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Evaluation of Ecosystem Simulation Models as Tools for Assessment of Power Plant Impacts on Fish Populations

Final Report

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report summarizes work on evaluating the usefulness of models in asssessing power plant impacts. Models were found to be most useful in suggesting frequency and replication for monitoring programs. Models also were useful in indicating where further data are needed. The modeling work on Lake Ontario and Lake Keowee indicated difficulties in using monitoring data for model construction and validation.

This final report gives progress and summarizes results on contract NRC-04-80-215 on assessing the usefulness of models for power plant impact assessment. This contract was conducted over a three and one half year period from October 1980 through June 1984. At this time we have substantively completed all research on this project except for some publications which are presently being submitted for publication.

The original objectives of this project were:

1. To intercompare and test a number of alternative whole ecosystem models using monitoring data from Lake Keowee and Lake Ontario and to evaluate model predictions of power plant effects on these sites.

2. To review a number of newer simulation models and to intercompare these with existing models already reviewed on a previous contract.

3. To revise the Process Notebook for Aquatic Ecosystem Simulation including new models reviewed, and new data, making it more usable and correcting mistakes in the original document.

4. To investigate stochastic models as possibly useful for impact assessment.

5. To consider, for the third year of the project, the possibility of testing the regional generality of simulation models. Proceeding in this direction was to result from agreement both by ourselves as the contractor and NRC as the contracting agency.

6. To produce occasional reports on modeling related topics judged of interest

As we will show in this final report project objectives have been met. Over the life of the project we have produced 6 technical reports (2 more are in preparation). One article has appeared in the open literature and two more have been submitted to journals. There have in addition been five articles published in proceedings of meetings and two articles published in books concerning research conducted under this contact. Copies of these papers are included as supporting material for the contract officer. A list of technical reports and publications is given in Table 1.

As much of the material produced by this project are included in technical reports and open literature this report will serve primarily as a summary of findings and will not attempt to reproduce details available elsewhere.

Process Notebook

Preparation of the process notebook required considerable revision of the original process notebook. While that document was not out of date we discovered a large number of typographical errors and some discrepancies in model equations and notation. There were also some units inconsistencies. New models reviewed as part of this contract as well as parameter estimates uncovered in our Lake Ontario and Lake Keowee work and in review of the additional models were included. We revamped the organization of the notebook to make it more coherent and gave examples of how to use it. The new Process Notebook reflects our intention of what we would have liked the original to be if we'd had more time to work on it.

Lake Model Evaluations

Much of the work in this contract went towards evaluation and intercomparison of existing models using data from Lake Keowee and Lake Ontario. For Lake Keowee a single composite model comprised of models reviewed was compared with data.

We found difficulties in some of the models spatial assumptions, and in our exclusion of benthos or important forage fish species. We also found discrepancies and inadequacies in the data especially in the phosphorous data which was not accurate enough to reveal whether phosphate was a controlling nutrient or not, and the lack of replicates at a site which gave us no direct variance estimates. We also found some inconsistencies between phytoplankton densities on Lake Keowee and those reported for neighboring reservoirs. Data and models comparison and model predictions of impact and general conclusions are given in technical reports and published papers (see Table 1.).

Our experience on Lake Keowee led us to some important modifications for Lake Ontario. First we replaced the assumption of spatial homogeneity by 4 regions in the neighborhood of the power plants (Nine Mile Point and Fitzpatrick Nuclear Power Stations). We included a broad range of fish groups and benthos as well. We had a longer time series of data to compare with. We replaced the cohort approach for the fish and zooplankton, which was wasteful of computer run time with a size class-dynamic pool where fish were divided into age class by species or functional groups.

We also developed a full set of alternative process equations to intercompare in various combinations. We corrected many of the difficulties with the Lake Keowee modeling comparison and also discovered new difficulties. The new model was extremely complex and very sensitive to some model parameters. Some of the data (e.g. phytoplankton and zooplankton) showed wide variability from one year to the next. Since there was a change in groups collecting the monitoring data some of these differences would have been due to methods. Absolute abundances of fish were not available. Given these difficulties model output agreed within reason with the data, though there were some glaring discrepancies especially with the predatory cyclipoid copepods. To conduct the model intercomparison we utilized a number of exploratory data analysis techniques. In doing this we learned a great deal about how to standardize different equations to each other so that differences between process constructs would be due to different equation forms and biological rationale rather than parameter values.

These results are given in a paper submitted for publication in Ecological Modeling. Given the great variability in the monitoring data we decided not to attempt testing of models on a regional basis.

Another aspect of ths project was to work with Dan McKenzie (Battelle PNL) on utilizing models to evaluate and direct monitoring programs. This innovative project involved using model output to indicate how often areas near the power plant are likely to be different by a chosen tolerance range from a control location. These windows of potential difference would then be used to assess how frequently and with how many replicates we must sample to maximize the power - the probability of detecting a significant input given that one occurs. This study (Swartzman, McKenzie and Harty 1983) indicated that the best sampling program depends on the biota of interest and considers the trade off between sampling frequency and sampling intensity. Of course, this approach assumes the model to be "true" and errors in the model can lead to erroneous monitoring recommendations. Actually we found the model results to be realistic and the method to be applicable nonetheless.

Special Investigations

In addition to the special investigation into models as tools for monitoring program evaluation we conducted a couple of short term studies on problems as they arose. The first was an investigation into methods for sensitivity analysis (TR # NUREG/CR-3392) and the second was an investigation of the implications of spatial heterogeneity in model predictions of consumption and predation (TR # NUREG/CR-2624). The first was needed to clarify, for purposes of model evaluation, how sensitivity analysis has been conducted and how we might improve the technique. The second resulted from our observation of patchy distributions for biota in monitoring data and our desire to investigate how this patchiness might be affecting model predictions.

Stochastic Models

As most simulation models are deterministic the outputs are interpreted as an average. We had some concern that results ought more realistically to be presented in probability terms, such as the chance that a population would drop below a certain size. We investigated such a stochastic model of Getz and Swartzman (1980) and applied it to the Hudson River striped bass problem. Results are given in a technical report (see Table 1). While the technique appears promising, we found striped bass long term catch data to be so sketchy as to be considered unreliable. Since recruitment in bass appears to be affected by river flow conditions at the time of spawning we see the striped bass as a primary candidate for a stochastic model provided a longer term catch record becomes available.

The important thing about using these kinds of models is that they deal directly with the question of risk. By describing populations in terms of their probability of being at a given level we are able to predict the probability or risk of the population falling below some predetermined minimum acceptable level.

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Table 1

REPORTS AND PUBLICATIONS PRODUCED UNDER CONTRACT NRC-04-80-215

Publications

Evaluation of ecological simulation modeling in power plant impact assessment by Gordon Swartzman, Robert Haar, Daniel McKenzie and Thomas Zaret in W. Mitsch, R. Bosserman and J. Klopatek eds. Energy and Ecological Modeling. Elsevier. pp 173-184. 1981.

A review and comparison of parameter sensitivity methods applicable to large simulation models. Masters thesis by Kenneth Rose. University of Washington. 1981.

A probability transition matrix model for yield estimation in fisheries with highly variable recruitment. by Wayne Getz and Gordon Swartzman. Canadian Journal of Fisheries and Aquatic Science 38, pp 847-855. 1981.

Simulating the effects of increased temperature in a plankton ecosystem: a case study by Virginia Dale and Gordon Swartzman. in L.E. Shubert, ed. Algae as Ecological Indicators, Academic Press, 1983.

Aquatic predator feeding in patchy environments: error introduced into models by assuming prey spatial homogeneity, by Robert Haar and Gordon Swartzman. in Analysis of Ecological Systems: State-of-the-Art in Ecological Modelling. W.K. Lauenroth et al. (eds.) Elsevier. pp 157-162. 1983

Using aquatic simulation models for impact assessment: Evaluation of monitoring programs. by Gordon Swartzman, Dan McKenzie and Rebecca Harty. in Proceedings of a workshop on Risk Assessment in Aquatic Ecology. Albuquerque N.M. April 13-15 1983 (in press).

Book review of "Environmental Biomonitoring, Assessment, Prediction and Management." by J. Cairns, G.P. Patil and W.E. Waters. for Jour. Amer. Stat. Soc. 1984. Review by Gordon Swartzman.

Sensitivity analysis methods applicable to large computer simulation models. by Kenneth Rose. to appear in Encyclopedia of systems and control. E. Halfon (ed) Pergamon Press. 1984

Long term research on simulaton models applied to environmental management. by Gordon Swartzman. Invited paper to CEQ session of long term research recommendations in environmental management. in press. 1984.

Simulation experiments comparing alternative process formulations using a factorial design. by Stephen Kaluzny and Gordon Swartzman. Submitted to Ecological Modelling.

Technical reports

Evaluation of Simulation models in power plant impact assessment: a case study using lake Keowee. by Robert Haar, Gordon Swartzman and Thomas Zaret. USNRC tech. rep. NUREG/CR-2436. 1981.

Aquatic Predator feeding in Patchy Environments. by Robert Haar and Gordon Swartzman USNRC tech. rep. NUREG/CR-2624. 1982.

Evaluation of ecosystem models in power plant impact assessment: A case study using lake Ontario. by Stephen Kaluzny, Gordon Swartzman, Kenneth Rose and Patrick Sullivan. Nuclear Regulatory Commission technical report NUREG/CR-3308 Vol. 1. 1983

Process notebook for aquatic ecosystem simulations. Second edition. by Patrick Sullivan, Gordon Swartzman and Andrew Bindman. USNRC tech. rep. NUREG/CR-3392. 182 pp. 1983

An age structured stochastic recruitment model for assesment of power plant impact. by Patrick Sullivan and Gordon Swartzman. USNRC tech. Rep. NUREG/CR-3698. 1984.

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EVALUATION OF ECOSYSTEM SIMULATION MODELS AS TOOLS FOR ASSESSMENT OF POWER PLANT IMPACTS ON FISH POPULATIONS

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