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User's Guide for GMPHEN: Gypsy Moth Phenology Model

Katharine A. Sheehan

Abstract

GMPHEN is a flexible, menu-driven computer model that uses daily temperatures and previously published data to predict the timing of gypsy moth and host development. This model simulates gypsy moth egg hatch, larval and pupal development, and budbreak and leaf expansion for six eastern hardwoods. At 1- to 10-day intervals (as selected by the user), GMPHEN reports the percentage of gypsy moths in each life stage, mean life stage, mean percent leaf expansion, and, for each host species, percent budbreak and leaf expansion. This guide contains instructions for using GMPHEN and presents examples of model simulations. The structure, assumptions, and default parameter values also are described.

The Author

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The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

For a copy of the GMPHEN model, please write:

GMPHEN
Silvicultural Options, RWU-4507
U.S. Department of Agriculture, Forest Service
Northeastern Forest Experiment Station
180 Canfield Street
Morgantown, WV 26505-3101

For questions on the model, please write:

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Introduction

As the gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), has expanded its geographic range in North America, it has encountered a widening array of microclimates. While extreme temperatures may result in direct mortality (Leonard 1972, Bradbury and LaBonte 1980), the indirect effects of local weather are probably of greater consequence to gypsy moth population dynamics in most areas. By changing gypsy moth development rates and thus the amount of time that gypsy moths are exposed to certain natural enemies, local temperatures may indirectly affect mortality (Weseloh 1976, Van Driesche 1983). Local weather also influences the synchrony of gypsy moth phenology relative to the phenology of its hosts, which affects gypsy moth survival and fecundity (Forbush and Fernald 1896, Hough and Pimentel 1978, Raupp and others 1988) and defoliation levels (Barbosa and others 1979).

Accurate phenology predictions that account for local weather would assist both managers and scientists in dealing with gypsy moth. During suppression programs, most pest managers rely on chemical or biological insecticides that have maximum effectiveness on specific life stages, and therefore try to schedule applications during this "biological window." Insecticide effectiveness also is affected by the degree of leaf expansion at the time of application. A knowledge of the gypsy moth life stages present and the current foliage status in various spray blocks would help managers optimize insecticide applications. Phenology information could be valuable to researchers who wish to sample specific life stages, or release natural enemies when target life stages are most abundant. Because biological processes are simulated in GMPHEN, this model should be a useful teaching tool.

Several studies of specific portions of gypsy moth and host phenology have been reported. Models of the timing and pattern of gypsy moth egg hatch have been reported by Johnson and others (1983), Lyons and Lysyk (1989), and Waggoner (1984), while Casagrande and others (1987) developed phenological models for larvae and pupae. These egg-hatch models do not account for the effect of winter weather on the pattern of egg hatch described by Masaki (1956). Valentine (1983) presented models that predict bud break and leaf growth for six eastern hardwoods: white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), and American beech (*Fagus grandifolia* Ehrh.).

The model described in this paper summarizes published information about gypsy moth and host phenology. GMPHEN—a Gypsy Moth Phenology Model—has a menu-driven format, and is flexible in that any parameter value can easily be changed. Separate versions are available for IBM-PC compatible microcomputers and Data General minicomputers.[1]

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Model Overview

GMPHEN simulates gypsy moth phenology by dividing the gypsy moth population into sets of cohorts. All gypsy moths that hatch in a given interval are considered one cohort; the length of the interval is measured in degree-days. From 1 to 30 cohorts can be simulated for 1 to 6 tree species. Separate sets of cohorts are simulated for females and for males on each tree species present.

Degree-day models assume that development is linearly related to temperatures, an assumption that is generally valid for intermediate temperatures but not for the upper and lower regions (Wagner and others 1984, Higley and others 1986). Wagner and others (1984) reviewed several approaches to modeling insect development and concluded that the method of Sharpe and DeMichelle, which assumes a curvilinear relation between temperature and development rate, is most suitable for predicting insect phenology. Hochberg and others (1986), however, found that a linear degree-day model provided better estimates of development for two aphid species than more complex, curvilinear models. Higley and others (1986) noted that recent interest in calculation methods has obscured the relative importance of accurate temperature data; they argued that temperature data is the chief limitation to more accurate degree-day accumulations because of (1) problems in adjusting ambient temperatures from one site to reflect those at another location, (2) differences between ambient temperatures and microhabitat temperatures, and (3) thermoregulation by mobile insect life stages. For most applications of GMPHEN, errors caused by inaccurate temperature estimates probably will far outweigh errors due to the development estimation method; consequently, a degree-day approach has been selected for simulating development.

Degree-days are calculated using daily maximum and minimum temperatures. Temperatures may be provided in metric or English units; in the latter case, temperatures are converted to metric units prior to degree-day calculations. Degree-days are calculated for each day using either the sine wave method (Allen 1976) or the rectangle method (Baskerville and Emin 1969), where the lower threshold temperature is subtracted from the average temperature to determine the degree-days for a given day. Users may set upper threshold temperatures, above which development rates do not increase. Eggs, female larvae, male larvae, female pupae, and male pupae may have different development thresholds, and thus may experience different degree-days on a given calendar day.

A series of degree-day measurements also may be entered; when this option is selected, all life stages are assumed to have identical development thresholds. An option to predict egg phenology using the variable rate model published by Lyons and Lysyk (1989) is also available.

Gypsy moths feeding on different tree species may have different degree-day requirements. For a given tree species and sex, gypsy moths in a given cohort are assumed to have identical development rates.

GMPHEN has two modes: the standard mode and the short mode. In standard mode, GMPHEN simulates gypsy moth phenology from egg hatch to adult emergence using the cohort distribution that is either assumed by default, provided by the user, or calculated based on winter weather. The short mode uses observed percentages of gypsy moths by life stage to estimate the underlying distribution of cohorts, and then predicts the life stages that will be present during the simulation based on daily temperatures. By default, GMPHEN operates in the standard mode.

Hardware and Software Requirements

Versions of GMPHEN have been written in Fortran-77 for both IBM-PC compatible microcomputers (PC) running the MS-DOS operating systems and Data General minicomputers (DG) running the AOS operating system. The only differences between the two versions occur in statements used to produce output and have no effect on the model's predictions.

Files associated with this model include:

File Name	*Required?*	*Description*
GMPHEN.EXE (for PC) or GMPHEN.PR (for DG)	yes	executable program
WDATA.DAT[2]	yes[3]	weather data
PARAMS.DAT[2]	no	parameters

Data Requirements

Weather file (required). Daily maximum and minimum temperatures or a series of accumulated degree-day measurements are required for the simulation; the units may be Fahrenheit or Centigrade. Users may provide weather data for a full year, part of a year, a full year plus the preceding winter, or part of a year plus the preceding winter. The data must be stored using one of the six formats described in appendix A. Leap years can be identified by the user.

Weather data can be stored on one or two files. The latter option can be used, for example, to simulate gypsy moth phenology using actual weather data to date (stored in the first file) and average weather data (stored in the second file) for the rest of the season. If two files are provided, the user specifies the date that GMPHEN should switch to the second file.

[2]Any file name (up to 12 characters in length) may be specified; files shown are supplied with the program and contain weather data for Cacapon, West Virginia, in 1980 (WDATA.DAT) or default parameter values (PARAMS.DAT).

[3]A weather data file is required when using GMPHEN in the standard mode, but not in the short mode.

When using GMPHEN in the short mode to project gypsy moth life stages for a limited number of days, users can use weather data stored in a file or enter data at the keyboard.

Parameter file (optional). Parameters and options can be set through an input menu or by specifying an external file. After the menu-driven package has been used to make desired changes, the current parameter and option values can be stored for later retrieval. Parameter files also can be created or modified using an ASCII file editor. The content and format required for parameter files are described in appendix B.

Model Output

Gypsy moth output can be in the form of a table, a file that can be used by a graphics package, or both table and graph file. While a stand-wide summary of leaf expansion is included in the gypsy moth output table, a detailed summary table for tree phenology is available as a separate option. Output tables include an initial section that lists the values for all parameters used in the simulation. The initial section also can include notes and warnings, such as a note that the short mode was used, or a warning that the weights provided for each host species do not sum to 1.0.

For the gypsy moth output table, the percentage of gypsy moths in each life stage, the average life stage, and the average percent leaf expansion are stored at intervals specified by the user. By default, output is stored every 2 days during the simulation.

Getting Started

General Instructions

* Either uppercase or lowercase letters may be used
* <NL> = press the ENTER or <—key on the PC or the NEW LINE key on the DG
* To back up to the previous menu, enter "! <NL>"
* To select the default option or value shown in brackets, enter "<NL>"
* To specify a date, enter either the day of year (Julian date, see chart inside back cover) or the month and day, separated by a "/", "-", ".", or "," (examples: 2/15, 11-7)

Figure 1 shows the menus used by GMPHEN and summarizes where different options and parameters may be changed.

How to Start GMPHEN

PC users:
The program and data file(s) can be stored on either a diskette or a hard disk. The following instructions assume that you start from the MS-DOS

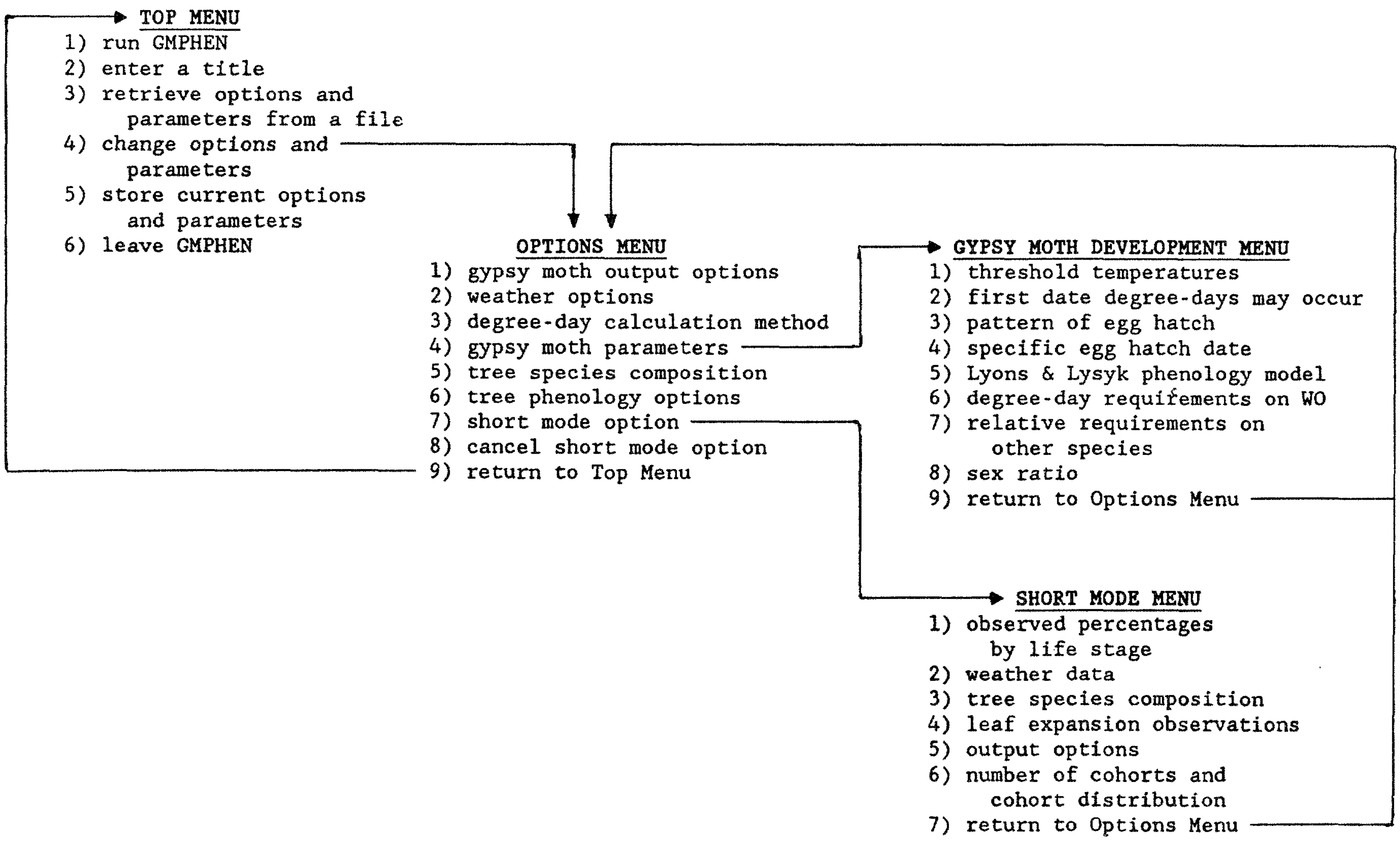

Figure 1.—Summary of menus used in GMPHEN.

prompt (">") and that the program and data files are stored in the current directory.

Type "gmphen <NL>".

DG users:
The program and data file(s) should be stored in CLI. The following instructions assume that you start from the CLI prompt (")") in the directory where the program and data files are stored.

Type "x gmphen <NL>".

How to View GMPHEN Output

After a simulation, GMPHEN displays the names of the files that contain output. By default, gypsy moth phenology output is stored in file MOTH.OUT and tree phenology is stored in TREE.OUT. To view an output file, you must first leave the GMPHEN program (select Leave GMPHEN from the Top Menu, described below), returning to MS-DOS (PC users) or CLI (DG users). Enter "type FILENAME <NL>", where FILENAME is the name of the file you want to examine (for example, MOTH.OUT, or another name that you specified when running GMPHEN).

Top Menu

Run the Model

If you select this choice, the model will simulate gypsy moth phenology using the current options and parameter values. When the simulation is complete, the message "all done!" appears and the files where the output has been stored are shown on the screen. By default, these output files are: MOTH.OUT, GRAPH.OUT, and TREE.OUT, though you may specify different file names using Option 4—Change Options and Parameters.

Enter a Title

Use this option to specify a title that will be printed at the top of both gypsy moth and tree output tables. The title may contain up to 40 characters.

Retrieve Options and Parameters from a File

When this option is selected, the model will ask you for the name of a file that contains gypsy moth phenology parameters and options. Such a file can be created using Option 5—Store a File—or by editing a file using EDLIN or other ASCII text editors (for PC users) or SED (for DG users). Appendix B describes the contents of a parameter file and includes an example. After the parameters and options stored on this file have been retrieved, you may make additional changes using Option 4—Change Options and Parameters—as described below.

Change Options and Parameters

This option, described in detail in the next section, may be used to change some or all of the options and parameters that are stored in the model (the default values) or have been read from a file using Option 3—Retrieve a File. Changes made using this option remain in effect until reset by the user, and they may be saved in a file (see Option 5). However, these changes are not stored automatically within the model, and will disappear when you exit GMPHEN. Whenever GMPHEN is started, parameters and options will be set to the default values.

Store Options and Parameters

Select this option if you want to save the current options and parameters. GMPHEN will ask you for a file name, which may be up to 12 characters long. If you give the name of a file that already exists, the old file will be deleted before the new file is created. You may also provide a title to identify the file; the title will be stored on the first line of the parameter file.

Leave GMPHEN

After you have completed the phenology simulation(s), choose this option to leave GMPHEN and return to DOS (PC users) or CLI (DG users). You can examine output files that were produced by GMPHEN by entering "type FILENAME <NL>".

Options Menu

Gypsy Moth Output Options

Output may be in the form of a table, or a file for a graphics package, or both table and graph file. You will be asked to enter a name for the output table or output graph file. A file name may be up to 12 characters long. If you enter the name of a file that already exists, the existing file will be deleted and a new one created for GMPHEN output.

The table and the graph file are identical except the headers have been removed from the graph file and, if desired by the user, the information can be packed into a smaller number of columns. Some graphics packages can handle only a limited number of data sets per graph; by packing the output into fewer columns, these graphics packages can be used to display GMPHEN output. If you select a graph file for output, you will be asked to specify the type of graph file desired: 8 data columns (for Graphwriter), 6 data columns (for Symphony), or 9 data columns (not packed).

You may also specify how often output is produced: every day, every second day, and so on. For example, someone who has weekly observations of gypsy moth life stages may wish to compare those data to GMPHEN output produced at 7-day intervals. By default, output is produced every second day in the form of a table in file MOTH.OUT.

Weather Options

To predict the timing of gypsy moth development, GMPHEN uses daily maximum and minimum temperatures that have been stored previously in one or more files. As an option, you may include weather data from the previous fall and winter as well as the current year because winter weather can affect the pattern of egg hatch (Masaki 1956). You may end the simulation at any time during the year, even if gypsy moth development has not been completed. You can also switch from one weather file to a second weather file at any time during the year. For example, if you have stored actual temperatures to date in one file and 10-year averages in a second file, you could simulate gypsy moth phenology using actual weather data up to the current date and then switch to the average weather data.

First, you will be asked whether the year to be simulated is a leap year. If so, GMPHEN will account for the leap year automatically by adjusting any calendar dates subsequently entered.

Next, you may specify weather files that include data from all or part of the year to be simulated, and data from the preceding fall and winter if available. You may also specify that you wish to enter degree-day measurements rather than daily temperatures. If your weather file contains only part of the current year, you will be asked to enter the last day in your file; GMPHEN will stop the simulation on the day that you have entered. If you include weather from the previous year, you will be asked if you want to let the number of cold days during the winter determine the pattern of egg hatch; if so, you may then change the threshold temperature to be used when identifying cold days.

You may use one or two weather files. For each file, you will be asked to enter the name of the file (up to 12 characters) and the first day of the weather data. Weather files may begin with any month, but they should always start on the first day of that month; see appendix A for details. If you use two weather files, you will be asked to specify the day that GMPHEN should switch to the second file.

Next, you may change the format and the units for your weather file. Format refers to how the data are stored: the number of characters per entry and the number of lines per month. The six format options that have been included are described in appendix A. Either metric (Celsius) or English (Fahrenheit) units may be entered; GMPHEN automatically converts English temperatures to metric units.

Finally, you may modify temperatures by adding a constant to each observation or by multiplying each observation by a constant. This option could be used to apply a standard lapse rate to account for the difference in elevation between a weather station and a stand where gypsy moth phenology is being simulated.

By default, GMPHEN will use weather data for one full, non-leap year that is stored in file WDATA.DAT using Format 1 and English units.

Degree-day Calculation Method

Two options for calculating degree-days are provided: Allen's (1976) sine wave method, or the rectangle method of Baskerville and Emin (1969). For the latter method (also known as the quick method), the lower threshold temperature is subtracted from the midpoint between the minimum and maximum temperatures for a given day to determine the degree-days that occur on that day. For both methods, an upper threshold temperature for development can be specified. The Allen sine wave method is used by default.

Gypsy Moth Parameters

The names and default values for parameters related to gypsy moth phenology are listed in appendix C.

Threshold temperatures. Lower and upper threshold temperatures for development may be specified for eggs, female larvae, male larvae, female pupae, and male pupae. When you select this option, the default value for each parameter will be shown in brackets; you may enter a new value or press <NL> to retain the default value.

First date that degree-days may occur. This option controls when gypsy moth eggs may start accumulating degree-days. By default, degree-days may accumulate starting on day 1 (January 1).

Pattern of egg hatch. The period of egg hatch is divided into intervals of equal length, measured in degree-days. All eggs that hatch during a given interval are considered to be in the same cohort, and GMPHEN simulates the development of each cohort separately. You may change the interval length, the number of intervals (which is the same as the number of cohorts), and the proportion of eggs that hatch in each interval.

Masaki (1956) found that the length of egg hatch increased as the number of days eggs were stored in cold temperatures decreased. The egg-hatch patterns associated with given numbers of cold days were estimated as described later in "How the Model Works" from data presented graphically by Masaki (1956), and are listed in Table 1. In GMPHEN, you may change the pattern of egg hatch by entering a specific pattern, identifying the number of cold days that occur, or providing weather data for the full winter and allowing GMPHEN to determine the number of cold days that have occurred. In the latter two cases GMPHEN automatically will choose the pattern whose associated number of days of cold storage most closely matches the observed number of cold days. By

Table 1.—Patterns of egg hatch at 23 degree-day intervals (proportions of total eggs that emerge during each interval) for varying numbers of days of cold storage; adapted from data presented graphically by Masaki (1956) as described in the text

	Number of days of cold storage										
Interval	70	80	90	100	110	120	125	130	140	147	160
1	.02	.02	.02	.02	.01	.01	.005	.01	.01	.01	.005
2	.03	.03	.04	.05	.04	.02	.015	.03	.03	.03	.015
3	.04	.03	.05	.10	.11	.07	.07	.12	.19	.26	.27
4	.04	.05	.06	.17	.14	.16	.15	.25	.30	.40	.45
5	.05	.07	.08	.11	.16	.25	.26	.17	.17	.16	.15
6	.05	.08	.09	.09	.14	.14	.20	.13	.10	.08	.07
7	.08	.10	.10	.09	.10	.11	.12	.10	.08	.04	.03
8	.08	.10	.10	.08	.08	.07	.07	.09	.07	.02	.01
9	.07	.09	.08	.05	.05	.05	.03	.04	.03	—	—
10	.06	.08	.07	.04	.04	.04	.03	.03	.02	—	—
11	.05	.07	.06	.04	.03	.03	.02	.02	—	—	—
12	.05	.05	.04	.03	.03	.02	.02	.01	—	—	—
13	.05	.05	.04	.02	.02	.01	.005	—	—	—	—
14	.04	.03	.03	.02	.02	.01	.005	—	—	—	—
15	.04	.03	.03	.015	.01	.005	—	—	—	—	—
16	.04	.02	.02	.015	.01	.005	—	—	—	—	—
17	.03	.02	.02	.015	.005	—	—	—	—	—	—
18	.01	.02	.02	.015	.005	—	—	—	—	—	—
19	.04	.02	.02	.015	—	—	—	—	—	—	—
20	.03	.01	.02	.015	—	—	—	—	—	—	—
21	.015	.01	.02	—	—	—	—	—	—	—	—
22	.015	.01	.02	—	—	—	—	—	—	—	—
23	.015	.005	—	—	—	—	—	—	—	—	—
24	.015	.005	—	—	—	—	—	—	—	—	—
25	.01	—	—	—	—	—	—	—	—	—	—
26	.01	—	—	—	—	—	—	—	—	—	—
27	.01	—	—	—	—	—	—	—	—	—	—
28	.01	—	—	—	—	—	—	—	—	—	—

default, GMPHEN uses the pattern of egg hatch associated with 110 cold days (Table 1).

If one pattern of egg hatch has been determined based on winter weather and another pattern has been entered directly, then the most recently entered or altered pattern will be used. For example, if you first enter a pattern of egg hatch using the current option and then later use Option 2 of the Options Menu to enter weather data for a full winter and specify that you want weather to determine the egg hatch pattern, GMPHEN will use the latter option.

Specific egg hatch date. You may specify that egg hatch start on a specific day regardless of the degree-days accumulated to date.

Lyons and Lysyk egg phenology model. You may choose to simulate the timing and pattern of egg hatch using the variable rate model published by Lyons and Lysyk (1989) instead of a degree-day model. Further, you also may modify the values of the six parameters specified by Lyons and Lysyk (1989)—three for the quadratic equations that describe development notes and three for the Weibull function that describes variability in development. This option may not be used if weather data is provided in degree-days or if the short-mode option is also selected.

Degree-day requirements on white oak. GMPHEN uses the total degree-days required on white oak by eggs, female larvae, male larvae, female pupae, and male pupae, plus the proportion of total larval degree-days required by each instar for females and males to determine the degree-days required on white oak for each life stage. If other tree species are present, the degree-day requirements can be adjusted for each species as described in the following section.

When you select this option, default values for total degree-days required by eggs, larvae, and pupae are first shown in brackets; you may enter new values or retain the default values by pressing <NL>. The proportions of total larval degree-days required by each instar are displayed next, first for females and then males. You may enter new proportions or press <NL> to keep the default values. If the proportions that you have entered do not sum to 1.0, you will be asked to enter new proportions. This procedure is then repeated for males.

Relative requirements on other species. You may use this option to enter correction factors that adjust gypsy moth development on tree species other than white oak. For each species, separate values may be assigned to female larvae, male larvae, female pupae, and male pupae. Values summarized from the literature by Casagrande and others (1987) are used by default. Alternatively, you may enter new values at the keyboard. If the latter option is chosen, the current values will be displayed in brackets.

Sex ratio. GMPHEN can simulate the development of females only, males only, or a sex ratio that you specify. Equal proportions of females and males are simulated by default.

Tree Species Composition

Parameters for six tree species have been included in the GMPHEN: white oak, northern red oak, black oak, red maple, sugar maple, and American beech. The parameter values may be changed or other tree species may be substituted by retrieving a parameter file that has the desired values; see appendix B for details.

You first will be asked to identify which tree species are present, and then, for each species, to enter the weighting factors to be used when calculating stand averages, such as mean life stage or mean percent leaf expansion.

By default, the stand is assumed to be 100 percent white oak.

Tree Phenology Options

GMPHEN automatically calculates average percentage of leaf expansion during the season and includes this variable in the gypsy moth output table or graph file. More detailed tree phenology information, such as the parameter values used, percentage of budbreak by species, and percentage of leaf expansion by species, may be printed in a separate output file using this option. You will be asked to enter the name of a file to store tree phenology output; the name may be up to 12 characters long. If this option is chosen, then tree phenology output will be directed to a file TREE.OUT by default.

Parameter values and methods for calculating budbreak and leaf expansion reported by both Valentine (1983) and Sheehan[4] have been incorporated into GMPHEN. By default, the phenology predictions of Valentine (1983) are used for both budbreak and leaf expansion.

Short Mode Option

If you have current observations of gypsy moths by life stage and wish to predict what life stages will be present during the remainder of the season, use the short mode. In this mode, you provide GMPHEN with observed percentages of gypsy moths in each life stage plus either daily maximum and minimum temperatures for the period to be simulated or the name of a file containing weather data. GMPHEN estimates the distribution of gypsy moths in cohorts based on the distribution of life stages, then predicts gypsy moth development for the rest of the season using daily temperatures.

Observed percentages by life stage. Use this option to enter the observed percentage of gypsy moths in each life stage. If the percentages entered do not sum to 100, you will receive an error message and the opportunity to enter new percentages. By default, the gypsy moth population is assumed to be 20 percent first instars, 50 percent second instars, and 30 percent third instars. Most users of this option will want to enter their own observed percentages.

Weather data. When this option is selected, the model will ask you for the date that the percentages entered by Option 1 were observed, the number of days to be simulated, and the source of weather data (either a data file or from the keyboard). If you choose to enter weather data, you will be prompted for the maximum and minimum temperatures for each. After the temperatures have been entered, you will be asked whether the units are metric (Celsius) or English (Fahrenheit). By default, the simulation would begin on day 121 (May 1) and run for 5 days with constant temperatures of 80°F.

Tree species composition. Changes in the tree species composition are handled identically in the standard and short modes. You will be asked to identify the tree species present, and then for each species, the relative weight to be assigned to that species. These weights will be used when calculating stand averages, such as mean life stage or mean percentage of leaf expansion. By default, GMPHEN assumes that all trees present are white oak.

Leaf expansion observations. This option allows you to enter percentage of leaf expansion for each tree species

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[4]Sheehan. Katharine A. Field test of GMPHEN: a Gypsy Moth Phenology Model. (in preparation).

present. GMPHEN then calculates how many degree-days must have occurred to date for each species to have resulted in the observed percentage of expansion. During the simulation, the daily temperatures will be used to predict further leaf expansion by species. Leaf expansion is not simulated in the short mode unless you enter initial estimates of expansion.

Output options. Output options are identical for the standard and short modes (see Output Options, Option Menu for details). By default in the short mode, output is produced every day in both table and graph file mode.

Number of cohorts and cohort distribution. In the short mode, GMPHEN adjusts the underlying distribution of cohorts to match the observed percentages of gypsy moths by life stage; you may use this option to change the underlying distribution of cohorts. You will be asked to enter both the number of cohorts present and the proportion of total gypsy moths in each cohort. The proportions that you enter should sum to 1.0. By default, GMPHEN uses the pattern of egg hatch associated with 110 days of cold storage (Table 1).

Return to options menu. Use this option to return to the Options Menu after you have selected options and parameters for a short mode simulation.

Cancel the Short Mode Option

If you previously have selected the Short Mode Option, you may use this option to cancel the short mode and return to the standard mode.

Return to Top Menu

Use this option to return to the Top Menu after you have selected options and parameters for a simulation.

Output Examples

Table 2 is an example of the gypsy moth output table produced by GMPHEN using the options and parameter values that are set by default. Model output summarizes the percentages of gypsy moths by life stage and percent leaf expansion at intervals determined by the user. If more than one tree species is simulated, users may assign

Table 2.—Example of GMPHEN output: gypsy moth phenology table produced in standard mode with default values and options

GMPHEN – Gypsy Moth Phenology Model (Version 2.0)

Parameter Values

Eggs: lower threshold = 3.0 C
upper threshold = 38.0 C
begin accumulating degree-days on Julian day 1. (= 1/1)
degree-days required for eggs to hatch = 282.0
18 intervals, each = 23.0 degree-days in length
proportion of eggs that hatch in each interval:
.0100 .0400 .1100 .1400 .1600 .1400 .1000 .0800 .0500 .0400 .0300 .0300 .0200 .0200 .0100 .0100 .0050 .0050

	female larvae	male larvae	female pupae	male pupae
lower threshold:	8.1	7.2	5.1	6.6
upper threshold:	41.0	41.0	41.0	41.0
total DD req:	650.0	583.0	234.0	277.0
degday modifier:				
white oak	1.000	1.000	1.000	1.000

cumulative degree-days required (adjusted for host species) —

tree species	1st in.	2nd in.	3rd in.	4th in.	5th in.	6th in	pupae
white oak F:	94.	159.	231.	325.	425.	651.	885.
M:	100.	169.	245.	343.	583.	583.	860.

Percent species composition:
white oak 100.0

Proportion of population that is female: .500

Degree-day calculation method: Allen sine wave

Budbreak calculations are based on Valentine (1983)
Leaf expansion calcs are based on Valentine (1983)

Weather data file used: wdata.dat
No adjustments made to weather data

continued

Table 2.—continued

Jday	mo	day	eggs	L1	L2	L3	L4	L5	L6	pupae	adults	ave. g.m. life stage	ave. % leaf expan
			percent by life stage										
108	4	18	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
110	4	20	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
112	4	22	95.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
114	4	24	84.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
116	4	26	70.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
118	4	28	70.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
120	4	30	54.0	46.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
122	5	2	40.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
124	5	4	30.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.4
126	5	6	22.0	75.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.1
128	5	8	13.0	71.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.5
130	5	10	13.0	64.0	23.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	8.2
132	5	12	7.0	33.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	18.7
134	5	14	5.0	17.0	73.0	5.0	0.0	0.0	0.0	0.0	0.0	1.8	37.9
136	5	16	3.0	19.0	62.0	16.0	0.0	0.0	0.0	0.0	0.0	1.9	47.6
138	5	18	2.0	15.0	45.0	38.0	0.0	0.0	0.0	0.0	0.0	2.2	60.8
140	5	20	1.0	10.5	28.5	60.0	0.0	0.0	0.0	0.0	0.0	2.5	75.6
142	5	22	0.0	7.0	19.0	71.0	3.0	0.0	0.0	0.0	0.0	2.7	83.8
144	5	24	0.0	5.0	14.5	57.5	23.0	0.0	0.0	0.0	0.0	3.0	91.1
146	5	26	0.0	3.0	10.0	34.0	53.0	0.0	0.0	0.0	0.0	3.4	94.8
148	5	28	0.0	1.0	6.0	23.0	70.0	0.0	0.0	0.0	0.0	3.6	96.9
150	5	30	0.0	0.0	5.0	17.0	75.0	3.0	0.0	0.0	0.0	3.8	98.4
152	6	1	0.0	0.0	1.0	10.5	65.5	23.0	0.0	0.0	0.0	4.1	99.3
154	6	3	0.0	0.0	0.0	7.0	28.0	65.0	0.0	0.0	0.0	4.6	99.7
156	6	5	0.0	0.0	0.0	3.0	19.0	78.0	0.0	0.0	0.0	4.7	99.8
158	6	7	0.0	0.0	0.0	1.0	16.0	82.5	0.5	0.0	0.0	4.8	99.9
160	6	9	0.0	0.0	0.0	0.5	9.5	82.0	8.0	0.0	0.0	5.0	99.9
162	6	11	0.0	0.0	0.0	0.0	7.0	78.0	15.0	0.0	0.0	5.1	100.0
164	6	13	0.0	0.0	0.0	0.0	7.0	63.0	30.0	0.0	0.0	5.2	100.0
166	6	15	0.0	0.0	0.0	0.0	3.0	62.0	35.0	0.0	0.0	5.3	100.0
168	6	17	0.0	0.0	0.0	0.0	1.5	59.5	39.0	0.0	0.0	5.4	100.0
170	6	19	0.0	0.0	0.0	0.0	1.0	57.0	41.5	0.5	0.0	5.4	100.0
172	6	21	0.0	0.0	0.0	0.0	0.0	47.0	45.0	8.0	0.0	5.6	100.0
174	6	23	0.0	0.0	0.0	0.0	0.0	30.5	46.5	23.0	0.0	5.9	100.0
176	6	25	0.0	0.0	0.0	0.0	0.0	16.5	48.5	35.0	0.0	6.2	100.0
178	6	27	0.0	0.0	0.0	0.0	0.0	11.5	49.5	39.0	0.0	6.3	100.0
180	6	29	0.0	0.0	0.0	0.0	0.0	5.0	47.5	47.5	0.0	6.4	100.0
182	7	1	0.0	0.0	0.0	0.0	0.0	3.5	27.0	69.5	0.0	6.7	100.0
184	7	3	0.0	0.0	0.0	0.0	0.0	1.5	11.0	87.5	0.0	6.9	100.0
186	7	5	0.0	0.0	0.0	0.0	0.0	0.5	8.5	91.0	0.0	6.9	100.0
188	7	7	0.0	0.0	0.0	0.0	0.0	0.0	3.5	96.0	0.5	7.0	100.0
190	7	9	0.0	0.0	0.0	0.0	0.0	0.0	3.5	88.5	8.0	7.0	100.0
192	7	11	0.0	0.0	0.0	0.0	0.0	0.0	1.0	69.0	30.0	7.3	100.0
194	7	13	0.0	0.0	0.0	0.0	0.0	0.0	0.2	52.7	47.0	7.5	100.0
196	7	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.5	73.5	7.7	100.0
198	7	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	85.5	7.9	100.0
200	7	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	93.5	7.9	100.0
202	7	21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	97.2	8.0	100.0
204	7	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	99.5	8.0	100.0
206	7	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	8.0	100.0
208	7	27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	8.0	100.0

weights to each species for calculating stand-wide average life stage or percent leaf expansion. At any given time, GMPHEN may predict that several gypsy moth life stages are present—such as eggs, first instars, and second instars—with the older life stages represented by the cohorts that hatched earliest and the younger life stages represented by the cohorts that hatched later.

Table 3 shows the results of using GMPHEN in the short mode, and an example of the tree phenology output table is shown in Table 4. For each table, all options and parameter values used during the simulation are printed first to ensure accurate records of model behavior. In Figure 2, gypsy moth output in graph file format has been plotted using a separate graphics package.

How the Model Works

GMPHEN uses a daily time-step, starting with the first day in the weather data file and ending when all gypsy moths have become adults or the last day in the weather file has been reached. Each day, degree-days are calculated separately for egg, female and male larvae, female and male pupae, and all tree species present. Development of these different categories is simulated as described below.

Table 3.—Example of GMPHEN output: tree phenology table produced with default parameter values and options

Tree Phenology Table

Parameter Values

Parameter	white oak	red oak	black oak	red maple	sugar maple	Amer. beech
DD starting date	105.	105.	105.	105.	105.	105.
lower threshold	4.4	4.4	4.4	4.4	4.4	4.4
upper threshold	45.0	45.0	45.0	45.0	45.0	45.0
min. DD for budbr.	144.3	118.0	109.7	86.3	113.9	129.7
% budbreak / DD	2.6	2.9	3.2	2.2	2.7	2.3
leaf param. C1	5.954	6.106	6.620	5.323	5.211	5.486
leaf param. C2	1.337	0.893	0.560	0.416	0.702	0.171
leaf param. C3	0.02055	0.01769	0.01293	0.01532	0.01311	0.01090
average leaf weight	385.3	448.5	749.9	205.0	183.3	241.3
average bud weight	3.5	5.9	11.1	8.3	5.6	19.6

Budbreak calculations are based on Valentine (1983)
Leaf expansion calcs are based on Valentine (1983)

Weather: data file used = wdata.dat

Budbreak and Leaf Expansion

		white oak		red oak		black oak		red maple		sugar maple		Amer. beech	
Jul day	date	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf
116	4 26	0.	0.	0.	0.	0.	0.	14.	1.	0.	0.	0.	0.
117	4 27	0.	0.	0.	0.	0.	0.	22.	1.	0.	0.	0.	0.
118	4 28	0.	0.	0.	0.	0.	0.	30.	1.	0.	0.	0.	0.
119	4 29	0.	0.	0.	0.	0.	0.	39.	2.	0.	0.	0.	0.
120	4 30	0.	0.	0.	0.	10.	0.	58.	3.	0.	0.	0.	0.
121	5 1	0.	0.	3.	0.	30.	1.	72.	4.	14.	0.	0.	0.
122	5 2	0.	0.	33.	1.	63.	1.	95.	6.	42.	1.	0.	0.
123	5 3	0.	0.	72.	1.	100.	2.	100.	9.	78.	2.	31.	2.
124	5 4	36.	0.	100.	3.	100.	3.	100.	13.	100.	3.	65.	5.
125	5 5	77.	1.	100.	5.	100.	5.	100.	19.	100.	5.	100.	8.
126	5 6	100.	2.	100.	8.	100.	7.	100.	26.	100.	8.	100.	12.
127	5 7		4.		12.		10.		32.		11.		16.
128	5 8		6.		16.		13.		37.		14.		19.
129	5 9		7.		19.		14.		40.		15.		21.

continued

Table 3.—continued

		Budbreak and Leaf Expansion											
		white oak		red oak		black oak		red maple		sugar maple		Amer. beech	
Jul day	date	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf	budbr	leaf
130	5 10		8.		21.		16.		43.		17.		23.
131	5 11		12.		27.		20.		49.		21.		27.
132	5 12		19.		36.		26.		57.		27.		33.
133	5 13		28.		46.		33.		64.		34.		39.
134	5 14		38.		54.		39.		70.		40.		45.
135	5 15		43.		58.		42.		73.		43.		47.
136	5 16		48.		62.		45.		75.		46.		50.
137	5 17		55.		67.		50.		79.		51.		54.
138	5 18		61.		72.		54.		81.		55.		57.
139	5 19		69.		77.		60.		85.		60.		62.
140	5 20		76.		82.		65.		88.		66.		66.
141	5 21		80.		85.		68.		89.		69.		69.
142	5 22		84.		87.		72.		91.		73.		72.
143	5 23		88.		90.		76.		93.		77.		76.
144	5 24		91.		93.		80.		94.		81.		80.
145	5 25		93.		94.		83.		95.		84.		82.
146	5 26		95.		95.		86.		96.		86.		84.
147	5 27		96.		96.		88.		97.		88.		86.
148	5 28		97.		97.		89.		97.		90.		88.
149	5 29		98.		98.		91.		98.		92.		90.
150	5 30		98.		98.		93.		98.		93.		91.
151	5 31		99.		99.		94.		99.		95.		93.
152	6 1		99.		99.		96.		99.		96.		94.
153	6 2		100.		99.		97.		99.		97.		95.
154	6 3		100.		100.		97.		100.		97.		96.
155	6 4		100.		100.		98.		100.		98.		97.
156	6 5		100.		100.		98.		100.		98.		97.
157	6 6		100.		100.		98.		100.		99.		98.
158	6 7		100.		100.		99.		100.		99.		98.
159	6 8		100.		100.		99.		100.		99.		98.
160	6 9		100.		100.		99.		100.		99.		98.
161	6 10		100.		100.		99.		100.		99.		99.
162	6 11		100.		100.		99.		100.		99.		99.
163	6 12		100.		100.		99.		100.		99.		99.
164	6 13		100.		100.		99.		100.		99.		99.
165	6 14		100.		100.		100.		100.		100.		99.
166	6 15		100.		100.		100.		100.		100.		99.
167	6 16		100.		100.		100.		100.		100.		99.
168	6 17		100.		100.		100.		100.		100.		99.
169	6 18		100.		100.		100.		100.		100.		100.
170	6 19		100.		100.		100.		100.		100.		100.
171	6 20		100.		100.		100.		100.		100.		100.

Table 4.—Example of GMPHEN output: gypsy moth phenology table produced in short mode with default parameter values and options

GMPHEN – Gypsy Moth Phenology Model (Version 2.0)

Parameter Values:

Eggs: lower threshold = 3.0 C
upper threshold = 38.0 C
begin accumulating degree-days on Julian day 1. (= 1/1)
degree-days required for eggs to hatch = 282.0
18 intervals, each = 23.0 degree-days in length
proportion of eggs that hatch in each interval:
.0100 .0400 .1100 .1400 .1600 .1400 .1000 .1000 .0300 .0400 .0300 .0300 .0200 .0200 .0100 .0100 .0050 .0050

	female larvae	male larvae	female pupae	male pupae
lower threshold:	8.1	7.2	5.1	6.6
upper threshold:	41.0	41.0	41.0	41.0
total DD req:	650.0	583.0	234.0	277.0
degday modifier:				
white oak	1.000	1.000	1.000	1.000

cumulative degree-days required (adjusted for host species) —

tree species	1st in.	2nd in.	3rd in.	4th in.	5th in.	6th in	pupae
white oak F:	94.	159.	231.	324.	424.	650.	884.
M:	100.	169.	245.	343.	583.	583.	860.

Percent species composition:
white oak 100.0

Proportion of population that is female: .500

Degree-day calculation method: Allen sine wave

Budbreak calculations are based on Valentine (1983)
Leaf expansion calcs are based on Valentine (1983)

Weather data file used: keyboard
No adjustments made to weather data

*** short version of GMPHEN used ***

			percent by life stage									ave. g.m. life	ave. % leaf
jday	mo	day	eggs	L1	L2	L3	L4	L5	L6	pupae	adults	stage	expan
121	5	1	.0	20.0	50.0	30.0	.0	.0	.0	.0	.0	2.1	.0
122	5	2	.0	13.0	41.0	45.0	1.0	.0	.0	.0	.0	2.3	.0
123	5	3	.0	7.0	33.0	55.0	5.0	.0	.0	.0	.0	2.6	.0
124	5	4	.0	3.0	27.0	54.0	16.0	.0	.0	.0	.0	2.8	.0
125	5	5	.0	1.0	16.0	53.0	30.0	.0	.0	.0	.0	3.1	.0
126	5	6	.0	.0	10.0	44.0	46.0	.0	.0	.0	.0	3.4	.0

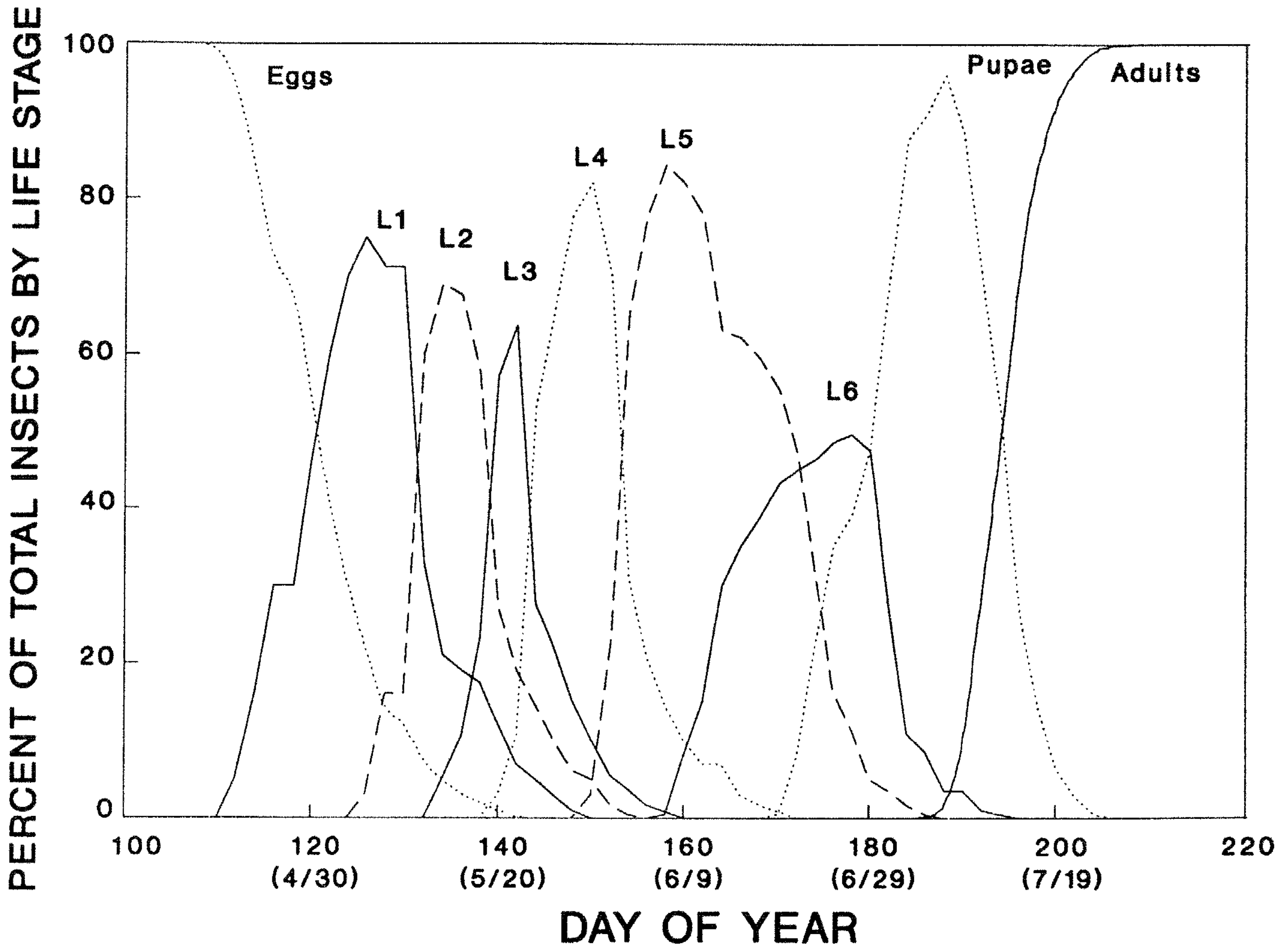

Figure 2.—Example of graphic output based on the data file produced by GMPHEN, showing the occurrence of gypsy moth life stages on white oak (assuming equal numbers of males and females, 1980 weather data from Cacapon, West Virginia and default values for all parameters; L1 = first instars, L2 = second instars, and so on).

Gypsy moth phenology

Eggs. GMPHEN assumes that egg hatch begins when a certain number of egg degree-days have accumulated after a starting date or on a specific date set by the user. Users may specify the date that eggs may start accumulating degree-days, the lower and upper threshold temperatures, and the number of degree-days required for egg hatch. If the user identifies a specific date for the start of egg hatch, then hatch will begin on that date regardless of degree-days accumulated to date. By default, gypsy moth egg hatch is assumed to begin when 282 degree-days Celsius have accumulated after January 1, using 3.0°C (37.4°F) as the lower threshold for development (Sanderson and Peairs 1913, Johnson and others 1983). The upper threshold for development has been set arbitrarily to 38.0°C (100°F), a temperature that normally would not be exceeded when eggs are present.

Once egg hatch has begun, the pattern of egg hatch over physiological time (as measured by degree-days) is assumed to be a function of the number of cold days experienced by the eggs during winter or set to a specific pattern identified by the user.

The effect of winter weather on the pattern of egg hatch was studied in the laboratory by Masaki (1956), who found that the length of the egg-hatch period increased as the storage time at low temperatures decreased. Masaki (1956) recorded the number of eggs that hatched at 2-day (46 degree-day) intervals for eggs stored at 5°C (41°F) for various lengths of time. Patterns for storage times of 70, 100, 125, and 147 days (representing the range of storage times studied) were estimated from data presented graphically by Masaki (1956) (Fig. 3). Patterns for intermediate storage times were arbitrarily assigned to make smooth transitions between the four patterns at daily (23 degree-day) intervals, and are listed in Table 1. If provided with weather data for the full winter, GMPHEN will sum the number of days when the daily average temperature was less than or equal to a chilling threshold temperature (set to 5°C by default), and then select from Table 1 the egg hatch pattern whose storage time most closely matches the observed number of cold days.

Users also may supply a specific egg-hatch pattern or select one of the patterns listed in Table 1 to be used regardless of winter weather. If neither weather for a full winter nor a specific pattern of egg hatch is supplied, the pattern estimated for 110 days of cold storage (Table 1) is used by default.

The pattern of egg hatch determines the number of cohorts, for all larvae that emerge in a given interval are considered to be one cohort. Up to 30 cohorts may be simulated for each sex and tree species.

A separate option is available for predicting the timing and pattern of gypsy moth egg hatch based on the model published by Lyons and Lysyk (1989). They describe temperature-dependent development rates and use a Weibull functin to estimate variability in development. When this option is used, all gypsy moths that hatch on a given day are assigned to the same cohort.

Larvae and pupae. Each day, degree-days are calculated separately for female larvae, male larvae, female pupae, and male pupae. Lower threshold temperatures were

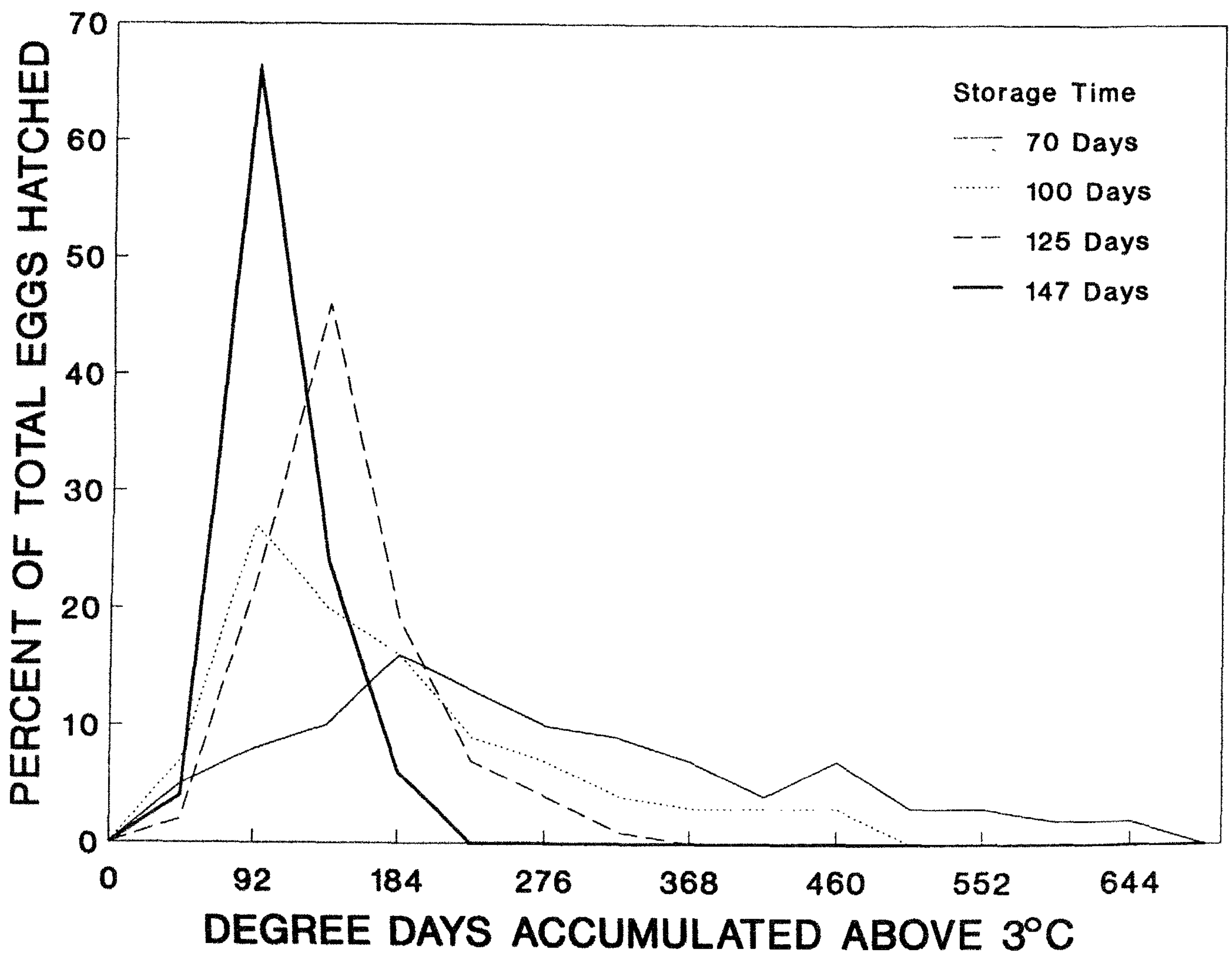

Figure 3.—Patterns of egg hatch representing a range of days of storage at 5°C; adapted from Masaki (1956).

calculated from data reported by Casagrande and others (1987) by plotting the reciprocal of the number of days required for the total larval period and for the pupal stage (keeping females and males separate), arbitrarily excluding points at higher temperatures that exhibited a dramatic decline in development rate, and then fitting a line to the remaining points (Fig. 4). The x-intercept for each line was interpreted as the lower threshold for development (Sanderson and Peairs 1913). These lower thresholds were then used to calculate degree-days required by larvae and pupae (by sex) for those rearing temperatures reported by Casagrande and others (1987) that had more than one surviving gypsy moth, and the average values (weighing all rearing temperatures equally) are shown in Table 5. By default, the upper threshold for development has been set arbitrarily to 41.0°C (106°F) for all larval stages and for pupae.

The total degree-days required by gypsy moth larvae are further partitioned to specific instars using proportions calculated from Casagrande and others (1987), as shown in Table 6. The proportions for females closely match those calculated from Figure 1 of Montgomery (1983), who reported results for females reared on red oak foliage. Default values for the degree-day requirements by instar, calculated from the total larval degree-day requirements (Table 5) and proportions required by each instar (Table 6), also are shown in Table 6.

The development requirements reported by Casagrande and others (1987) were based on gypsy moths reared on white oak foliage. For other host species, degree-day requirements are adjusted using published results of relative development as summarized by Casagrande and others (1987) and shown for selected tree species in Table 7.

For each host and sex, the degree-days experienced to date by each cohort are accumulated separately. At intervals

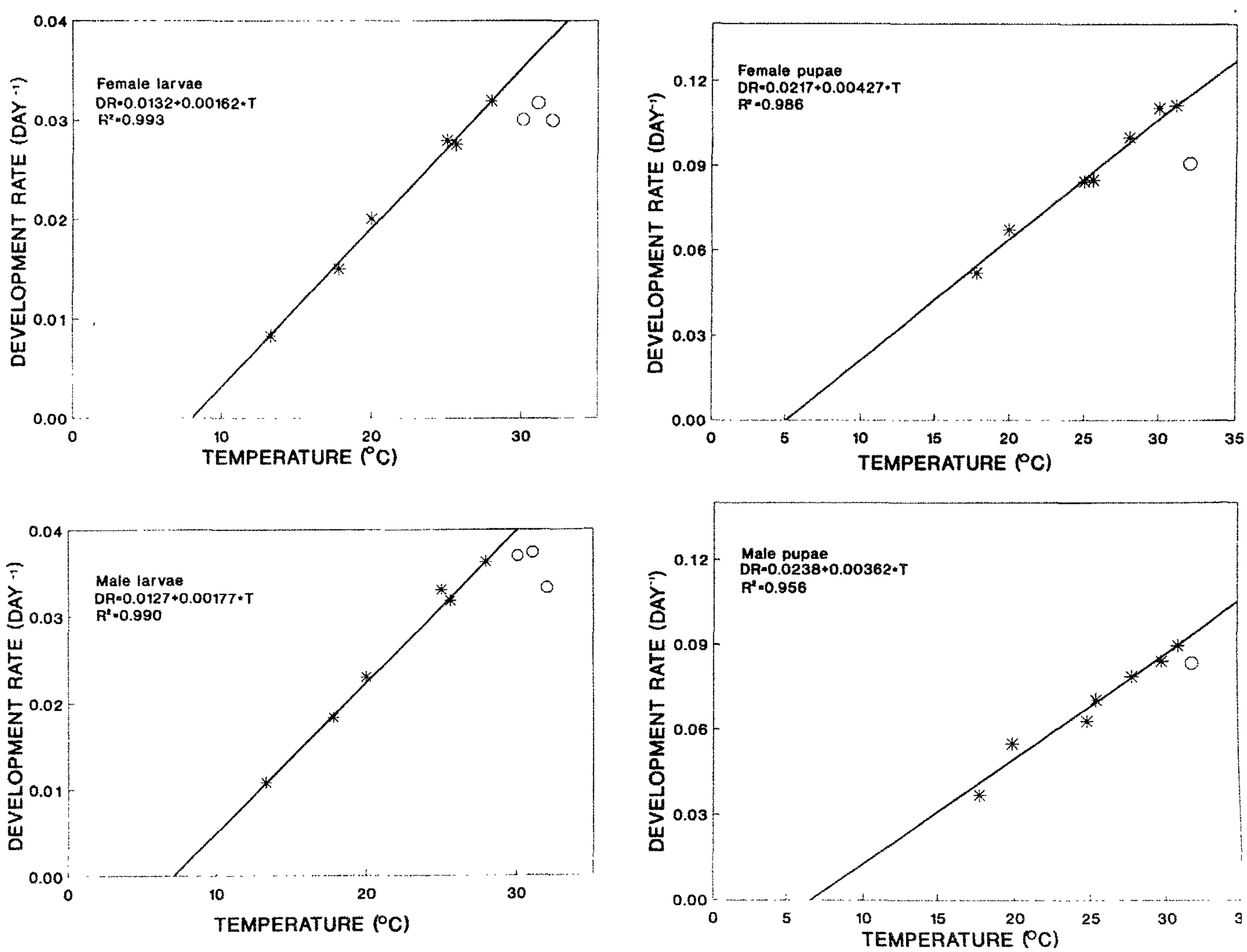

Figure 4.—Development rates at various rearing temperatures for: female larvae, female pupae, male larvae, and male pupae. When fitting the lines shown, the highest temperatures (open circles) were excluded.

selected by the user, these accumulated degree-days are compared with the cumulative degree-days required by each life stage to determine the current life stage of each cohort. The percentages of gypsy moths in each life stage are displayed in the output file. By default, these percentages are calculated using equal proportions of females and males, though users may specify that only females or only males be included. When more than one host species is present, specific weights may be assigned to each species, and the reported percentages will be weighted averages for the species present. The simulation ends when either gypsy moths from the youngest cohort become adults or the last day of the weather data file has been reached.

Tree Phenology

Functions provided by Valentine (1983) are used with minor modifications to estimate the timing of budbreak and leaf expansion for white oak, red oak, black oak, red maple, sugar maple, and American beech. GMPHEN has been designed to allow incorporation of other species when the appropriate phenology parameters are known.

In predicting the timing of both budbreak and leaf expansion, Valentine (1983) assumed that the lower threshold temperature for development was 4.4°C (40°F) for all tree species. By default, the lower and upper thresholds have been set to 4.4°C and 41°C for all trees in this model, though users may specify separate thresholds for each species.

To predict percent budbreak for a given tree species, Valentine (1983) used degree-days accumulated since day 105 (April 15). Percent budbreak was defined as the percentage of buds that have produced foliage that could be consumed by defoliating insects. In GMPHEN, three

Table 5.—Lower threshold temperatures, degree-day requirements, and linear regression analysis summary for larvae and pupae (calculated from Casagrande and others 1987, as described in the text)

Life stage	Sex	Threshold (C)	Degree-days required	Intercept	Slope	R^2
larva	female	8.1	650	−0.0132	0.00162	.993
larva	male	7.2	583	−0.0127	0.00177	.990
pupa	female	5.1	234	−0.0217	0.00427	.986
pupa	male	6.6	277	−0.0238	0.00362	.956

Table 6.—Proportion of total larval degree-day requirements by instar (sources: Montgomery 1983, Casagrande and others 1987), and degree-day requirements on white oak used by default in GMPHEN

	Montgomery (1983)	Casagrande and others (1987)		Cumulative degree-days required	
Life stage	Females	Females	Males	Females	Males
first instar	16.9%	14.5%	17.2%	94	100
second instar	8.5	9.9	11.7	159	169
third instar	11.2	11.1	13.1	231	245
fourth instar	12.7	14.4	16.9	324	343
fifth instar	15.5	—[a]	41.1	424	583
sixth instar	35.2	—[a]	—	650	—
fifth & sixth instars	50.7	50.1	—		

[a]Because Casagrande and others (1987) did not report separate values for fifth and sixth instar females, ratios calculated from Montgomery (1983) were used to partition the amount reported by Casagrande and others (1987) resulting in values of 15.3 and 34.8 respectively.

Table 7.—Degree-day requirements for gypsy moths reared on selected tree species relative to those on white oak (from summary by Casagrande and others, 1987)

Tree species number	Species	Larvae		Pupae	
		Female	Male	Female	Male
1	White oak	1.000	1.000	1.000	1.000
2	Red oak	0.984	0.963	1.025	0.980
3	Black oak	1.363	1.268	0.936	0.950
4	Red maple	1.381	1.411	0.966	0.924
5	Sugar maple	1.270	1.189	0.949	0.953
6	American beech	1.021	1.034	0.941	0.953

parameters control the simulation of budbreak: the starting date for accumulating degree-days, the number of degree-days that must accumulate before budbreak begins, and the increase in percent budbreak per degree-day. Values used by default are from Valentine (1983).

The leaf-growth functions developed by Valentine (1983, model 2) predicted the natural log of leaf dry weight based on elapsed degree-days since budbreak. To convert estimates of leaf dry weight to estimates of leaf expansion, two additional parameters were first calculated from data presented by Valentine (1983): the weight of buds that have not expanded (i.e., when degree-days since budbreak is zero) and the weight of buds that have fully expanded. Current leaf weight can then be converted to percent leaf expansion as follows:

$$\text{\% leaf expansion} = \frac{(\text{current leaf weight} - \text{initial bud weight})}{(\text{maximum leaf weight} - \text{initial bud weight})} * 100.0 \qquad (1)$$

Whenever current gypsy moth life stages are summarized for output, average percent leaf expansion is also reported. When there is more than one tree species present and the user has provided weights for each species, the percent leaf expansion reported will be a weighted average.

A separate, more detailed output that shows percent budbreak and percent leaf expansion for all six species during the course of a season is available as an option.

Short Mode

GMPHEN can be used in the "short mode" to accept observed proportions of gypsy moths in each life stage, and then predict the proportions that will occur during following days based on weather estimates provided by the user.

In the short mode, GMPHEN first sets the proportion in the youngest cohort equal to the proportion in the youngest life stage present and then compares the cohort pattern (which is based on the egg-hatch pattern—either determined by winter weather or specified by the user) to the observed percentages of gypsy moths in each life stage.

If necessary, GMPHEN modifies the cohort pattern to match the proportions in each life stage that were observed by the user. GMPHEN warns the user if the observed life-stage pattern is not compatible with the current cohort pattern; for example, a warning would be printed if the user tried to simulate three different life stages using only two cohorts.

The degree-days experienced to date are then estimated for each cohort based on its current life stage. If "n" cohorts have been assigned to a given life stage, then the degree-days required for that life stage are divided into "n" equal portions. One cohort is assigned to each portion, and the number of degree-days experienced to date for that cohort is set to the midpoint for that portion. For example, if three cohorts were assigned to a life stage, and that life stage began at 100 degree-days and took 90 degree-days to complete, then the total degree-days for the stage are split into three portions (30 degree-days each) and the degree-days experienced to date for the three cohorts are assumed to be 115 degree-days, 145 degree-days, and 175 degree-days.

If the user enters leaf-expansion estimates, then the degree-days experienced to date for each tree species are also calculated.

After these initial calculations, GMPHEN returns to the daily time-step of its standard mode. Each day, the degree-days experienced by gypsy moths are accumulated, and the percentages of gypsy moths in each life stage are calculated and stored in the output file. Host degree-days and current leaf expansion are calculated only if the user has provided initial leaf-expansion estimates.

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Appendix A.—Weather Data File

GMPHEN requires daily maximum and minimum temperatures for the period to be simulated. Either metric (Celsius) or English (Fahrenheit) units may be used. The daily temperatures should be stored in an ASCII file using one of the following six formats:

Format No.	*Description*
1	3 characters per entry, 6 lines per month
2	5 characters per entry, 6 lines per month
3	6 characters per entry, 10 lines per month
4	1 line per day (minimum temperature, maximum temperature)
5	1 line per day (maximum temperature, minimum temperature)
6	Julian day, degree-days accumulated to date

Tables 8-13 show examples of weather files for each format. Users may include values for February 29 in leap years. Weather data files may include one full year of data or a partial year; they also may include data for the previous fall or winter.

Formats 1 through 3

Maximum temperatures for a given month are listed first, followed by minimum temperatures for the month. Note that Format 3 requires 31 entries for every month, even if a given month has only 30 days, to maintain a constant number of lines of data per month; a value for April 31 must be included in the data, for example, though that value will not be used by GMPHEN. For Formats 1 and 2, the number of entries for a month should equal the number of days in that month; extra values (such as for April 31) are ignored by GMPHEN.

Weather data files should start at the beginning of a month, and the first month does not have to be January. If you have weather data that starts in the middle of a month, use zero for earlier values and set the first day of the weather file to the date when your actual data begins. For example, if you have weather data that begins on February 9, store "0.0" in the data file for February 1-8, and use the "Weather Options" feature (Options Menu) to identify the name of the file and the first day of weather data (day 40 or 2/8).

Table 8.—Example of 3 months of weather data stored using Format 1

```
                   1         2         3         4         5
column: 1234567890         0         0         0         0

line 1: month  1  maximum temps.
         46 41 33 39 27 27 35 42 38 31 34 48 34 32 40 43
         49 44 42 41 42 42 45 35 25 42 36 34 34 29 26
        month  1  minimum temps.
         19 21 29 26 21 21 21 26 26  9  9 29 19 20 30 25
         25 33 35 33 26 28 34 11 12 19 14 19 25 12 13
        month  2  maximum temps.
         25 22 22 26 29 35 26 34 37 33 33 37 32 39 49 43
         37 25 41 52 59 52 49 52 48 44 28 35 28
        month  2  minimum temps.
         10 10 11 12 15 17 14 19 21 18 12 15 11 12 31 31
         14 15 15 18 24 36 31 41 34 25 18 21  7
        month  3  maximum temps.
         20 15 24 38 53 55 46 63 75 49 61 37 34 34 37 48
         56 57 46 56 59 56 39 56 49 45 46 57 50 56 55
        month  3  minimum temps.
          6  7  5 13 35 29 26 31 36 29 24 20 21 22 17 24
         29 35 28 35 39 31 26 34 39 33 23 33 39 41 42
```

Table 9.—Example of 3 months of weather data stored using Format 2

```
                   1         2         3         4         5         6         7         8
col.  : 1234567890         0         0         0         0         0         0         0

ln.1: month  4  maximum temps.
        22.3 24.2 21.8 21.9 20.1 18.7 15.8 14.6 20.4 20.9 23.1 22.5 19.8 17.4 16.2 15.6
        14.2 17.8 16.0 21.6 22.3 24.5 21.3 23.5 18.5 19.3 17.4 20.3 21.7 24.5
      month  4  minimum temps.
        12.8 13.5 11.4 12.3 10.2  9.7  6.7  5.6  9.3 10.1 12.0 11.5  9.3  8.2  4.4  5.0
         3.3  6.9  6.4 10.1 11.9 13.7 12.9 12.4  7.4  8.2  8.5  9.8 10.2 12.8
      month  5  maximum temps.
        17.2 16.1 11.7  8.3  6.7 12.2 22.8 16.7 22.8 27.9 22.2 23.9 17.8 18.3 19.4 18.9
        27.2 25.0 13.0 12.2 20.0 22.5 25.5 20.6 15.5 17.8 14.4 22.7 31.1 30.6 30.2
      month  5  minimum temps.
         2.8  5.6  6.1  5.6  4.4  6.1  4.4 10.6  5.6 10.6 14.4 10.6  7.8  1.1  6.8 10.0
        11.7 14.4 10.0  7.7 10.0 12.2 17.2 11.6 11.1 10.6  9.2 12.8 19.6 21.7 19.6
      month  6  maximum temps.
        32.3 34.2 31.8 31.9 30.1 28.7 25.8 24.6 30.4 30.9 33.1 32.5 29.8 27.4 26.2 25.6
        24.2 27.8 26.0 31.6 32.3 34.5 31.3 33.5 28.5 29.3 27.4 30.3 31.7 34.5
      month  6  minimum temps.
        22.8 23.5 21.4 22.3 20.2 19.7 16.7 15.6 19.3 20.1 22.0 21.5 19.3 18.2 14.4 15.0
        13.3 16.9 16.4 20.1 21.9 23.7 22.9 22.4 17.4 18.2 18.5 19.8 20.2 22.8
```

Table 10.—Example of 3 months of weather data stored using Format 3

```
                  1         2         3         4         5         6
column: 1234567890          0         0         0         0         0

line 1: month   4  maximum temps.
           72.4  67.5  54.0  50.5  49.4  52.6  41.0  47.2  55.0  42.7
           54.5  66.4  60.5  50.2  63.8  53.3  45.8  53.4  62.9  64.4
           68.6  75.9  81.3  70.8  71.2  79.7  61.4  62.6  65.5  56.2
            0.0
        month   4  minimum temps.
           52.7  45.2  45.0  33.0  38.7  36.5  25.2  28.6  34.2  33.3
           28.3  40.5  46.1  37.3  39.3  40.0  41.1  38.7  36.4  33.8
           35.9  48.8  53.3  48.5  54.6  60.8  56.0  39.9  39.3  32.9
            0.0
        month   5  maximum temps.
           70.7  64.2  73.0  69.0  58.7  57.5  74.2  81.6  86.2  89.3
           89.3  88.5  80.1  68.3  71.3  75.0  68.1  68.7  71.4  71.8
           70.9  69.8  75.3  70.5  60.6  56.8  63.0  70.9  75.3  80.9
           75.1
        month   5  minimum temps.
           38.4  32.5  40.0  55.5  41.4  43.6  44.0  53.2  56.0  60.7
           60.5  62.4  63.5  53.2  44.8  47.3  38.8  38.4  49.9  52.4
           53.6  47.9  50.3  58.8  53.2  46.7  41.4  42.6  44.5  44.2
           50.8
        month   6  maximum temps.
           71.4  80.5  83.0  68.5  78.4  82.6  80.0  83.2  85.0  85.7
           87.5  67.4  70.5  72.2  79.8  86.3  83.8  72.4  78.9  77.4
           78.6  66.9  87.3  84.8  60.2  72.7  75.4  78.6  80.5  82.2
            0.0
        month   6  minimum temps.
           57.7  62.2  62.0  55.0  52.7  55.5  57.2  60.6  64.2  65.3
           56.3  47.5  45.1  41.3  50.3  53.0  56.1  57.7  51.4  48.8
           51.9  56.8  57.3  51.5  41.6  41.8  45.0  52.9  56.3  60.9
            0.0
```

Formats 4 through 6

Each line contains weather data for 1 day. Formats 4 and 5 contain two temperatures for each day, with minimum temperatures listed first for Format 4 and maximum temperatures listed first for Format 5. Temperatures must be supplied for each day—no missing days are allowed. For Format 6, the Julian day of the observation is followed by the number of degree-days that have been accumulated by that day. For Formats 4 through 6, the two numbers per line may be separated by commas or one or more blank spaces.

By default, GMPHEN expects a full year of weather data in file WDATA.DAT using Format 1 and English units. Select "Weather Options" from the Options Menu to enter the name of a weather file, change first or last day of the file, identify leap years, or change the format or units of the weather file.

Table 11.—Example of 10 days of weather data stored using Format 4; several alternatives for separating entries are shown

```
                 1         2         3         4         5         6
column: 1234567890         0         0         0         0         0

line 1:  54.5 72.4
         56.3 71.2
         57.8, 75.8
         57.0, 74.3
         52.9, 68.2
         48.5,65.9
         50.3,71.2
         54.2,73.9
         56.9,    77.0
         58.5     78.3
```

Table 12.—Example of 10 days of weather data stored using Format 5; several alternatives for separating entries are shown

```
                 1         2         3         4         5         6
column: 1234567890         0         0         0         0         0

line 1:  74.5 52.4
         76.3 55.2
         77.8, 55.8
         77.0, 54.3
         72.9, 48.2
         68.5,45.9
         70.3,51.2
         74.2,53.9
         76.9,    57.0
         78.5     58.3
```

Table 13.—Example of 10 days of weather data stored using Format 6; several alternatives for separating entries are shown

```
                  1         2         3         4         5         6
column:  1234567890         0         0         0         0         0

line 1:  110  280
         112  282.2
         114.,286
         116.,290.3
         118, 296
         120,303.9
         122,307
         124,310
         126,   314.5
         126    319.4
```

Appendix B.—Parameter File

A parameter file may be created either by selecting Option 5 from the Top Menu or by using a text editor such as EDLIN (for PC users) or SED (for DG users) that creates ASCII files. Table 14 shows an example of a parameter file that has default values for all options and parameters. The variables stored in a parameter file are described below. The first 10 characters of most lines are for identification only, and are ignored by GMPHEN.

line 1: title line – not used by GMPHEN

line 2: general parameters

parameter:

1 sex ratio (proportion that is female)
2 degree-day calculation method (1 = sine wave, 2 = quick)
3 degree-day requirements on other species (1 = use values reported by Casagrande and others [1987], 2 = use values observed by Sheehan[4])
4 method for calculating budbreak (1 = based on Valentine [1983], 2 = based on Sheehan[4])
5 method for calculating leaf expansion (1 = based on Valentine [1983], 2 = based on Sheehan[4])

line 3: output parameters

parameter:

1 output type (1 = table, 2 = graph file, 3 = both table & graph file)
2 graph file type (1 = eight columns, 2 = six columns, 3 = nine columns)
3 output interval in days (1 = every day, 2 = every 2 days, and so on)
4 tree phenology table option (1 = yes, 2 = no)
5 name of output file: table (12 characters)
6 name of output file: graph file (12 characters)
7 name of output file: tree phenology table (12 characters)

line 4: weather parameters – part 1

parameter:

1 weather data file format (1 = Format 1, 2 = Format 2, 3 = Format 3, etc.)
2 type of weather file (1 = one full year, 2 = part of one year, 3 = previous winter plus one full year, 4 = previous winter plus part of next year)
3 units of weather data (1 = metric, 2 = English)
4 last Julian day in weather file
5 leap year index (1 = yes, 2 = no)
6 number of weather files to be used (1 or 2)
7 Julian day when GMPHEN should switch from the first weather file to the second weather file
8 Julian day that weather data begin (first weather file)
9 Julian day that weather data begin (second weather file)
10 name of first weather file (12 characters)
11 name of second weather file (12 characters)

line 5: weather parameters – part 2

parameter:

1 index for whether winter weather is to determine egg hatch pattern (1 = yes, 2 = no)
2 index for method of selecting the pattern of egg hatch (1 = determine pattern based on number of cold days during winter, 2 = determine pattern based on number of cold days provided by user, and 3 = use default pattern or other pattern provided by the user)
3 threshold temperature used for identifying cold days (Celsius)

4 index for whether a specific date for start of egg hatch has been selected (1 = no, 2 = yes)
5 specific Julian day for egg hatch to start

line 6: short mode – general parameters

parameter:
1 mode (1 = standard mode, 2 = short mode)
2 index for weather data source (1 = keyboard, 2 = a file)
3 number of days to be simulated in the short mode
4 Julian day that observations were made

line 7: short mode – observed life stages

parameter:
1-9 observed percentages of gypsy moths by life stage (eggs, first instars, second instars, . . . adults)

line 8: short mode – observed leaf expansion

parameter:
1-6 observed percent leaf expansion for each tree species

line 9: short mode – maximum temperatures

parameter:
1-10 maximum temperature for each day to be simulated (Celsius if parameter 3 of line 4 is 1, otherwise Fahrenheit)

line 10: short mode – minimum temperatures

parameter:
1-10 minimum temperature for each day to be simulated (Celsius if parameter 3 of line 4 is 1, otherwise Fahrenheit)

line 11: egg parameters

parameter:
1 lower threshold for egg development (Celsius)
2 upper threshold for egg development (Celsius)
3 earliest Julian day that degree-days may begin to occur for eggs
4 degree-days required for first eggs to hatch
5 number of cohorts (= number of intervals during the egg hatch period)
6 length of intervals, in degree-days

lines 12-14: pattern of egg hatch

parameter:
1-10 proportions of gypsy moths in cohorts 1-10 (= proportions of gypsy moths that hatch in intervals 1-10)
11-20 proportions of gypsy moths in cohorts 11-20
21-30 proportions of gypsy moths in cohorts 21-20

line 15: Lyons and Lysyk (1989) egg phenology model parameters

parameter:
1-3 quadratic function parameters (A, B, and C)
4-6 Weibull function parameters (gamma, nu, and beta)

line 16: larval and pupal thresholds

parameter:

1 lower threshold for development of female larvae (Celsius)
2 lower threshold for development of male larvae (Celsius)
3 lower threshold for development of female pupae (Celsius)
4 lower threshold for development of male pupae (Celsius)
5 upper threshold for development of female larvae (Celsius)
6 upper threshold for development of male larvae (Celsius)
7 upper threshold for development of female pupae (Celsius)
8 upper threshold for development of male pupae (Celsius)

line 17: total larval and pupal degree-day requirements

parameter:

1 degree-days required for female larvae
2 degree-days required for male larvae
3 degree-days required for female pupae
4 degree-days required for male pupae

line 18: degree-day requirements by instar (females)

parameter:

1-6 proportions of total larval degree-days required by instars 1-6

line 19: degree-day requirements by instar (males)

parameter:

1-5 proportions of total larval degree-days required by instars 1-5

line 20: tree parameters – general

parameter:

1 number of tree species to be simulated
2-6 weight to be given to each tree species when calculating means

lines 21-26: tree parameters – phenology (by species)

parameter:

1 species name (12 characters)
2 earliest day that a species may start accumulating degree-days
3 lower threshold for development (Celsius)
4 upper threshold for development (Celsius)
5-9 parameters T_0, C, C1, C2, and C3 (from Valentine 1983)

lines 27-32: tree parameters – values from Sheehan[4]

parameter:

1-4 parameters T_0, C, A, and B (from Sheehan[4])

lines 33-38: tree parameters – biomass, relative development rates (by species, based on review by Casagrande and others [1987])

parameter:

1 average leaf weight when fully expanded (mg dry weight)
2 average weight of an unexpanded leaf bud (mg dry weight)
3 development rate of female larvae relative to white oak
4 development rate of male larvae relative to white oak
5 development rate of female pupae relative to white oak
6 development rate of male pupae relative to white oak

line 39-44: tree parameters – relative development rates (by species, based on Sheehan[4]) parameter:

1 development rate of female larvae relative to white oak
2 development rate of male larvae relative to white oak
3 development rate of female pupae relative to white oak
4 development rate of male pupae relative to white oak

line 45: tree parameters – miscellaneous

parameter:

1-6 codes for tree species to be simulated

Table 14.—Example of a GMPHEN parameter file, showing default values for all options and parameters

```
default parameter set — Version 2.0
general   .500 1 1 1 1
output  1 1 2 2moth.out  graph.out  tree.out  x
weather  1 1 2 365 1 1 365 1  1wdata.dat wdata2.dat x
weather2 2 3 5.0 1 125 1 1.00
short gen. 1 1 5.0 121
short dist    .0 20.0 50.0 30.0   .0   .0   .0   .0   .0
short tree    .0   .0   .0   .0   .0   .0
short tmax  80.0 80.0 80.0 80.0 80.0
short tmin  80.0 80.0 80.0 80.0 80.0
eggs ddays   3.0 38.0  1.0 282.0 18 23.0
.0100 .0400 .1100 .1400 .1600 .1400 .1000 .0800 .0500 .0400
.0300 .0300 .0200 .0200 .0100 .0100 .0050 .0050 .0000 .0000
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000
Lyons mod. 0 -.1079 .0145 -.0002 .7519 .2704 2.9442
l&p thres  8.1  7.2  5.1  6.6 41.0 41.0 41.0 41.0
l&p ddreq 650.0 583.0 234.0 277.0
l&p propf .1450 .0990 .1110 .1450 .1530 .3480
l&p propm .1720 .1170 .1310 .1690 .4120
tree gen. 1 1.000 .000 .000 .000 .000 .000
tphen sp1 white oak    105.0 4.4 45.0 144.3 2.6 5.954 1.337 .02055
tphen sp2 red oak      105.0 4.4 45.0 118.0 2.9 6.106  .893 .01769
tphen sp3 black oak    105.0 4.4 45.0 109.7 3.2 6.620  .560 .01293
tphen sp4 red maple    105.0 4.4 45.0  86.3 2.2 5.323  .416 .01532
tphen sp5 sugar maple  105.0 4.4 45.0 113.9 2.7 5.211  .702 .01311
tphen sp6 Amer. beech  105.0 4.4 45.0 129.7 2.3 5.486 -.171  .01090
tphen2 sp1 119.2 1.73 3.938 .02334
tphen2 sp2 107.1 1.51 3.472 .02198
tphen2 sp3  95.0 1.72 4.121 .02653
tphen2 sp4  77.2 2.53 4.364 .03032
tphen2 sp5  84.2 3.18 4.057 .02992
tphen2 sp6 131.3 2.50 2.086 .01482
tmisc sp1 385.3  3.4503 1.0000 1.0000 1.0000 1.0000
tmisc sp2 448.5  5.8928  .9840  .9630 1.0250  .9800
tmisc sp3 749.9 11.0971 1.3630 1.2680  .9360  .9500
tmisc sp4 250.0  8.2959 1.3810 1.4110  .9660  .9240
tmisc sp5 183.3  5.6224 1.2700 1.1890  .9490  .9530
tmisc sp6 241.3 19.6280 1.0210 1.0340  .9410  .9530
tmisc2 sp1 1.0000 1.0000 1.0000 1.0000
tmisc2 sp2  .9730  .9730 1.0250  .9800
tmisc2 sp3 1.0080 1.0080  .9360  .9500
tmisc2 sp4 1.0050 1.0050  .9660  .9240
tmisc2 sp5 1.0050 1.0050  .9490  .9530
tmisc2 sp6 1.0210 1.0340  .9410  .9530
tmisc3  1 2 3 4 5 6
```

Appendix C.—Gypsy Moth Phenology Parameters

Variable name	Default value	Variable description
Eggs:		
ETHRLO	3.0	lower threshold for egg development (C)
ETHRHI	38.0	upper threshold for egg development (C)
ESTART	1.0	day of year that eggs may begin to accumulate degree-days
EWAIT	282.0	degree-days required for first egg to hatch
DDINT	23.0	egg hatch period is divided into intervals of equal length; DDINT = length of interval (in degree-days)
NCMAX	18	number of intervals during which egg hatch occurs
PEMERG(C)[a]	—>	proportion of eggs that hatch during a given interval to form cohort C (values shown for 110 cold days in Table 1 are used by default)
CHILL	5.0	chilling threshold temperature (C), used only if winter weather determines the egg hatch pattern
JEGDAY	125.0	day of year specified by user as the date of first egg hatch
Larvae and pupae:		
GTHRLO(S)[b]	—>	lower threshold temperatures for stage/sex S (Table 3)
GTHRHI(S)	41.0	upper threshold temperature for all stage/sex S
GDDAYS(S)	—>	degree-days required by stage/sex S when reared on white oak (Table 3)
HOSTFL(T)[c]	—>	ratio of degree-days required by female larvae reared on tree species T to degree-days required by female larvae on white oak (Table 4)
HOSTML(T)	—>	ratio of degree-days required by male larvae reared on tree species T to degree-days required by male larvae on white oak (Table 4)
HOSTFP(T)	—>	ratio of degree-days required by female pupae reared on tree species T to degree-days required by female pupae on white oak (Table 4)
HOSTMP(T)	—>	ratio of degree-days required by male pupae reared on tree species T to degree-days required by male pupae on white oak (Table 4)
PROPF(I)[d]	—>	proportion of total female larval degree-days required by instar I (Table 5)
PROPM(I)	—>	proportion of total male larval degree-days required by instar I (Table 5)

[a]C = cohort number (1 = oldest cohort, 2 = second oldest cohort, etc.)
[b]S = index to life stage and sex (1 = female larvae, 2 = male larvae, 3 = female pupae, 4 = male pupae)
[c]T = tree species number (default values shown in Table 5)
[d]I = instar (1 = first instar, etc.)

Appendix D.—Tree Phenology Parameters (source: Valentine, 1983)

Tree species	Starting date (HSTART)	Minimum DD req. (T0)	Budbreak per DD (C)	Leaf growth parameters (C1)	(C2)	(C3)	Maximum leaf weight (WTLEAF)	Bud weight (BUDWT)
WO	105	144.3	2.6	5.954	1.337	.02055	385.3	3.450
RO	105	118.0	2.9	6.106	0.893	.01769	448.5	5.893
BO	105	109.7	3.2	6.620	0.560	.01293	749.9	11.097
RM	105	86.3	2.2	5.323	0.416	.01532	205.0	8.296
SM	105	113.9	2.7	5.211	0.702	.01311	183.3	5.622
AB	105	129.7	2.3	5.486	−0.171	.01090	241.3	19.628

Appendix E.—Julian Date Calendar

(PERPETUAL)

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	1
2	002	033	061	092	122	153	183	214	245	275	306	336	2
3	003	034	062	093	123	154	184	215	246	276	307	337	3
4	004	035	063	094	124	155	185	216	247	277	308	338	4
5	005	036	064	095	125	156	186	217	248	278	309	339	5
6	006	037	065	096	126	157	187	218	249	279	310	340	6
7	007	038	066	097	127	158	188	219	250	280	311	341	7
8	008	039	067	098	128	159	189	220	251	281	312	342	8
9	009	040	068	099	129	160	190	221	252	282	313	343	9
10	010	041	069	100	130	161	191	222	253	283	314	344	10
11	011	042	070	101	131	162	192	223	254	284	315	345	11
12	012	043	071	102	132	163	193	224	255	285	316	346	12
13	013	044	072	103	133	164	194	225	256	286	317	347	13
14	014	045	073	104	134	165	195	226	257	287	318	348	14
15	015	046	074	105	135	166	196	227	258	288	319	349	15
16	016	047	075	106	136	167	197	228	259	289	320	350	16
17	017	048	076	107	137	168	198	229	260	290	321	351	17
18	018	049	077	108	138	169	199	230	261	291	322	352	18
19	019	050	078	109	139	170	200	231	262	292	323	353	19
20	020	051	079	110	140	171	201	232	263	293	324	354	20
21	021	052	080	111	141	172	202	233	264	294	325	355	21
22	022	053	081	112	142	173	203	234	265	295	326	356	22
23	023	054	082	113	143	174	204	235	266	296	327	357	23
24	024	055	083	114	144	175	205	236	267	297	328	358	24
25	025	056	084	115	145	176	206	237	268	298	329	359	25
26	026	057	085	116	146	177	207	238	269	299	330	360	26
27	027	058	086	117	147	178	208	239	270	300	331	361	27
28	028	059	087	118	148	179	209	240	271	301	332	362	28
29	029		088	119	149	180	210	241	272	302	333	363	29
30	030		089	120	150	181	211	242	273	303	334	364	30
31	031		090		151		212	243		304		365	31

FOR LEAP YEAR ADD 1 AFTER FEB. 28