

GENMOD: A GENERALIZED INSECT POPULATION MODEL¹

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ABSTRACT

GENMOD, a generalized model using the Leslie projection matrix is composed of four independent modules which can project the population of insect pests of cereals, vegetables, and field crops. Aphids and thrips are grouped in a separate module. A simple pest management game is included to demonstrate the effect of biological control and insecticide sprays on pest population dynamics. Populations are projected at discrete time intervals. The model can project the population of any species with known biology (age-specific reproductive and survival rates). Population trends ranged from exponential to cyclic curves. The model is most useful as a teaching tool in the study of pest population dynamics.

The modules were programmed using Turbo Basic version 1.1 and can be run separately on a modest IBMPC compatible without a hard disk or a laptop computer with only one disk drive.

Key words: GENMOD, cereal, field and vegetable crop insect pests.

INTRODUCTION

Modeling and computer simulation are tools for studying the behavior of pest populations through time. Simulation models are now being employed as tools for assessing potential benefits of biological control (Teng and Hofer, 1990) and as decision aids for pest management such as EPIPPE ((Zadoks, 1984) in Europe. SIRATAC (Ives and Hearn, 1987) and TEXCIM (Harstack and Sterling, 1988) for cotton in Australia and USA. In the Philippines, single species population models have already been developed but still await practical field applications such as corn borer (Jackman and Benigno, 1983; Cayabyab and Benigno, 1983) rice leaffolder (Benigno *et al.* 1988), yellow stemborer (Xia *et al.* 1989) green leafhopper (Palis *et al.* 1984) and rat (Benigno *et al.* 1983). These models were programmed using different computer languages (FORTRAN, HP enhanced BASIC, Turbo BASIC, Turbo Pascal, and PCSMP).

There are special languages for simulation, like CSMP (IBM, 1975) which simplify modeling and programming. Lately, the software STELLA (Richmond *et al.* 1987) was developed specifically for the Apple Macintosh. STELLA further simplifies modeling to flowcharting and defining functional relationships among

variables. The software takes care of the more tedious encoding of the program. Its only limitation is that it is not transportable to the IBM PC. This study aimed to construct a generalized summary model for different pest species of major crops. The simple user-friendly model could provide a quick overview of pest population dynamics and could also serve as the starting point for building the more detailed models.

MATERIALS AND METHODS

Biological information particularly reproductive and survival rates were reviewed from various sources (Alba *et al.* 1985; Aterrado and Abad, 1984; Baltazar, 1970; Barrion and Litsinger, 1984; Cadapan and Sanchez, 1972; Catindig *et al.* 1989; Catindig *et al.* 1986; Cendaña and Baltazar, 1948; Ching-Huan and Pathak, 1971, Corpuz 1969; Cruz and Bernardo, 1971; Gallego *et al.* 1983; Gapasin, 1978; Hartstack and Sterling, 1988; Navasero and Calilung, 1990; Ooi, 1985; Perez, 1972; Sanchez and Laigo, 1968; Tabibullah and Gabriel, 1975). Information on factors affecting population dynamics were also included. Thus, for the diamondback moth, separate biological information were obtained for the highlands (lower temperature) and the lowlands (Ooi, 1985). For the Asian corn borer, the model used different data sets for corn and cotton crops. The model was based on the Leslie matrix (Leslie, 1945 and Leslie, 1948). The number of insect stages and the time interval for projection was based on the average or modal duration (in days) of the different stages. The population at time t (N_t) was computed as:

$$N_t = MN_{t-1}$$

where:

N_t = population vector at time t

M = Leslie projection matrix

N_{t-1} = population vector at time $t-1$

Survival and reproductive rates, however, were varied using known functional relationships (e.g. temperature, density-dependent factors) of the insect species. Thus, survival rates were updated at each time interval:

$$S_{ij} = S_{ij} (1-f1_{ij}) (1-f2_{ij}) \dots \text{ where:}$$

S_{ij} = survival rate of the 9th stage at j th time interval

$f1_{ij}$, $f2_{ij}$, ... = weighting coefficient (between 0 to 1) of the different contributory factors

Density dependence functions for reproduction and mortality (Conway and Mudie, 1971) were used only in the aphid module as follows:

$$AVMORT = 1 - \text{EXP} (-K * \text{DENS})$$

Where:

- AVMORT = average mortality for the stage
- EXP = base of natural logarithm raised to a power
- K = mortality coefficient
- DENS = population density

and

FEC = $BFEC * EXP(-K * DENS)$

where:

- FEC = number of eggs laid
- BFEC = basic fecundity
- K = density of coefficient of fecundity
- EXP and DENS = as defined above

The biological data were kept in separate files for each species that could be called by the main program when a species is selected. To allow projection of varying durations and number of growth stages of different species, the third line in the data file code defined the duration of each stage, the number of sub-stages of the egg, three immature and the adult stages. An example of a biological data file structure is as follows:

ARWRICE. BDT - File name

"*Pseudaletia separata* (True armyworm)" - Species

"Duration Noegg Noim1 Noim2 Noimo Ad" - Header

2,1,5,5,5,8 - Stage duration (days), number of sub-stages for eggs, immatures, and adults

"Stage Surv. Repro" - Header

"Egg",0.99,0 stage-specific survival and reproductive rates

"Larval ",0.85,0

"Larva2 ",0.85,0

"Larva3 ",0.85,0

"Larva4 ",0.85,0

"Larva5 ",0.85,0

"Larva61 ",0.85,0

"Larva62 ",0.85,0

"Larva63 ",0.85,0

"Larva64 ",0.85,0

"Larva65 ",0.85,0

"Pupal ",0.93,0

"Pupa2 ",0.85,0

"Pupa3 ",0.85,0

"Pupa4 ",0.85,0

"Pupa5 ",0.85,0

"Adult1 ",0.8,0

"Adult2 ",0.8,33.36
 "Adult3 ",0.8,33.36
 "Adult4 ",0.8,33.36
 "Adult5 ",0.8,33.36
 "Adult6 ",0.8,33.36
 "Adult7 ",0.8,33.36
 "Adult8 ",0,33.36

The file represents the default biological data based on studies on this species (Cadapan and Sanchez, 1972) and can be updated at run time. The life stages were divided into sub-stages of two-day durations. Thus, the sixth instar larval stage was divided into five sub-stages (Noim2). The columns of numbers represents the survival and reproductive rates per substages per time interval. The adult stages were divided into pre-ovipositing (Adult1) and ovipositing adults. Only the ovipositing adults have non-zero reproductive rates. The last sub-stage (Adult 8) had a zero survival rate as it dies out in the next time interval. For many of the species reviewed with incomplete biological information, survival and reproductive rates were assumed at levels that generate reasonable population curves.

In a way, the splitting of stages into sub-stages of uniform duration is similar to the use of the box cars in other simulation techniques.

Programming was done in Turbo Basic so that the model could be readily modified even by not so experienced programmers. The flowchart of the computer program is shown in Fig. 1. The first part deals with selection of crop and pest followed by the reading in or updating of biological information, and the initialization of the population including options for pest management games and output of results. The second part is the population projection proper. The population array is computed at each step in the time loop. The last part is the display/printing of results and option for re-runs. For the pest management subroutines, options for combinations of insecticide spray and biological control schedules are provided.

Sample Runs

Sample runs using different species were presented to show the range of population trends that the model can project.

Other Models

Existing models employing different approaches, programming languages and computer environments were also reviewed. The user is prompted on the screen for the selected species regarding other known models. Examples of these models are: rice stem borer and rice leaf folder programmed in PCSMP (Xia *et al.* 1991; Benigno *et al.* 1983), Asian corn borer in HPBasic and Turbo Basic for IBM PC, rice whorl maggot, and rice green leafhopper in HPBasic (Jackman and Benigno, 1983; Palis *et al.* 1984) and TEXCIM (Texas Cotton Insect Model for budworm and bollworm) originally written in FORTRAN (Hartstack and Sterling, 1988).

Validation

Although the objectives of the study did not include field validation, population projections by this model were compared with actual field monitoring data using a brown planthopper population data taken from Lumban, Laguna in 1980. The data for the first sampling period were used as initial population (data broken down into approximate model age classes) to project the population throughout the crop season.

Field data were plotted as points while the corresponding projected population was drawn as a line graph. The two data sets (observed and projected) have a common x-axis (time) but separate y-axis (density). The y-axis of the projected population is relative density while that of the observed is the mean density per unit area of plant.

The model was also compared with other modeling approaches such as temperature-driven or degree-day model (Jackman and Benigno, 1983) the IBM PC and delay model (Teng and Hofer, 1990) on the Macintosh computer using the Asian corn borer as the test species. The first 10 days trap catch were inputted as immigration data for the degree-day and Leslie models, while a pulse of two adults at 14-day interval starting at day 4 was used in the delay model.

RESULTS AND DISCUSSION

Most of the biological information available lack basic data on reproduction and survival as affected by environmental factors, population density, host and other factors. The model can project different population trends from exponential to cyclic curves.

The whole model was programmed into four independent modules: cereals, vegetables, field crops, aphids and thrips. The modules can be run separately to IBM PC compatibles and laptops with only one disk drive (no hard disk). At present, the modules cover about 50 species (Table 1) with enough room for others especially new pests that may occur. The populations can be projected over a period of time longer than one crop season.

Sample Runs

Results of simulation runs using rice yellow stemborer and the melon aphid are shown in Figures 2 and 3. For the yellow stemborer, the partial population curve of the small larvae is shown under conditions of no spray throughout and "ETL"-based spray schedule. The economic threshold level (ETL) was arbitrarily set at 15 units of small larvae. Under this criterion, two sprays were necessary between day 10 and day 30. With this schedule, the second peak at around day 70 was significantly reduced. The area between the two curves (no spray and with spray) represents the potential small larval population controlled by the sprays. It is interesting to note that the two populations were similar at 40-50 days and at day 90. This has also been observed in field experiments where at times no significant differences could be detected between treated and untreated populations.

The aphid population trend shows how the model can project insect

populations at extended period of time (e.g. 160 days). The aphid population exhibited a cyclic population with increasing amplitude through time.

Validation

Fitting of projected population trend of rice brown planthopper to the observed data is shown in Fig. 4. The model can only provide relative densities since prediction of absolute densities is difficult to achieve. The projected population peak in the figure is about 3 days later than the observed. After this peak, the observed population decreased faster than the projected.

The peak of the projected population was about three days later than the observed. After this peak the observed population decreased faster than the projected. The excess projected population may reflect the immigrating hoppers in the field.

For the Asian corn borer, the Leslie model was compared with the temperature driven model (similar to degree-day model) (Benigno *et al.* 1983) and a delay model using STELLA (Teng and Hofer, 1990), using a common immigration data based on 10 days of pheromone trapping. All models showed increasing population starting at 40 days. The first model simulated an earlier peak at around 53 days, while the delay model displayed an exponential curve that increased with time. This model has an intermediate time of peak around 70 days (Fig. 5).

As a decision aid for pest management, the degree-day model would seem to be most useful in forecasting peak populations. The Leslie model assumes constant development times and does not make full use of immigration data because of its being discrete in nature. This model lumps the daily immigration data into discrete time periods equal to the stage interval. However it compares satisfactorily with the other modeling approaches predicting the same first small peak at around 40 days for the Asian corn borer. In terms of computing time, the Leslie model is the fastest.

The programs are now available for users, with enough space reserved for additional pests. The programs and the biological data files can be conveniently modified using Turbo Basic Ver. 1 or 1.1. The model will most likely find its application in the classroom.

For practical purposes, the model could be useful in predicting the timing of peaks especially when control measures need to be applied. It is also useful in studying the population dynamics of a new species of interest.

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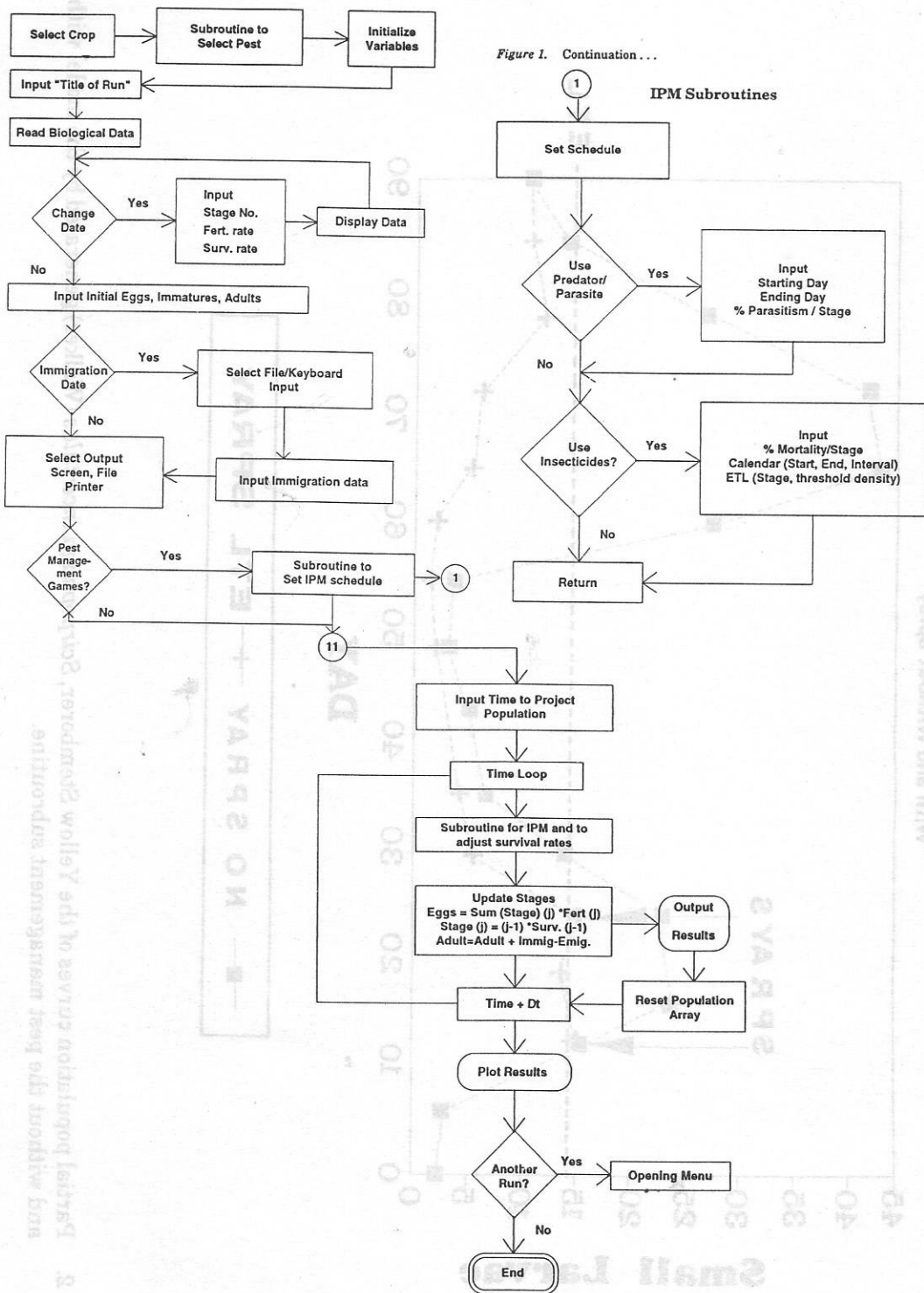


Figure 1. Flowchart of the GENMOD computer system.

Yellow Stemborer Simulation
With and Without Spray

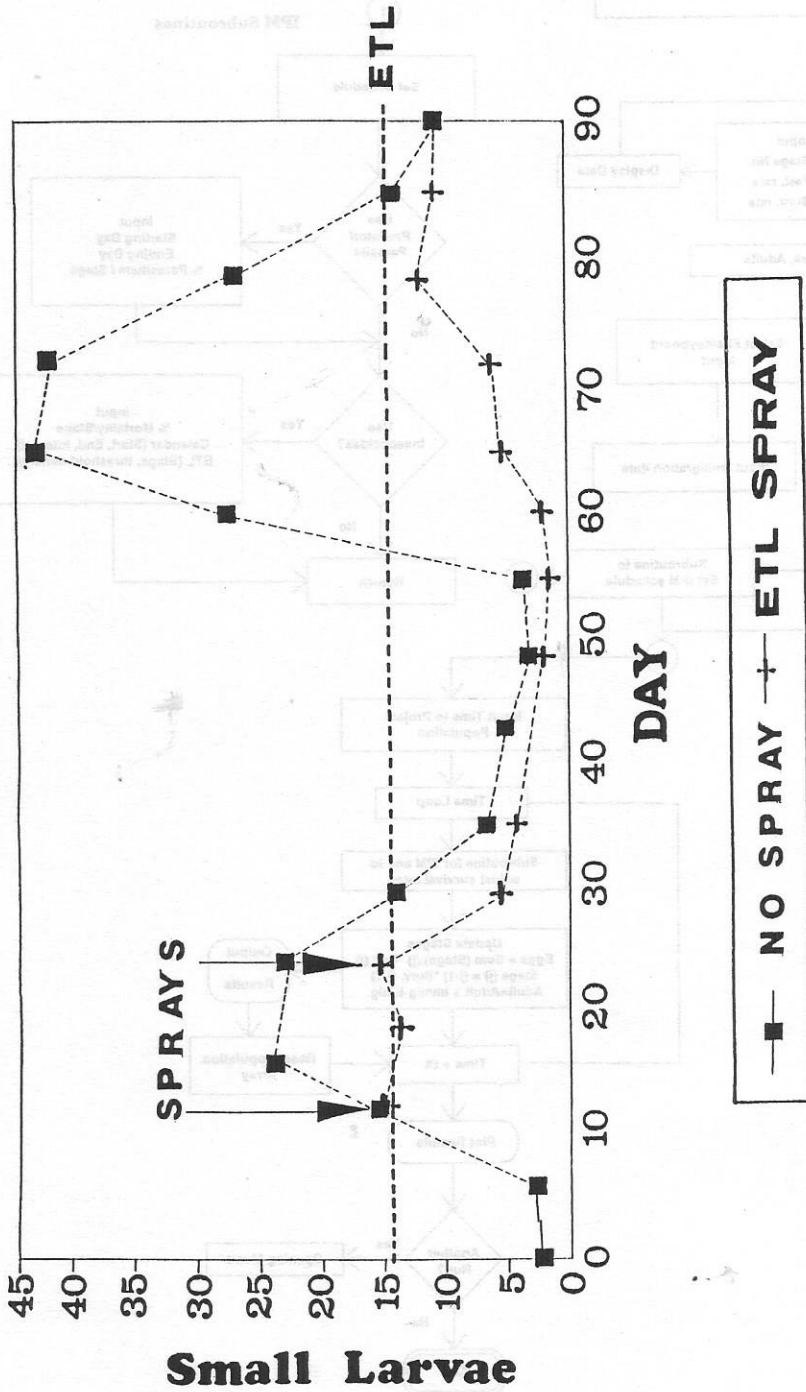


Figure 2. Partial population curves of the Yellow Stemborer, *Scirpophaga incertulas* (Walker) generated by the model with and without the pest management subroutine.

Simulation of Aphid Population Sample Run

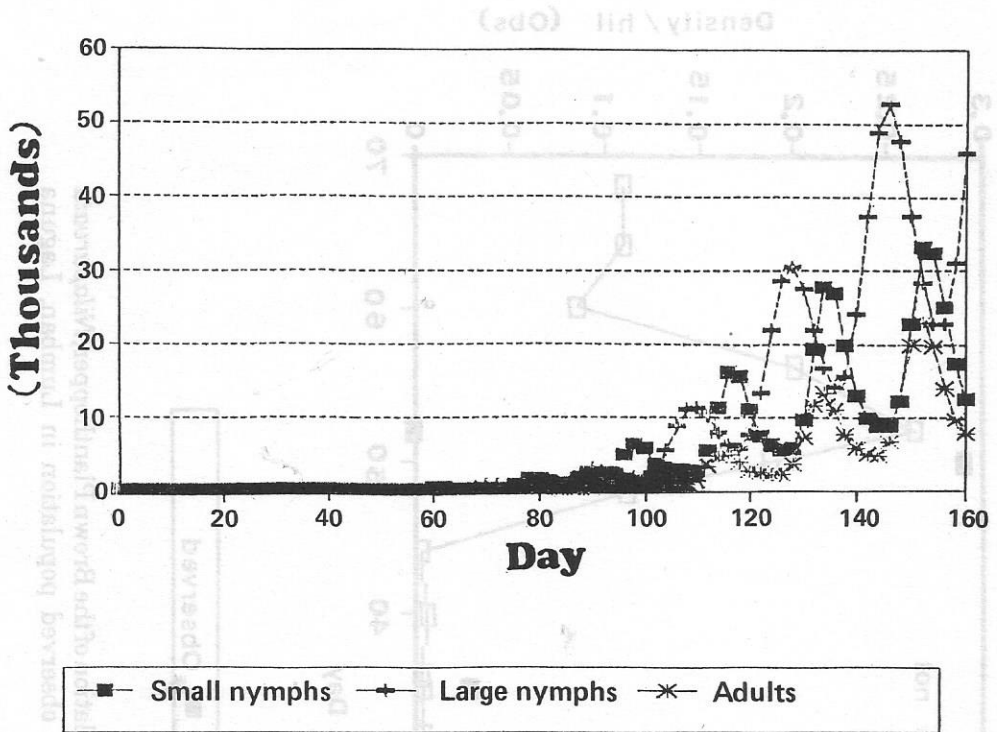


Figure 3. Population of the Melon Aphid, *Aphis gosyphyii* Glover over a period of time.

Brown Planthopper Simulation
Lumban, Laguna, 1980

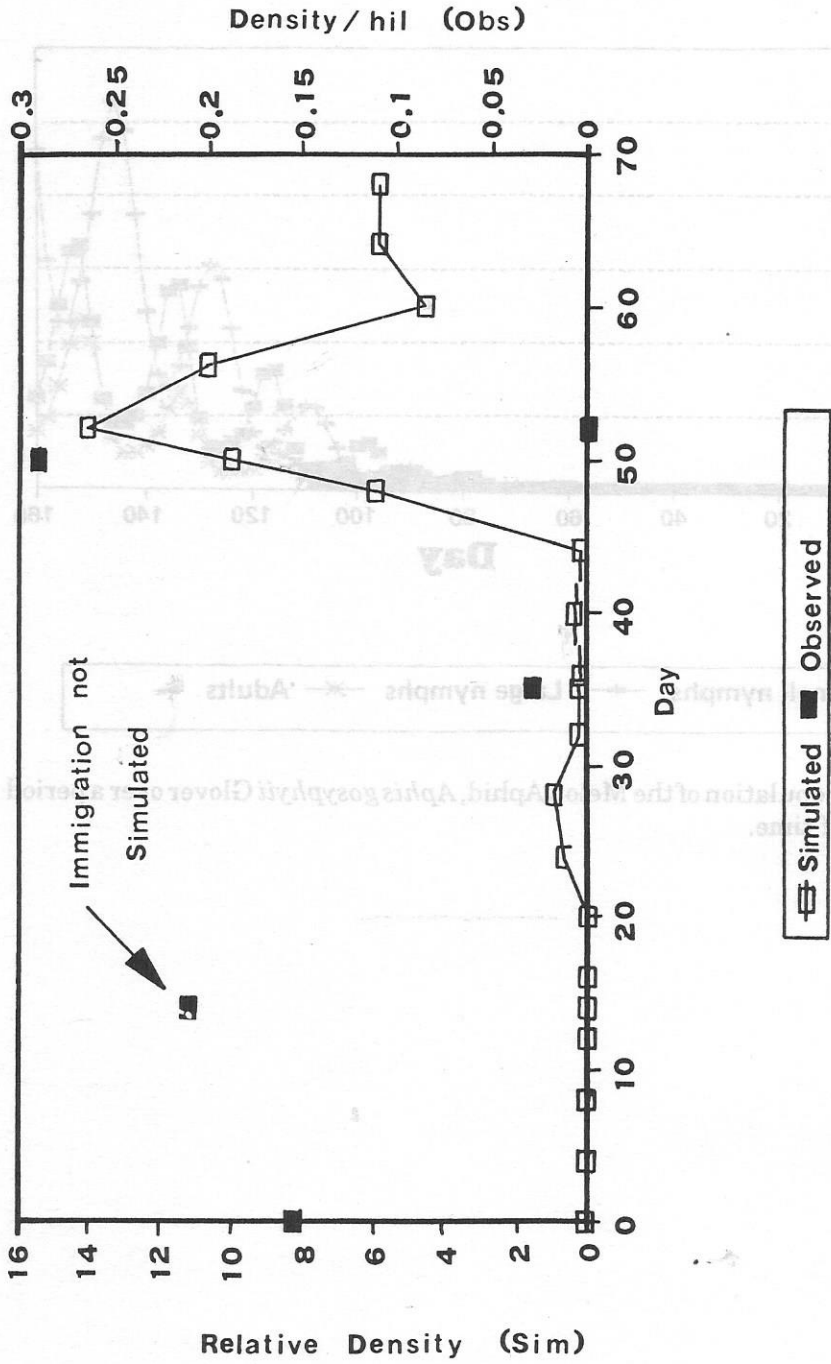


Figure 4. Fit of the projected population of the Brown Planthopper, *Nilaparvata lugens* (Stal) with an observed population in Lumban, Laguna (1980).

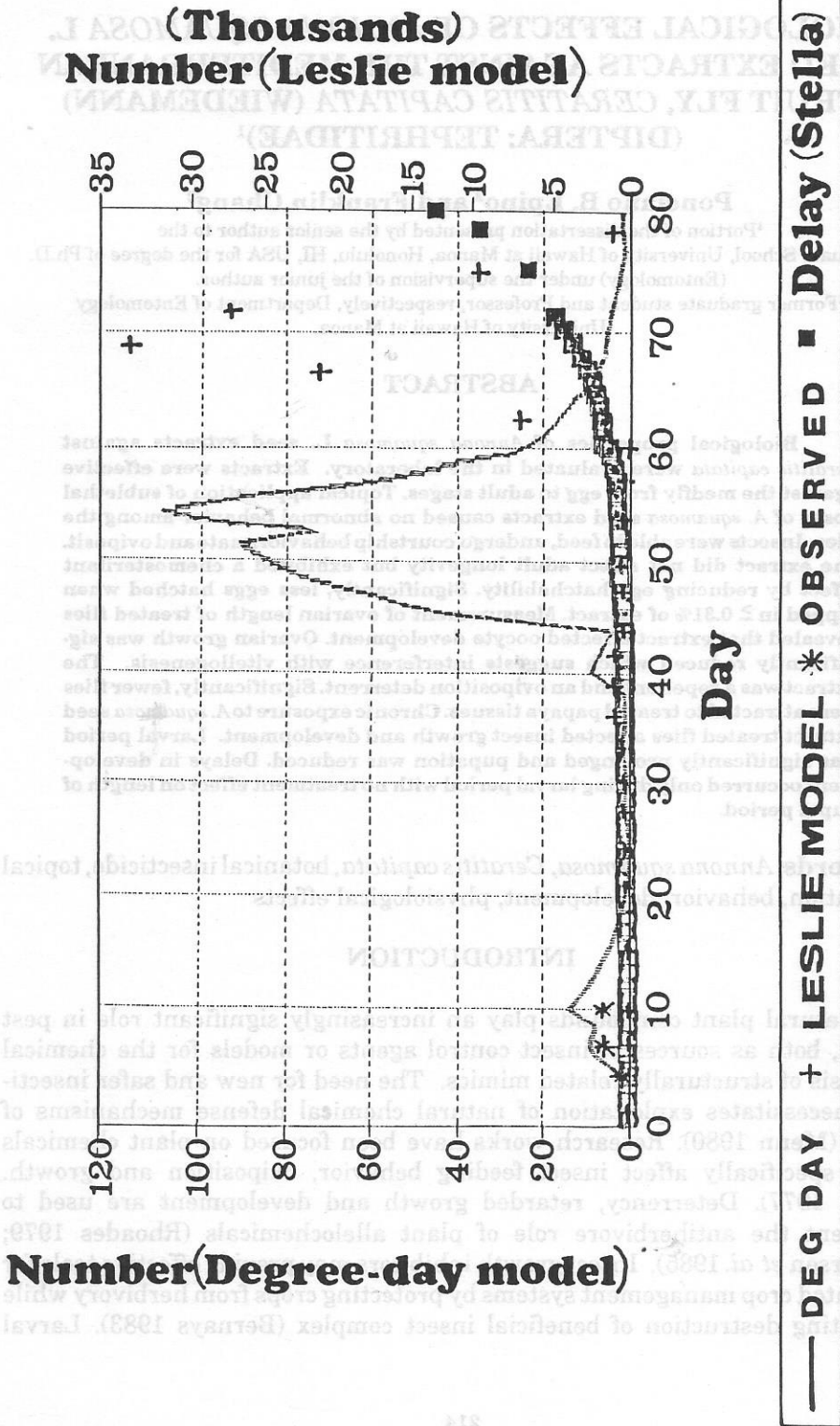


Figure 5. Comparison of modelling approaches in simulating the adult population of the Asian corn borer, *Ostrinia furnacalis* (Guenee) in Batangas (1991).