A Technique for Improving Decision Analysis in Fisheries and Wildlife Management

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Abstract— Computer implemented modeling has clearly benefited managers in industrial and military management positions. Improvements in the cost effectiveness of computer use should allow fisheries and wildlife managers to make increasing use of computerized decision models. A modeling technique developed for industrial purposes to utilize the full state of knowledge of a decision problem is presented here and proposed for use in fisheries and wildlife management. The technique uses the Weibull function for subjective probability assignment to help solve the problem of making decisions based upon incomplete or inadequate data.

An effective and realistic fisheries and wildlife manager must consider economic, political, technological, and biological components of the system he manages. Any one of these components can be difficult to understand, so it is no surprise that fisheries and wildlife management can be, and usually is, extremely complex. Management personnel would welcome analytical techniques which have the potential to improve efficiency and effectiveness. Computer implemented modeling is one such technique. Simulation and other types of modeling can be applied, with the aid of a computer, to help identify optimal decision policies for complex systems. Computer assisted modeling has received wide application in the military and industrial complexes (Schmidt and Taylor 1970, Raser 1972, Taha 1971). These applications have often resulted in substantial improvement of management efficiency and effectiveness.

Most decision-making problems in fisheries and wildlife management can be approached in a fairly standard manner (Figure 1). The philosophy underlying the approach to problem-solving outlined in Figure 1 is an adaptation of the classical scientific method with an added dimension of time (Lackey 1974). The step involving evaluation of alternative management strategies is particularly amenable to analysis by computer implemented modeling.

Many types of models are used in decision analysis. Monte Carlo simulation is probably the most commonly used type (Lamb 1967), and it may be the most useful technique for fisheries and wildlife managers (Clark and Lackey 1975). We will focus our attention on Monte Carlo simulation in this paper.

A Monte Carlo simulator produces frequency distributions of many possible outcomes for a simulation problem, rather than providing any single solution. Frequency distributions allow calculation of an expected outcome or mean, as well as a variance. A more extensive discussion of Monte Carlo simulation can be found in texts by Schmidt and Taylor (1970), Raser (1972), or Taha (1971).

Monte Carlo simulation is based on the availability of probabilistic information regarding relevant decision variables. This information should consist of a fairly extensive and complete data set for each variable. The data are usually obtained from past records or through experimental analysis.

One of the problems in modeling fisheries and wildlife systems is that scientific technology is presently unable to measure or quantify many fisheries and wildlife variables. For example, one of the major outputs of recreational fisheries is angler benefits, but no widely accepted measure of these benefits exists. Other variables which can be measured often require unrealistic and unjustifiable effort by biologists and field technicians to obtain each datum.

Another problem is that experimental analysis of fisheries and wildlife variables may be impractical. Fisheries and wildlife managers have economic and political constraints. For example, it would not be feasible to run an extensive experiment to determine the relationship between the cost of a fishing license and the number of licenses sold. The analysis would require different, in fact random, license fees to be levied each year for 5 to 10 years. As a result, the quantitative information necessary for decision models in fisheries and wildlife management is usually incomplete.

Managers *must* make decisions about complex problems despite the lack of quantitative data. Subjective information may be the best or only available information upon which to base a decision. Even when this occurs, it should benefit managers to use a systematic approach, including use of models, for the particularly complex decision problems.

A technique of probability assignment developed by Lamb (1967) can be utilized to take advantage of subjective information. Decision models can be developed which utilize the full range of knowledge of a particular decision problem.

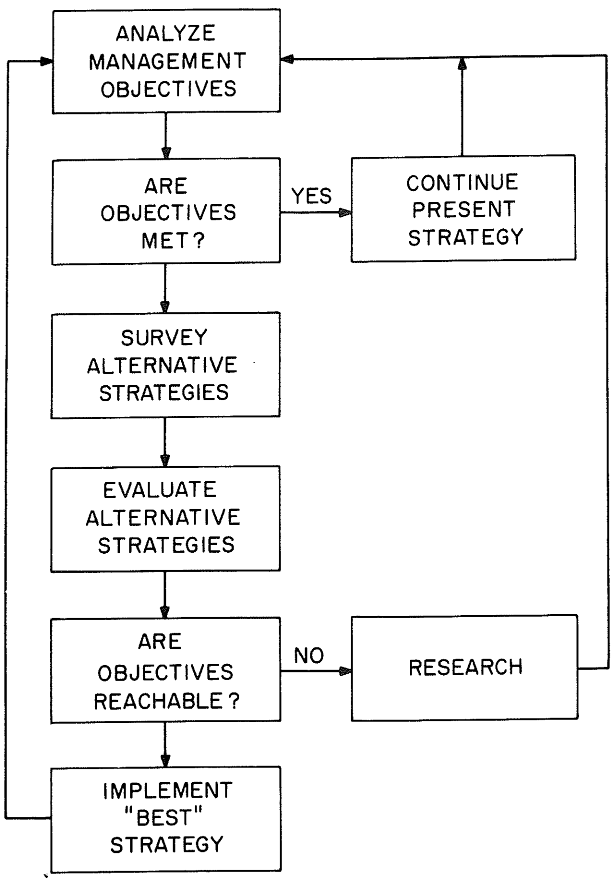

FIG. 1—General fisheries and wildlife management decision-making model based on the scientific method for problem-solving [reproduced from Lackey (1974)].

The Weibull Function

Lamb used the Weibull probability density function (PDF) because of its desirable analytical properties, and because the user can fit the function to available data, along with his personal judgment about the behavior of a variable. The Weibull PDF is capable of depicting or approximating the full range of unimodal shapes of variable distributions (Figure 2). In addition, it is fairly simple mathematically.

There are some examples of the use of the Weibull PDF in natural resource management. Bailey and Dell (1973) summarize the history and literature of the Weibull PDF and its application in forestry. Lobdell (1972) applied subjective Weibull distributions in MAST, a linear programming model for wildlife agency budget allocation. A Monte Carlo simulator, PISCES, has been developed to aid planning in state fisheries management agencies (Clark and Lackey 1975). PISCES is based entirely upon subjective Weibull probability distributions to describe random variables. A Monte Carlo simulator of walleye population dynamics utilizing Weibull probability distributions was recently developed for use by Texas Parks and Wildlife Department. This model, WALLEYE, has been used with considerable success for predicting which reservoirs in Texas are suitable for walleye fisheries.

We will summarize Lamb's development of the technique for using the Weibull PDF in Monte Carlo simulators because of the relative inaccessibility of his paper.

Low, most probable (mode), and high estimates of a random variable are the only information required to fit the Weibull PDF. To illustrate the technique let:

X = random variable;
$p(X)$ = probability density function for X;
X_0 = mode of the PDF;
X_1 = estimate of the lowest value of X that can occur;

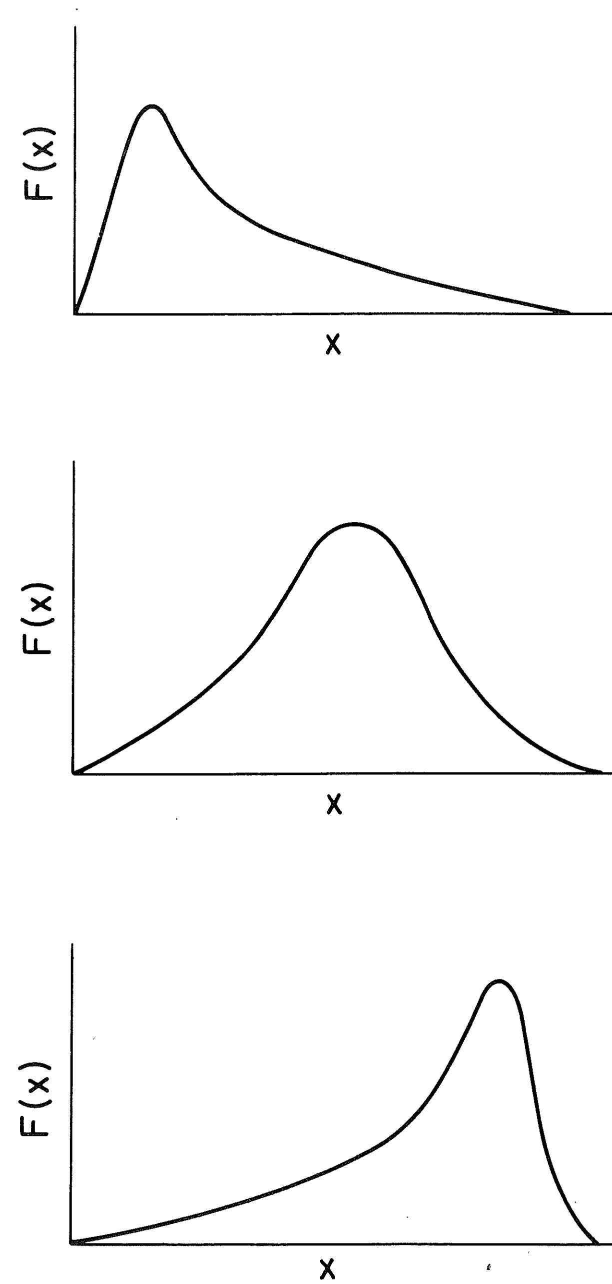

FIG. 2—Three possible (and likely) unimodal shapes for probability distributions encountered in fisheries and wildlife management decision analysis.

P_1 = probability that X is less than X_1;
X_2 = estimate of the highest value of X that can occur; and
P_2 = probability that X is greater than X_2.

If P_1 and P_2 are assigned extremely small values so that their probabilities are essentially zero, then X_1 and X_2 are endpoints of a range of possible values to which the variable X can be assigned.

The above estimates describe properties of the probability distribution for X and form the basis for the following constraints:

$$\left.\frac{d[p(X)]}{dX}\right|_{X_0} = 0 \qquad (1)$$

$$P_1 = \int_0^{X_1} p(X)\,dx \simeq 0 \qquad (2)$$

$$P_2 = \int_{X_2}^{\infty} p(X)\,dx \simeq 0 \qquad (3)$$

Theoretically, there are an infinite number of PDF's which would satisfy the above constraints. When the true distribution form is not known, the Weibull distribution can be assumed for convenience and versatility. The three-parameter Weibull PDF can be written in the form:

$$p(x) = \frac{m}{L^m}(X - K)^{m-1} \exp\left[-\left(\frac{X-K}{L}\right)^m\right] \qquad (4)$$

where

$$X \geq K$$
$$m \geq 0$$

and,

m = shape parameter

L = scale parameter

K = constant

Values for m, K, and L can be approximated for any unimodal variable by an iterative technique. The family of Weibull distributions which results is nearly symmetrical. The bell-shaped normal distribution is approximated when the shape parameter, m, is equal to 3.5. For higher values of m, the distribution assumes a skewed shape "tailing" to the left, and for values less than 3.5, the distribution tails to the right.

Once the three parameters for the Weibull PDF have been determined for a given variable, common methods of random number generation (Schmidt and Taylor 1970) can be used to incorporate the distribution into Monte Carlo simulators.

Lobdell (1972) wrote a computer program, WEIBUL, to generate Weibull distributions for a linear programming model. We revised the program so that it can be used with a process generator (random number generator), for Monte Carlo simulators. WEIBUL, written in FORTRAN IV, calculates the parameters of a Weibull PDF, given low, most probable, and high estimates of a random variable, and then the parameters are used in another subroutine RANDOM, to generate a random value within the distribution. The program listing and documentation are available from the authors.

Discussion

Computer-implemented modeling has the potential to benefit fisheries and wildlife management. It has benefited the military and industrial complexes, and their problems are as complex as fisheries and wildlife problems. With today's advances in electronics, computational costs are relatively low. Cost effectiveness of computer use is excellent, and continues to improve. The future trend of computer usage by fisheries and wildlife management should be an upward one.

The technique developed by Lamb (1967) for assigning probability distributions to variables should help fisheries and wildlife managers incorporate their full range of knowledge into decision-making models. This technique is not proposed to substitute for biological research, management research, or data collection, but to be used in conjunction with these activities.

A good rule to follow is to assign distributions to variables based on experimentation and hard data whenever possible. Subjective information should be used when:

(1) the event concerning the variable has never occurred in the past and experimental analysis is impractical;
(2) very little or no data exist for the event concerning the variable and experimental analysis is impractical; and/or
(3) no data for the event concerning the variable can be obtained prior to the time it is necessary to render a terminal decision.

The result should be models which would make the best predictions from the available information.

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