 = 0.66$, $k_5 = 0.32$, and $k_6 = 0.20$.

Let us briefly comment on two differences between the lure and net fishermen's utility functions. First, the lure fishermen are more risk averse in the monetary attribute. This is mainly because they work most of the year and have little chance to subsidize their fishing incomes. The net fishermen however have a season and can recover from a bad fishing year more easily by working during that part of the year when they are not fishing. The other main difference is in the lure and net fishermen's utility functions for days worked. To see this compare Figures 9B and 10B. The lure fishermen work mainly in the daytime in pleasant weather whereas the net fishermen must fish at night in all kinds of weather during the season.

The Sport Fishermen's Utility Function

The certainty equivalent for the 50-50 lottery yielding 0 or 1,000,000 was 200,000. Fitting an exponential utility function to this, we found

$$v_S(x_7) = 1.039\left(1 - e^{-.00000328x_7}\right) , \qquad (39)$$

where x_7 is the number of fish in the annual catch. This utility function is illustrated in Figure 11.

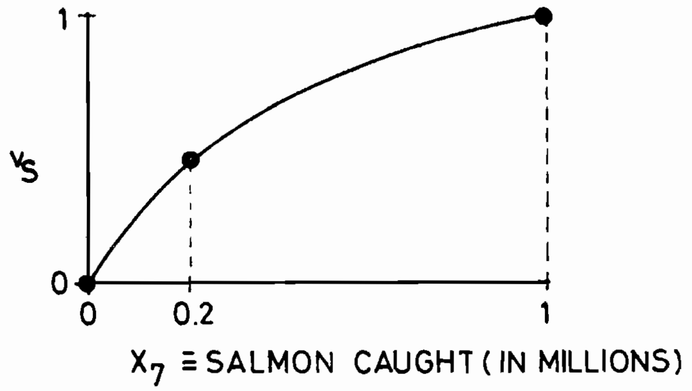

FIG. 11. WALTERS' UTILITY FUNCTION FOR THE SPORT FISHERMAN

The Utility Function for the Region

The information used to assess the utility function for the region is illustrated in Figure 12. This was done exactly as in previous cases except for the fact that the lottery used to assess v_8 did not cover the entire range. That is, we did not use the certainty equivalent to the lottery <0,5000>. Rather we found 2000 indifferent to <1000,5000> which avoids the extra difficulty of thinking about the extreme of 0 employment.

The final scaling factors were $k_8 = 0.81$, $k_9 = 0.34$, and $k_{10} = 0.07$ implying $k = -0.64$. The final utility function was

$$v_R(x_8,x_9,x_{10}) = \frac{1}{-0.64}\left[\left(1-0.52v_8(x_8)\right)\left(1-0.22v_9(x_9)\right)\left(1-0.044v_{10}(x_{10})\right) - 1\right] \qquad (40a)$$

where

$$v_8(x_8) = 1.05\left(1 - e^{-.000609x_8}\right), \qquad (40b)$$

$$v_9(x_9) = 1.01\left(1 - e^{-0.455x_9}\right), \qquad (40c)$$

and

$$v_{10}(x_{10}) = -5.64 + 1.118e^{-0.529x_{10}}. \qquad (40d)$$

The Indians' Utility Function

We found 10,000 was indifferent to a lottery yielding either 0 or 100,000 each with probability of one-half. Fitting this, we find

$$v_I(x_{11}) = 1.001\left(1 - e^{-.0000692x_{11}}\right), \qquad (41)$$

which is illustrated in Figure 13.

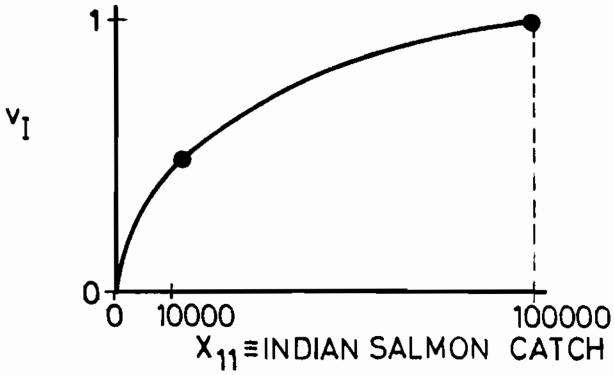

FIG.13. WALTERS' UTILITY FUNCTION FOR THE INDIANS

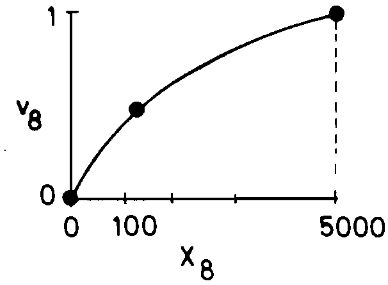

FIG.12A. UTILITY FUNCTION FOR EMPLOYMENT

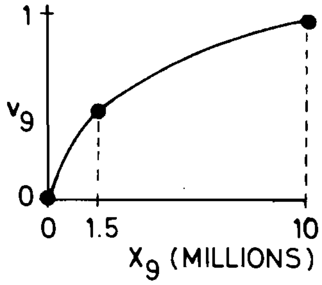

FIG.12B. UTILITY FUNCTION FOR RECREATIONAL INCOME

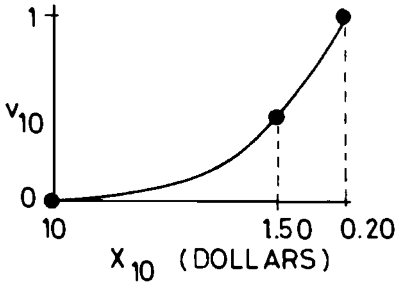

FIG.12C. UTILITY FUNCTION FOR SALMON PRICE

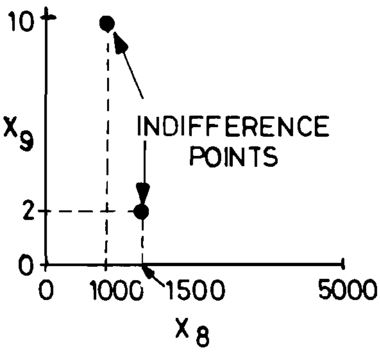

FIG.12D. TRADEOFFS BETWEEN X_8 AND X_9

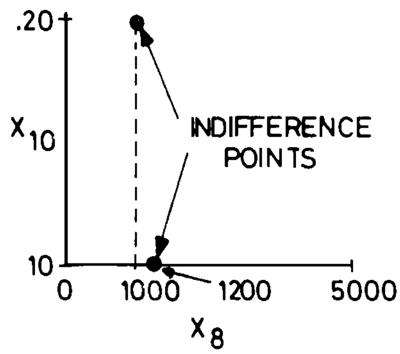

FIG.12E. TRADEOFFS BETWEEN X_8 AND X_{10}

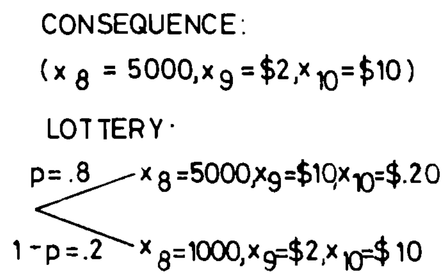

FIG.12F. ASSESS p FOR INDIFFERENCE

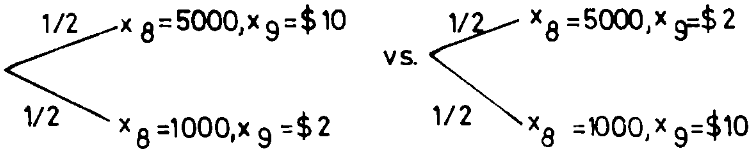

FIG. 12G. COMPARING TWO LOTTERIES (THE SECOND WAS PREFERRED)

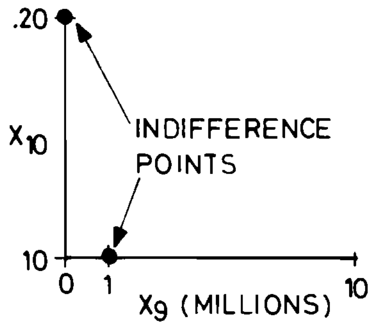

FIG.12H. TRADEOFFS BETWEEN X_9 AND X_{10}

FIG.12. ASSESSING WALTERS' UTILITY FUNCTION FOR THE REGION

6. Walters' Overall Utility Function for the Canadian Department of the Environment

Having assessed the five groups' utility functions, we can consider the problem of the CDE to aggregate six attributes: V_N, V_L, V_S, V_R, V_I, and X_{12}, which are measured by v_N, v_L, v_S, v_R, v_I, and x_{12} respectively.

The Assumptions

First we examined the assumptions necessary to directly invoke Theorem 1 for these six attributes. For instance, an important check can be illustrated by the four pairs of lotteries illustrated in Figure 14. Notice that the first of each of these pairs offers either both of the attributes at their best levels or both at their worst, whereas the second lottery in each pair has one attribute at the best level and the other at the worst level for each of the two possible consequences. In all cases, the second lottery was preferred indicating a strong tendency to 'do well by at least some of the measures.' Had it not been the case that either the first or the second lottery was preferred for all four sets, then the preferential independence assumptions necessary for Theorem 1 would have been violated. Direct examination of some tradeoffs led us to conclude the assumptions did hold and that we could use Theorem 1.

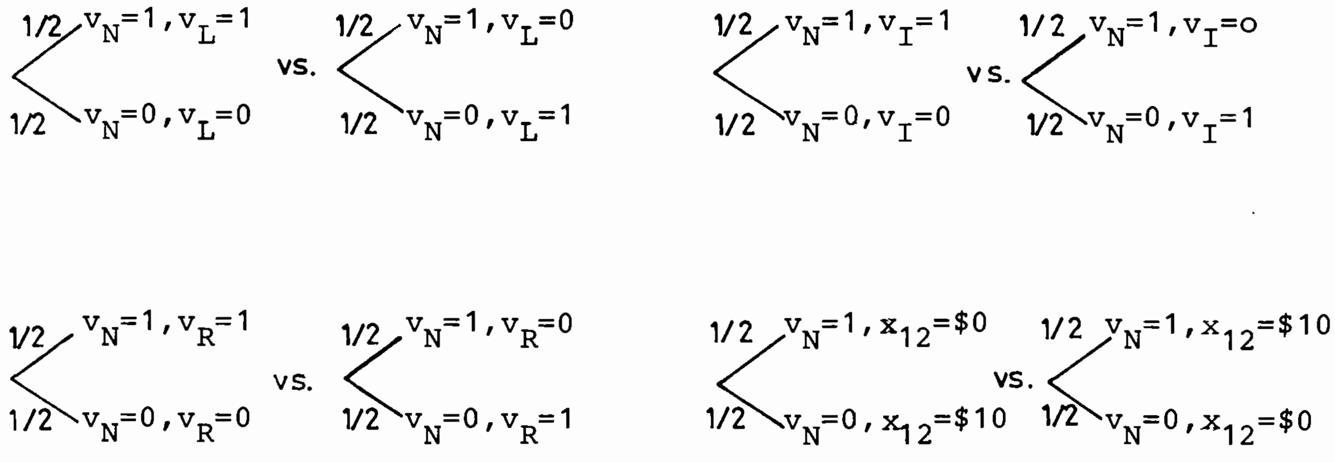

Figure 14 . Comparing Lotteries (The Second was Always Preferred)

The Assessments

Since we had already assessed all the necessary component utility functions except for v_{12}, the remaining task was to do this and then determine the scaling constants for the overall additive or multiplicative utility function.

A different range, zero to fifty million dollars, was used on assessing v_{12} than on the corresponding u_{12} in Hilborn's utility function. Walters felt 25 was indifferent to the lottery <0,50> and that the utility function should be linear. It is

$$v_{12}(x_{12}) = 1 - 0.02x_{12} \quad , \quad x_{12} \text{ in millions} \quad . \qquad (42)$$

To assess the scaling constants, tradeoffs between X_8 and an attribute within each of the other five groups of attributes were examined. The pairs of indifference points are shown in Figure 15, parts A through E. Equating the utilities of the indifference points gives us five equations with six unknowns, the scaling constants for V_N, V_L, V_S, V_R, V_I, and X_{12}. A sixth equation is provided by assessing the indifference probability in Figure 15F. Such a high indifference probability again indicates the strong desire to have at least some measures look good.

The scaling constants were calculated to be $\lambda_N = 0.76$, $\lambda_L = 0.9$, $\lambda_S = 0.57$, $\lambda_R = 0.9$, $\lambda_I = 0.24$, and $\lambda_{12} = 0.66$ implying $\lambda = -0.999$. The final CDE utility function is

$$v_G(v_N,v_L,v_S,v_R,v_I,x_{12}) = \frac{1}{-0.999}\Big[\big(1 - .76v_N\big)\big(1 -.9v_L\big)\big(1 - .57v_S\big)$$

$$\big(1 - .9v_R\big)\big(1 - .24v_I\big)\big(1 - .66v_{12}(x_{12})\big) - 1\Big] \quad , \qquad (43)$$

where v_N, v_L, v_S, v_R, v_I, and v_{12} are defined by (37) through (42) respectively.

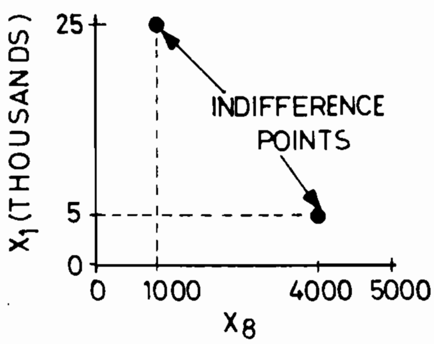

FIG.15A. TRADEOFFS BETWEEN NET FISHERMAN AND REGIONAL DEVELOPMENT

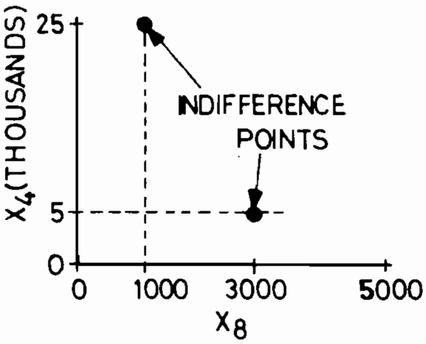

FIG.15B. TRADEOFFS BETWEEN LURE FISHERMAN AND REGIONAL DEVELOPMENT

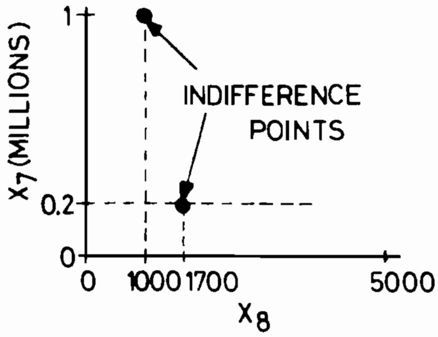

FIG.15C. TRADEOFFS BETWEEN SPORT FISHERMAN AND REGIONAL DEVELOPMENT

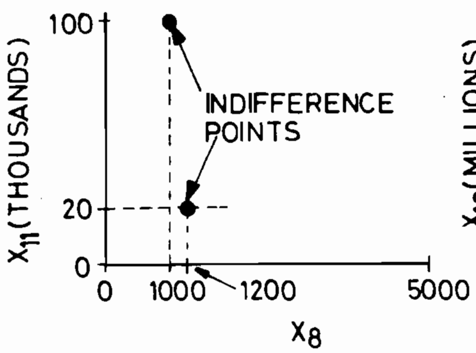

FIG.15D. TRADEOFFS BETWEEN INDIANS AND REGIONAL DEVELOPMENT

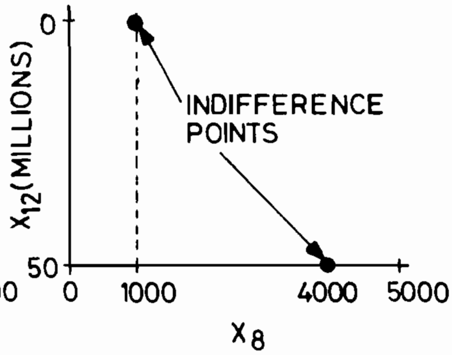

FIG.15E. TRADEOFFS BETWEEN CDE COSTS AND REGIONAL DEVELOPMENT

CONSEQUENCE:

$x_8 = 5000$, $x_9 = \$10$, $x_{10} = \$.20$,
$X_1, \ldots\ldots, X_7, X_{11}, X_{12}$ AT WORST LEVEL OF THEIR RANGES.

LOTTERY:

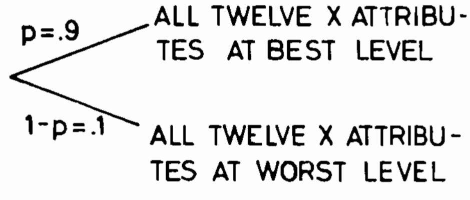

FIG.15F. ASSESS p FOR INDIFFERENCE

FIG.15. ASSESSING WALTERS' UTILITY FUNCTION FOR THE CANADIAN DEPARTMENT OF THE ENVIRONMENT

7. Comparing the Two Overall Utility Functions

In this section, we will examine briefly some of the similarities and differences implied by Hilborn's utility function u_G and Walters' utility function v_G. The purpose is twofold:

1. to illustrate the wide variety of preference attitudes which can be captured by the multiplicative utility functions, and
2. to set the stage for suggestions for further work in Section 8.

In interpreting these comparisons, two things should be kept in mind. First, there are no objectively right or wrong utility functions. These functions formalize subjective preferences and different individuals can (and do) have different preferences. Secondly, both Hilborn's and Walters' utility functions are first-cut utility functions. We did do some preliminary consistency checks while assessing these utility functions as indicated in this report. However, we have not had the opportunity for in-depth examinations needed to obtain a final representation that one feels captures all of the basic preference attitudes. With these caveats, let us first look at the various group's utility functions, and then at the overall CDE's preferences.

The Net Fishermen's Utility Functions

In comparing the utility functions, let us first look at the single attribute utility functions and then at the tradeoffs among attributes. Hilborn's utility function for the net fisherman is given in Figure 2 and Walters' in Figure 9. One immediately sees that u_1 and v_1 and also u_3 and v_3 are identical. However, u_2 and v_2 are very different. With u_2, the less one works, assuming constant income as measured by attribute X_1, the better. With v_2, preferences increase up to a maximum at 50 days and then decrease. This implies, for instance, that a net fisherman would be willing to give up some amount of income in order to increase fishing time from 20 to 50 days. The function u_2 implies a dislike for fishing per se, whereas v_2 implies that there is a positive value in itself to fish as long as it is not too much fishing.

For the tradeoffs, we can look at the values assigned to k_1, k_2, and k_3. Hilborn's preferences implied $k_1 = 0.8$, $k_2 = 0.36$, and $k_3 = 0.17$, and Walters' were $k_1 = 0.84$, $k_2 = 0.29$, and $k_3 = 0.49$. The major difference here is in the weighting of k_3. Walters considered it much more important, relative to net fishermen's incomes, to keep X_3 high. As one indication, Hilborn would allow X_3 to drop from 10 to 1 in order to have X_1 increase from 0 to \$2400. To accept this same decrease in X_3, Walters required income to increase from 0 to \$9800.

The Lure Fishermen's Utility Functions

Recall that Hilborn used the same utility functions for lure and net fishermen. Hence to compare Hilborn's and Walters' lure fishermen's utility functions, refer to Figures 2 and 10. The utility functions u_6 and v_6 are identical. For income v_4 is more risk averse than u_4. As explained in Section 5, Walters felt the lure fishermen would be more risk averse because they fish more or less over the entire year and have little chance to subsidize their income from other activities. The utility functions u_5 and v_5 are quite different for the same reason as discussed for the net fisherman.

The scaling constants are $k_4 = 0.8$, $k_5 = 0.36$, and $k_6 = 0.17$ for Hilborn and $k_4 = 0.66$, $k_5 = 0.32$, and $k_6 = 0.20$ for Walters. The relative values here are about the same, implying one would be willing to give up, for example, roughly the same in income (as measured by utility for income) to increase a fixed degree in either workdays or variety (as measured by their respective utility functions).

By observing Figures 2G and 10G, it is clear that both Hilborn and Walters prefer a lottery which has one of two attributes at a desirable level to a lottery with either both at a desirable or undesirable level. Such an attitude implies $k_1 + k_2 + k_3 > 1$.

The Sport Fishermen's Utility Function

Comparing Figures 3 and 11, we see v_S is a little more risk averse than u_S. Hilborn was indifferent between 0.3 million fish caught for sure or a 50-50 chance at 0 or 1 million, whereas Walters preferred 0.3 million to the lottery. On the other hand, Walters was indifferent between 0.2 million for sure and a 50-50 chance at 0 or 1 million. Hilborn would choose the lottery in this last situation. Both are risk averse, however, and the differences would likely not be critical for policy decisions. Of course, this could be checked in any evaluation of potential policies.

The Region's Utility Function

The three component utility functions for the region: u_8, u_9, and u_{10} and v_8, v_9, and v_{10} respectively are quite similar to each other. This can be seen by comparing Figures 4 and 12. The only real difference seems to be that 1800 is indifferent to the lottery <0,5000> using u_8 whereas 1100 is indifferent using v_8. Both utility functions for employment and both for recreational income are risk averse, whereas those for salmon price are risk prone.

The scaling factors for u_R are $k_8 = 0.8$, $k_9 = 0.43$, and $k_{10} = 0.125$ and for v_R are $k_8 = 0.81$, $k_9 = 0.34$, and $k_{10} = 0.07$. These two sets have quite similar implications. The differences in the k_{10} result in a big difference in tradeoffs between X_8 and X_{10}. Hilborn would allow the price of salmon to rise from \$.20 to \$10 only if employment would increase from 0 to 485. That is ($x_8 = 0$, $x_{10} = \$.20$) is indifferent to ($x_8 = 485$, $x_{10} = \$10$). On the other hand, Walters would allow the same price increase to increase employment to 140. This means for him ($x_8 = 0$, $x_{10} = \$.20$) is indifferent to ($x_8 = 140$, $x_{10} = \$10$).

Again, by comparing part G of Figures 4 and 12, one sees both individuals felt it was better to do well by at least one measure than risk a one-half chance of a poor performance on both.

The Indians' Utility Function

Both Hilborn and Walters assessed very risk averse utility functions for the Indians. They would be willing to give up significant chances of a big catch in order to insure some small catch. Hilborn felt 20,000 was indifferent to a 50-50 chance at 0 or 100,000, whereas Walters felt this indifference point was 10,000. The utility functions u_I and v_I are illustrated in Figures 5 and 13 respectively.

The Overall CDE Utility Function

Recall that the methods of aggregating the component utility functions into an overall utility function were different for Hilborn and Walters. Hilborn required that one 'nest' three levels of multiplicative utility functions, whereas one level was required for Walters. The additional levels provide for more complicated interaction of preferences among the groups.

From Figure 14, one can see that for Walters, whenever two lotteries were given which had the same possible outcomes when viewed one attribute at a time, the lottery which guaranteed at least one attribute to be at a desirable level was preferred. This was not always the case with Hilborn. As seen from Figure 6A, it was the case if the two attributes indicated respectively the net and lure fishermen's interests.

However, considering the four groups: commercial fishermen, sport fishermen, the region, and Indians, the situation altered for Hilborn. This is illustrated in Figures 2E and 2F. Hilborn preferred the first lottery in each case, reasoning that both outcomes of the second lottery were unfair--one group always did great and the other group terribly. In the first lottery, at least the groups were 'in the same boat.' This attitude implied the scaling factors λ_R, λ_C, λ_I, and λ_S in (32) need to sum to less than one. As seen from Figure 14, this attitude is not shared by Walters. He still prefers to have some group doing well and is willing to give up a little in 'fairness' to achieve this.

When one gets down to possible combinations of group satisfaction and CDE costs, Hilborn and Walters are in general agreement again. Compare the last lottery pair in Figure 14 with Figure 8A. In both cases the second lottery was preferred, because one could perhaps justify either spending a lot to get many desirable benefits or spending nothing to get few benefits. However, there is a chance in the first lottery of spending a lot and getting nothing in return. That combination is particularly undesirable.

If one looks at the scaling factors of u_G and v_G, a direct comparison is not possible because the functional forms are different. However, we can look at the utility of having attribute U_j (or V_j) at its best level while all other attributes are at their worst levels, call this $\bar{u}_j$ (or $\bar{v}_j$), measured relative to the scale of u_G (or v_G) from zero to one. Doing this we find $\bar{u}_N = 0.09$, $\bar{u}_L = 0.09$, $\bar{u}_S = 0.02$, $\bar{u}_R = 0.36$, and $\bar{u}_I = 0.04$ and $\bar{v}_N = 0.76$, $\bar{v}_L = 0.9$, $\bar{v}_S = 0.57$, $\bar{v}_R = 0.9$, and $\bar{v}_I = 0.24$. This is a major difference mainly due to the differences among preferences for lottery pairs discussed earlier. It means that the indifference probability for the lottery in Figure 15F using Hilborn's preferences would be 0.36 rather than 0.9 as was the case with Walters.

The utility functions for the expenses of the CDE, attribute X_{12}, are different. Walters felt preferences should be linear, implying an expenditure of 5 million dollars indifferent to a 50-50 chance of 0 or 10. Hilborn felt 6 million was indifferent to $\langle 0,10 \rangle$.

8. Use of Utility Analysis of the Skeena Problem

To date, we have only made rough assessments of utility functions for two members of the ecology project. What are some of the possible uses of these? One is to more clearly articulate substantive issues of the problem and sensitize various individuals to these issues. For instance, some of the basic preference attitudes indicated by u_G and v_G may be critical in evaluating policy options. To identify these as important should lead to more concrete discussion of these aspects. Note that this is true whether or not the final choice of policy will be made assisted by a utility model (or any model) or by an in-the-head evaluation.

By addressing the preference issues, some ambiguities in the problem structure often appear. For instance, it may become apparent that difficulties in assessment are due to double counting--for example, does one prefer more fishing days only for the income it brings or for the fishing itself? Having identified such difficulties, they can often be clarified.

The individual utility functions aid communication among members of a team working on a problem. They should help to isolate differences in judgments about possible impacts of a policy from differences in preferences for these impacts. This could be an important step toward resolving these differences.

It may be possible for the different members of the study team to come to some agreement on a reasonable utility function for evaluating Skeena development. To do this would require detailed examination of the implications of the utility function to make sure it does imply all preference attitudes that seemed relevant. This would involve significant interaction among the group members, as well as with outside experts including members of the groups involved in the problem. If it is not possible for the team members to agree on one utility function, they can maybe use two or three and examine differences in implications for policy.

Given we do have utility functions, they can be used to aid in examining and evaluating policies. For this they would need to be used in conjunction with the dynamic model which generates the impacts of various possible policies. Suppose one option is fine for all the groups but one. By investigating why this group fares so poorly in terms of its component attributes, we may find a hint toward generating a new alternative which raises that 'low' group significantly at little expense to the other groups.

If there is no agreement on an overall utility function, perhaps each of the possibilities will lead to the same 'best' options; or at least each utility function may imply that some options can be discarded from future consideration.

Possible Future Work

To be brief, four general categories of research should be considered. The first is to generate a (or two or three) utility function(s) representing the teams' understanding of the preferences. Secondly, it would be very interesting to directly assess utility functions of various members in the groups of net fishermen, lure fishermen, Indians, CDE, etc. These could be used to refine an overall government utility function. Third, it would be important to try to account for the time aspects of the problem. Certainly, any major policy adopted now would likely have impact for at least a few years to come. At present, the variety indicators are proxy variables for 'the future,' but this is not really adequate. Along this line, some recent work of Bell [1] concerning time preferences for evaluating control strategies for the spruce budworm, a forest pest, may prove helpful. As a final suggestion, I feel it would be worthwhile to begin examining possible policies with the utility model. It certainly is not perfect but the alternative is to somehow aggregate all those output data in one's head--and that's not perfect either.

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[1] Bell, D.E. "A Utility Function for Time Streams Having Inter Period Dependencies," RR-75-22, IIASA, 1975.

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