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Kunter S. Akbay
Marquette University

F. G. Howell
University of Southern Mississippi

J. W. Wooten
University of Southern Mississippi

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KUNTER S. AKBAY², F. G. HOWELL³, AND J. W. WOOTEN³

ABSTRACT

A personal computer simulation model termed "INSECT" has been developed to evaluate biological control of waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.) by two species of weevil (*Neochetina eichhorniae* Warner, and *N. bruchi* Hustache). The model results were compared with the data from three different locations. For each data set, the simulated plant biomass, adult and larva populations were plotted against the 95% confidence intervals of the actual field observations. In many cases, the simulation results were within the 95% confidence intervals, and especially during the growing season, they indicated trends similar to those seen in the field data. However, there were discrepancies in both the magnitude and the trend for early and the late periods of the year. These initial results suggest that development of a model to simulate the impact of a biocontrol agent on waterhyacinth populations is a feasible approach to better understand the interactions within this control system.

Key words: Aquatic plants, waterhyacinth, *Neochetina*, biological control, computer simulation models.

INTRODUCTION

The severity of the problems caused by waterhyacinth plants has resulted in the development of a number of management procedures such as physical, mechanical, chemical, and biological control. INSECT is a computer simulation model designed to reflect certain aspects of the population dynamics of waterhyacinth and two insect

species, *Neochetina eichhorniae* and *Neochetina bruchi* over extended time periods (Akabay et al., 1988; Akabay et al., 1986; Howell et al., 1988; Howell et al., 1987). However, the scarcity of published data for the effects of *Neochetina* spp. on the plants has forced the authors to make assumptions for basic components of this system.

The long-term objective for initiating development of the INSECT model was to develop a predictive tool for *Neochetina* impacts on waterhyacinth. Once completed, information provided by the model will help users confidently and effectively use *Neochetina* as an operational control agent of waterhyacinth. In practice, data collected from field sites will be used to initialize the model. The simulation can then help to predict the impacts that a resident *Neochetina* population will have on the waterhyacinth infestation through time. With this information, operational control activities can be structured that will achieve the maximum benefits from this biological agent.

The INSECT model has two modules. The plant module generates an estimate for the total biomass available. The insect module is composed of two independent sub-modules, one for *N. eichhorniae*, and one for *N. bruchi*. After both the plant and insect modules are utilized, impact by the weevils on the waterhyacinth biomass is simulated.

SIMULATION MODEL

Plant module. The INSECT model simulates weevil development and waterhyacinth growth and their interactions within a given homogenous square meter and assumes consistent response in the adjacent areas. The model also assumes that nutrients for plant growth are not limited. A nonlinear relationship (with light and temperature as independent variables) is used as in the model of Lorber et al. (1984), based on data of Mitsch (1975) and Knippling et al. (1970). Photosynthesis and respiration rates of the plants are functions of the prevailing temperature and light intensity. Past temperatures and light regimes

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²Department of Mechanical and Industrial Engineering, Marquette University, Milwaukee, WI 53233.

³Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, MS 39406.

have no effect on the current photosynthesis and respiration rates, other than through the effects on plants. Growth takes place by a series of added daily increments of leaf, rhizome and root tissue; each is determined by the prevailing temperature and light intensity and biomass density. Thus, any adaptive changes in leaf structure and function, which may occur in response to the environment, are not accounted for in this model.

Additional assumptions of the plant module are: 1) day and night respiration rates are equal; 2) rates of respiration are not dependent on plant age and size; 3) maintenance respiration cost increases linearly with density of plants; 4) detritus consists only of dead leaf material and therefore contributions of root material as detritus are not included.

In the model, the daily change in waterhyacinth biomass (in grams per square meter) is affected by gross photosynthesis, respiratory maintenance, efficiency of conversion, and detrital production (Lorber et al. 1984).

The gross photosynthesis is a function of maximum photosynthesis (Mitsch 1975 and Lorber et al. 1984) and the limiting factors due to the air temperature (Knippling et al. 1970) and the density (Lorber et al. 1984). Since the model assumes that the nutrients are not limited, the gross photosynthesis is not affected by the availability of nitrogen and phosphorus.

The relationship for daily respiratory maintenance rate is established from ranges presented by Penning de Vries (1975a). This rate appears to vary due to climatic conditions; hence, geographic localities may differ in the coefficients used in the model. The respiration coefficient is calibrated to be 0.019 and 0.015 for Florida and Louisiana, respectively.

The efficiency of conversion factor is calibrated from estimates for several genera of plants given by Penning de Vries (1975b). The model assumes that the efficiency of conversion factor for Florida is 0.65 during the flowering season and 0.75, otherwise. For Louisiana, the factor is 0.73 during the flowering season and 0.83, otherwise.

Leaf detrital production is based on the assumption that a leaf dies every 10.2 days⁴. The model assumes that the detrital production is a function of the number of dead leaves and the average weight of a leaf. The average number of plants are estimated by the total plant biomass, the estimated daily percent leaf material, and the average total leaf weight of one plant.

Weevil module. The weevil module was designed after Brown et al. (1982). The values used in the algorithms to simulate the population dynamics of *Neochetina* spp. are based upon modified biological and ecological information found in Center and Durden (1986), Center and Spencer (1981), Center and Spencer⁵, DeLoach and Cordo (1976a,b), and Stark and Goyer (1983).

The model assumes that the temperature is the governing force that dictates weevil development. No diapause or arrested development occurs during winter or summer months. Distributions of eggs, larvae, pupae, and adults are uniform on or in plants and within one square meter area. No immigration occurs to the *Neochetina* spp. popula-

tions since this is difficult to define. Emigration occurs whenever carrying capacity is exceeded. Natural mortalities include predation and other unexplained losses to the weevil populations. Explained mortalities include losses due to subfreezing temperatures, detritus production, and emigration. Other herbivores or weevil waterhyacinth predators are not present. Larvae that have attained two-thirds of their thermal constant are considered to be third instar larvae. Reduction in plant biomass is a result of bud predation by third instar larvae.

The weevil module was developed to predict numbers of individuals in the existing populations, including numbers of individuals entering or leaving the populations on a given simulation day. Therefore, weevil cohorts (egg, larva, pupa, and adult) are updated on a daily basis as per Brown et al. (1982).

Development of weevils is accomplished via accumulation of physiological age in day-degrees based upon average daily air temperatures in degrees celsius. It is assumed that below the threshold temperature of 11C no development occurs. Between 11C and 27C, development is advanced by day-degrees calculated on the difference between 11C and the average daily temperature up to 27C. Between 27C and 29C, only 8 degree-day units are allowed and none is accumulated above 29C. Therefore, development of each cohort is delayed for each day in which average air temperature exceeds 27C.

The model assumes that the required number of day-degrees for egg development is 88 for *N. eichhorniae* (Stark and Goyer 1983) and 83.6 day-degrees for *N. bruchi* (DeLoach and Cordo 1976a). The development of larvae to pupae requires 451 day-degrees for *N. eichhorniae* (Stark and Goyer 1983) and 433.4 day-degrees for *N. bruchi* (DeLoach and Cordo 1976a). 330 day-degrees for both *N. eichhorniae* and *N. bruchi* is required for pupa development (Stark and Goyer 1983, DeLoach and Cordo 1976a).

In the weevil module, fecundity rates are based upon the assumption that 50% of the adult population is female (Stark and Goyer, 1983) and that fecundity varies according to the age of the female and the average daily air temperature.

Variation in fecundity is achieved by recognizing that females up to 7 days are more fecund than older females. A given female is expected to produce 50% of her eggs by the 7th day (1.5 and 1.75 eggs per day for *N. eichhorniae* and *N. bruchi* respectively) and 95% by her 33rd day (0.34 and 0.35 eggs per day for *N. eichhorniae* and *N. bruchi* respectively, DeLoach and Cordo, 1976a). In the model, females older than 33 days do not produce eggs. Temperature affects fecundity by a proportional factor: at 15C, only 48% of the fecundity value is used; at 20C, 100% is used; at 22C, only 78%, and at 25C, only 40% is used. Beyond 30C, no eggs are produced.

Mortality can be due to natural causes, subfreezing temperatures, and detrital production. Two classes of natural mortalities are recognized in the weevil module. These were set to reflect the differences in seasonal dynamics of predators and other factors which may impact *Neochetina*

⁴Empirically derived using Center's unpublished data.

⁵Unpublished manuscript.

spp. Winter and spring (through Julian Day 180) mortalities are highly reduced: 0.1% per day for eggs, larvae and pupae; 0.5% for adults. Summer and fall (Julian Day 180 through 365) are 0.90%, 0.75%, 0.16% and 3.4% per day for eggs, larvae, pupae, and adults, respectively.

The effects of subfreezing temperatures are included in the model since it is assumed that they affect the population considerably. Accordingly, the model assumes the following mortalities due to subfreezing temperatures: For light frost-freeze (-1.5 to -0.5C): 50% mortality for eggs; 1% for larvae and pupae; and 3% for adults. Below -1.5C, the mortality is 95%, 30%, 1.5%, and 10% for eggs, larvae, pupae and adults, respectively. Furthermore, these mortalities are adjusted so that the impact of the subfreezing temperatures is less during early season (January 1 through March 1) compared to late season. The assumption is that early winter populations (end of year) are more susceptible to freezing conditions, whereas late winter populations (early year) have either already been selected for freeze tolerance or individuals have adjusted their positions within the habitat and are in less vulnerable places. Eggs, however, remain vulnerable regardless of the time of year. The assumptions made in the model regarding the effect of subfreezing temperatures on the weevil population are speculative at this point in the model development.

It is assumed that detrital production impacts oviposition sites and host plant habitat available to incoming eggs and larvae. For this reason, the model removes the number of larvae occupying the equivalent amount of leaf biomass lost to detritus. Weevil populations are also reduced due to migration and extremely low waterhyacinth biomass. It is assumed that if the total number of adults exceeds 225 per square meter regardless of plant biomass, 15% of the first day adults is removed from the population. This portion of losses is assumed to be due to migration to other areas. Furthermore, if waterhyacinth biomass decreases to 100 grams per square meter, then individuals from adults, larvae, and eggs are removed at the rate of 5.63% per day. Pupae, confined to the root zone of host plants, are removed at a rate of 1% per day.

The impact on waterhyacinth is produced by large larvae (approximate third instar) consuming plant biomass and, in process, removing meristematic tissue. The algorithm assumes that one large larva will consume a biomass equivalent of two leaves over an 11 day period⁶.

RESULTS AND DISCUSSION

The field data sets used for initial comparison studies are from Florida (Howell et al. 1988). For the simulation runs, the initial plant biomass values were estimated from the field data available (Howell et al. 1988). The starting numbers for weevils were estimated by using the first three sampling periods from a site-specific data set, and back-calculating to determine the numbers of individuals (Howell et al. 1988).

1976 Lake Alice. The initial conditions for the 1976 Lake Alice simulation runs were as follows: plant biomass - 0.705

⁶Empirically derived using Center and Spencer unpublished manuscript.

kg/sq m; number of adults/sq m - 5, 5, and 10 on Julian Days 42, 68, and 95, respectively; number of pupae/sq m - 8 on Julian Day 42. This site contained only the *N. eichhorniae*.

Simulation results plotted against the 95% confidence intervals for the 1976 Lake Alice data are presented in Figures 1 through 3. Plant biomass values generated by the model produced seasonal trends similar to those indicated by the monthly means for field biomass data (Figure 1). However, during the months of March, April, and May, and starting November, the model predictions were below the field observations. Especially for the months of November and December, the simulated values showed very drastic reduction in plant biomass compared to the field data. For adult *N. eichhorniae*, the model results compared extremely well during March through October (Figure 2). Out of 51 cases, there were 18 cases where the simulated results were outside the 95% confidence intervals. However, of these 18 cases, 8 occurred during the first two months and 5 occurred from mid October through December. This may be due to the assumptions made in the model for the winter conditions. However, the simulation results generated by the model indicated trends similar to those indicated by the field data. For the third instar larvae, simulated results compared well with the field data until the end of June (Figure 3). During July through September, the simulated values were consistently above the field observations even though the trends were similar. This may be due to the difference in the definition of the third instar larvae in the model and in the field observations. There was a major discrepancy between the simulated results and the field data for the last two months. Again, this may be due to the model assumptions for the winter conditions.

1986 North Florida Site "PP". The initial conditions for the simulation runs were as follows: plant biomass - 1.11 kg/sq m; number of pupae/sq m - 25 on Julian Day 1;

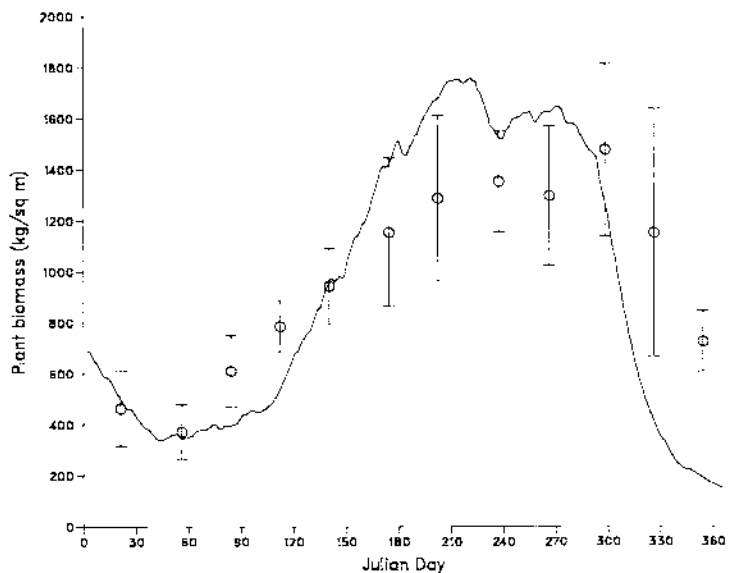


Figure 1. Simulated plant biomass values plotted against the 95% confidence intervals for the 1976 Lake Alice data.

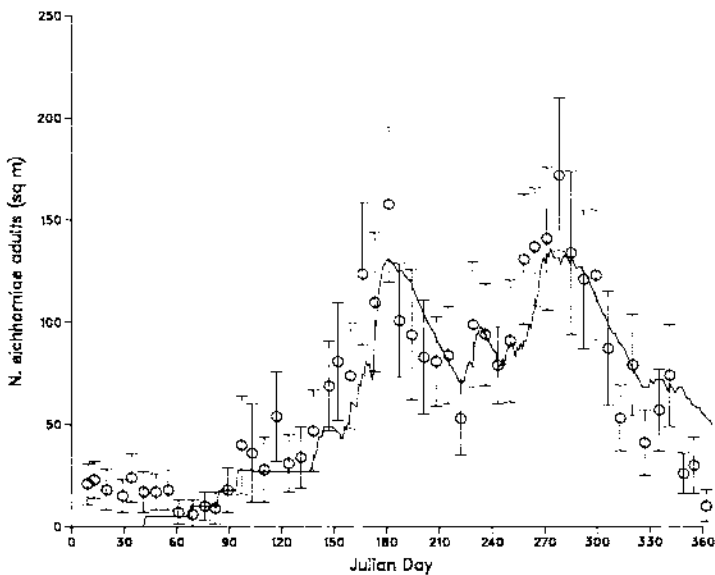


Figure 2. Simulated adult *N. eichhorniae* population plotted against the 95% confidence intervals for the 1976 Lake Alice data.

number of larvae/sq m - 37 on Julian Day 1. This site contained *N. eichhorniae* as well as *N. bruchi* where *N. eichhorniae* exceeded *N. bruchi* by about 10 to 1. The results are shown in Figures 4 through 7.

In general simulated plant biomass values closely tracked the monthly means for field biomass data (Figure 4). Only two of 10 cases were not within the 95% confidence intervals. A major departure between model predictions and field data occurred during the last two months of the year. In this case, the model showed a continual decrease in plant biomass after approximately Julian Day 250, while field data estimates showed a gradual increase during this same time period.

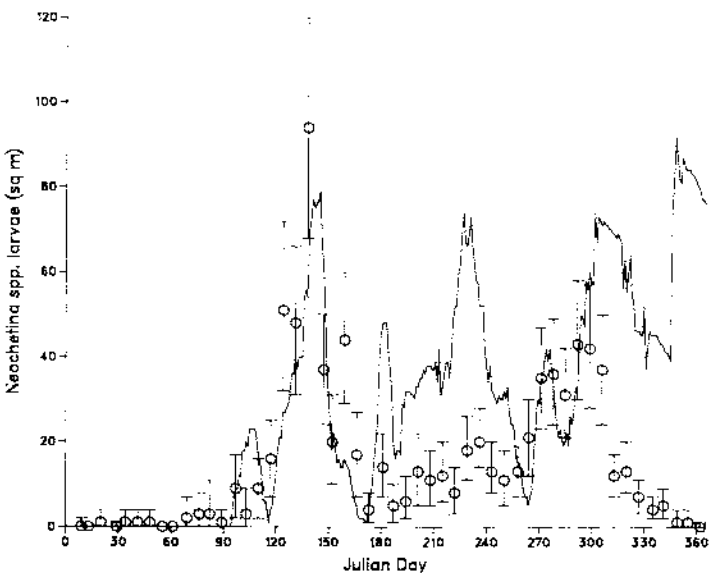


Figure 3. Simulated third instar *N. eichhorniae* larvae population plotted against the 95% confidence intervals for the 1976 Lake Alice data.

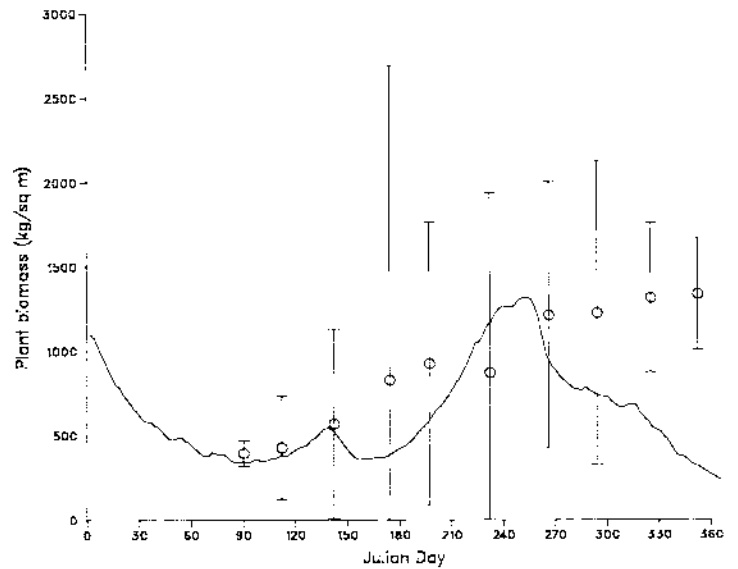


Figure 4. Simulated plant biomass values plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.

Model predictions for adult *N. eichhorniae* rarely exceeded the 95% confidence intervals for the field data (Figure 5). However, the model suggested first a drop and then an increase in the population levels between the Julian Days 180 and 220, where as the field data indicated a gradual increase during the same time period. However, despite of the difference in the trend, the simulated values were still within the 95% confidence intervals. Another discrepancy occurred during the months of November and December. The field data indicated a continual decrease in the adult population during this time period whereas the model first showed an increase in the population during November and then a decrease during December. Simulations for *N. bruchi* adults were always within the 95%

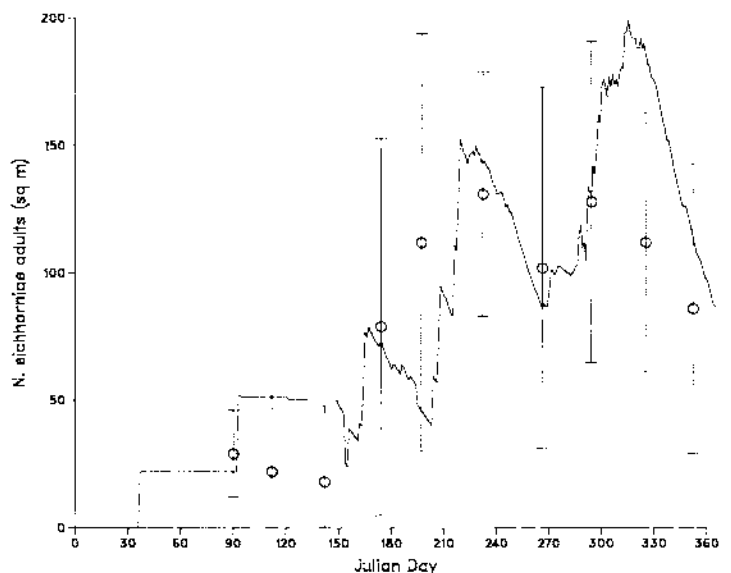


Figure 5. Simulated adult *N. eichhorniae* population plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.

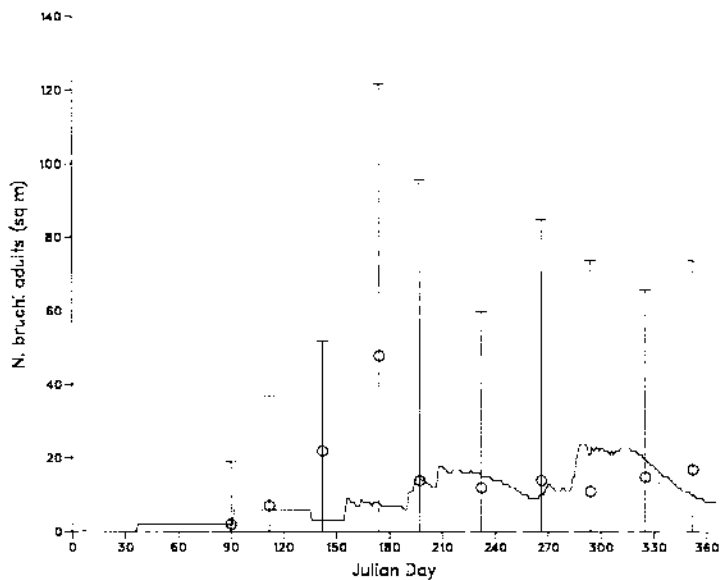


Figure 6. Simulated adult *N. bruchi* population plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.

confidence intervals of associated field data (Figure 6). However, the field data suggested an increase in the population during May and June which was not seen in the simulated values.

Model predictions for the third instar larval populations at the North Florida site, for the most part, did not deliver good representations of those collected from the field (Figure 7). Five of nine cases were not within the 95% confidence intervals. However, model predictions followed a similar trend with the field data with the exception of two excessive peaks in early June and late September.

1986 South Florida Site "CA". The initial conditions for the simulation runs were as follows: plant biomass - 1.2

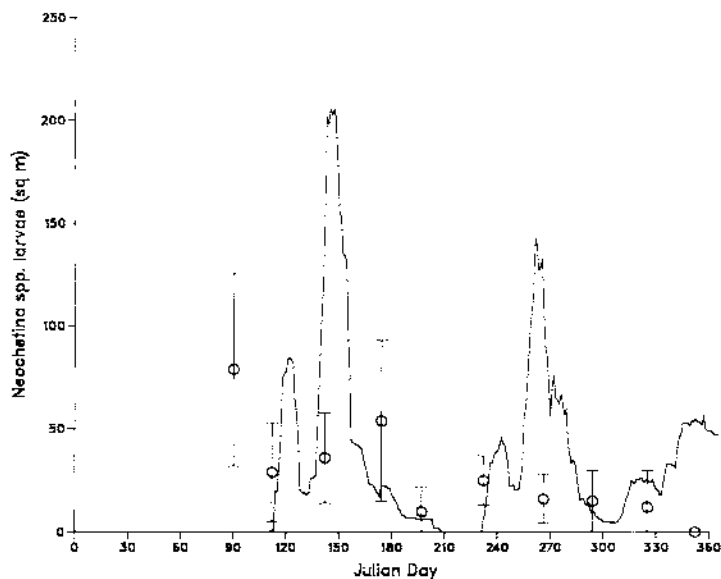


Figure 7. Simulated third instar *Neochetina* spp. larvae population plotted against the 95% confidence intervals for the 1986 North Florida site "PP" data.

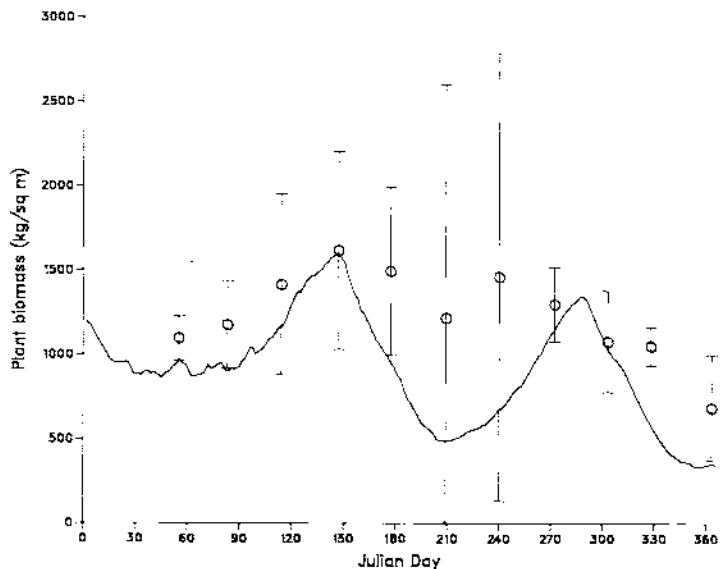


Figure 8. Simulated plant biomass values plotted against the 95% confidence intervals for the 1986 South Florida site "CA" data.

kg/sq m; number of adults/sq m - 7 on Julian Day 23; number of pupae/sq m - 14 on Julian Day 1; number of larvae/sq m - 17 on Julian Day 1. Percent *N. eichhorniae* and *N. bruchi* were 62% and 38%, respectively.

Plant biomass values generated by the model for South Florida site "CA" are shown in Figure 8. Here the trends within field data and model data were almost identical. Unlike the ending numbers for the North Florida sites, field data estimates of plant biomass at the end of the year showed a trend of decreasing magnitudes. Model simulations of plant biomass reflected this same trend.

Model predictions for adult *N. eichhorniae* showed good agreement with field data collected from this site (Figure 9). The magnitudes were within or close to 95% confidence

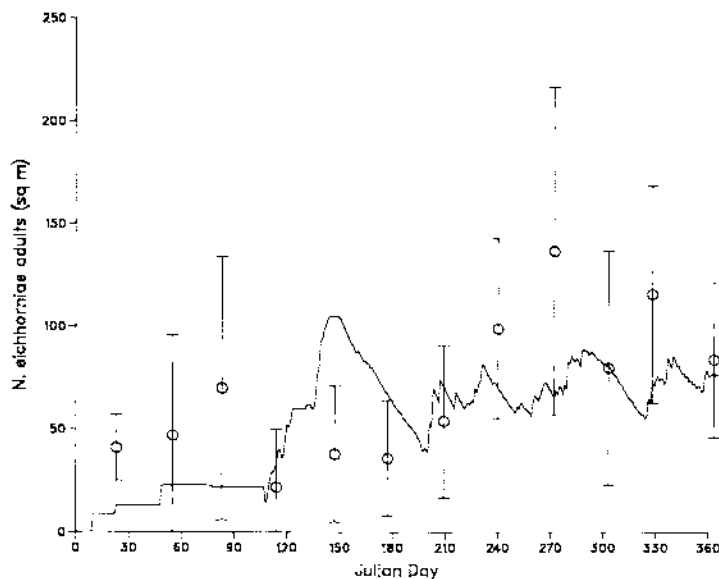


Figure 9. Simulated adult *N. eichhorniae* population plotted against the 95% confidence intervals for the 1986 South Florida site "CA" data.

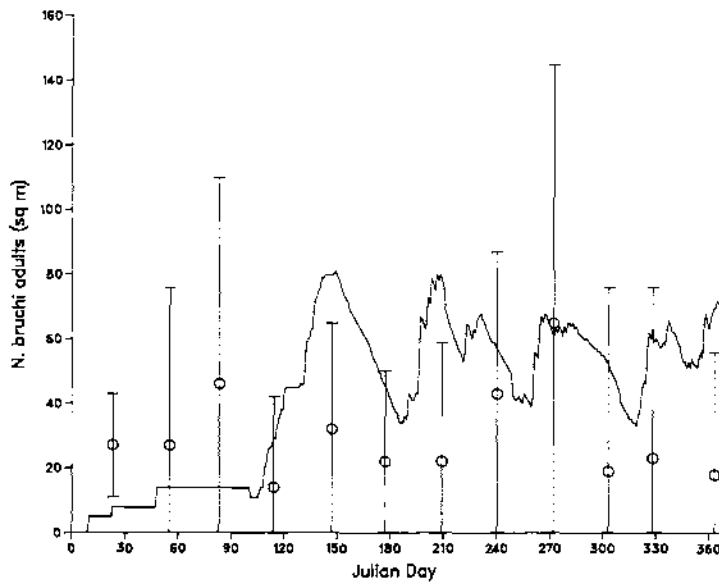


Figure 10. Simulated adult *N. bruchi* population plotted against the 95% confidence intervals for the 1986 South Florida site "CA" data.

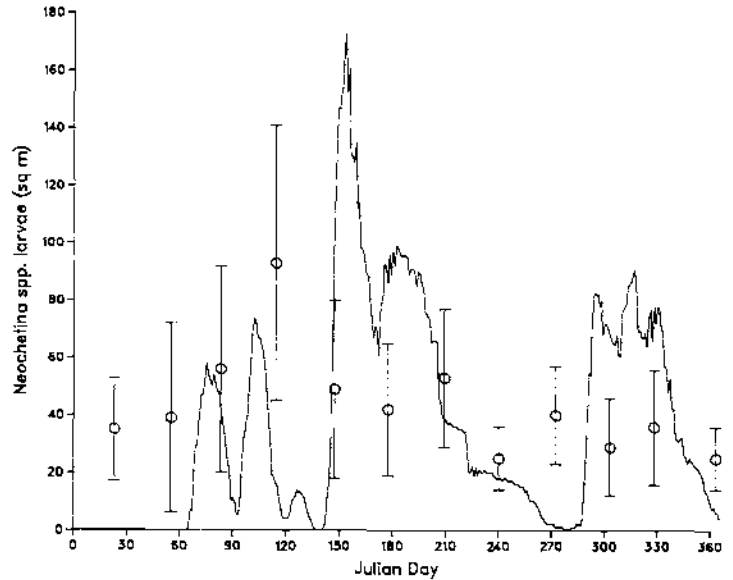


Figure 11. Simulated third instar *Neochetina* spp. larvac population plotted against the 95% confidence intervals for the 1986 South Florida site "CA" data.

intervals. Simulations for adult *N. bruchi* met the 95% confidence intervals in all but three cases (Figure 10). The simulated trends were in good agreement with the field data. However, the simulated adult population showed an increase at the end of December as opposed to a decrease indicated by the field data.

Model predictions for the third instar larval population at the South Florida site followed a similar trend with the field data with the exception that they were lagging approximately a week behind the field data (Figure 11).

The comparison of the simulated results with the field data sets from three different locations were encouraging. In many cases, the simulation results were within the 95% confidence intervals, and, especially during the growing season, they indicated trends similar to those seen in the field data. However, there were discrepancies in both the magnitude and the trend for early and the late periods of the year. Much more and complete information is needed to modify the assumptions of the model to be able to make multiple-year predictions for operational use.

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