1-1-1991

Using Optimization and Simulation Techniques to Estimate Initial Weevil Populations

Kunter S. Akbay
Marquette University

Using Optimization and Simulation Techniques to Estimate Initial Weevil Populations

KUNTER S. AKBAY[1]

ABSTRACT

In this paper, a mathematical programming and simulation method is used to estimate the number of weevils (*Neochetina bruchi* Hustache, and *N. eichhorniae* Warner) necessary to initilialize the INSECT model which simulates the biological control of waterhyacinth by the weevils. The objective is to estimate the initial input values for the adult population so that the sum of the absolute differences between the observed and the simulated numbers of weevils is minimized. In general, the simulated values using the initial values obtained from the mathematical programming problem were within the 95% confidence intervals of the actual field observations. Also, in many cases, the simulation results indicated trends similar to those indicated by the field data in both timing and the numbers of weevils.

Key words: Waterhyacinth, *Neochetina*, computer simulation models, mathematical programming.

INTRODUCTION

INSECT is a computer model developed for personal computers (Akbay et al. 1988) that simulates biological control of waterhyacinth (*Eichhornia crassipes* (Solms.) Mart.) by the weevils. The long-term objective for development of the INSECT model is to predict *Neochetina* impacts on waterhyacinth.

The INSECT model requires information about the initial weevil population to be input at the start of the simulation. However, the actual field data to specify the initial weevil levels are rarely obtainable. Howell et al. (1988) estimated starting numbers for weevils by using the first three sampling periods from a site specific data set, and back-calculating to determine the number of individuals based on the cumulative day-degrees. Often multiple runs were made to arrive at reasonable starting numbers.

Herein, as an alternative to the back-calculation method, the INSECT model will be incorporated in a mathematical programming approach to estimate the number of adult weevils which enter a field based on observed population values.

METHODS

Goal programming is a type of linear programming where the objective is to minimize the deviations from certain goals (Charnes and Cooper 1961). For this, a separate

[1]Department of Mechanical and Industrial Engineering, Marquette University, Milwaukee, Wisconsin 53233.

goal constraint must be formulated for each goal. A goal can be defined as a desired level of performance that one wants to achieve. The objective function will be minimized when all the goals are met.

In the method described in this paper, the goals are the actual field data observations. The objective is to determine the initial weevil population so that the sum of the absolute difference between the observed counts of weevils and the simulated values is minimized (McClendon et al. 1984).

Mathematical Programming Formulation. In general, this mathematical programming problem can be defined as follows: Let,

I = the set of days for which comparisons will be made with the observed larvae/adults data (i is an element of this set),

J = the set of permissible range of days which is defined as the time interval during which the adult weevils are expected to emerge or enter the field (j is an element of this set),

X_j = number of adults emerging or entering the field on day j (unknown),

a_{ij} = total number of simulated larvae/adults on day i resulting from *one* adult entering the field on day j,

b_i = number of total larvae/adults observed (goal) on day i,

d_i^- = amount that the total number of simulated larvae/adults on day i is *below* b_i, and

d_i^+ = amount that the total number of simulated larvae/adults on day i is *above* b_i.

In order to minimize the sum of the absolute deviations between the observed values and the simulated values, the problem can be formulated as follows:

Minimize: (1)
$$Z = d_1^- + d_1^+ + d_2^- + d_2^+ + \ldots + d_m^- + d_m^+$$

Subject to: (2)
$$a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n}X_n + d_1^- - d_1^+ = b_1$$
$$a_{21}X_1 + a_{22}X_2 + \ldots + a_{2n}X_n + d_2^- - d_2^+ = b_2$$
$$\vdots$$
$$a_{m1}X_1 + a_{m2}X_2 + \ldots + a_{mn}X_n + d_m^- - d_m^+ = b_m$$

$$X_1, X_2, \ldots, X_n \geq 0$$
$$d_1^-, d_2^-, \ldots, d_m^- \geq 0$$
$$d_1^+, d_2^+, \ldots, d_m^+ \geq 0$$

The solution to this problem would be the number of adult insects entering the field on permissible days in order to minimize the sum of the absolute differences between the observed weevil counts and the simulated values. If any of the deviational variables are positive in the final solution, that would indicate that the corresponding goals are not exactly met.

General Methodology. The initialization method using a mathematical programming approach has basically four phases:

Phase 1: In the first phase of the method, the INSECT model must be run several times to generate a large database. In each run, the model is initialized with only one adult on a permissible day. The range for permissible days must be input by the user. For example, if the user assumes that the adult weevils will emerge during the Julian days 4 through 80 with increments of 4 days (i.e. on days 4, 8, 12, . . . , 72, 76, and 80), then 20 runs will be made. The output for weevil development from each run is stored in a large database.

Phase 2: In the second phase, a smaller database is generated to provide information for the goal constraint equations (2) in the mathematical programming formulation. Basically, this information consists of the a_{ij} values (the total number of simulated larvae/adults on a field observation day i resulting from *one* adult entering the field on a permissible day j).

Phase 3: In this phase, a linear programming algorithm is used to find the optimum solution to the problem.

Phase 4: In the final phase, the INSECT model is initialized with the optimum solution and the results are plotted. At this point the user may decide to make additional runs with different permissible range and/or different field data.

RESULTS AND DISCUSSION

The data sets used to test the mathematical programming approach described in the previous section are from Florida. These data sets were used during the initial field comparison studies for the INSECT model and the results based on the back-calculation method were summarized in Howell et al. (1988).

In this paper, for each field data set, the initial weevil population is estimated by using the mathematical programming approach described above.

Lake Alice 1976 Data. Initial conditions for the 1976 Lake Alice simulation runs were as follows:

initial plant biomass (kg/sq m):   0.705,
permissible range: January 4 through April 10 with increments of 4 days,
adults (number/sq m)
based on mathematical
programming results: 6.15 on January 4,
6.85 on January 8,
3.77 on January 20,
15.15 on March 21, and
0.17 on March 25.

The goals in the mathematical programming formulation represent the actual field observations for *N. eichhorniae* adults. There are 52 field observations.

The model results compared very well when the INSECT model was initialized with the values obtained from the mathematical programming problem. In Figure 1, the INSECT model predictions for adults are plotted against the mean and the 95% confidence intervals for the 1976 Lake Alice data. Only eight of 52 cases were not within the 95% confidence intervals. These occurred mainly during the month of March and December. Also, the simulation results generated by the INSECT model indicated trends similar to those indicated by the field data in both timing and numbers of adult weevils. During the second portion of the month of December, the simulation results showed a smaller rate of decrease in the population than suggested by the field data.

North Florida 1986 Site "PP". Starting numbers for model simulations of waterhyacinth and *Neochetina* spp. dynamics at site "PP" in North Florida were determined to be as follows:

initial plant biomass (kg/sq m): 1.110,
permissible range: January 4 through March 21 with increments of 4 days,
adults (number/sq m)
based on mathematical
programming results: 20.36 on March 5, and
14.90 on March 21.

This site contained *N. eichhorniae* as well as *N. bruchi*, where *N. eichhorniae* exceeded *N. bruchi* by about 10 to 1. The goals in the mathematical programming formulation represent the actual field observations for *N. eichhorniae* adults. There are 10 field observations.

Model predictions for adult *N. eichhorniae* and for *N. bruchi* were always within the 95% confidence intervals as
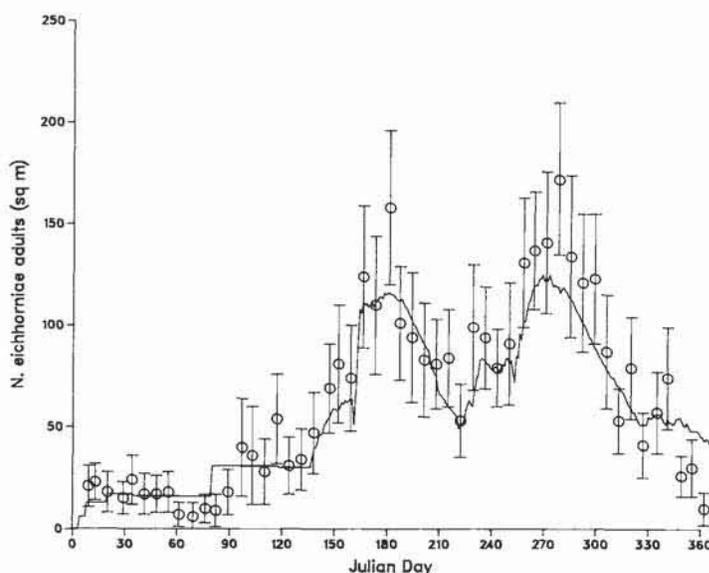

Figure 1. Simulated adult *N. eichhorniae* population plotted against the 95% confidence intervals for the 1976 Lake Alice data.
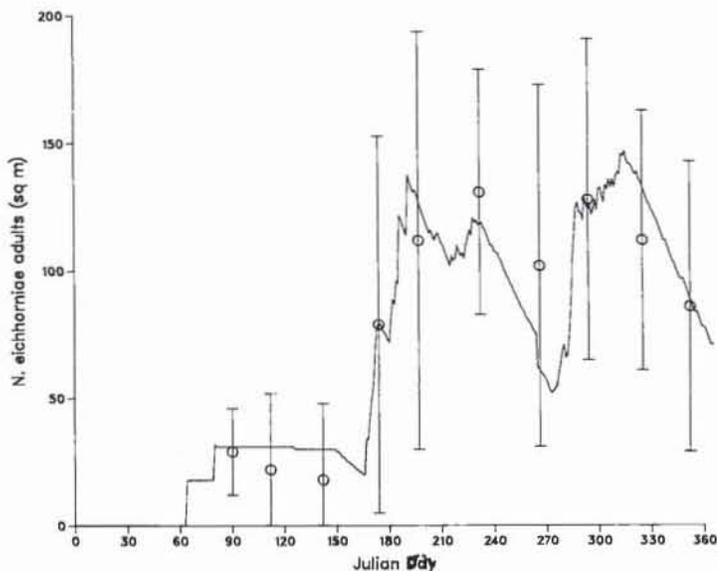
Figure 2. Simulated adult *N. eichhorniae* population plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.

seen in Figures 2 and 3, respectively. For adult *N. eichhorniae*, population peaks between the field and simulation data sets were consistent both in terms of timing and the magnitude. During the end of September and the beginning of October, the simulated population for adult *N. eichhorniae* was considerably lower than the actual field observations during that period. However, the simulated values were still within the 95% confidence interval.

For adult *N. bruchi*, the field data observations indicated a gradual increase in the population from April to the middle of June. However, the simulated adult *N. bruchi* population showed a constant pattern during the same period, and both the magnitude and the timing of the peak around Julian day 174 were missed. However, the simulated values were still within the 95% confidence interval.
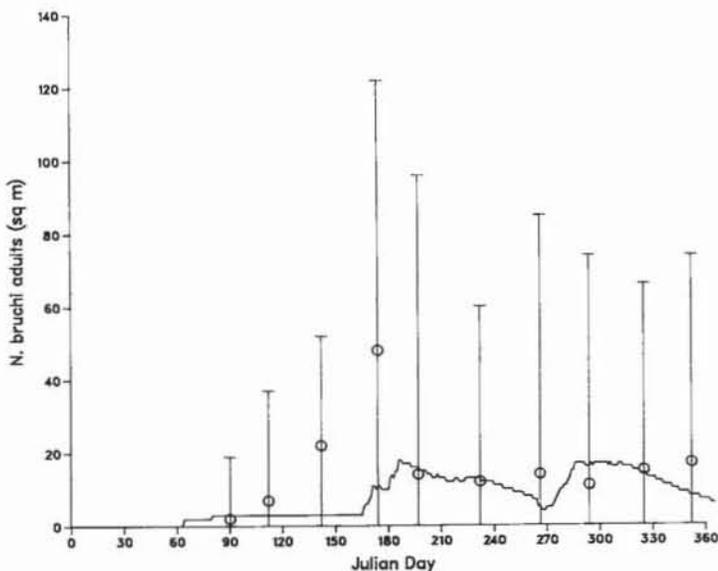
South Florida 1986 Site "CA". Starting numbers for model simulations of waterhyacinth and *Neochetina* spp. dynamics at the site were as follows:

initial plant biomass (kg/sq m): 1.200,
permissible range: January 4 through March 21
                      with increments of 4 days,
adults (number/sq m)
based on mathematical
programming results: 6.63 on January 4,
                      11.29 on February 1,
                      7.52 on March 5, and
                      38.21 on March 9.

Percent *N. eichhorniae* and *N. bruchi* were 62% and 38%, respectively. The goals in the mathematical programming formulation represent the actual field observations for the third instar *Neochetina* spp. larvae. There are 12 field observations. As it can be seen in Figure 4, four of 12 cases were not within the 95% confidence intervals of the field data. However, the simulated values of third instar *Neochetina* spp. larvae for Julian days 55 and 328 missed the confidence intervals by a very small amount. The simulated values for the first three field data observations were consistently lower. However, the population peak on Julian day 114 (April 24) as suggested by the field data was met by the model. The simulated values for the third instar *Neochetina* spp. larvae generally agreed with the actual field data observations during the months of May, June, July, August, September, October, and November. At the beginning of December, the model predicted a peak in the population which was not suggested by the field data.

These results are similar to those presented in Howell et al. (1988). Therefore, both methods can be used to initialize the weevil population for the INSECT model. Since both methods are still being developed, the purpose of this paper is not to make comparisons between them. Instead,

Figure 3. Simulated adult *N. bruchi* population plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.
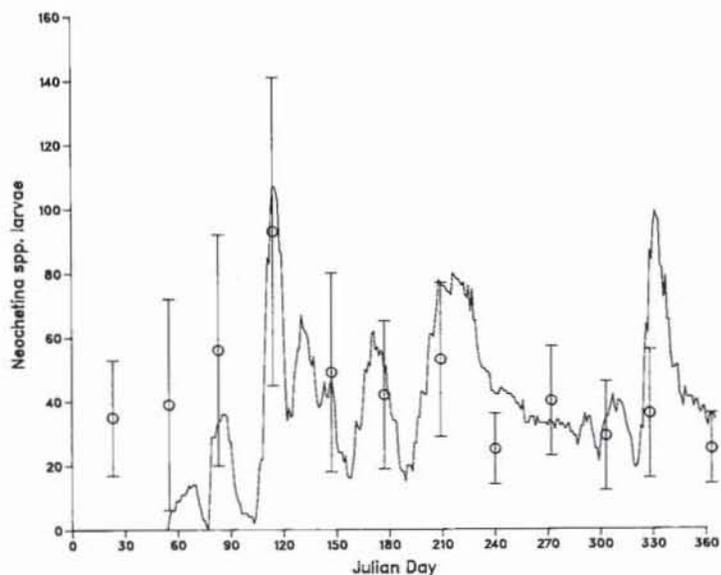
Figure 4. Simulated third instar *Neochetina* spp. larvae population plotted against the 95% confidence intervals for the 1986 North Florida site "CA" data.

the purpose is to describe the mathematical programming method and to summarize the results obtained from the initial comparison studies. It is also possible that both the method of back-calculating and the mathematical programming approach can be used together to estimate the initial weevil population. For example, the initial weevil population obtained from the mathematical programming approach can be modified by the method of back-calculating in order to improve the match between the simulated and the actual field data observations.

Finally, this approach illustrates how mathematical programming and simulation modeling can be used in a complementary manner. The approach is general in nature and can be used for other insect models where the actual field data for initialization of the model is not available.

ACKNOWLEDGEMENTS

LITERATURE CITED

Akbay, K. S., Wooten, J. W., and Howell, F. G. 1988. "Simulation Model of Waterhyacinth and Its Biocontrol Agents; Report 1, First-Generation Model," Technical Report A-88-8, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Charnes, A., and Cooper, W. W. 1961. *Management Models and Industrial Applications of Linear Programming.* Vol's. 1 and 2. Wiley and Sons. New York, NY.

Howell, F. G., Akbay, K. S., and Stewart R. M. 1988. "Field Validation and Improvements to INSECT, a Personal Computer Simulation Model," Proceedings of the 22nd Annual Meeting of Aquatic Plant Control Research Program, Portland, OR. 160-168.

McClendon, R. W., Brown, L. G., and Akbay, K. S. 1984. "A Goal Programming Approach for estimating Insect Pest Migration and Initial Influx," Presented at the Institute of Management Sciences XXVI Meeting, Copenhagen, Denmark.