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Title: Application of Multiattribute Utility Analysis in Determining Coho Salmon Policy

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Policy decisions in fishery management are becoming increasingly complex and difficult. This is especially true for the salmon fisheries where policy outcomes affect the productivity of the salmon resource and the subsequent well-being of commercial fishermen, charter boat operators, Indian fishermen, and sport anglers. The objective of this study was to advance methodology from statistical decision analysis which would assist fishery managers in Oregon who must make particularly difficult choices with respect to allocation and production of coho salmon while recognizing uncertainties in the environment, incomplete state of knowledge, and the conflicting needs and desires of different interest groups.

The method chosen given multiple objectives and uncertainty is multiattribute utility analysis. The approach consists of two main components: (1) a computer model which simulates the life cycle of hatchery and stream spawning coho salmon given environmental variation, different hatchery juvenile release levels and harvest rates; and (2) an objective function which relates the different outcomes from alternative release levels and harvest rates to an assessment of the degree to which individual objectives are met.

The approach was used to evaluate and rank the expected outcomes from twelve proposed policies under different hypothesized ocean environments. Analysis of the results suggest that (1) the most effective policy is achieved with a relatively low harvest rate and high smolt release level; (2) selection of a particular harvest rate is the most important decision variable; and (3) a large smolt release level can be maintained unless such releases adversely decreases the ocean survival of stream spawning coho.

Because the coho fishery is a mixed stock fishery consisting of hatchery and wild stocks, the results suggest that too high a harvest rate will lead to depletion of wild stocks, considered important because of their potential contribution to production and diverse genetic traits and characteristics. Conversely, too low a harvest rate will lead to excessive escapement of coho and thus reduce the total catch.

As is illustrated, formulating the coho decision problem in a multiattribute utility analysis framework is useful in two ways. First, by quantifying the objectives of the decision maker, consistent results from following alternative policies can be determined. These results provide a basis for comparison and serve as a guide for decision making involving uncertainty. Second, the approach is useful in isolating major objectives and conflicts, value judgments, trade-offs, and needed empirical evidence.

Application of Multiattribute Utility Analysis in Determining Coho Salmon Policy

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I. Introduction

During the last decade policy decisions in fishery management have become increasingly complex. This is particularly true for the salmon resource which provide for commercial, recreational, and non-consumptive benefits to a large array of user groups. These user groups, which with time have become more specialized, include charter, troll and net commercial fisheries, Indian and sport fisheries, and private aquaculture. With specialization and growth of these groups, the number of management agencies and thus the number of regulations have increased. In Oregon the lead agency charged with the responsibility for maintaining a viable salmon resource and adopting policies which provide maximum benefits to all groups is the Oregon Department of Fish and Wildlife (ODFW). However, in formulating policy not only must ODFW be concerned with the salmon and user groups, but it must also coordinate efforts with other agencies such as the Pacific Fisheries Management Council, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and many others. Compounding the difficulty in arriving at policy decisions is the large fluctuation in the total number of recruits; i.e., the number of salmon who because of age, size, and location are available for catch. Upon entering the ocean young salmon may journey more than 2,000 miles before either being captured or escaping back to their original spawning grounds. As a result, the salmon are subject to many variations which alter their survival and thus the total number of recruits.

In enacting policy, decision makers are charged with the responsibility of seeking to balance the needs and desires of different user groups concurrent with their understanding of the salmon resource. To be sure, deciding on a "best" policy is no easy task. User groups have multiple interests or objectives and any decision will affect each group differently. Further, the common property characteristic of the valuable salmon resource (Crutchfield) implies both difficult choices when allocating salmon among user groups at one point in time and even harder decisions concerning the acceptable harvest levels for fishermen in one year given the costs of fewer spawning salmon needed to provide production in future years. Uncertainty about environmental forces and response by fishermen to alternative regulations in an uncertain market further complicate these allocation decisions. Most decisions require trade-offs or value judgments. For example, questions concerning the appropriate size of sport angler harvest and the number of salmon which private agencies should be allowed to propagate and release rely heavily on the preference structure of the decision maker. These preferences are based on many factors including the decision maker's perception of the needs and desires of the different user groups, historical performance of the resource, attitude toward risk and research.

The complexities of formulating policy decisions given uncertainty are evident in the Oregon coho salmon (Oncorhynchus kisutch) fishery. The majority of coho recruits come from salmon released at public and private hatcheries. The remaining portion originates naturally from coastal rivers and streams. Coho provide many recreational opportunities to sport fishermen and are an important source of income for commercial fishermen. One reason why the number of participants in the commercial fisheries has continued to increase is the price of coho. Over the past decade the price paid to troll fishermen for coho salmon rose at an annual rate of 16.5 percent as compared to the annual rate of increase of the GNP implicit price deflator of 6.9 percent. The relative value of coho has also influenced the decision of private ventures in salmon ranching to expand. In 1981 coho salmon releases from private hatcheries accounted for about one-third of total hatchery production.

Since 1976, in spite of efforts by ODFW to enhance the coho resource, the total number of recruits has steadily declined. With this decline pressure on management by user groups and the importance of policy decisions have increased. Fewer coho implied that more difficult decisions on allocation and trade-offs between user groups be made. These decisions have led to tighter restrictions on when and where fishing seasons would open and close for commercial and sport fisheries in order to reduce the total number of recruits which would be caught. Policy decisions did not go uncontested as the different groups lobbied for their own best interests and required careful documentation of all policy decisions. In an effort to arrest and reverse the decline in the total number of coho recruits, a major project was undertaken by ODFW to conduct and bring together research about the biological system in which coho operate. The agency hoped that this research would improve understanding on such factors as environmental variation and how this variation affected the performance or survival of hatchery coho.

Given the multiple objectives of the user groups and the biological elements involving uncertainty, the intent of this research was to reduce these components to manageable size for analysis and discussion. One approach whereby complex decision problems can be addressed is multiattribute utility analysis (MUA, Keeney and Raiffa). MUA consists of two major components: an objective function and a simulation model. The objective function--more commonly referred to as a utility function--examines the preferences and trade-offs of the decision maker. The simulation model indicates the impact in terms of the utility function from following alternative policies or strategies given uncertainty associated with the system in which coho operate.

Throughout the analysis several discussions were held with the assistant fisheries chief of ODFW. This individual has considerable knowledge and experience in fisheries management and policy formulation and is directly involved in planning, monitoring, and improving the coho salmon resource. In order to initiate specification of the objective, the decision maker was asked to list the user groups in Oregon affected by the coho fishery. The attributes or performance measures of the fishery with which each group would be concerned were then specified. In choosing between plans, the various levels of the attributes should help to indicate how much better or worse off a particular group would be. The groups and attributes selected are shown in Table 1. Similar results are reported by Hilborn and Walters. Having determined the attributes and user groups, selection of the most significant performance measures was conducted. In doing this, it became apparent that the most important attributes centered on the stock concept; i.e., the idea that the fishery is actually an aggregation of many subgroups of coho salmon each with distinctive characteristics and traits. Further, it was felt that the stock issue was the key component to policy decisions and paramount to analysis of the attributes in Table 1. That is, the coho decision problem can be thought of as consisting of a hierarchy of objectives with the most important objective centering on recognition of stocks in policy formulation.

The purpose of this thesis is to determine whether multiattribute utility analysis can improve the capability of the Oregon Department of Fish and Wildlife to reach an effective policy decision with respect to coho salmon. The next section is devoted to an examination of the stock concept, identification of objectives, and selection of attributes. In the third section the methodology and assessment of the utility function is described. Following that, the simulation model is specified. During the course of the study described, additional biological research was being conducted. Where possible, this information was incorporated into the model. The fourth section is devoted to a description of the results of the

Table 1. User groups and attributes considered in specifying the coho decision problem.

I. Commercial fishermen
- Timing of season
- Length of season
- Variability of returns over time
- Run size - number and weight of fish
- Allocation
- Days/week work
- Number of fish released
- Number of fishermen
- Gear
- Private aquaculture

II. Sports fishermen
- Length of season
- Timing of season
- Run size
- Allocation
- Expectations (variation)
- Bag limit
- Catch per unit of effort
- License and fishing costs
- Alternative activities
- Gear
- Availability of support services
- Total catch

III. Management
- Distribution of run
- Run size
- Stock size and diversity
- Allocation
- Variation over time
- Survival rate - public, private, wild
- Contribution rate - public, private, wild
- Escapement - wild, hatchery
- Quality/viability of hatchery stocks
- Habitat considerations
- Predictability
- Fleet size
- Fishing effort
- Total catch - wild, hatchery
- Costs

IV. Private aquaculture
- ODFW operational requirements
  - stock transfer
  - size and time of release
  - number of fish marked
- Timing of fishing season
- Allocation - harvest time
- Availability of eggs
- Number of fish can release
- Harvest rate

V. Community
- Packing companies
  - present capacity
  - quality
  - size
  - run timing
- Commercial residents
  - length of season
  - days per week
  - number of fishermen
  - opportunity cost
- Regional population
  - size of run
  - number of fishermen
  - nonconsumptive use
  - educational opportunities
  - latent use
- Fish eaters
  - price
  - quality
  - availability of fresh fish through time
- Conservationists
  - total run
  - stock diversity
  - habitat

multiattribute utility analysis including sensitivity analysis. In the concluding section, the usefulness of work to date and possible approaches to expand the analysis are described.

II. THE COHO DECISION PROBLEM

The Stock Concept

Formulation of policy for the salmon resource is based on the concept that while there is only one species of coho there are many subgroups or stocks. The importance of stocks and stock guidelines is explained in Wagner, Thompson, and the Comprehensive Plan for Production and Management of Oregon's Anadromous Salmon and Trout (this document contains many of the important concepts as well as much of the relevant data. To simplify citations, it will be referred to by a shortened version of the title of its most important section, i.e., the Coho Plan.). The basic stock concept can be explained by examining the life cycle of coho. The adult salmon dies shortly after spawning in fresh water. Fry emerge from eggs after incubating in stream gravel. Once the juvenile salmon have gone through a transformation which readies them for salt water (smoltification), the coho go to sea. There they feed, grow, and eventually return as adults to their natal stream. Because coho return to a selected place at a particular time, many distinct coho stocks exist. These stocks, for the most part, do not interbreed with other stocks and with time select for different characteristics and traits in response to their particular environment. As a result the coho fishery is actually a mixed stock fishery.

The stock concept is important in deciding what ratio of fish caught to total recruits should be allowed. Define this ratio as the harvest rate. Because the harvest rate is applied across the entire fishery, determination of an optimal rate becomes an important policy decision. Some stocks are commonly regarded as being more productive than others. That is, they can sustain a higher harvest rate yet still have sufficient returns to produce as many recruits as the last generation. The differences in productivity are most apparent between salmon produced at hatcheries and salmon spawned and reared naturally in rivers and streams. For decision analysis define hatchery stocks as coho produced in an environment partially controlled and manipulated by man and wild stocks as all other coho. Hatchery coho stocks originate from eggs which are artificially spawned and incubated. Most of the emergent fry are propagated at the hatchery for about eighteen months and then released as smolts to migrate seaward. The ability of man to partially regulate their early environment enables a higher survival from egg to smolt than what is realized in wild stocks. As a result, fewer recruits are needed back to spawn, and in this sense hatchery stocks are thought of as being more productive than their counterpart. Wild stocks live the first part of their lives in more adverse conditions and accordingly must learn to adapt to more pronounced environmental variations. These include fluctuating water flows and stream temperature, suitable habitat that can be used for spawning and rearing, and abundance of food sources. Because of the large differences in the two environments only about three percent of the eggs spawned by wild coho survive to smolt size versus seventy percent for hatchery coho. In deciding on a harvest rate, the effect of that rate on the two different stocks must be estimated.

Selection of a relatively high harvest rate, while allowing a large catch to be taken, may lead to severe depletion of the wild stocks. Conversely, a relatively low harvest rate, while allowing the wild stocks to be more productive, would reduce the total allowable catch by the different user groups.

The number of hatchery coho released along with the historical performance of wild coho and total recruits for the past twenty years are reported in Table 2. Some interesting trends and orders of magnitude are worth noting. First, the number of wild smolts has trended downward and constitutes a very small percentage of total smolts. Second, whereas the number of wild coho has decreased, the quantity of hatchery smolts released has steadily increased. Third, the total number of recruits generally increased during the sixties, experienced large fluctuations during the seventies, and in the past five years has shown a strong downward trend. Given the depressed level of wild coho, the recent years of low recruits and the high number of hatchery smolt releases, policy decisions have become increasingly complex.

The coho decision problem is illustrated in Figure 1. Policy control is through determining how many smolts to release and what harvest rate to maintain. The outcome or consequences from following different policies eventually alters the quantity or size of each of the four major components. The objective of the decision maker is to choose that policy strategy which results in the best outcome. In order to measure the different consequences from alternative policy strategies, formal specification of the decision maker's objectives

Table 2. Number of coho salmon smolts released from hatcheries, wild coho smolts, and total recruits, 1961-1981.

Year of return (n)	Hatchery smolts released year n-1 (x1000)	Wild coho smolts year n-1 (x1000)[a]	Total recruits[b]
1961	8,517	3,791	742
1962	16,536	10,219	862
1963	17,391	4,864	1,237
1964	25,609	13,564	1,720
1965	20,923	11,119	2,135
1966	23,861	6,960	2,297
1967	26,023	16,358	2,949
1968	27,553	11,989	2,224
1969	24,011	10,459	1,685
1970	32,962	7,916	2,769
1971	24,902	6,691	3,672
1972	34,385	4,997	2,042
1973	39,343	8,846	1,998
1974	34,688	11,340	3,126
1975	33,875	4,523	1,758
1976	35,637	5,550	4,110
1977	36,609	4,890	1,127
1978	33,371	5,918	1,784
1979	46,908	6,064	1,606
1980	(42,804)[c]	2,359	1,314
1981	(47,600)[c]	2,794	(1,400)[c]

Source: Comprehensive Plan for Production and Management of Oregon's Anadromous Salmon and Trout.

[a] Derived from estimates of parental stock (page 131) assuming 2,500 eggs per two adults and 3 percent survival (page 33).

[b] Total recruits based on annual index of 3 year-old adult coho salmon south of Ilwaco, Washington to northern California.

[c] Preliminary estimates.

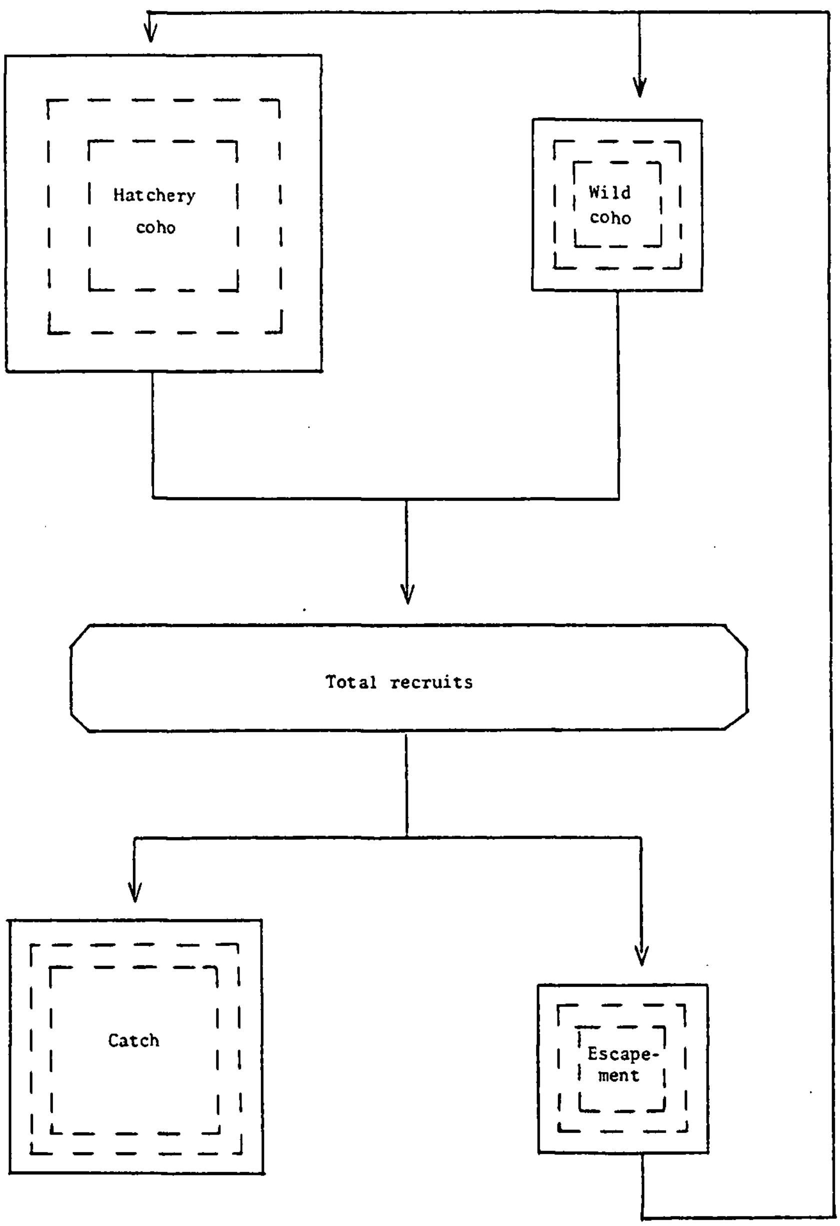


Figure 1. The coho decision problem.

and attributes is necessary.

The Objectives

The main goal of ODFW is to maintain a strong and healthy salmon resource while providing as many benefits as possible to both present and future user groups. Translation of the above goal into a set of objectives allows the decision makers within the department considerable latitude in interpreting and providing for the needs of the user groups and the coho resource as well. Therefore, in order to more clearly identify major points of interest let objectives be defined by the preferences of each decision maker.

In the coho decision problem the assistant fisheries chief has two main objectives: maximize catch to user groups and maximize escapement of wild coho back to natal streams. The latter objective was chosen because the decision maker felt that the long run health and viability of the coho resource depended on maintaining sufficient populations and distributions of wild stocks to be used in improving and developing better hatchery stocks. That is, wild stocks, in order to survive, have adapted to a broader range of environmental variation and possess more diverse traits and characteristics than hatchery coho. Because of this, the manager felt that the failure to consider the wild stocks in policy formulation could lead to a fishery totally dependent on hatchery production. Moreover, he expressed a concern that the more homogeneous conditions to which hatchery coho adapt would lead to fewer and less diversified hatchery stocks which would increase the risk of losing large segments of the smolt production due to disease or other catastrophe.

The Attributes

For each of the objectives, Table 3 lists an attribute as well as ranges of possible effects from policy decisions on each performance measure. The attributes were chosen to (a) reflect the degree to which the objectives are met over an extended time horizon (in this case twenty years), and (b) facilitate understanding of tradeoffs between objectives and implications from alternative policy strategies. From historical data it was determined that catch could range from a low of 500,000 recruits to a high of 4,500,000 recruits. For wild escapement, the decision maker felt that maintaining fewer than 100,000 wild coho would unacceptably increase the likelihood of losing all wild stock production. The maximum limit of 250,000 was based in part on fresh water limitations. That is, as wild coho return to natal habitat, eggs are deposited in the stream gravel. If too many coho (relative to the available spawing habitat) return, the eggs which were previously deposited may be displaced by other coho searching for suitable places to deposit their eggs.

Table 3. Objectives and attributes for the coho salmon problem.

Objective	Attribute	Minimun level	Maximum level
Maximize catch	Average annual catch	500,000	4,500,000
Maximize wild escapement	Average annual wild escapement	100,000	250,000

III. THE UTILITY FUNCTION

The Methodology

With the objectives and attributes specified, multiattribute utility theory can be used to derive a utility function which quantifies the preferences of the decision maker over alternative policy strategies. While multiattribute utility theory is explained in Keeney (1972a), Keeney and Raiffa, and Raiffa, briefly discussing the methodology facilitates understanding of how utility functions may be assessed. In its least restrictive form, a utility function can be expressed as:

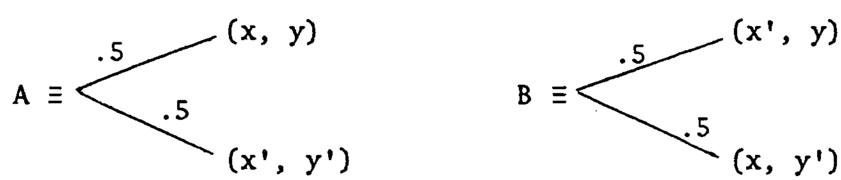
$$Eu(x, y \ldots x) \tag{1}$$

where expected utility is a function of the performance measures x, y ... z. As shown by Keeney and Raiffa, provided that certain independence properties are satisfied, this expected utility function can be used as an appropriate guide for decision making under uncertainty. That is, for some policy decision involving uncertainty, the calculated expected utility should be a measure of the desirability of that policy strategy. To illustrate, let the outcome from following some strategy be measured by the attributes (x, y) where (x, y) can be assigned a utility value u(x, y). Then, for two different strategies i and j, $u(x^i, y^j) > u(x^j, y^j)$ if and only if the outcome (x^i, y^i) is preferred to the outcome (x^j, y^j).

Utility functions can also be used to find trade-offs between x and y. If $u(x^1, y^1) = u(x^2, y^2)$ then a change from x^1 to x^2 exactly compensates for a change from y^1 to y^2. Utility functions are also unique up to positive linear transformations. Given u(x, y) is a valid utility function, $u'(x, y) = a_1 + a_2 u(x, y)$ where $a_1, a_2 > 0$ is also a valid utility function which is strategically equivalent; i.e., u and u' have identical implications for action. Positive linear transformations enable utility from all policy decisions to be measured relative to an arbitrarily chosen origin and unit of measure. As a result, a ranking of alternative strategies can be comprised with the most desirable strategy having the highest utility measure.

Because direct assessment of utility functions with $n > 1$ attributes is difficult, verification of independence relationships allow univariate utility funcitons u(x) to be assessed. For results to be presented in the next section, two independence relationships--additive and utility independence--are summarized.

The attributes (x, y) are said to be additive independent if lotteries A and B where,



(2)

are equally preferable or indifferent for all (x, y) and any arbitrarily chosen (x', y'). Additive independence is reflexive.

To establish utility independence, define $u_x(x, y^0)$ as the conditional utility function for x given y^0 is some arbitrarily chosen value. X is said to be utility independent of y if preferences over any lotteries on x, for a fixed amount of y--denoted y^0--are the same regardless of the chosen level y^0. Utility independence is not reflexive. However, if x is utility independent of y and y is utility independent of x then (x, y) are said to be mutual utility independent.

Keeney and Raiffa and Keeney (1972a) have shown that if additive independence holds, the utility function is of the form,

$$u(x, y) = k_x u_x(x) + k_y u_y(y) \tag{3}$$

If additive independence does not hold but mutual utility independence can be established, the utility function is of the form (again after Keeney and Raiffa),

$$u(x, y) = k_x u_x(x) + k_y u_y(y) + k u_x(x) u_y(y) \tag{4}$$

where

i) $u_x(x)$ is a conditional utility function for x for arbitrary y^0.

ii) $u_y(y)$ is a conditional utility function for y for arbitrary x^0.

iii) k_x and k_y are the scaling constants for the conditional utility functions $u_x(x)$ and $u_y(y)$ respectively.

iv) $k = 1 - k_x - k_y$ is the aggregate scaling constant.

Assessing the Utility Function

The procedure for assessing the utility function can be described as follows. First, the relevant independence relationships are identified. Second, the conditional functions for each attribute are assessed. Third, the conditional utility functions are scaled. Fourth, two checks for consistency are conducted.

Identifying Relevant Independence Assumptions

To determine whether wild escapement was utility independent of catch Figure 2 was used. Points I, J, K, etc. represent different outcomes of wild escapement given a fixed catch of 500 coho.[1/] The procedure involves establishing a point of indifference between a risky prospect or lottery and a sure prospect or certainty equivalent. For notation let [I:J] denote a lottery which yields I or J with equal probabilities. The decision maker was asked whether he preferred consequence K for certain or [I:J]. He replied that the lottery was preferred. Next he was asked if he preferred L or [I:J]. This time the certainty equivalent L was chosen. Progressively more difficult questions about his preferences were posed until the decision maker said he was indifferent to P and [I:J]. Catch was then increased to 2000 and the same procedure repeated using [I':J'] instead of [I:J]. Indifference was established at the same level as before. In response to general questioning, the decision maker felt that his indifference point would not change given any level of catch. Hence, it was established that wild escapement was utility independent of catch. Using the same procedure, utility independence of catch fixing wild escapement at different levels was tested. It was determined that the manager was indifferent between 1250 and [500:4500]. Thus, mutual utility independence was established.

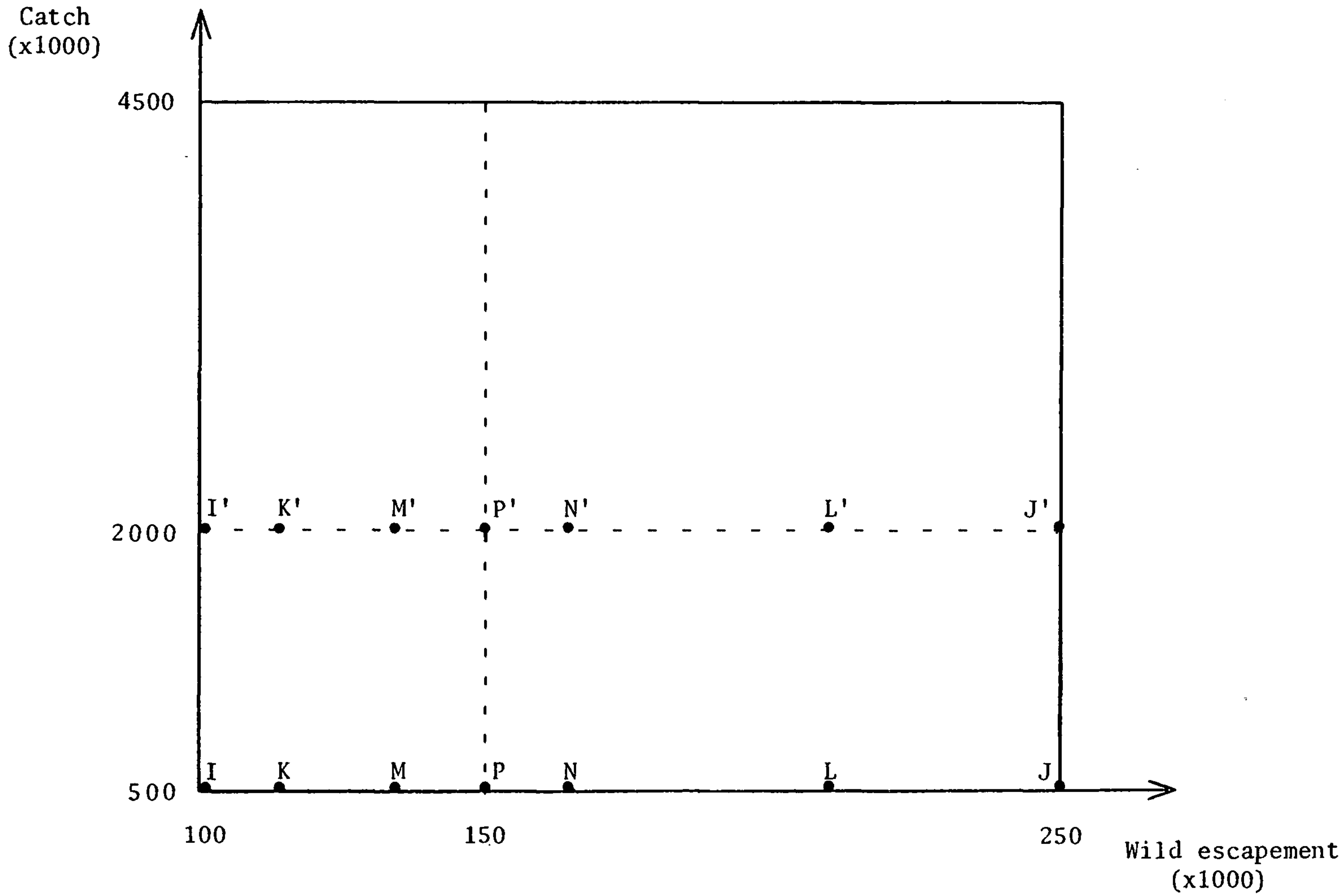
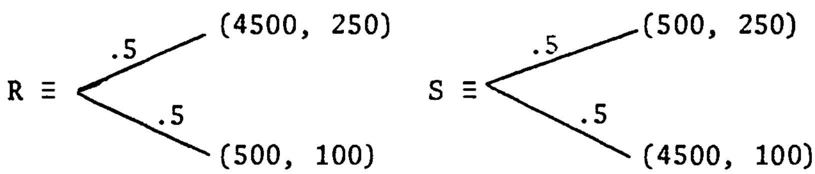


Figure 2. Catch - wild escapement outcome space.

To test if the stronger property of additive independence could be established, the decision maker was asked whether he was indifferent between R and S where,



(5)

Indifference could not be established, hence the correct utility function was equation (4).

Assessing Conditional Utility Functions

With mutual utility independence established, conditional utility functions for catch $u_c(C)$ and wild escapement $u_w(W)$ could be assessed. For catch [500:1250] was indifferent to 900 and [1250:4500] indifferent to 2900. As a result, $u_c(C)$ was judged to be risk averse and monotonically increasing in preferences for catch. Arbitrarily setting the origin and unit of measure at

$$u_c(500) = 0 \tag{6}$$

and

$$u_c(4500) = 1 \tag{7}$$

The points on the utility function (Figure 3), were fit to the simple functional form a - b exp(λ·C) (see Keeney and Raiffa) with the resulting equation,

$$u_c(C) = 1.05 - 1.62 \exp(-.00086 \cdot C) \tag{8}$$

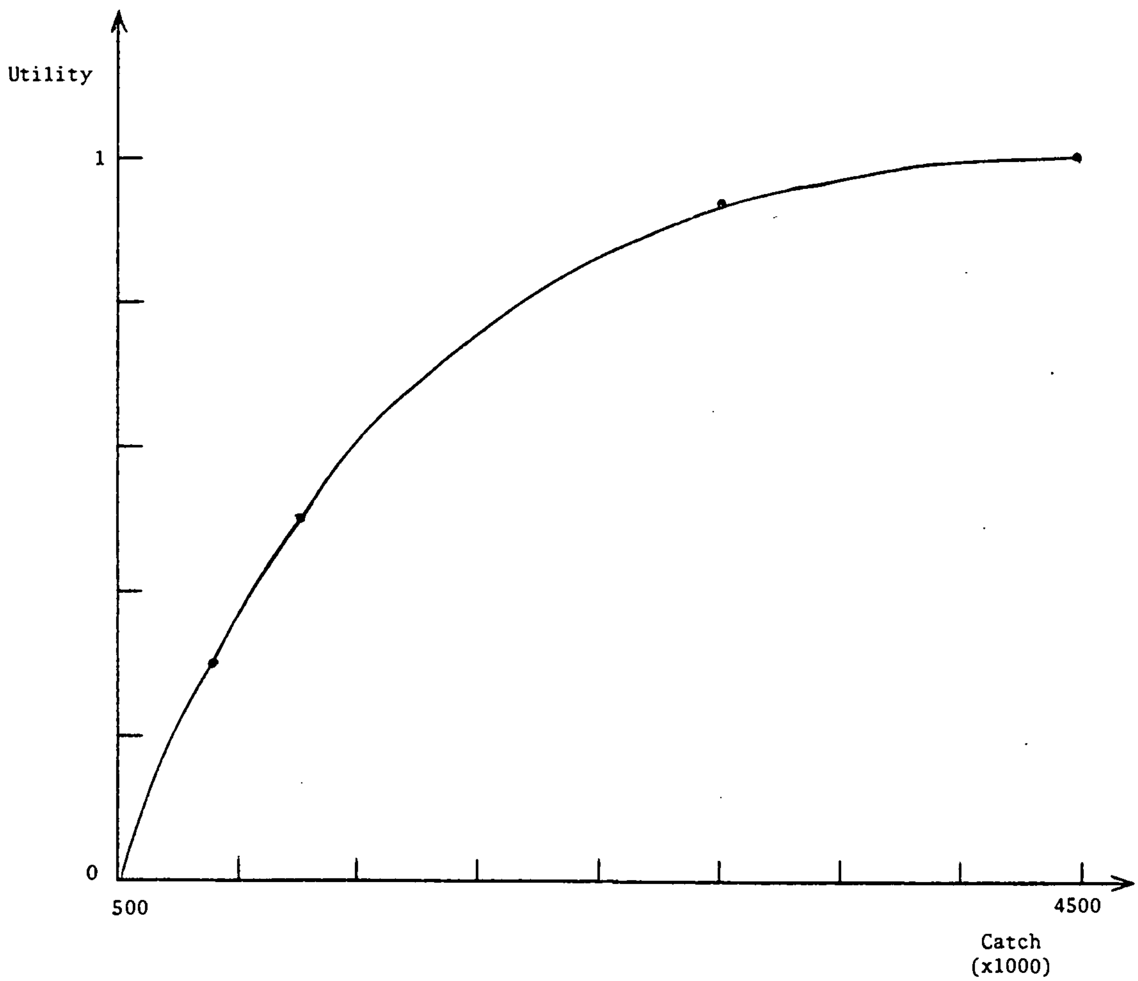


Figure 3. Utility function for catch.

Likewise for wild escapement, [100:250] was indifferent to 150. Also, it was determined that [100:150] was indifferent to 125 and [150:250] indifferent to 200. Accordingly, $u_w(W)$ was also judged to be risk averse with preferences monotonically increasing. Setting the origin and unit of measure by

$$u_w(100) = 0 \tag{9}$$

and

$$u_w(250) = 1 \tag{10}$$

the points as plotted in Figure 4 were fit yielding the equation

$$u_w(W) = 1.3 - 3.4 \exp(-.0096 \cdot W) \tag{11}$$

<u>Scaling the Conditional Utility Functions</u>

To assess the scaling constants it was first determined that (4500, 100) was preferred to (500, 250), (500, 250) was preferred to (800, 100) and finally that (1000, 100) was indifferent to (500, 250). Then setting

$$u(500, 100) = 0 \tag{12}$$

and

$$u(4500, 250) = 1 \tag{13}$$

Also, defining k_c and k_w by

$$u(4500, 100) = k_c \tag{14}$$

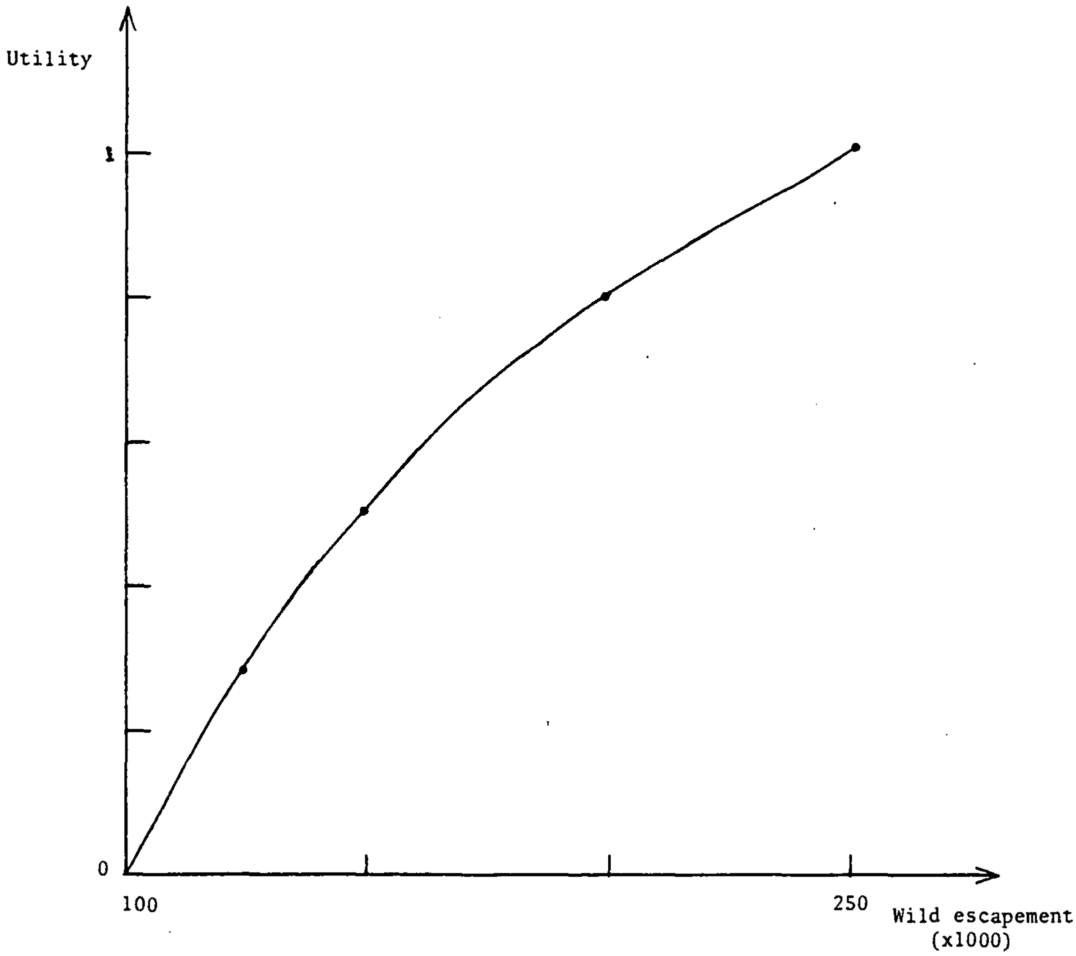


Figure 4. Utility function for wild escapement.

and

$$u(500, 250) = k_w \tag{15}$$

It follows from (6), (7), (12), and (14) that

$$u(C, 100) = k_c\ u_c(C) \tag{16}$$

Similarly, from (9), (10), (12), and (15),

$$u(500, W) = k_w\ u_w(W) \tag{17}$$

Previously it was determined that (1000, 100) was indifferent to (500, 250). It follows that

$$u(1000, 100) = u(500, 250) \tag{18}$$

By substitution with (10), (16), (17), and (18),

$$k_c\ u_c(1000) = k_w \tag{19}$$

Evaluating (8) at $u_c(1000, 100)$ and substituting (19) yields,

$$k_c(.365) = k_w. \tag{20}$$

u(C, W) can now be calculated using (4), (8), (11), (16), (17), and (19),

$$u(C, W) = k_c\ u_c(C) + .365k_c\ u_w(W) + (1 - k_c - .365k_c) \cdot u_c(C) \cdot u_w(W) \tag{21}$$

To solve for k_c, the decision maker was indifferent to [(4500, 250):(500, 100)] and (1500, 140). Then using (12) and (13),

$$u(1500, 140) = .5\ u(4500, 250) + .5\ \mu(500, 100)$$
$$= .5 \qquad (22)$$

Equation (21) can now be evaluated at (1500, 140) and equated to (22) to yield

$$\begin{aligned} u(C, W) = {} & .60[1.05 - 1.62 \exp(-.00086 \cdot C)] \\ & + .22[1.3 - 3.4 \exp(-.0096 \cdot W)] \\ & + .18[1.05 - 1.62 \exp(-.0086 \cdot C)] \\ & [1.3 - 3.4 \exp(-.0096 \cdot W)] \end{aligned} \qquad (23)$$

Two points about the above utility function are worth noting. First, total utility depends not only on the marginal distributions of catch and wild escapement but the joint distributions as well. In addition, a positive k value indicates that the two attributes complement each other; i.e., the full worth of an increase in catch cannot be realized without an increase in wild escapement. Second, because the assumption of mutual utility independence implies that conditional preferences on each attribute do not depend on the chosen level of the other attribute, the trade-off between C and W can be calculated as

$$\frac{dc}{dw} = - \frac{[1.31 + .0329 \exp(-.0096 \cdot W)][.409 - .292 \exp(-.00086 \cdot C)]}{[1.05 + .0014 \exp(-.00086 \cdot C)][.836 - .617 \exp(-.0096 \cdot W)]} \qquad (24)$$

where the sign of $\frac{dc}{dw} < 0$. Consequently, for a constant level of utility, an increase in catch must be accompanied by a decrease in wild escapement.

Checking for Inconsistencies

To determine whether any inconsistencies in preferences existed, the utility function was reassessed at a later date. In addition, a check involving pairwise comparisons as shown in Table 4 was conducted. In response to questioning, the decision maker said A was preferred to F, A preferred to B, B preferred to C, E preferred to D and F preferred to B. Using equation (23) utilities of these consequences were determined. Inspection shows the values calculated to be consistent with the decision maker's preferences.

Table 4. Check for consistency.

	Catch	Wild escapement	Total utility
A	2800	200	.8530
B	2400	160	.7207
C	3400	110	.6250
D	1200	170	.4802
E	1400	150	.4997
F	2000	240	.8027

IV. THE SIMULATION MODEL

The coho problem can be described as follows. The decision maker has to decide what harvest rate to maintain and how many smolts to release. The long term outcome from his decision is measured by the utility function, equation (23), which is based on his preferences and is a function of the attributes--average annual catch and wild escapement. The determination of an optimal strategy is complicated by significant periods of time which elapse between the time a particular decision is made and the time that the outcome is reached. That is, uncertainty usually exists as to events which take place during this time interval and are beyond the control of the decision maker. One approach which incorporates uncertainty to provide better estimates of different outcomes over time from alternative policy strategies is simulation modelling.

The construction of a simulation model for the coho decision problem is divided into four parts. The first part involves specification of alternative strategies or plans. The second part identifies uncertain events and functional models which measure the performance or survival of hatchery and wild coho. For wild coho, one model is used. For hatchery coho different models are used in concert with uncertain events which are believed to alter their survival. In part three, uncertain events are quantified by assigning probabilities. Probabilities are based on historical data, statistical analysis, and the subjective perceptions of the decision maker. Finally, part four describes the simulation model that is used to evaluate the alternative strategies and uncertain events.

The Alternative Strategies

Table 5 shows a total of twelve plans from three harvest rates and four smolt releases levels. The plans were based on discussions with the decision maker and were chosen to (1) reflect past and anticipated management policies, and (2) provide a broad range of possible outcomes each of which would impact the attributes differently.

The Functional Models and Uncertain Events

The process of determining the outcomes from alternative strategies is made easier if functional models for wild and hatchery coho can be identified. Models which have seen widespread application in analysis of salmon population dynamics include the Ricker, Beverton-Holt and multiplicative functions (Ricker, Walters and Hilborn, Peterman). As pointed out by Walters (1977) functional models facilitate understanding of whatever biological processes are involved and usually provide better predictions about outcomes over time given environmental variations.

To model wild coho a Ricker curve is used based on work by ODFW biologists which is summarized in the Coho Plan (Figure 5). The shape of the curve which reaches a maximum point then slopes downward, reflects the limited amount of fresh-water spawning and rearing habitat. That is, as the number of wild coho returning to natal streams increases, so does the competition for available habitat. This results in a decrease in the subsequent surviving number of coho produced. The Ricker model is expressed (Ricker) as

Table 5. Alternative plans for the coho salmon problem.

Plan	Harvest rate	Hatchery smolt release (x1000)
1	.65	31,000
2	.65	48,000
3	.65	60,000
4	.69	31,000
5	.69	48,000
6	.69	60,000
7	.75	31,000
8	.75	48,000
9	.75	60,000
10	.80	31,000
11	.80	48,000
12	.80	60,000

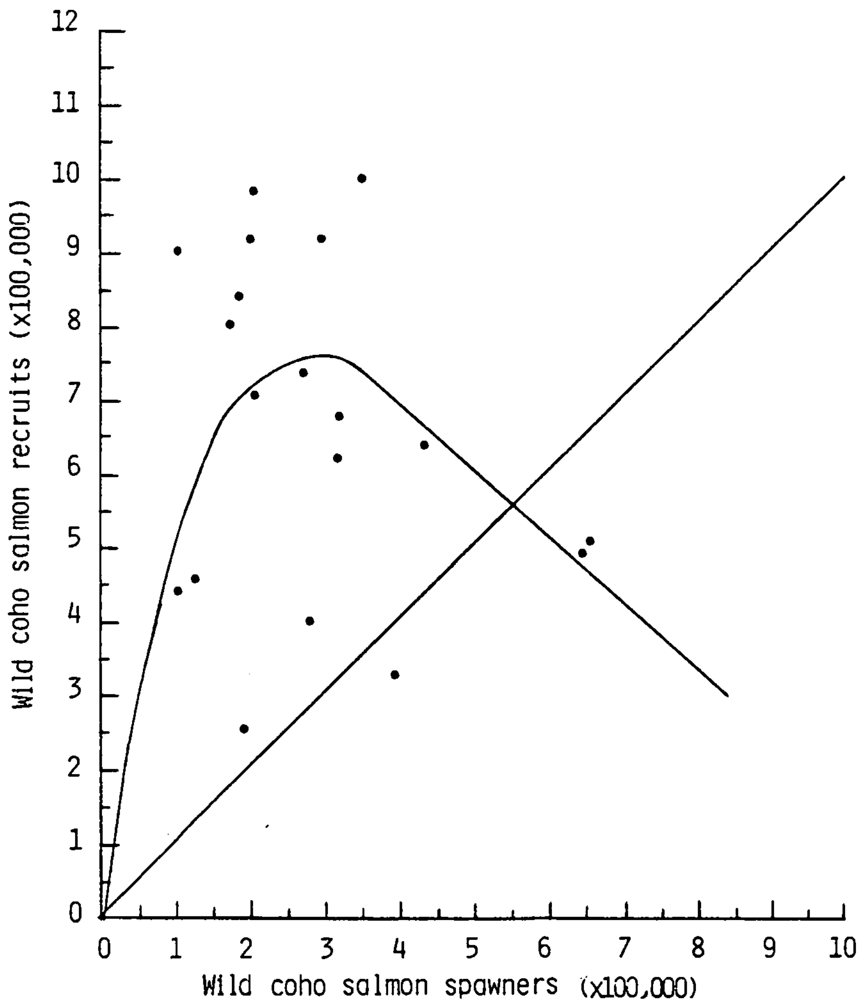


Figure 5. Ricker cruve for wild coho.

Source: Comprehensive Plan for Production of Oregon's Anadromous Salmon and Trout.

$$WR_t = WS_{t-1} \exp(\alpha - \beta WS_{t-1} + u_t) \quad (25)$$

where

WR_t = wild recruits at the end of generation t.

WS_{t-1} = wild spawners at the start of generation t.

α = coefficient of density-independent mortality.

β = coefficient of density-dependent mortality.

u_t = a random environmental factor, normally distributed with mean 0.0 and variance σ^2.

To derive the parameters for (25), the function may be written (after Walters and Hilborn) as,

$$Ln^{WR}t/WS_{t-1} = \alpha - \beta WS_{t-1} + u_t \quad (26)$$

which is a linear regression of the form $y = \alpha+\beta X$ with $y = Ln^{WR}t/WS_{t-1}$ and $X = -WS_{t-1}$. α and β are estimated as 1.96 and 539 respectively.

For hatchery coho, specification of a functional model depends on uncertain events which affect performance or survival. To analyze performance, much evidence has been compiled in the Coho Plan which shows that survival of hatchery coho during the first few months in the ocean is strongly dependent on a number of environmental factors. While the actual mechanisms affecting the salmon are of crucial importance to the overall understanding of coho, this analysis draws only on the strong correlation between survival and an index in the Coho Plan developed by Gunsolus from data assembled by Bakun. This particular index measures upwelling (displacement of coastal surface water by cold, nutrient-rich water from lower depths) at certain locations along the Oregon coast early in the summer. The degree of upwelling is highly correlated with a number of factors affecting smolt survival including total productivity and availability of smolts to their predators. The effects of upwelling on survival are shown in Figure 6 where years are split between high upwelling (indices > 300) and low upwelling (indices $\leq$ 300). In years of high upwelling there is no evidence of a decrease in survival due to higher smolt releases. However, for years with low upwelling it appears that large releases (e.g., 40 million) may not lead to significant increases in recruits and might even lead to a decrease in total recruits. Ideally, if the decision maker knew what upwelling was going to be at the time smolts were to enter the ocean, he could plan smolt production to give an optimal number of recruits. Unfortunately, there is no available technique for forecasting upwelling. As a result, determination of the number of smolts to produce must be based on a priori belief of future upwelling.

To facilitate specification of a functional model for hatchery coho, upwelling is split between years of high upwelling and years of low upwelling (as described above). For years of high upwelling the assumption is made that increases in smolt releases do not lead to decreases in recruits. To model this a multiplicative function

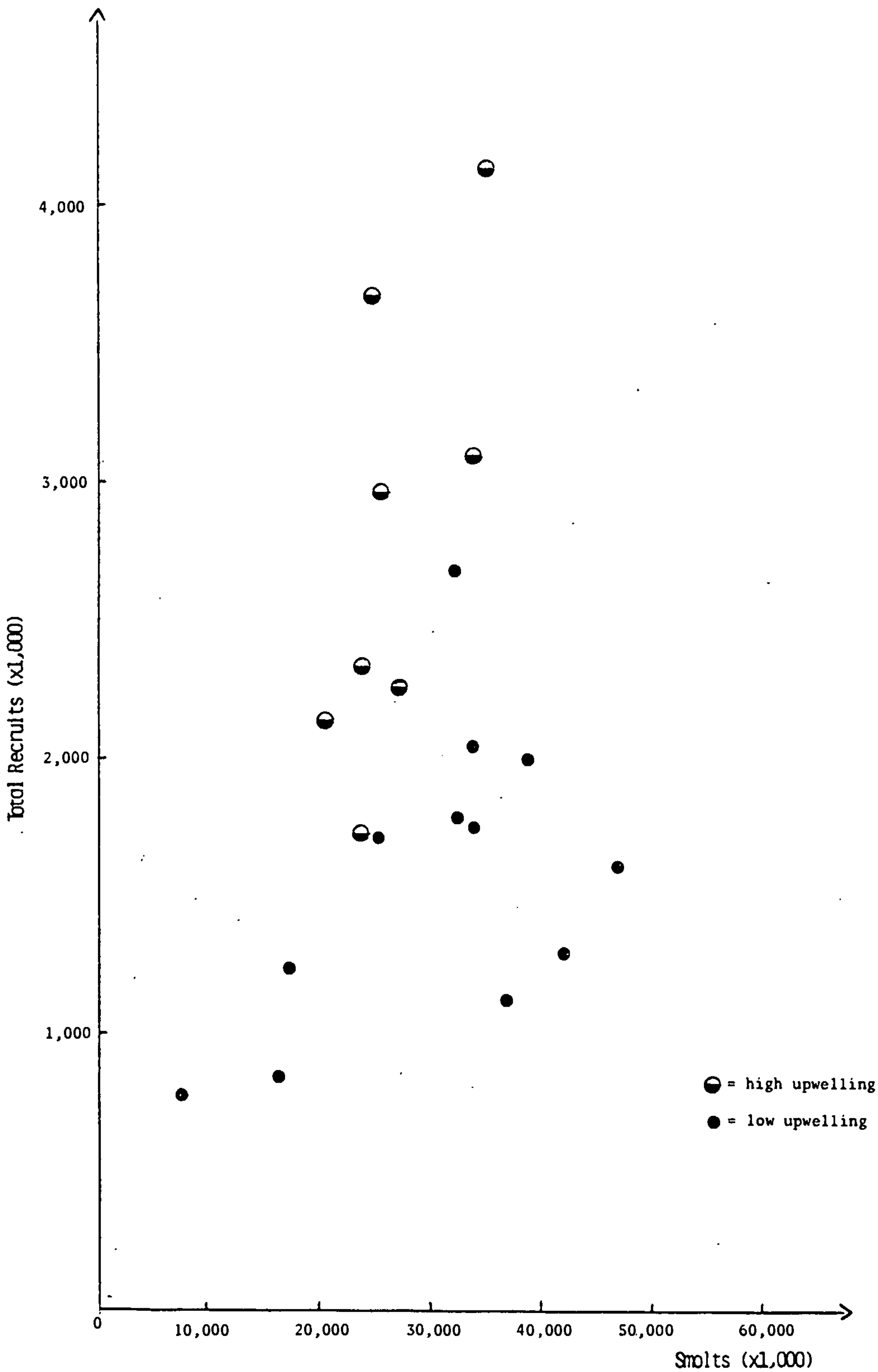


Figure 6. Relationship between smolts released and total recruits for high and low upwelling years.

(Figure 7) expressed (after Peterman) as

$$R_t = \alpha \, S_{t-1}^{\beta} \exp(u_t) \tag{27}$$

where

R_t = hatchery recruits in year t.

S_{t-1} = hatchery smolts released in year t-1.

α and β = production parameters.

u_t = random environmental factor as in equation (25).

is used where $\alpha = .055$ and $\beta = 1.06$.

In years of low upwelling two possibilities (based on evidence given in the Coho Plan and historical data) seem equally reasonable, or at least scientists who subscribe to each of these forms have not been able to reject the alternative hypothesis. The first is that there exist ocean limitations as to the amount of coho that can be supported. If hatchery releases exceed these limits, mortality due to such density dependent factors as competition for food can lead to a decrease in the total number of recruits. Limitations in the ocean environment can be specified using a Ricker model (Figure 8) as:

$$R_t = \alpha \, S_{t-1} \exp(S_{t-1} \cdot \beta + u_t) \tag{28}$$

where $\alpha = .114$ and $\beta = -.000254$.

The second possibility is that as the number of hatchery coho continues to increase, the marginal gains in additional numbers of

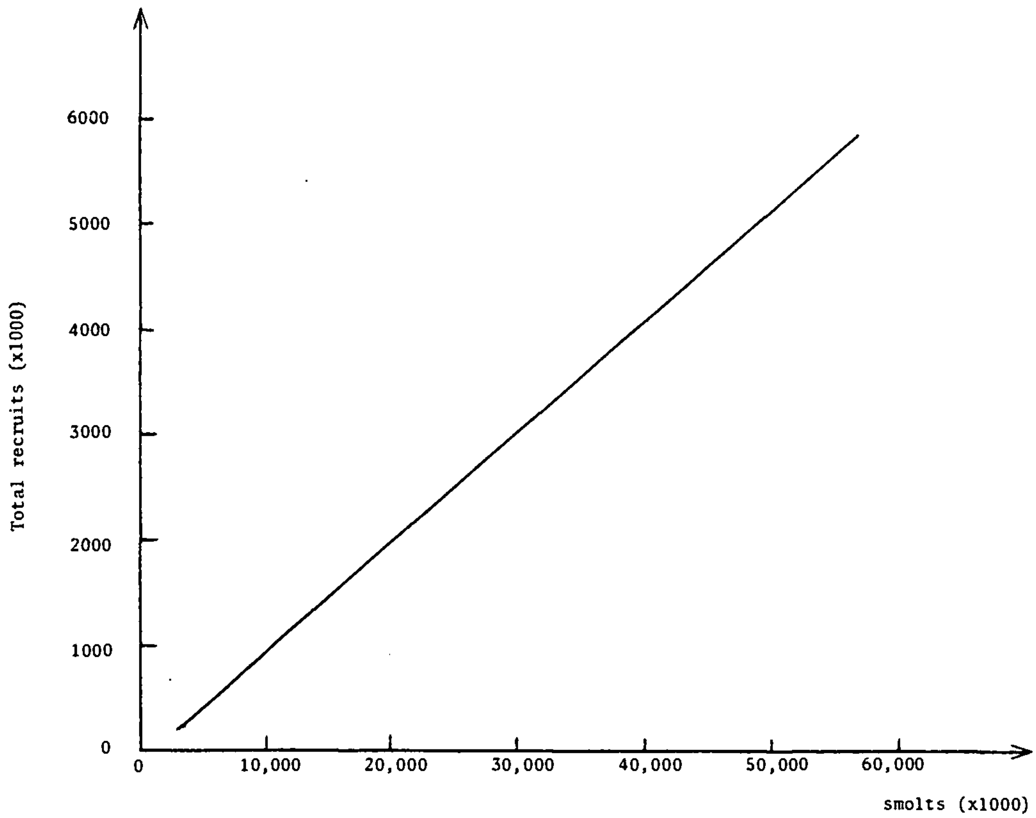


Figure 7. Multiplicative model for high upwelling years.

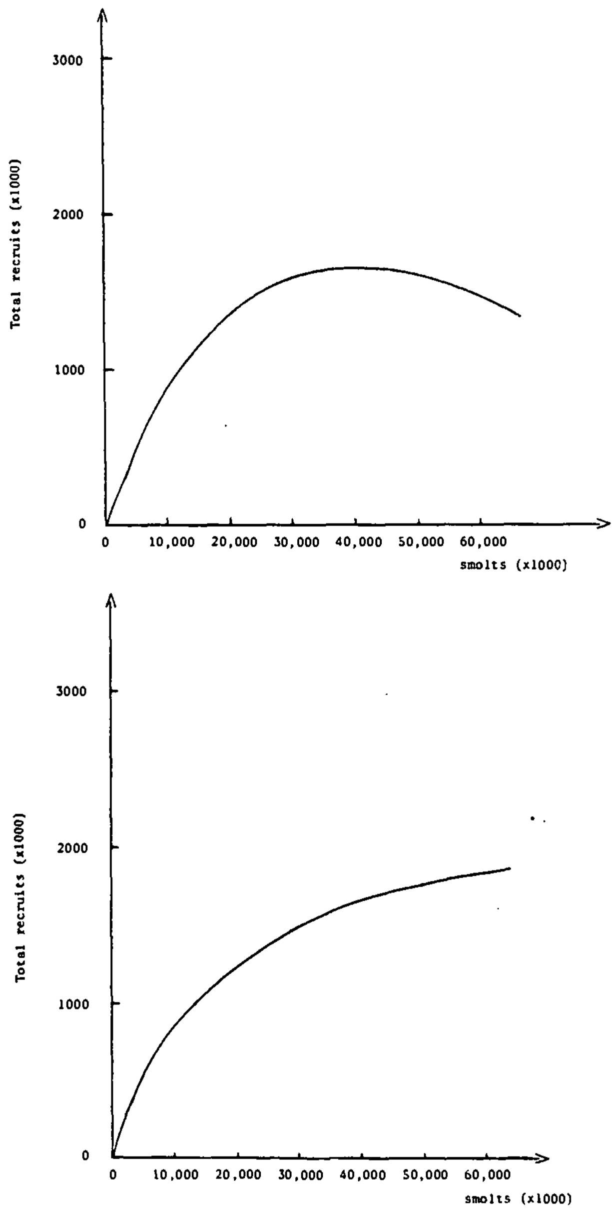


Figure 8. Ricker model (top) and Beverton-Holt model (bottom) for low upwelling years.

recruits become less. This can be expressed using a Beverton-Holt model (Ricker, Figure 8),

$$R_t = \frac{e^{u_t}}{\alpha + \beta/S_{t-1}} \tag{24}$$

where

$\alpha = {}^1/(\text{replacement level of the stock})$

$\beta = {}^1/(\text{maximum recruits per spawner})$

$\alpha = .00043$ and $\beta = 7.43$ are estimated from the regression $y = \alpha + \beta_x$ where $y = {}^1/R_t$ and $x = {}^1/S_{t-1}$.

Two uncertainties just discussed are the occurrence of high versus low upwelling and the performance of hatchery coho when low upwelling occurs. Another uncertainty is: if low upwelling occurs, does the large number of hatchery coho released alter the ocean survival of wild coho?

As evidenced by Figure 6 and represented by the Beverton-Holt and Ricker models, in years of low upwelling increases in smolt releases lead to increases in density and decreases in the survival of hatchery coho. If the large volume of hatchery coho also decreases the ocean survival of wild coho, then further reduction of wild stocks over and above fresh water limitations is possible.

In modelling this uncertainty the objective is to determine the reduction in wild coho based on the degree of belief that hatchery salmon adversely affect wild stocks. To accomplish this, the reduction in survival of hatchery stocks from larger releases must first be determined. Define the base survival rate (BS) as the survival rate of hatchery smolts to recruits when the number of smolt releases is small (e.g., one million). Thus, BS can be thought of as the expected survival rate independent of density effects. Let the actual survival rate (AS) be defined as the expected survival of smolts to recruits when the number of smolts released is large (e.g., 40 million). AS can be thought of as the survival rate with density dependent effects. The expected rate of reduction in survival (RS) can then be defined as:

$$RS = 1 - {}^{AS}/BS \tag{30}$$

That is, RS is the percentage reduction in survival which is attributed to increased density due to large smolt releases. Thus, as the number of smolts released increases RS also increases. To link the effects of increased density of hatchery releases with wild stocks, let C be defined as the degree of interaction or correlation such that the higher the value of C the more adverse the impact hatchery coho have on wild coho. Then, given a level of wild recruits (WR_t) and hatchery recruits, RS can be calculated and the change in WR_t can be determined as:

$$WR'_t = (1 - RS)C \cdot WR_t \tag{31}$$

where $0 \leq C \leq 1$.

The Assignment of Probabilities

The belief that hatchery coho performance most resembles a

Ricker function, or that high upwelling will occur a certain percentage of the time, can be quantified by identifying and assigning probabilities to the range of possible alternatives for each uncertainty. The possible alternatives and corresponding probabilities for the three uncertainties just presented are shown in Table 6. For the specification of uncertainty about upwelling, historical data indicate that high upwelling has occurred 30 percent of the time in the past 30 years and 40 percent of the time in the past 20 years. To reflect all possibilities, two additional alternatives are used and a normal distribution--which allocates the greatest weight to alternatives (2) and (3)--is assumed.

In order to incorporate uncertainty about the degree of interaction between hatchery and wild coho, three alternatives are considered. Thus, C = 0 implies no adverse effects on survival of wild coho due to increased density of hatchery releases, C = .35 represents moderate effects and C = .75 severe effects. No evidence was found which would favor one alternative over another. Therefore, equal probabilities are used.

The third uncertainty concerns the functional model for low upwelling years. Because the Ricker and Beverton-Holt models both seem reasonable and appear to fit the data equally well, equal probabilities are used.

The Actual Model

Define a possible environment or state of nature as a combination of alternatives from each of the three sources of uncertainty.

Table 6. Alternatives and probabilities for each uncertainty.

	Alternatives (1)	(2)	(3)	(4)	Total
Uncertainty:					
A) Percentage occurrence of high upwelling:	20	30	40	50	4
probability	.16	.34	.34	.16	
B) Degree of interaction (C) between hatchery and wild coho:	0	.35	.75		3
probability	.33	.33	.33		
C) Functional model for low upwelling years:	Ricker	Beverton-Holt			2
probability	.5	.5			
Total number of states of nature:					24

For example, state of nature θj could be represented as:

(1) High upwelling occurs 20 percent of the time;

(2) C = 0 interaction between wild and hatchery coho;

(3) performance of hatchery coho in years of low upwelling resembles the Ricker model.

The number of states of nature is equal to the product of the sum of alternatives in each uncertainty. In this problem there are 4 x 3 x 2 = 24 states of nature.

The belief that state of nature θj is the true state of nature is reflected in the probability assignments. Define P_j as the product of probabilities from the alternatives which make up θj. All states of nature are adequately represented if and only if $\sum_{j=1}^{24} P_j = 1$. (This result automatically follows if the sum of the probabilities within each uncertainty equals one.)

Before the expected utility from following some alternative strategy can be determined, the utility from each state of nature and plan must first be calculated. The total combination of plans and states of nature can be represented in matrix form (Figure 9), where the element A_{ij} is the utility of following plan i given state of nature θj. A simulation model as depicted in Figure 10 is used to determine each A_{ij}. Starting with an initial level of wild coho, plan i, state of nature θj, and a sequence of random environmental inputs, catch and wild escapement are simulated forward for 20 years. At the end of the time period, average annual catch and wild

States of Nature

	θ_1	θ_2	•	•	•	•	•	•	•		θ_n
Plan $_1$	A_{11}	A_{12}	•	•	•	•	•	•	•		A_{1n}
Plan $_2$	A_{21}	A_{22}	•	•	•	•	•	•	•		A_{2n}
•	•	•									•
•	•	•	•								•
•	•	•		•							•
•	•	•			•						•
•	•	•				•					•
•	•	•					•				•
•	•	•						•			•
•	•	•							•		•
•	•	•								•	•
Plan $_m$	A_{m1}	•	•	•	•	•	•	•	•	•	A_{mn}

Figure 9. Matrix of alternative plans and states of nature.

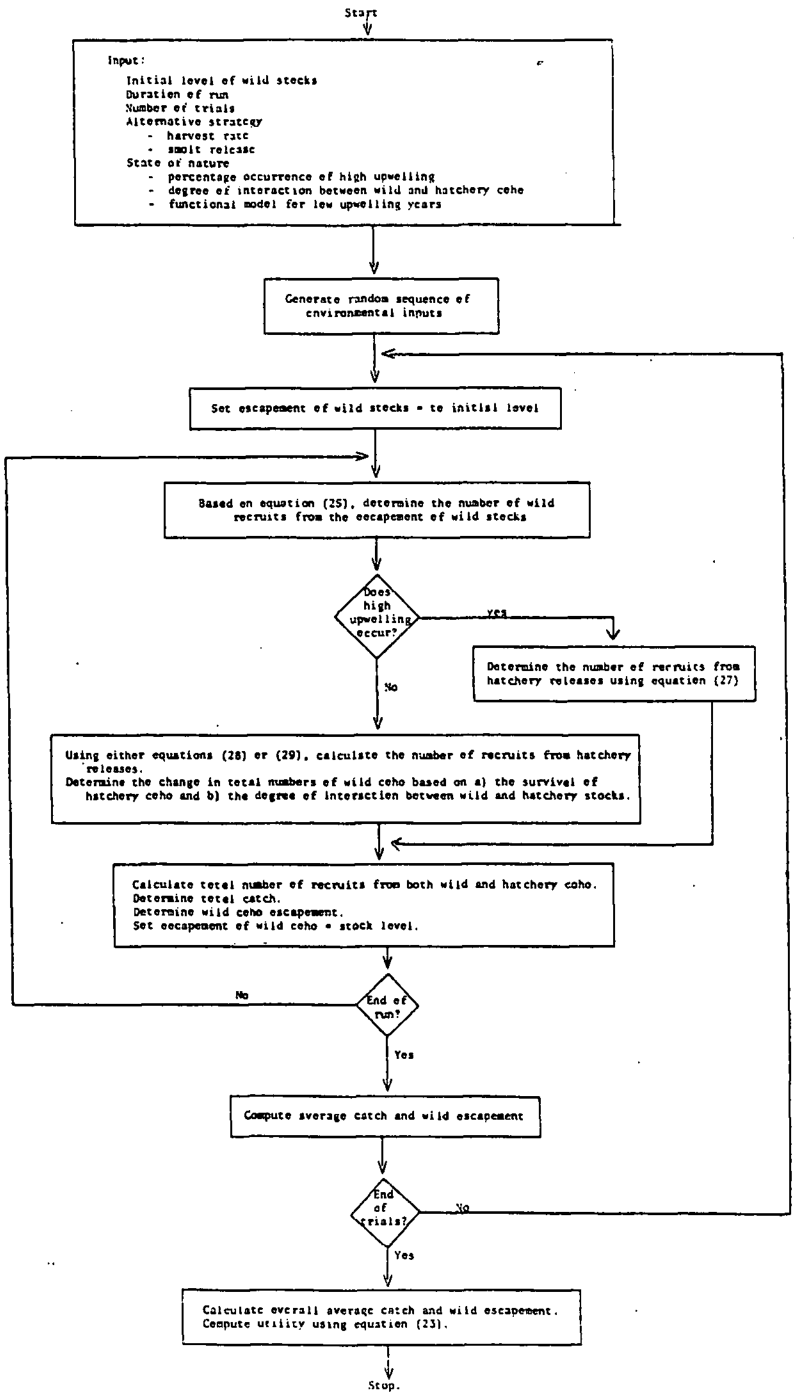


Figure 10. Flow diagram to determine utility for each plan and state of nature.

escapement are then determined. The stimulation process is repeated (using a different sequence of random environmental inputs) until a total of ten trials have been run. Overall annual average catch and wild escapement are then determined and substituted into the utility function (equation (23)). Provided that the outcome for plan i and each state of nature θ_j has been determined, the overall expected utility for plan i is:

$$E\ U(\text{plan}_i) = \sum_{j=1}^{24} A_{ij}\ P_j \tag{32}$$

V. THE EMPIRICAL RESULTS

Prior to determining expected utility for each alternative strategy, plans and states of nature were examined for dominance. That is, were there certain plans which had higher utility values than other plans for all states of nature? To check for dominance, plans were separated into two categories: (1) plans with similar smolt releases but different harvest rates and (2) plans with different smolt releases but similar harvest rates. In the first category, plans with lower harvest rates dominated plans with higher harvest rates. For example, plan 1 consisting of a harvest rate of .65 and smolt release of 31 million, dominated plan 4 which was made up of a harvest rate of .69 and smolt release of 31 million. Examining plans with similar harvest rates but different smolt releases revealed that the optimal smolt release relied heavily on whether a high degree of interaction (C = .75) existed. Excluding those states of nature which assumed C = .75 degree of interaction between hatchery and wild coho, showed that higher smolt releases dominated lower releases. However, analysis of only those states of nature with C = .75 revealed that when high upwelling occurred less than 40 percent of the time, lower smolt releases dominated higher releases. One explanation why lower smolt releases resulted in higher utility value when C = .75 was that as smolt releases increased, density also increased and survival of coho decreased. This reduced survival translated into fewer numbers of wild coho and thus lower utility values.

Partial explanation of the dominance of high smolt releases for most of the states of nature was found by analyzing the influence of upwelling on production. The objective was to determine whether given different percentage occurrences of high upwelling, an optimal smolt release between 31 and 60 million existed. With the Beverton-Holt function, the optimal release, no matter what percentage occurrence of high upwelling, was 60 million. For the Ricker function, various smolt releases were simulated to determine what release number resulted in the highest average hatchery recruits for different levels of high upwelling. For example, setting the level of high upwelling equal to 30 percent and using equations (27) and (28) various smolt release levels were simulated forward in time until an optimal release which resulted in the highest average hatchery recruits was determined. Of interest for the analysis, high upwelling $\geq$ 20 percent always resulted in an optimal smolt release of 60 million. Thus, within the smolt release range considered and in spite of the maximum release implied by the Ricker function, more smolts were preferred to fewer.

Expected utility values for each plan are reported in Table 7. For comparison, utility values for each plan excluding states of nature with C = .75 and assigning equal probabilities to C = 0 and C = .35 are also shown. In both cases the top two plans remain unchanged. However, a successive ranking of plans from lower to higher harvest rates does not hold for the latter. That is, as measured by the utility function, a progressively higher harvest rate of .69 and smolt release of 60 million is preferred to a lower

Table 7. Expected utility values for alternative strategies.

Harvest rate : smolt release	All states of nature	States of nature excluding C = .75
.65 : 60,000	.8278 (1)	.8904 (1)
.65 : 48,000	.8195 (2)	.8643 (2)
.65 : 31,000	.7841 (3)	.8062 (5)
.69 : 60,000	.7615 (4)	.8463 (3)
.69 : 48,000	.7573 (5)	.8248 (4)
.69 : 31,000	.7399 (6)	.7750 (6)
.75 : 60,000	.6488 (7)	.6978 (7)
.75 : 48,000	.6288 (8)	.6848 (8)
.75 : 31,000	.6002 (9)	.6527 (9)
.80 : 60,000	.5580 (10)	.5687 (10)
.80 : 48,000	.5374 (11)	.5444 (11)
.80 : 31,000	.4901 (12)	.4997 (12)

harvest rate of .65 and smolt release of 31 million.

When presented with the utility measures of policy options, the decision maker may find it difficult to interpret the small differences in expected utility values. For example, the difference in utility between plan 1 (.8278) and plan 2 (.8196) is .0082. The small changes are due to the assessment procedure which scales utility between zero and one. However, these slight numerical differences may actually reflect significant changes in the levels of the two attributes--catch and wild escapement.

Rausser and Yassour have suggested an approach to aid the decision maker in interpreting the expected utility values. Specifically, if all attributes except one are held constant at some relevant value, and the certainty equivalent is chosen for the remaining attribute which would generate the expected utility calculated for each policy alternative, analyzing the differences in these "expected-utility-equivalents" may facilitate the decision making process.

In this case, the expected-utility-equivalent can be determined by fixing the level of one attribute and given the expected utility for some plan, solve the utility function (23) for the other attribute. For example, fixing wild escapement at an arbitrarily specified value of 200,000 such that $u_W(W) = .8$, and given the expected utility of plan 3 = .7841, the utility function (23) is solved obtaining $U_c(C) = .817$. Substituting the computed value .817 into equation (8) results in an expected-utility-equivalent of catch = 2,254,000. A similar procedure is followed to determine the expected-utility-equivalents of the two performance measures across the top six plans (Table 8).

Expected-utility-equivalents are helpful in comparing individual performance measures across plans. For example, the expected-utility-equivalent comparison of catch between plan 2 and plan 3 is a difference of 2,520,000 less 2,254,000 or 266,000 coho. This means that at the level specified for wild escapement and in terms of the utility function (23), the decision maker should be indifferent between the actual catch in plan 2 plus 266,000 coho and the catch in plan 3. For wild excapement, note that higher smolt releases result in higher expected-utility-equivalents. This is because all the gains in utility from increased smolt releases translates into increases in the wild escapement equivalent measure. In actuality, increases in smolt releases while maintaining the same harvest rate do not lead to increases in wild escapement; but the gain in catch when translated into utility equivalents for wild escapements more than compensates for the decline in numbers of wild spawners.

Sensitivity Analysis

Sensitivity analysis was conducted to determine how the ranking of alternative strategies changed with different probabilities for each uncertainty and different values for the scaling constants. Initially the scaling constants were determined as $k_c = .6$, $k_w = .22$, and $k = 1 - k_c - k_w$. To determine changes in the ranking of plans

Table 8. Comparisons between top six plans.

	Plans					
	(1) .65:60,000	(2) .65:48,000	(3) .65:31,000	(4) .69:60,000	(5) .69:48,000	(6) .69:31,000
Expected Utility	.8278	.8196	.7841	.7615	.7573	.7399
Expected-utility-equivalent						
Catch[a/]	2,591,000	2,520,000	2,254,000	2,112,000	2,087,000	1,990,000
Wild escapement[b/]	236,000	229,000	206,000	193,000	191,000	182,000

a/ Assessed at wild escapement = 200,000.

b/ Assessed at catch = 2,200,000.

yet still maintain values of $k_c > k_w$, nine combination of k_c = .5, .6, .7 and k_w = .12, .22, .32 were tested. These results for selected probability distributions of the three uncertainties are shown in Table 9. For example, assuming a normal distribution for the different percentage occurrences of high upwelling, equal probabilities for the different degrees of interaction between hatchery and wild coho and equal probabilities for the Beverton-Holt and Ricker functions results in a harvest rate of .65 and smolt release of 60 million eight times and a harvest rate of .65 and smolt release of 48 million once.

The empirical results and sensitivity analysis of the coho decision problem suggest the following conclusions. First, in terms of the expected utility values, determination of the harvest rate is more important than the smolt release in choosing between alternative strategies. For example, as shown by Table 9, a common ordering of top plans may be:

(1) .65:60,000

(2) .65:48,000

(3) .65:31,000

However, an ordering of plans such as:

(1) .65:60,000

(2) .69:60,000

(3) .75:60,000

Table 9. Sensitivity analysis with different scaling constants and probability distributions.

		$k_c = .5$			$k_c = .6$			$k_c = .7$		
		$k_w = .12$	$k_w = .22$	$k_w = .32$	$k_w = .12$	$k_w = .22$	$k_w = .32$	$k_w = .12$	$k_w = .22$	$k_w = .32$
A) UP[.16, .34, .34, .16][a/]	1)	.65:60,000	.65:60,000	.65:48,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000
C[.33, .33, .33][b/]	2)	.65:48,000	.65:48,000	.65:60,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000
FM[.5, .5][c/]	3)	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.69:60,000	.69:60,000	.65:31,000
	4)	.69:60,000	.69:48,000	.69:48,000	.69:60,000	.69:60,000	.69:60,000	.69:48,000	.65:31,000	.69:60,000
B) UP[.16, .34, .34, .16]	1)	.65:48,000	.65:48,000	.65:31,000	.65:60,000	.65:48,000	.65:48,000	.65:60,000	.65:60,000	.65:60,000
C[.15, .15, .7]	2)	.65:60,000	.65:31,000	.65:48,000	.65:48,000	.65:60,000	.65:31,000	.65:48,000	.65:48,000	.65:48,000
FM [.5, .5]	3)	.65:31,000	.65:60,000	.65:60,000	.65:31,000	.65:31,000	.65:60,000	.65:31,000	.65:31,000	.65:31,000
	4)	.69:31,000	.69:31,000	.69:31,000	.69:48,000	.65:31,000	.65:31,000	.69:31,000	.69:31,000	.69:31,000
C) UP[.25, .25, .25, .25]	1)	.65:60,000	.65:60,000	.65:48,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000
C[.33, .33, .33]	2)	.65:48,000	.65:48,000	.65:60,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000
FM[.4, .6]	3)	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.69:60,000	.69:60,000	.65:31,000
	4)	.69:60,000	.69:48,000	.69:31,000	.69:60,000	.69:60,000	.69:60,000	.69:48,000	.69:31,000	.69:60,000
D) UP[.25, .25, .25, .25]	1)	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000	.65:60,000
C[.17, .66, .17]	2)	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000	.65:48,000
FM[.4, .6]	3)	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.65:31,000	.69:60,000	.69:60,000	.69:60,000
	4)	.69:60,000	.69:60,000	.69:60,000	.69:60,000	.69:60,000	.69:60,000	.69:48,000	.69:48,000	.65:31,000

a/ Probabilities which correspond to different percentage occurrences of high upwelling (.16:20% occurrence of high upwelling, .34:30%, .34:40%, .16:50%).

b/ Probabilities which correspond with different degrees of interaction between wild and hatchery coho (.33:C=0, .33:C=.35, .33:C=.75).

c/ Probabilities for the Beverton-Holt and Ricker models respectively.

(4) .80:60,000

never appears. Maintenance of lower harvest rates (e.g., .65) serves to not only protect the diversity of wild coho, but also enables these coho to contribute significantly to the total number of recruits. From the analysis, following plans with high harvest rates (e.g., .80) results in the total number of wild coho being severely deplete over time. As a result, utility depends almost entirely on catch from coho produced in hatcheries. Second, the driving factor in determining an optimal smolt release is the percentage occurrence of high upwelling. If high upwelling occurs at least 20 percent of the time, then a smolt release of 60 million results in the highest average catch. Third, a decrease in smolt releases from 60 million to 48 or 31 million depends on whether a high degree of interaction between wild and hatchery coho occurs. Given the belief that a high degree of interaction does exist, then based on the preference structure of the decision maker, release levels of 48 or 31 million should be considered.

VI. EXTENSION OF THE ANALYSIS

The purpose of this research has been to illustrate how multi-attribute utility analysis could enhance the capability of ODFW to reach an effective policy decision with respect to coho salmon. Originally, several user groups who derived benefits from the coho resource were identified. In addition, attributes with which each group would be concerned were also specified. In analyzing the coho decision problem it became apparent that the dominant issue centered on differences in wild and hatchery coho and how those differences affect policy formulation. As a result, MUA was used to analyze trade-offs between the two stocks and to compare alternative plans consisting of various harvest rates and smolt releases. Perhaps the greatest benefit of MUA is in isolating major objectives and conflicts, value judgments, trade-offs and needed empirical evidence. The process is useful in narrowing down the final list of alternative strategies and promoting discussion on these strategies. MUA is helpful in showing how individuals differ in their preferences, how conflicts can be identified and how consensus solutions can more easily be explored.

In order to improve and expand the analysis of the coho problem, several approaches can be taken. For example, one approach is to conduct a similar analysis with other decision makers involved in the coho decision problem. By quantifying the preferences of these decision makers, major agreements and disagreements can be identified and alternative policies and consensus solutions can be explored.

A second approach involves expansion of the objectives and performance measures to more accurately reflect the needs and desires of the different user groups. That is, given that the decision makers have concurred on the wild and hatchery stock issue, MUA can be used to focus on the other objectives and performance measures as listed in Table 1. To illustrate, in the above analysis the the objectives of the user groups are aggregated and measured by the attribute, average annual catch. Over an extended time period of 20 years, the smolt release which results in the highest annual catch is 60 million. However, one drawback of large releases is the additional increase in variation of total recruits. Given that entry into and exit from the fishery is not symmetric; i.e., more participants enter after a year of high catch than leave after a year of low catch, many fishermen may be willing to trade-off higher releases for lower variation. Hence, in formulating decision policy an attribute which measures variation in catch may be important.

Where different objectives imply trade-offs between performance measures, workshops (see for example, Hilborn and Walters) can be conducted. This may include assessment of preferences of user groups such as commercial and recreational fishermen. This information can be used to refine the agencies understanding of the needs and desires of the different groups, and greatly assist in evaluating and examining policies. Where conflicts arise or where one user group fares poorly, consensus solutions or alternative policies can more easily be developed.

A third approach is in further disaggregation of stocks. This is especially appropriate for hatchery coho. In the present analysis, no distinction is made as to whether smolts are propagated at public or private facilities. Consequently, the implied assumption is that all smolts perform equally well. However, because the advent of private facilities is relatively new (first truly large scale releases in 1978), optimal development of stocks to specific hatchery practices is still taking place. To date the size of the recruits produced at private facilities have averaged less than those produced at public hatcheries. In addition, research underway at ODFW suggests that private hatchery coho survive at about one-third the rate of hatchery coho. Should this conclusion hold true and should production from private hatcheries continue to constitute a substantial portion of total smolt releases, disaggregation of public and private coho and revision of the simulation model is needed. Also, one way to incorporate this into the objective function could be accomplished with an attribute which reflects a ratio of public to private smolts.

If both the second and third approaches were taken, the analysis could deal more effectively with estimates of monetary benefits and costs. For example, historically, the increase from 48 to 60 million smolts has come from expanded operations at private facilities. Except for minor costs incurred by ODFW to license and set guidelines for the number of smolts that can be propagated at private facilities, the large expenditures for actual production of salmon which eventually become part of a common property resource are assumed by the private sector.

In analyzing production at public hatcheries, large cost differentials exist between facilities. Major factors which affect costs include size, location, species reared and age of the hatchery. Some hatcheries are out-dated, require substantial expenditures for maintenance and are relatively expensive to operate. Given the large differences in costs and the diverse objectives of the several user groups, analysis of marginal benefits and costs as to hatchery operations and facilities could assist the decision maker in deciding between a release level of 48 or 60 million smolts. Options could include updating the facilities at antiquated hatcheries or phasing out that production and allowing an increase in private production at the same time that restrictions are placed on choice of species and stocks to be reared.

A final approach concerns a closer analysis of the harvest rate. The harvest rate is controlled primarily via different geographic fishing boundaries, timing of fishing seasons and gear restrictions. Pressure by user groups to allow more fish to be caught by extending fishing seasons is greatest when the total number of recruits (relative to other years) is low. To complicate the issue further, the need to insure adequate escapement of stocks is also greatest for years with low numbers of recruits. As a result maintenance of a specified harvest rate may be extremely difficult.

The achievement of a particular harvest rate may serve as a separate application of MUA. Different policy controls such as timing or length of seasons alters the behavior on the part of the user groups. For example, if a shorter season is adopted as a policy control for the commercial fisheries, the participants may respond by fishing longer hours per day and/or fishing during poor weather conditions. The timing of the salmon season would affect the ability of the commercial fishermen to profitably engage in more than one fishery. For example, many trollers pursue the dungeness crab fishery in the winter. Delayed salmon seasons create periods of unemployment. Closing salmon fisheries in the middle of the season also causes unemployment. Uncertainty, about the end of the season may impair trollers abilities to switch profitably to the albacore fishery. Length and timing of seasons controls also affect recreational user groups. This is especially true for the ocean recreational fisheries with a subsequent adverse economic impact on charter boat operators, where fishing activity is most intensive from Memorial Day through Labor Day. To address these complexities, MUA can be used to refine the decision maker's understanding of how different groups will react to alternative controls. With this information, socio-economic consequences can more easily be identified. The process can assist to investigate ways to reduce costs, improve seasonal patterns for specific groups (eg. troll fishermen), isolate conflicts and explore consensus solutions.

Multiattribute utility analysis is a formal approach to address issues commonly faced by decision makers. The essence of the problem is to make consistent decisions given multiple--and often conflicting--objectives. To this end, recognition and investigation of important performance measures, trade-offs, and value judgments is an integral part of making better decisions.

FOOTNOTE

1/ For notation, numbers of coho are expressed in thousands.

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