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An Adaptive Framework for Ecological Assessment and Management

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Abstract: In this paper, we present a conceptual framework for integrating ecological models into a process for management of complex ecological systems. This conceptual framework, that we call Adaptive Ecological Risk Analysis, is an iterative process based upon ecological modeling, the development and implementation of management alternatives, and the evaluation of their effectiveness. Adaptive Ecological Risk Analysis depends heavily on the use of ecological models to perform both prospective and retrospective risk assessments and to analyze the outcomes of alternative management strategies. In order to illustrate the use of Adaptive Ecological Risk Analysis, we use the AQUATOX simulation model to examine the relative risks to the bass population of Coralville Reservoir in Iowa from the pesticide dieldrin. The objective of maintaining a viable recreational bass fishery will be used to evaluate alternative strategies for reducing risks to the bass population. The model is used to quantify the potential effectiveness of these alternative management strategies and to provide feedback for policy refinements.

Keywords: Modeling; Adaptive Management; Adaptive assessment

1. INTRODUCTION

One of the most important and challenging aspects of managing natural systems is the implementation of a rational process for the development and evaluation of alternative management strategies. Ecological modeling has been increasingly employed as a tool because of the capability of addressing multiple factors in a dynamic and quantitative fashion. In this paper, we apply a conceptual framework for environmental management that integrates ecological modelling into a process for developing, implementing, and evaluating strategies for managing natural systems.

2. ADAPTIVE ECOLOGICAL ANALYSIS

The Adaptive Ecological Risk Analysis (AERA) concept was developed at the U.S. Department of Agriculture for evaluating the effectiveness of conservation programs administered by the Department (Meekhof et al., 1997). The genesis of Adaptive Ecological Risk Analysis can be found in the EPA guidelines for Ecological Risk Assessment (US EPA, 1998). The EPA ecological risk assessment paradigm emphasizes an iterative, quantitative approach to assessing ecological risks, depending heavily on the use of models for identification of suitable endpoints and for the characterization of ecological risk. The AERA framework is shown in Figure 1.

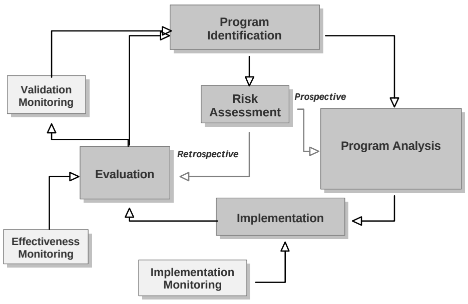

Figure 1. Adaptive Ecological Risk Analysis

The principal components of AERA are *Program Identification*, prospective and retrospective *Risk Assessment*, *Analysis* of risk characterization with respect to program objectives, *Implementation* of management strategies, and *Evaluation* of results. *Monitoring* is central to several phases of the AERA process.

2.1 Program Identification

Program Identification is concerned with the overall objectives of the program and the identification of strategies to achieve them. This involves a determination of the scope and scale of the analysis, development of a system description, or conceptual model, identifying important system attributes (assessment endpoints) as well as measures (measurement endpoints) logically related to those attributes. Further, one or more scenarios for implementing management strategies are developed in this phase.

2.2 Risk Assessment

With respect to AERA, risk assessment is employed to assess the ecological consequences of each scenario, and the probability of occurrence. The risk assessments can be either prospective, explaining what may occur, or retrospective, explaining what has already occurred. The result should represent the magnitude and probabilities associated with outcomes of the various strategies associated with the management scenarios. These are the adverse and beneficial outcomes as measured by each of the endpoints selected for evaluation.

2.3 Program Analysis

Program Analysis is concerned with the ranking of scenarios with respect to their potential for resource improvement, as quantified by the risk assessment, cost effectiveness, and the uncertainties associated with each scenario. Assessments are made of the effectiveness of competing scenarios in reducing harm to environmental resources, degrees of feasibility, unintended effects, and, the effectiveness of the alternatives in achieving program objectives. The analysis may be facilitated by prospective risk assessment that can be used to quantify the magnitude and likelihood of impacts to assessment endpoints of importance.

2.4 Implementation

In this phase of AERA, one or more scenarios surviving the Analysis process are implemented.

2.5 Evaluation

Evaluation is the retrospective mirror image of Program Analysis and provides feedback for iterative changes in program objectives that may lead to improved performance. The evaluation process may be enhanced through the use of retrospective risk assessment, which can characterize the actual results of the Implementation.

2.6 Monitoring

Direct and indirect measurements of the status of assessment endpoints are essential to the proper functioning of the AERA process. As shown in Figure 1, there are three separate monitoring phases: implementation, effectiveness, and validation. The greatest deficiency in managing resources is often the absence of evaluation data, provided by monitoring, which generates the necessary feedback for the iterative improvement of management objectives, scenarios, and methodologies.

3. MODELS AND AERA

The selection and use of an appropriate model or models is central to the effective application of AERA. Modeling can be employed for both prospective and retrospective ecological risk assessments to characterize the outcomes of simulated scenarios identified in the Program Identification. Models must be sufficiently flexible to incorporate a variety of assessment endpoints, stressors, and to characterize risk and uncertainty in a quantitative fashion.

4. EXAMPLE: CORALVILLE RESERVOIR

Coralville Reservoir is a large, shallow, eutrophic reservoir formed when the Iowa River was impounded for flood control in 1958. The surrounding drainage area of 12350 ha was and still is, over 90% agricultural, with the remainder divided between urban and suburban landscapes. The majority of the agricultural areas are devoted to the production of corn or the grazing of livestock. Runoff from the agricultural activities carries large amounts of fertilizer, animal wastes, silt, and pesticides into the reservoir (Sato and Schnoor, 1991). The reservoir supports a popular recreational fishery for largemouth bass (*Micropterus salmoides*) as well as an important commercial fishery for buffalofish (*Ictiobus cyprinellus*). By the early 1970's, the population of largemouth bass and other fish began to decline and residues of the pesticides aldrin and dieldrin greatly increased in tissue samples. Bioaccumulation of the organochlorine pesticide dieldrin threatened the viability of the recreational fishery and resulted in a ban on commercial fishing during the early 1970's (Schnoor, 1981).

4.1 Program Identification

As an exercise in the application of Adaptive Ecological Risk Analysis, we will conduct a retrospective analysis of the fisheries management problem at Coralville Reservoir which emerged in the 1970's. Aldrin and dieldrin were used extensively on corn crops during that period. As dieldrin is a breakdown product of aldrin, we will concentrate on the dieldrin as a focus of our analysis. Both substances are persistent organochlorines that bioaccumulate in the fatty tissues of fish and mammals (U.S. EPA, 1980). Dieldrin has been shown to be highly toxic to aquatic organisms and to be highly persistent in the environment, accumulating in the tissues of mammals and fish (U.S. EPA, 1980). Because of the mounting evidence that dieldrin was accumulating in aquatic organisms and that the compounds had caused cancer in laboratory animals, agricultural uses of these chemicals were discontinued after 1974.

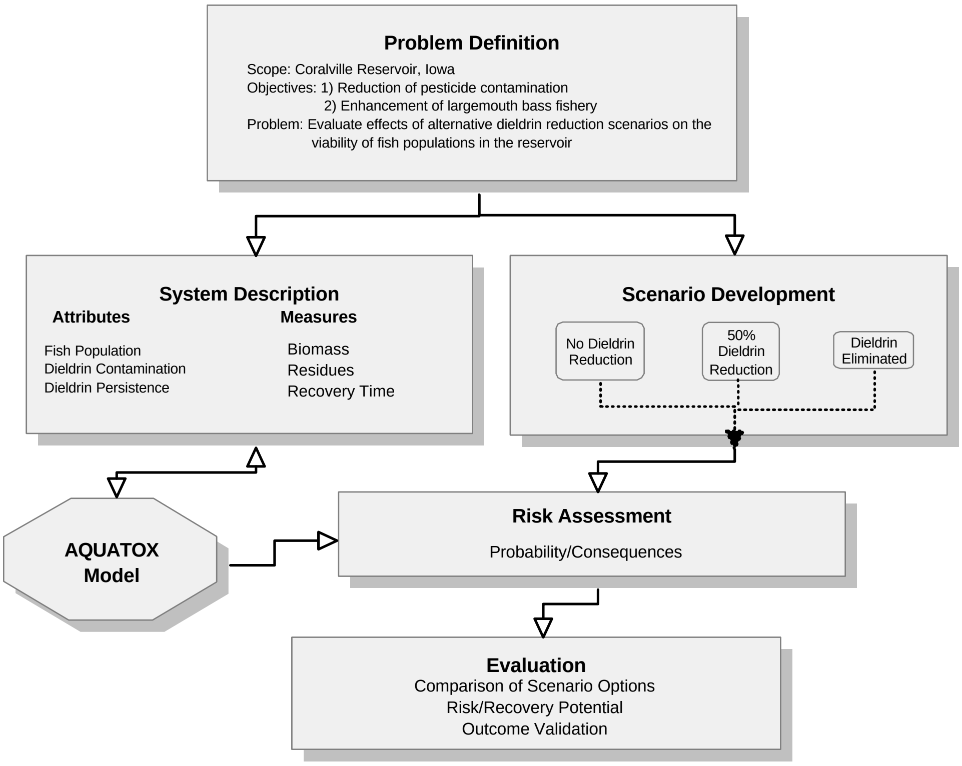

Figure 2. Outline of Coralville Reservoir retrospective fishery analysis.

The focus of our study is encompassed by the Program Identification, Risk Assessment, and Evaluation phases of the Adaptive Environmental Risk Assessment paradigm.

While it is not unexpected to find that the fishery in Coralville Reservoir recovered after pesticide inputs were eliminated, it is legitimate to ask whether there were other alternatives strategies for maintaining the fishery. Also, it is important to quantify the state of the recovery process, the degree of contamination that still exists in the reservoir, and to identify the extent of recovery if pesticides had not been eliminated from the input to the reservoir. We can use this analysis to explain the recovery process and the extent of risk still present. With these overall objectives, we proceed to define the scope of the problem to be addressed, a description of the system, assessment and measurement endpoints, and development of appropriate scenarios. These are represented diagrammatically in Figure 2.

4.1.1 Problem Definition

The scope of the analysis will be limited to the ecological community of Coralville Reservoir, not the surrounding watershed area or the Iowa River. The main objectives of the analysis are to document the degree of reduction in pesticide contamination, and to examine the potential for enhancing populations of largemouth bass. Thus the problem is to evaluate the risks to the viability of the bass population under different pesticide reduction scenarios and evaluate the results with respect to actual events.

4.1.2 System Description

The principle system attributes or assessment endpoints chosen should reflect the problem to be addressed. In this case, fish populations, dieldrin contamination, and the persistence of dieldrin in the reservoir ecosystem are the attributes that best describe the state of the bass fishery through time. These variables are then mapped to measurement endpoints which will serve as analogues to the assessment endpoints. The variables selected are biomass, dieldrin residues, and recovery time.

4.1.3 Scenario Development

As shown in Figure 2, three scenarios were chosen for evaluation. In the first scenario, there is no reduction in the input of dieldrin into the system. We will evaluate the effect of continued dieldrin inputs on the bass population, as well as the contamination of fish tissue. In fact, recent monitoring has demonstrated continuing runoff and persistence of dieldrin in the Coralville Reservoir ecosystem (Schnoebelen et al., 1999). In the second scenario, dieldrin input is reduced by 50 percent to evaluate the impact of reducing toxic inputs. The final scenario examines the case where dieldrin inputs are completely eliminated from the system. This should serve as a validation of the actual result in Coralville Reservoir, where bass populations have recovered from the reductions observed in the 1970’s.

4.1.4 Model Selection

The AQUATOX model (US EPA, 2000) was selected to simulate the scenarios outlined above. AQUATOX is a dynamic simulation model for aquatic ecosystems, specifically designed to evaluate the impacts of toxic organic substances on aquatic ecosystems. The model can also be used to examine the impacts of eutrophication and has sufficient flexibility to examine both site-specific and generic scenarios. In addition, AQUATOX employs Latin hypercube simulation to calculate risk directly, in terms of the probability of specific outcomes for state variables.

4.2 Results

The dynamics of the Coralville Reservoir ecosystem were simulated from 1968 to 1985, to incorporate the actual periods of both pesticide input and pesticide-free input. Pesticide and nutrient inputs, fish biomass, and input flows of water for the simulated period were based on measured inputs from monitoring studies (US EPA Validation study). Probabilistic risk simulations varied the input levels of dieldrin according to a triangular probability distribution. The results of the simulation runs are summarized in Figures 3-6.

4.2.1 Risk to Largemouth Bass

The risk to the largemouth bass population in Coralville Reservoir from the three dieldrin loading scenarios is shown in Figure 3. The risk graph (Mauriello, 1988) plots the probability that biomass will be reduced by a given percentage by the completion of the simulation period. Under the full dieldrin loading scenario, the probability of at least a 90 percent reduction in the biomass of largemouth bass is almost 1.0. Reducing dieldrin inputs by 50 percent does not appreciably lower the risk of biomass reduction. The probability of at least a 90 percent biomass reduction drops only to 0.8. When dieldrin inputs are eliminated from Coralville Reservoir after 1975, the risk to the largemouth bass population drops dramatically, with the probability of only a 20 percent decline in biomass falling nearly to 0.

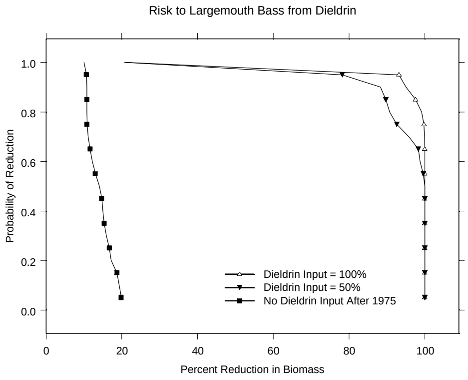

Figure 3. Risk to Largemouth Bass from Dieldrin

4.2.2 Recovery of Largemouth Bass Population

The risk graph provides a snapshot of the status of the largemouth bass population at the end of the simulation. We can also examine the degree of recovery directly by plotting the differences between perturbed state variable trajectories and a control simulation. The difference graph, shown in Figure 4, plots the percentage difference between a control run and each of the three dieldrin input scenarios. A negative value indicates that the largemouth bass biomass is less that that of the control run. The first scenario, where dieldrin inputs are at a maximum, results in a biomass trajectory which is greater than 80 percent below the control simulation. Reducing dieldrin inputs by 50 percent results in biomass levels leveling off at least 70 percent below control levels. Only the third scenario, where dieldrin inputs are eliminated after 1975, results in a recovery of the largemouth bass population. By 1977, biomass has recovered to control levels and by the end of the simulation, exceeds the control trajectory by approximately 10 percent.

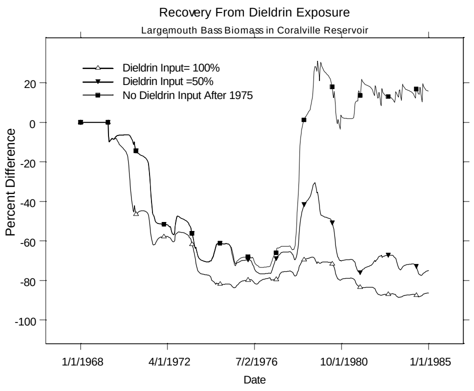

Figure 4. Recovery of largemouth bass population from expose to dieldrin

4.2.3 Dieldrin Contamination in Fish

Simulations of dieldrin concentrations in largemouth bass are illustrated in Figure 5. In all the simulations, concentrations of dieldrin rise rapidly after the pesticide is introduced into the reservoir system. At the highest input level, dieldrin concentration reaches levels of approximately 20 ppb. Reducing dieldrin inputs by 50 percent results only in a reduction of body burdens in the bass population to around 14 ppb.

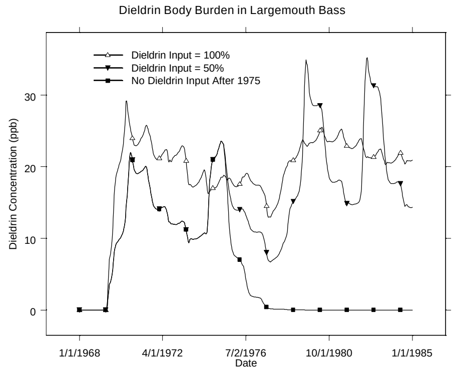

Figure 5. Dieldrin concentration in largemouth bass.

When dieldrin input is eliminated after 1975, concentrations in the bass population fall rapidly, reaching control levels by 1977.

5. CONCLUSIONS

The results of the simulation studies confirms the decision to ban the use of dieldrin for agricultural uses and prevent exposure to aquatic organisms. Only the third scenario, simulating the complete elimination of dieldrin from the Coralville ecosystem, permitted a recovery of the largemouth bass population and reduced body burdens in the exposed fish to acceptable levels. However, while the bass population recovered and body burdens declined under this scenario, much of the dieldrin input into the system remains there until the end of the simulated period. As shown in Figure 6, the total amount of dieldrin in the reservoir system reaches a peak just after the final input in 1975, but declines to constant value of about one half the peak value. The continued presence of high dieldrin concentrations is an indication that the pesticide is trapped in the sediment layers of the reservoir.

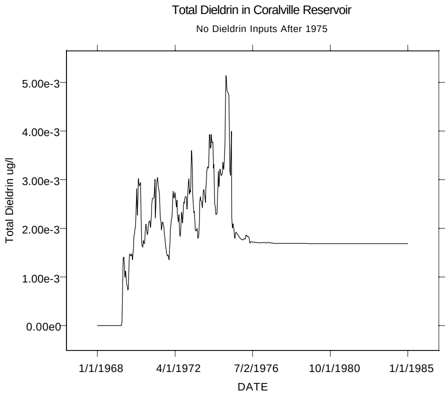

Figure 6. Total Dieldrin in Coralville Reservoir.

Recent studies of core samples extracted from Coralville Reservoir (Van Metre, et al., 1997) confirm these predictions. The core samples exhibit high concentrations of dieldrin and other persistent pesticide compounds long absent from inputs to the reservoir. In addition, other recent studies have demonstrated that storm water runoff events are still carrying measurable amounts of dieldrin and other persistent pesticide compounds into the reservoir (Schnoebelen et al., 1999).

The Adaptive Ecological Risk Assessment Process (AERA) provides a useful framework for organizing and interpreting our modeling studies of the impacts of the pesticide dieldrin in Coralville Reservoir. The AQUATOX model has also been shown to be a flexible and powerful vehicle for simulating the resultant scenarios and a unique tool for characterizing the risk and recovery of aquatic ecosystems.

The recent monitoring studies of Coralville Reservoir indicate that there may still be residual effects from dieldrin, long after it has been banned from application on crops. The AERA paradigm could be utilized to conduct prospective analyses of future impacts of storm-water borne runoff of dieldrin as well as the potential risk from agricultural chemicals in current use. In addition, inputs of nutrients, silt, fluctuations in water input and reservoir levels, as well as recreational fishing may all have potential impacts on the future viability of the bass population that can be assessed through the use of the AERA methodology.

The AERA paradigm is both iterative and adaptive in nature. The successful application of this methodology depends on a balanced combination of modeling and monitoring to drive the organization, implementation, and evaluation of objectives and management policies. Without the adoption of such a balanced, integrated approach, management of critical environmental resources is likely to continue to be only sporadically successful.

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