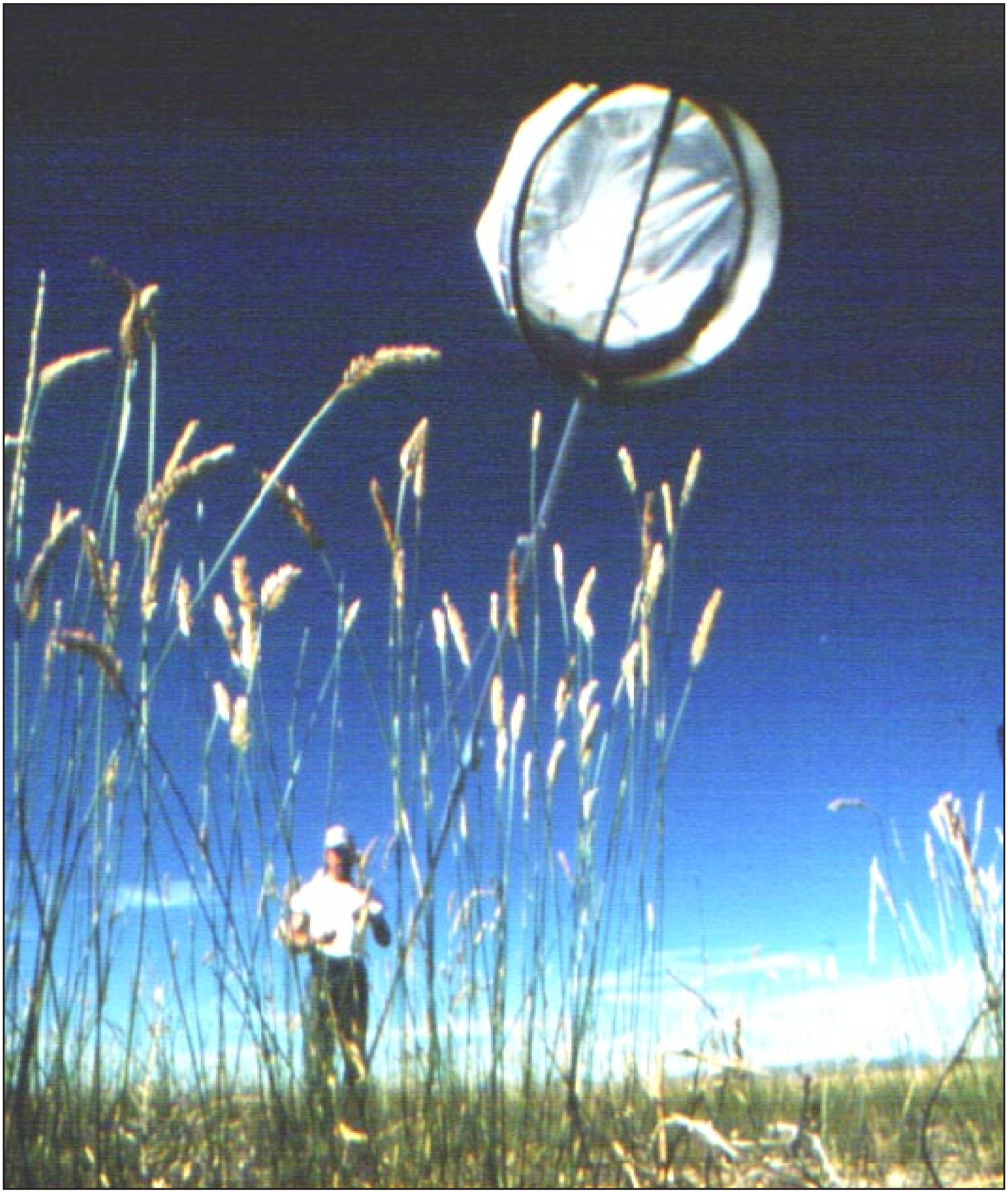
VI. Decision Support Tools



The sweep net is a valuable tool for identifying grasshopper species. Knowing the species composition of a grasshopper population is a key element for making correct decisions. (USDA photo.)

VI.1 The Importance of Making Correct Decisions

Jerome A. Onsager

Within the general arena of grasshopper management, it is possible to make decisions that reduce or cancel out expected potential benefits. According to my dictionary, such decisions possibly could qualify as "blunders" (arising from stupidity, ignorance, or carelessness), "mistakes" (arising from misconception or inattention), or "errors" (arising from a violation of standard guidelines). I do not know what to call strict adherence to guidelines based on misconceptions, but that seems to be another possibility for making faulty decisions. Regardless of what we as pest managers call such decisions, an examination of their origins reveals that most are preventable.

Incorrect decisions within grasshopper management can cause us either to take incorrect actions or fail to take correct actions. Examples of the former include treating rangelands too early, treating too late, treating populations of species that are not chronic pests, selecting suboptimal treatments, and treating noneconomical grasshopper infestations. Examples of the latter— failing to take correct actions—include failing to detect infestations in a timely manner, deciding not to treat injurious infestations, and failing to reduce undesirable consequences of treatments. The following chapters on decision support tools are intended to help both novices and experienced personnel gather accurate information about grasshopper populations and thereby increase the probability of making correct management decisions.

W. J. Cushing's chapter (VI.8) on seasonal occurrence of selected grasshopper species is helpful in the proper timing of surveys. Timing of nymphal (immature grasshopper) surveys is critical if managers are to assess accurately the threat of current infestations at a time when all treatment options are available and before irreparable damage occurs. Timing of adult grasshopper surveys must coincide with the adult period of major pest species if managers are to have accuracy in assessing the potential for future infestations. The chapter of J. S. Berry et al. on sampling techniques and sampling intensity (VI.10) provides guidelines that should cover most survey situations.

R. J. Dysart's chapter (VI.6) shows that some of the 400 grasshopper species in the West are serious pests, that the majority of species are fairly innocuous (harmless), and that a few species even have beneficial attributes. Cushing's "Hopper Helper" (VI.7) and R. J. Pfadt's "Field Guide to Common Western Grasshoppers" (VI.5) are useful in deciding if a grasshopper population contains important pest species. Having identification tools and knowing the makeup of a grasshopper population are vital in deciding to control the population.

An example of where timely grasshopper identification averted unnecessary treatment occurred during the first season of the Grasshopper Integrated Pest Management (GHIPM) Project in 1988 in western North Dakota. Potentially threatening grasshopper densities were reported in an area along the Little Missouri River, where nearness to water might have required a complicated integration of chemical spray, carbaryl bait, and *Nosema locustae* bait treatments. However, surveyors determined that the infestation was mostly *Melanoplus keeleri*, a species that feeds abundantly on coarse brushy forbs and that never has been implicated as a major participant in a sustained outbreak. GHIPM Project personnel correctly decided to take no action, and the "outbreak" subsided the following year.

From its inception in 1987, the GHIPM Project placed major emphasis on consolidation of massive sets of information related to biology and control of grasshoppers, on interdisciplinary analysis and interpretation of complex interactions within that body of information, and on organization and presentation of pertinent conclusions in a useful format. The process relied heavily on computer technology to provide solutions to long-standing problems.

Some of the project's products and tools are described in chapters on economic considerations, by M. D. Skold and coworkers (VI.3 and 4); geographic information systems, by W. P. Kemp (VI.9); and the Hopper decision support system, by J. S. Berry (VI.2). These chapters discuss useful but complex analyses that are well beyond the capabilities of many managers who could benefit from those analyses. Fortunately, the authors have contributed to computer software that allows any computer-literate individual to follow the reasoning powers of a panel of experts when trying to make treatment decisions.

The concepts of economic injury levels and economic thresholds are cornerstones in the foundation of IPM. The chapters by Skold and coworkers represent the state of the art in applying economic considerations to grasshopper management. Chapters show very clearly that chemical control is but one of several available management options and is not universally the most economical tactic. Analyses described in the Skold chapters are an integral part of Hopper, which managers can use to estimate public, private, or total benefits versus costs for either public, private, or cooperative rangeland grasshopper control projects.

Clearly, the decision to control or not control rangeland grasshoppers is not simple. Also, the general public rightfully expects a high level of technical competence within the decisionmaking process. This section of the GHIPM User Handbook represents a concerted effort to equip managers with a complete list of definitive questions as well as the means to obtain accurate answers to those questions. Adherence to the suggestions and guidelines in this section will help managers avoid blunders, mistakes, and errors—and will help support rational pest management on public and private rangelands.

Warning

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Hopper, which is described in section VI.2, can be freely copied. All third-party software used in Hopper can be distributed royalty free.

Hopper Disclaimer

Hopper has been tested as much as possible with the available data and experts and has performed satisfactorily. However, the rangeland ecosystem is very complex and unpredictable. In addition, Hopper does not have any control over the data entered by each user. Therefore, the results derived from Hopper cannot be guaranteed. The following disclaimer applies:

Hopper and its associated files and documentation are distributed without any expressed or implied warranty of any kind. The author, supplier, or distributor shall not be liable for errors contained herein or for incidental or consequential damages in connection with furnishing, performance, use, or misuse of these materials.

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

VI.2 Hopper, Version 4.0, Users' Guide: Decision Support System for Rangeland Grasshopper Management

James S. Berry, William P. Kemp, and Jerome A. Onsager

Preface

The Users' Guide Is a Teaching Tool.—The goal is to present you with the most critical information and the most likely scenarios you will encounter using Hopper and Hopper Lite. In this way, you can learn the program fast and be free of the documentation soon.

Use the Guide Even If You Can Run Hopper Without It.—Initially, you should follow this Users' Guide, even if you intuitively understand how the programs work. The Users' Guide presents you with the options and situations under which you would use Hopper and Hopper Lite and provides background information to help you understand the data and results.

Hopper and Hopper Lite are simple and intuitive, but the data they require are *not.* Ranching economics and rangeland ecology are complex. Consequently, while the data are easy to enter, they are sometimes hard to collect and understand. The Users' Guide provides useful background information and hints to help you learn and use the system correctly. Used properly, Hopper and Hopper Lite will improve the reliability of your treatment decisions.

Acknowledgments

Hopper was developed for the Grasshopper Integrated Pest Management (GHIPM) Project, a multiyear research and development effort that ended in 1995. Many individuals contributed to Hopper over the life of the Project. We wish to acknowledge the following for their support:

Economics Models: Melvin Skold (Colorado State University, Ft. Collins, CO) and Rob Davis (U.S. Department of the Interior's Bureau of Reclamation, Denver, CO).

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Hopper Implementation Team (Special Advisory Committee):

Gary L. Cunningham, USDA, APHIS, Plant Protection and Quarantine (PPQ)

Robert Averill, USDA, Forest Service

Bob Brittingham, USDA, APHIS, PPQ (retired)

Nelson Foster, USDA, APHIS, PPQ

J. Bruce Helbig, Plant Health Director for South Dakota, USDA, APHIS, PPQ

J. Dan Kail, PPQ Officer for Nevada, USDA, APHIS, PPQ

Jim Krsnak, Division of Regulatory Services, South Dakota (Plant Board Representative)

John Larsen, Plant Health Director for Wyoming, USDA, APHIS, PPQ

David Legg, Department of Plant, Soil and Insect Sciences, University of Wyoming (Extension Service representative)

Melvin Skold, Department of Agricultural and Resource Economics, Colorado State University

B. Barte Smith, Plant Health Director for Nebraska, USDA, APHIS, PPQ

Larry Zaleski, Instructional Design Specialist, USDA, APHIS, Recruitment and Development (R&D)

Original Hopper Users' Guide:

Jim Berry, APHIS, PPQ, Phoenix, AZ

Larry Zaleski, R&D, Frederick, MD

Introduction

There are two versions of the Hopper Decision Support Software, "Hopper" and "Hopper Lite." Hopper Lite is for the infrequent user and could be used without consulting a printed manual. Hopper provides more features and flexibility than Hopper Lite. Consequently, Hopper is more complex and not as simple to use. However, Hopper and Hopper Lite use the same analyses and produce the same results. Each time you start Hopper, you will be asked whether you would like to use Hopper or Hopper Lite.

What Is Hopper?—Hopper and Hopper Lite will allow you to evaluate the validity and cost effectiveness of treating outbreaks of rangeland grasshoppers to protect rangeland in western North America. These analyses are based on the best scientific knowledge currently available. This knowledge represents more than 40 years of research and practical field experience of scientists and field personnel.

Hopper is designed around a menu system that you use to select the options and features you need. On the other hand, Hopper Lite will guide you step-by-step through the treatment selection process. Hopper and Hopper Lite are designed for experienced agriculturalists and resource managers who must make informed treatment decisions. Hopper and Hopper Lite cannot be used to evaluate land enrolled in the Conservation Reserve Program (CRP) or protection of crops adjacent to rangeland. In addition, the economic analysis is based on the value of rangeland forage as a food source for free-roaming cattle. Other values, such as long-term resource protection, wildlife, or social impact, are not considered. Hopper does provide some information that a land manager can use to evaluate some of these factors. For example, forage yield may be useful to big-game managers. The analysis allocates reserve forage to be left after grazing (determined by the proper use factor and the Peak Standing Crop parameter). Grasshoppers consume nonreserve forage according to their need. Any remaining nonreserve forage is available to cattle.

Why Use Hopper?—You should use Hopper or Hopper Lite to assist with and improve the reliability of your treatment decisions. Treating grasshopper outbreaks is costly and complicated; you don't want to waste time and money treating when treatment is *not* needed.

Treatment decisions are serious business. On the one hand, unneeded treatment wastes money. But failure to treat when treatment is needed may damage the local ranching economy.

Consequently, you want to make the right decision, and you need reliable information to do so. Hopper provides reliability by evaluating your data scientifically.

What Hopper Does.—Hopper and Hopper Lite provide you with a list of treatments and an estimate of cost effectiveness. To provide this information, Hopper asks you for data about your site. Then Hopper analyzes your data using computer models. These models evaluate factors that are critical for making treatment decisions, including many that are otherwise too time consuming for field personnel to consider.

Hopper gives you a benefit–cost ratio (BC) that you can use to help make your decisions. The BC replaces the static treatment thresholds used previously. The BC depends on many factors that change over time and locations (see appendix A, "How Hopper Works and Why"). The BC is based on the benefits and costs incurred during a single year's operation. The single-year BC does *not* account for multiyear effects, such as the effect of reduced egg deposit on next year's grasshopper population density. Hopper can calculate a multiyear BC, compounded from the single-year BC. Also, Hopper does not account for environmental costs or benefits, value of beneficial species, and other nonforage-related values.

In summary, Hopper's economic evaluations include only the value of forage for livestock consumption in a single season. However, there are many other factors that a rancher may consider in addition to possible multiple-year benefits. One factor is maintenance of the brood herd and long-term survivability and profitability of the operation. A 1-year loss may be acceptable over a 10-year cycle of 9 profitable years.

When the BC is 1.0 or more, treatment is economically justified, and you would treat the outbreak to protect forage. But when the BC is less than 1, treatment is economically unjustified, and you would *not* treat the outbreak just to protect the current forage crop. The final decision to treat or not depends on Hopper's analysis and any other factors important to the ranching community and general public.

Thus, by using Hopper, you can include cost effectiveness in the decisionmaking process.

When To Use Hopper *versus* Hopper Lite.—New users, infrequent users, and managers who need only to evaluate normal treatment scenarios should use Hopper Lite, at least initially. These managers include USDA, APHIS, PPQ personnel. Hopper Lite will direct you, step by step, through Hopper's essential features to evaluate a potential treatment scenario. The most needed features of Hopper are provided, such as input screens for treatment cost and efficacy and grasshopper information.
After becoming familiar with Hopper Lite, frequent users will probably find Hopper easier to use because of its increased flexibility. Also, Hopper provides the opportunity to determine an economic threshold, change additional economic information, create hard-copy data-entry

forms, print graphs, configure attached printers, and run a generalized simulation of rangeland grasshoppers. If you need any of these features, you must choose Hopper. However, remember that the analysis in Hopper Lite is the same as Hopper. There is no reason to use Hopper unless you need its additional features.

Getting Started

System Requirements.—Hopper will run on an IBM™ compatible computer with at least 640 kilobytes (KB) of memory. (A central processing unit 80386, –486, or higher is strongly recommended.) Hopper will probably run with less memory, but the absolute lower limit is not known. Your computer must be running DOS version 3.1 or higher. A VGA monitor is required to view the hazard maps and graphs of the grasshopper and forage simulation results but is not required for other parts of Hopper. To save and print graphs of Hopper's simulations for dot matrix and laser printers, 512–1024 KB of expanded memory (EMS) is required. (See the Installation section of your DOS or MS–Windows™ manual to modify your `config.sys` file with the `emm386.exe` driver.) You can use a mouse to make selections from menus, but the mouse is not required.

A hard drive is required, and there must be at least 3.5 megabytes (MB) free disk space before Hopper is installed. A math coprocessor will speed the simulations in the economic analysis module by almost a factor of 10. However, the math coprocessor is only recommended, not required.

Installation.—There is a simple program (`INSTALL`) supplied with Hopper that will guide you through the installation process and install Hopper on your computer's hard disk. `INSTALL` will also identify the computer's hardware so you can verify system requirements. To install Hopper and Hopper Lite, put the Hopper disk in the floppy disk drive. Then type the letter of the floppy disk drive, a colon, and `INSTALL` (e.g., `A:INSTALL`); do not type any blank spaces; then press the enter key `<ENTER>`. Then follow the directions on the screen. Hopper is supplied in an archived format to save diskette space. `INSTALL` will unarchive the files and copy them to your hard disk. **Note:** Hopper cannot be installed by simply copying the files to your hard disk. You must use the installation program.

If you have previously installed an older version of Hopper in the `\Hopper` directory, you may want to erase the old Hopper files from your hard drive **(Note:** Data files from previous versions and data files (`*.fct` and `*.ec3`) are not compatible with the current version). Removing outdated files will free some disk space for future use. You can keep the old version of Hopper, but you will need to specify a directory other than `\Hopper` when you are prompted by `INSTALL`. If you attempt to install Hopper into a directory where any files exist, `INSTALL` can erase the files for you after prompting you for permission. In this case, all previous information you have saved in that directory will be lost.

If you have at least 2 MB of memory on your computer, you can make some of that memory available to Hopper for creating graphs. To add expanded memory for saving and printing simulation graphics for dot matrix and laser printers, add the following line to your `config.sys` file after the `HIMEM.SYS` line (if present) or on the first line.

```
device=c:\dos\emm386.exe 1024
```

Hopper's default graphic printer (HPGL/2) does not require this line to be added.

Starting Hopper and Hopper Lite.—After `INSTALL` finishes installing Hopper to the hard drive, Hopper is ready for use. Typically, Hopper will be located in a directory called `C:\Hopper`, unless a different drive and directory were specified during installation. Hopper needs to find several of its files while it is running. Therefore, Hopper can be started only from its own directory. To change to the Hopper directory and then to run Hopper, type:

```
cd\hopper <ENTER>
hopper <ENTER>
```

This assumes that Hopper was installed in `C:\Hopper`. If Hopper is started from a menu system, the menu must be programmed to make the Hopper directory the current directory before starting Hopper (similar to the above commands). Each time you start Hopper, you will be asked whether you would like to use Hopper or Hopper Lite.

The User Interface.—In this manual, keystroke commands are in pointed brackets such as <>. The keys are:

<ENTER>...Enter key
<ESC>...Escape key
<DEL>...Delete key
<INSERT>...Insert key
<PageUp>...Page up key
<PageDown>...Page down key
<Down>...Down arrow
<Up>...Up arrow
<Left>...Left arrow
<Right>...Right arrow
<F1>, <F2>...Function keys.

At times, text or numbers must be entered. These will appear in this Users' Guide without brackets (e.g., 23, some text).

When Hopper or Hopper Lite is started (by typing Hopper <ENTER>, or Hopper MONO <ENTER> if you have a monochrome monitor or monochrome liquid crystal display [LCD] screen), a disclaimer appears and waits for any key to be pressed before continuing. Next, the option to select Hopper or Hopper Lite is presented. If you select Hopper Lite, you will be guided through the treatment selection process. Many of Hopper's and Hopper Lite's features and screens are identical. If you choose Hopper, the main menu screen appears (fig. VI.2–1). This screen contains a title window in the center of the screen. Across the top of the screen is a list of main menu items available. (In this text, main menu items are printed in boldface type.) Use the arrow keys (or mouse) to move to a main menu item and then press <ENTER> (or left mouse button) to select that item. When you select one of these main menu items, a submenu of items appears. (Submenu items are always printed in italics.) You can leave any menu or submenu by pressing <ESC>. In fact, pressing <ESC> will allow you to jump out of most areas in Hopper or back up one step.

Hopper is operated by using menus, so you do not have to remember complicated commands. Instead, look through the menus to find the desired item and press <ESC> to leave the menu if the item is not found. Also, you can press <F1> at any time to get context-sensitive help information (fig. VI.2–2). Therefore, you do not have to remember commands or syntax. This menu-driven architecture increases the ease of operation of Hopper while maintaining flexibility for you. You are always returned to the main menu after exiting from a submenu.

Some information Hopper needs is entered onto onscreen data-entry forms (fig. VI.2–3). At times you will need to type numbers or dates on a form. Use the tab key <TAB>, <ENTER>, or arrow keys to navigate between the fields on a form. Data within a field on a form can be edited using the delete key <DEL> or arrow keys, and by

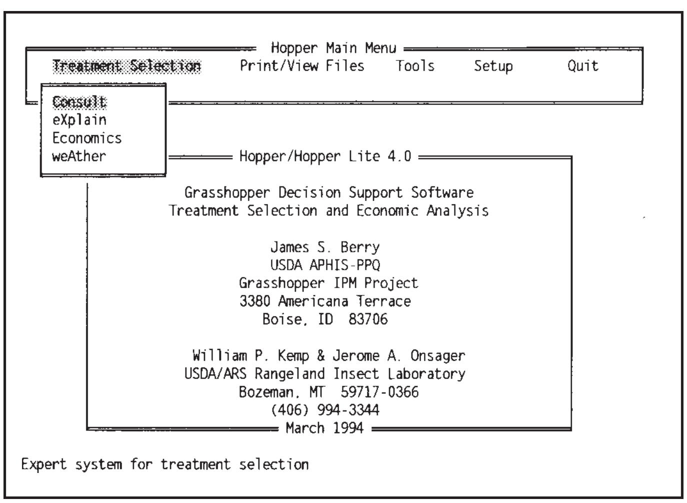


Figure VI.2–1—Main screen showing the **Treatment Selection** submenu.

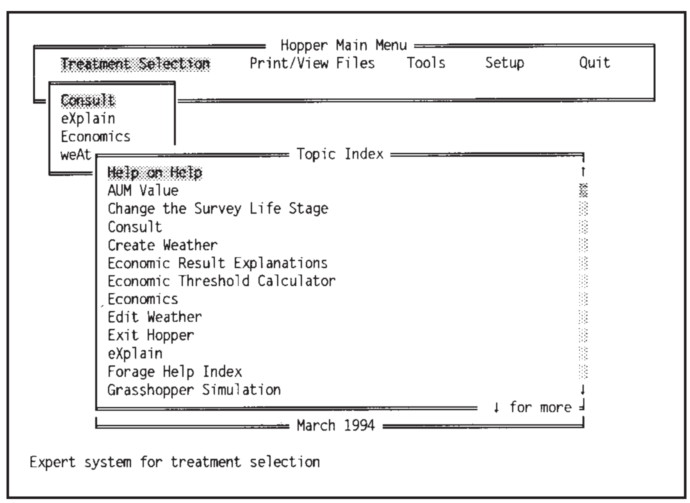
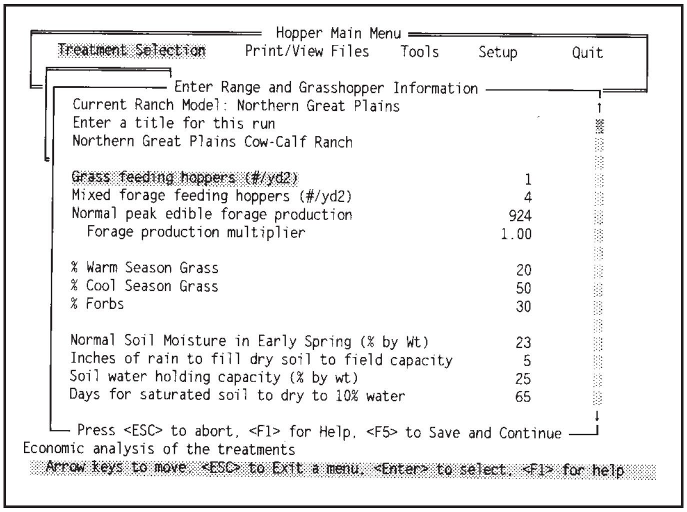


Figure VI.2–2—Main screen help after pressing <F1> twice to get the Help index.


Hopper Main Menu
Treatment Selection   Print/View Files   Tools   Setup   Quit

Enter Range and Grasshopper Information
Current Ranch Model: Northern Great Plains
Enter a title for this run
Northern Great Plains Cow-Calf Ranch

Grass feeding hoppers (#/yd2)	1
Mixed forage feeding hoppers (#/yd2)	4
Normal peak edible forage production	924
Forage production multiplier	1.00
% Warm Season Grass	20
% Cool Season Grass	50
% Forbs	30
Normal Soil Moisture in Early Spring (% by Wt)	23
Inches of rain to fill dry soil to field capacity	5
Soil water holding capacity (% by wt)	25
Days for saturated soil to dry to 10% water	65

Press <ESC> to abort, <F1> for Help, <F5> to Save and Continue
Economic analysis of the treatments
Arrow keys to move <ESC> to Exit a menu, <Enter> to select, <F1> for help

Figure VI.2–3—Example of the fields in an onscreen data-entry form.

typing the desired information. Forms are preloaded with default values so that you often do not need to enter much information. Usually you will just change a couple of values on a form.

A good way to learn Hopper is to explore the menu system and try the various features. Hopper filters your input so that you can enter appropriate information only. Hopper is designed to be robust so that you can easily explore its capabilities as you learn how to use it.

Technical Support.—For help in using Hopper or Hopper Lite, contact Jim Berry by telephone at (602) 379–6014 between 8:00 a.m. and 5:00 p.m. (Mountain Standard Time), weekdays. Facsimilies can be sent any time to (602) 379–6005. Send Internet mail to pmdc@xroads.com with "Jim Berry" (minus the quotation marks) in the Subject line.

Hopper Lite Version 4.0 A Simple Decision Support System for Rangeland Grasshopper Management

Hopper Lite is very easy to use. It asks you questions and controls the whole process to the end. A typical scenario should take about 2 to 10 minutes to complete, depending on the speed of your computer.

Installation.—Hopper Lite is installed automatically with Hopper. Hopper Lite is a subset of Hopper and uses the same files as Hopper.

Operation.—Make the Hopper drive and directory current (e.g., `cd\hopper`). Then type `Hopper` `<ENTER>` to start the program. You will be asked if you would like to use Hopper Lite. Enter `Y` to select Hopper Lite. Then enter the information requested at each prompt. The arrow keys can be used to highlight an answer; then press `<ENTER>` to select that answer. Much of this Users' Guide is contained on the computer and is available by pressing the `<F1>` key. This information will often provide additional explanation or help each step of the way. **Note:** To configure your printer or generate hard-copy data-entry forms, you will need to run Hopper.

For the economic analysis, select a data file that corresponds to your situation (e.g., `NPH_CC.ec3` for northern high plains cow–calf operation, or a generic model [files with "`.gn3`" extension] if no models are available for your area or situation). For more information on economic analysis, see the Economics section.

The economic analysis display at the conclusion of the process shows what treatments were selected and benefit–cost ratio (BC) for each. Remember, these results are the same as those provided by Hopper.

You can change the text printers (default = Hewlett–Packard LaserJet™) or graphics printers (default = HPGL™/2) only in Hopper. In addition, Hopper Lite can only save graphs, not print them. Select **Print/View Files** from the main menu in Hopper to print graphs.

Overview of Hopper

Summary of Features.—There are four items accessible from the main menu. The first is **Treatment Selection**. The submenu provides access to an expert system for selecting appropriate treatments and computer models for economic analyses of those treatments. You can easily try different scenarios to evaluate their economic consequences. The computer simulations for forage production, grasshopper population dynamics, and ranch economic linear programming models in version 4.0 of Hopper and Hopper Lite expand this flexibility for evaluating alternative scenarios.

The second main menu item **(Print/View Files)** will allow you to view on the screen or print any output that

Hopper or Hopper Lite produces. Outputs include reports and data-entry forms. Graphs you save during the economic analysis of treatments can be printed but not viewed.

The third main menu item **(Tools)** has five submenus. There is an interactive *Tutorial* designed to teach a new user how to use Hopper. Next, there is a generalized simulation model of grasshopper population dynamics and treatment effects *(SimHop)*. This is useful for demonstrating the effects of several factors on the overall utility of a control program. *Maps* allows you to select and view rangeland grasshopper hazard maps for several States. These maps are derived, using geostatistical techniques, from surveys of adult grasshoppers in the previous year. Because grasshopper densities are highly correlated with densities 1 year earlier, the maps indicate probable areas of high grasshopper populations. The *Economic Threshold* submenu item will estimate the grasshopper density necessary to produce a benefit–cost ratio you specify. The last submenu item is *Forms*, which will allow you to create hard-copy data-entry forms based on an existing economics data file.

The main menu item **Setup** contains functions to set up printers for text and graphics. Hopper prints graphics indirectly after creating disk files compatible with the graphics printer established in **Setup**. Once you set up both a text and graphic printer, you will not need to set them up again unless you want to use a different printer. The configuration you specify will be used by both Hopper and Hopper Lite.

Strategy for Use.—The main use for Hopper is to select a list of appropriate treatments and then evaluate their economic utility. The *Tutorial* in the **Tools** submenu will demonstrate a typical usage of Hopper. The *Tutorial* will work fine when Hopper is first installed but may not work properly after you have modified some of Hopper's data files. The **Treatment Selection** submenu contains all of the functions for grasshopper control analysis. To develop and evaluate potential treatments, first use the arrow keys to move the highlighted bar to **Treatment Selection** on the main menu and press `<ENTER>`. *Consult* should then be highlighted in the submenu. Press `<ENTER>` to select *Consult* and begin the process to develop a list of appropriate treatments. *Consult* will guide you through this process and ask you for information along the way. In *Consult,* survey and treatment dates are entered. These are used to determine the average grasshopper life stage in *Consult* as a factor for selecting certain treatments. Note that these dates are also used later in the economic analysis to simulate treatment effect on forage availability for livestock. After *Consult* has been used, the treatment list is available to be used for economic analysis. *Economics* is listed below *Consult* in the **Treatment Selection** submenu.

After you select the appropriate economic data file from Hopper's list, Hopper presents onscreen data-entry forms that must be completed. You can accept all the default values except grasshopper density. Typically, of all the data requested by Hopper for the economic analysis, only grasshopper density needs to be entered. More experienced users may change treatment cost and efficacy on the Treatment form. There, scenarios for increasing swath width and the resulting decrease in cost and efficacy can be evaluated.

Once data are correct on an onscreen data-entry form, press `<F5>` to cause Hopper to continue to the next form or function. Most onscreen data-entry forms can just be bypassed by pressing `<F5>` to accept the displayed values when the form appears.

After all data have been entered, the analysis begins. Graphs of the forage and grasshopper simulations can be displayed and/or saved. The economic analysis uses results from the simulations to calculate the benefits and costs of each treatment. The final results can be saved and are also displayed on the screen. Experimenting ("gaming") by changing some values, such as grasshopper density or treatment date, can be very useful and interesting.

The Modules

Treatment Selection

***Consult.*—**The first item in the **Treatment Selection** submenu is *Consult* (fig. VI.2–4). This is the expert system that selects treatments that are valid for a given situation. Select *Consult* by moving the highlighted bar to *Consult* and pressing `<ENTER>`. The program will ask you relevant questions about the situation and current conditions. Often, *Consult* presents several options on the screen. To select one of the options, use the cursor keys (arrow keys), or you can use a mouse and click once on the left mouse button to move the highlighted bar to the appropriate option. Press <ENTER> or click once on the left mouse button to make your selection and continue with the consultation (fig. VI.2–5). At times you may be asked for data that you will need to type in from the keyboard (e.g., dates). In these situations, you will not use the cursor keys to select an option. Instead, you will type your response (fig. VI.2–6).

First, *Consult* will require you to select weather data for your site unless you have already loaded weather data. The *Weather* submenu will open and present three items. The most common choice is to create a weather file for the site. *Weather* also allows existing files to be used or new files to be created in a spreadsheetlike editor. Once Hopper has weather data for the site, Hopper will present an option to load existing facts into memory. If you choose to load existing facts, Hopper will provide a list of available files from which to select. Hopper will take control and guide the treatment selection process. Just answer any questions that are asked. A second window (Current Value Window) at the bottom of the screen will display the information you have entered.

More explanation or help for a question being asked can be obtained by pressing <F1>. These explanations will help you make sure that your answers are appropriate for the way they will be used in the system (fig. VI.2–7).

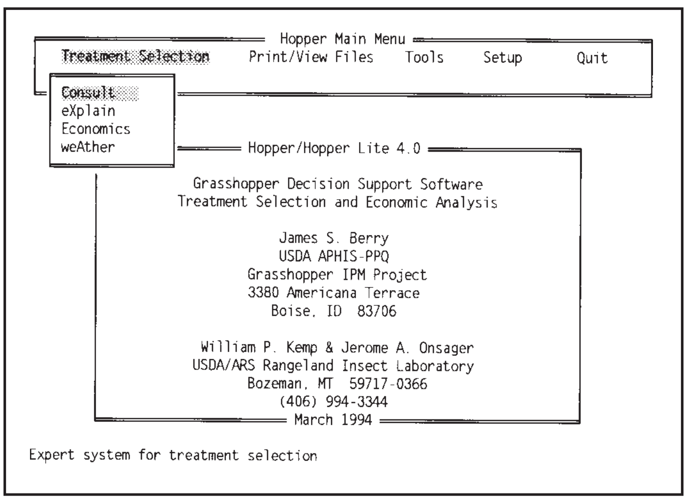


Figure VI.2–4—*Consult* is highlighted and will be selected by pressing <Enter>.

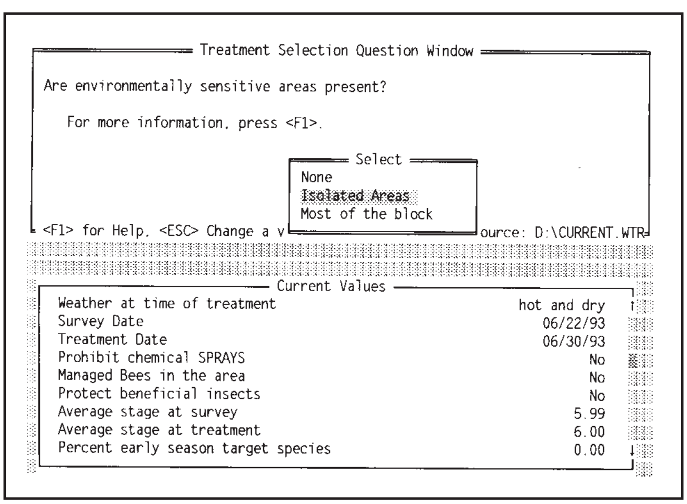


Figure VI.2–5—Typical multiple-choice data entry in *Consult.*

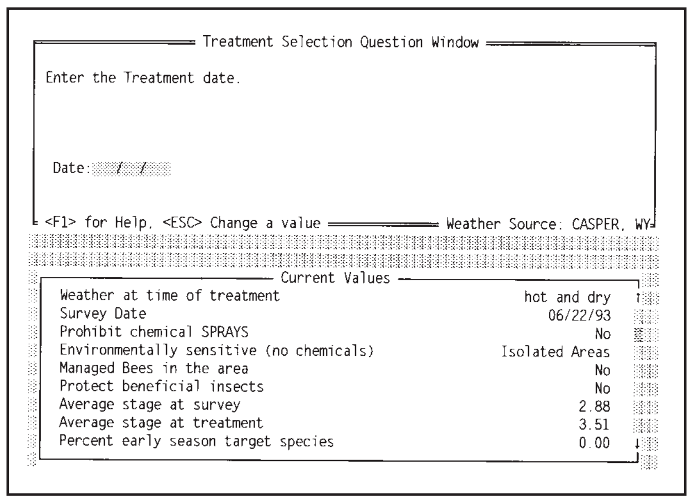


Figure VI.2–6—Typical numeric entry in *Consult.*

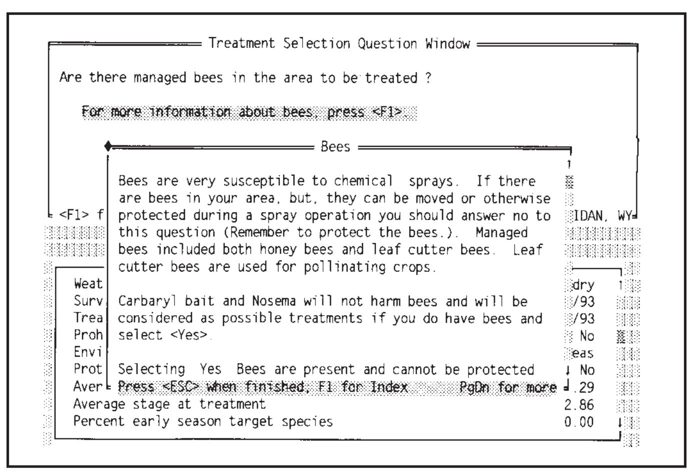


Figure VI.2–7—While entering information in the *Consult* expert system, help and ancillary information can be displayed.

To change or delete a value (e.g., an incorrectly entered value), you can temporarily exit from the Treatment Selection Question Window by pressing <ESC>. The cursor will be placed in the Current Values Window (fig. VI.2–8). There you can see or delete (highlight the value then press <DEL>) any values you have entered. When you are ready to continue with *Consult* again, press <F5>. Only deleted values and any new information needed by the expert system must be entered during the new or continued run with *Consult.* This feature allows you to build treatment lists rapidly from different scenarios. To quit without selecting a treatment and return to the main menu, press <ESC> while the cursor is in the Current Values Window.

Note: After *Consult* is finished, the information that was entered by you for treatment selection can be saved to a file. This information can later be retrieved when you begin *Consult* again, as previously described. When asked for a file name to save facts, only the filename (eight or fewer characters in length), without an extension, should be entered (e.g., FACT2).

When *Consult* is finished, a list of treatments with corresponding application dates will be displayed (fig. VI.2–9). In some situations, other information will be displayed to show the outcome of the consultation. You could delete some facts and press <F5> to run another scenario. When you press <F5> without deleting any facts, you will be returned to the **Treatment Selection** submenu. Hopper will retain in memory the list of treatments you obtained from *Consult.* This list

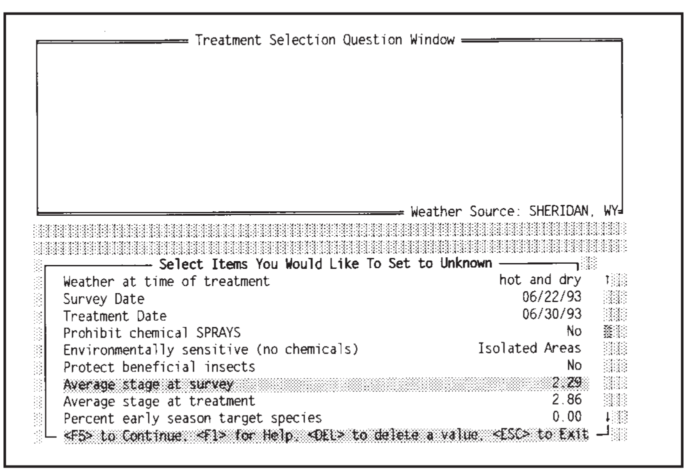


Figure VI.2–8—Screen used to delete data from *Consult.*

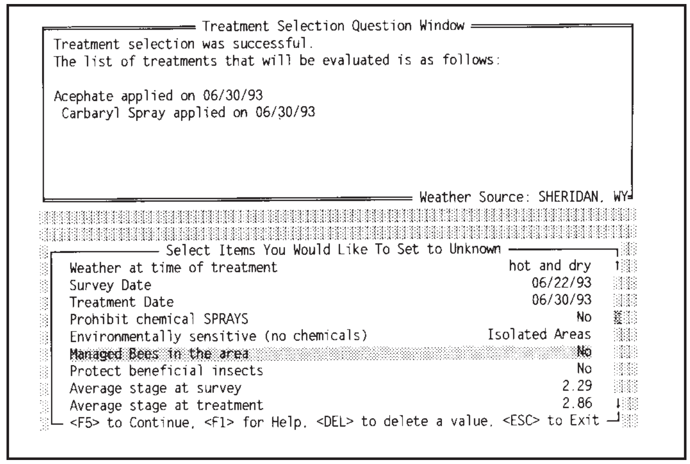


Figure VI.2–9—*Consult* ends by displaying a list of treatments that can be analyzed in the *Economics* module.

will be used each time you select the *Economics* module until *Consult* is run with different data.

Explain.—The *eXplain* option tells you why Hopper selected or rejected treatments for a given consultation.

You may either:
1. View the explanation onscreen (Read)

Use <PageUp> and <PageDown> to move around the explanation. After reading the explanation, press <ESC> to return to the main menu.

2. Print the explanation (Print)

Follow the onscreen directions to print the explanation. See **Setup** for information on setting up your printer.

Economics.—*Economics* prompts you to enter economic and environmental data about the infested site. Then, Hopper runs the data through simulation models that provide an economic analysis of the treatments selected by *Consult.* By varying the data, you can evaluate the benefit–cost ratio of treatments for various scenarios. This allows you to determine

- Whether or *not* treatment is cost effective,
- Which treatment is most cost effective, and
- When to use the treatment for maximum effect.

The *Economics* module gives you access to a virtually unlimited number of scenarios for evaluating the economic robustness of the treatments that were selected by the *Consult* module (fig. VI.2–9). This flexibility and power come by using forage and grasshopper simulation models. The *Economics* module manages the models and the details of each simulation. Therefore, it is very easy for you to do the economic analyses. In fact, the only way a user even knows that models are being used is that a display indicates when a simulation is active.

After *Economics* is selected from the submenu, you must select an option to load economic data into Hopper (fig. VI.2–10). Information for the economic analysis is stored in files. The last information used by Hopper can be retrieved by selecting "Last Values." Information for regional economic models provided with Hopper can be selected by choosing "Saved or Default Values." In addition, any specific economic information you have saved can also be retrieved this way. Press <F1> for descriptions of the economic files. Usually, on the first run for a given area you will select the option for "Saved or Default Values" (existing data file). There are several data files that represent data typical for an area. For example, NGP_CC.ec3 represents a northern Great Plains cow–calf operation. There is also a generic model available for areas that do not have a specific model. These models use data files that have the extension .GN3 and can be used anywhere in North America. For a description of the economic models and data files currently available, see appendix B of this Users' Guide or press <F1>.

Six data-entry windows are used to get information from you before the simulations are started. **Help and explanation (press <F1>) are available for most parameters.** See figure VI.2–11. These explanations should be read so that you will be able to enter correct information and understand the potential effects of a variable on the economic analyses. To change a value, use the arrow keys or <TAB> to move the highlight to the value. Type a new value or use <DEL> to edit the value. When you are finished entering information on an onscreen data-entry form, press <F5> to move to the next onscreen data-entry form.

The first onscreen data-entry form (Forage and Grasshopper Models) is for information used to simulate forage growth and grasshopper population dynamics (fig. VI.2.–12). Densities of grasshoppers that eat only grass and

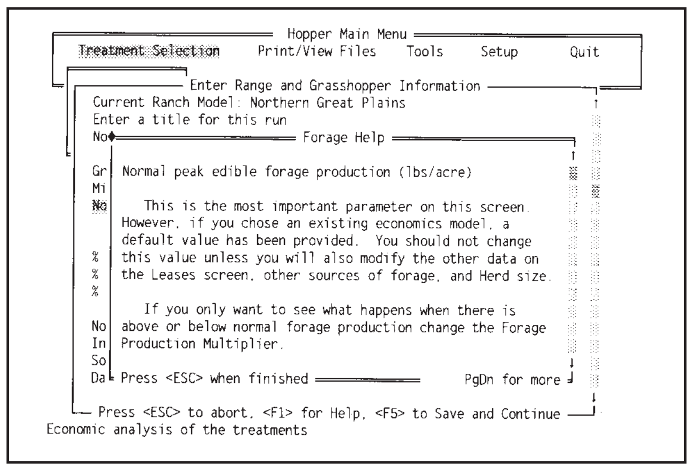


Figure VI.2–11—Grasshopper and rangeland data entry with help information for peak standing crop displayed.

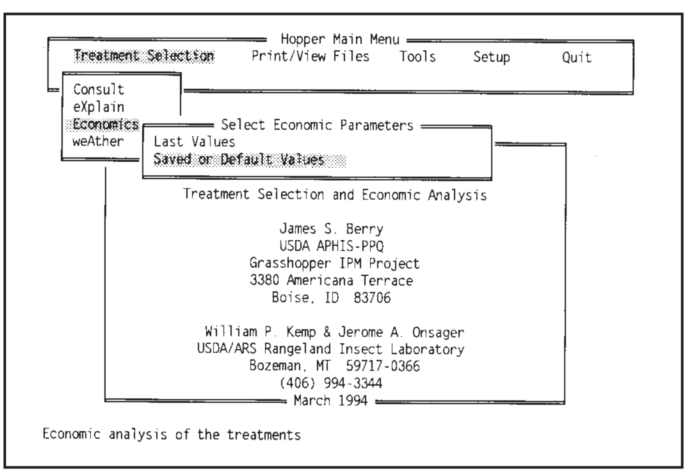


Figure VI.2–10—With *Economics* selected, Hopper then prompts for economic parameters file to use.

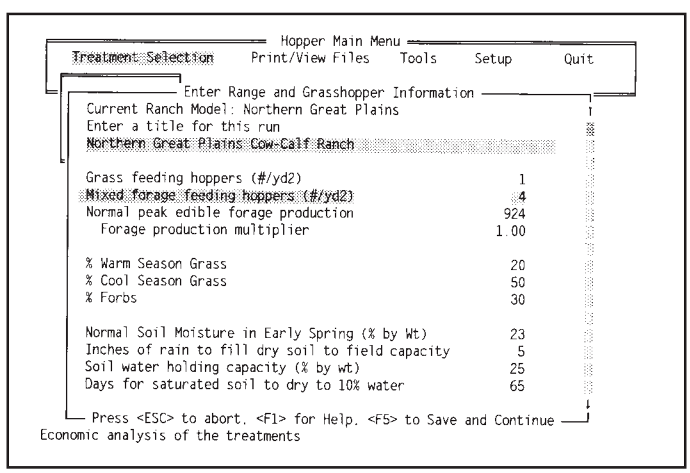


Figure VI.2–12—Grasshopper and rangeland onscreen data-entry form.

those that eat mixed vegetation and, occasionally, a forage-production multiplier should be entered. Remember to press <F1> for more explanation for each parameter (fig. VI.–11 shows a help screen). The rest of the values are reasonable estimates if you do not have better information. Press <F5> to continue when you are satisfied with the values that are displayed. Percent forbs is calculated by Hopper, based on cool- and warm-season grasses.

The second onscreen data-entry form (Treatment Cost) displays the list of treatments, with their costs and mortalities, selected by the *Consult* module (fig. VI.2–13). The total cost (material plus application cost) and mortality can be entered (press <ENTER> after typing each value) for each treatment except *Nosema* bait. Only cost can be entered for *Nosema* bait because mortality calculations are too complicated for most users. After all the costs have been entered correctly, press <F5> to accept your entries and continue to the next onscreen data-entry form.

The third onscreen data-entry form allows you to indicate the potential for multiple-year benefit from control. Be sure to read the information on the screen (fig. VI.2–14). Multiple-year benefits are calculated only by compounding single-year benefits over the number of years you enter on this onscreen data-entry form. This is the last screen of data presented when a generic model is used.

The fourth onscreen data-entry form (Hay Information) shows data used in the ranch economic model (fig. VI.2–15). Press <F5> to continue when you are satisfied with the values that are displayed. Only change this information if you have data for a specific ranch or a ranch typical for the treatment block. The values provided by Hopper are for a typical ranch in the area.

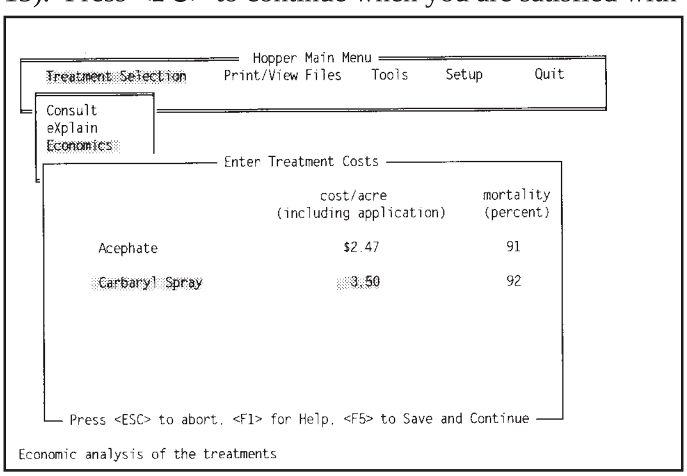


Figure VI.2–13—Treatment cost and mortality onscreen data-entry form.

The fifth onscreen data-entry form (Herd Size) shows livestock data used in the ranch economic model (fig. VI.2–16). A land manager may choose to evaluate the effect of reduced herd size versus paying for grasshopper control. Press <F5> to continue when you are satisfied with the values that are displayed.

The sixth onscreen data-entry form (Lease Information) shows lease data used in the ranch economic model (fig. VI.2–17). Press <F5> to continue when you are satisfied with the values that are displayed. Only change this information if you have data for a specific ranch or a

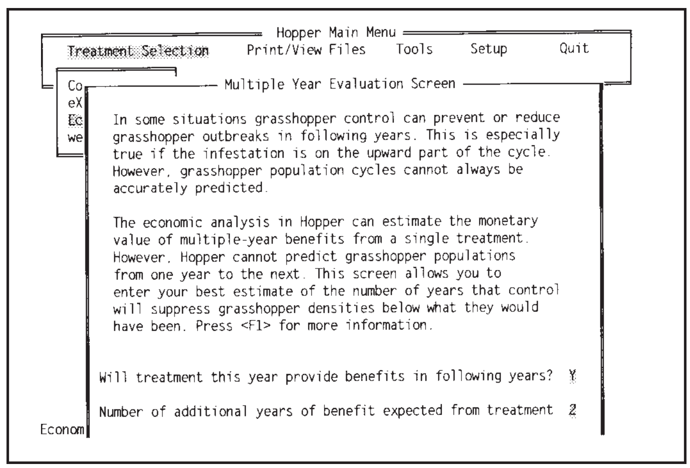


Figure VI.2–14—Multiple-year onscreen data-entry form.

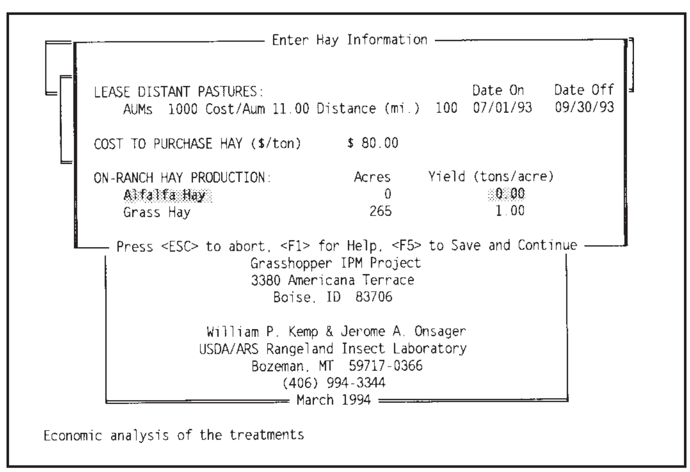


Figure VI.2–15—Hay information onscreen data-entry form and livestock data display.

ranch typical for the treatment block. The values provided by Hopper are for a typical ranch in the area.

Your last entered values for the economic analysis are saved automatically in a file called `Last.ec3`. Before the economic calculations begin, Hopper will ask if you would also like to save in a specific file the information just entered. You could reload and use this information later (fig. VI.2–10).

Then you will be asked if you want to continue with the economic analysis. This process can take several minutes on slow computers without math coprocessors. If `N` is entered, the economic analysis will end and the Treatment Selection menu will be displayed. If `Y` is entered, the economic analysis will proceed. The progress of the analysis can be monitored in a window in the center of the screen. You can view graphs after each treatment simulation. Then the ranch economic model will run. There is no user intervention required until the analyses are complete (fig. VI.2–18). (However, you can press <`Ctrl-Break`> to interrupt the economic analysis and return the Hopper menus.) The results are automatically saved in a file called `Results.rpt`. You will be asked if you would like to save this information in a specific file. **Note:** The Primal/Dual Degenerate Problem message should be ignored.

The results of a ranch economic analysis (not generic analysis) are displayed in a window (fig. VI.2–19). The

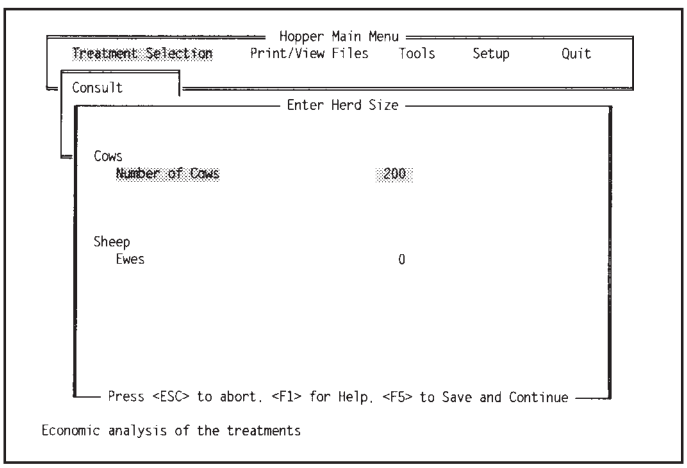


Figure VI.2–16—Livestock herd-size onscreen data-entry form. Yearlings and sheep are not in the model.

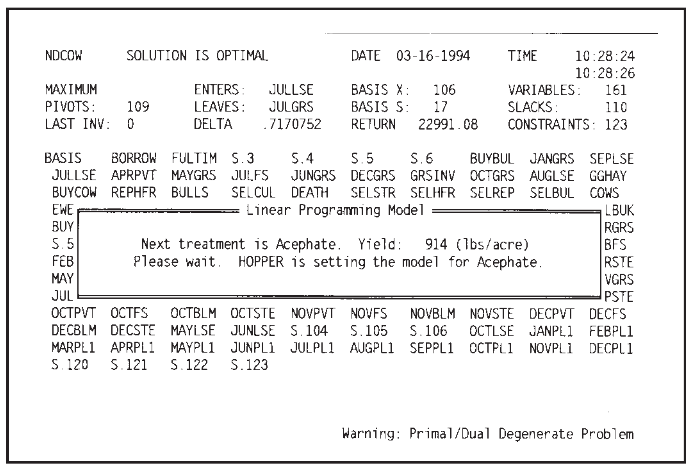


Figure VI.2–18—Working screen for the ranch economic model.

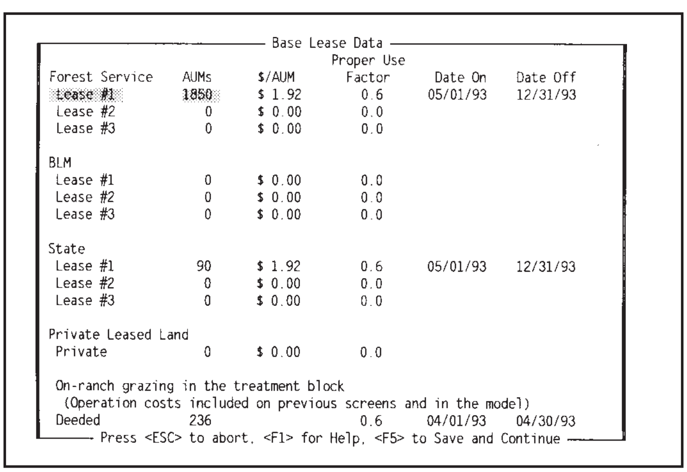


Figure VI.2–17—Range lease onscreen data-entry form.

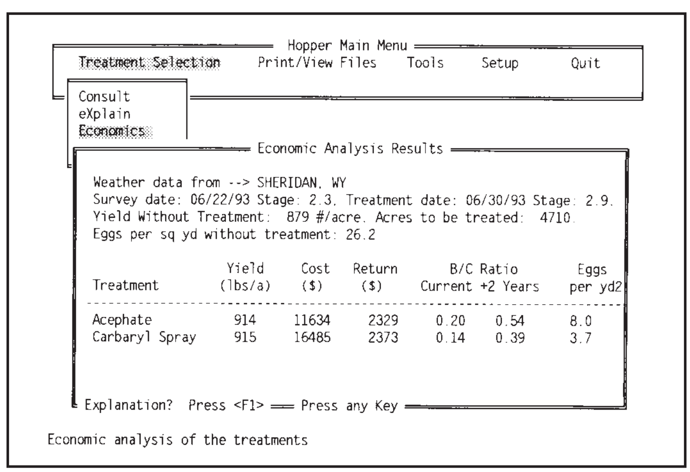


Figure VI.2–19—Final results from the economic analysis.

top few lines describe some general results of the analyses. The yields from the simulations are dependent on the scenario you described (Forage and Grasshopper Parameters Window) and on the weather scenario. The yield with grasshoppers accounts only for grasshopper consumption since the survey date or date of average fourth instar, whichever is earlier. The acres to be treated are calculated from the total Animal Unit Months (AUM's) grazed on the ranch, normal production of peak edible forage, and the proper use factor for each lease and total deeded land. [An AUM represents the average amount of forage consumed by one cow and one calf in 1 month—about 800 lb.] Therefore, the acres to be treated represent the total acres grazed by the ranch, except distant pastures on the Hay Information Screen (fig. VI.2–15). The eggs deposited per square yard is an estimate of the density of grasshopper eggs deposited by the end of October. The number of later instar grasshoppers that will be produced next year by these eggs depends on winter survival of the eggs and spring survival of the young instars.

The simulation results from the individual treatments (includes treatment mortality) and their corresponding application dates are listed in tabular form. The dollar return is total return for the ranch and is calculated from the value of an AUM (determined by the ranch economic model or entered by you in the case with the generic economic models), the cost of control, and the AUM's gained from control.

In some situations, the monetary value of forage saved from a treatment does not justify the application of that treatment for short-term economic reasons. However, there may be carryover benefits for the coming year that cannot be quantified economically. For example, the number of eggs deposited may be reduced, possibly preventing continued high densities of grasshoppers during the next growing season. Eggs deposited per square yard are shown for each treatment in the last column. These densities can be compared to the densities simulated for the untreated grasshopper populations (shown at the top of the window). In this way, relative effectiveness of the treatments (and application dates) for reducing next year's potential population can be evaluated. The return is the gain for the ranch if the treatment is applied. Cost is the total cost to treat the ranch (all AUM's on the lease data-entry form, fig. VI.2–17). The benefit–cost ratio (BC) shows if the benefit is greater than the cost (BC > 1.0). Two BC's are displayed. The first is for a single year. The second is combined for a single year plus the number of subsequent years shown. In the example, figure VI.2–20 shows the current year and 2 subsequent years. Although Hopper provides for benefits to be calculated for up to 10 years, 4 or 5 years is more realistic. See Help `<F1>` for additional information about multiple-year benefits. If current BC (single-year) is less than 1.0, the treatment may still be cost effective if you think you will get as much benefit in subsequent years (multiple-year effects BC).

The results from a generic economic analysis are very similar to the results from the ranch models. A difference to note is the acres to be treated. The generic analysis always shows 1.0 acre, whereas the ranch models show the number of treated acres associated with a ranch. The cost and return for the generic model are also for 1.0 acre, not for an entire ranch. In addition, the forage model is not used by the generic model. Therefore, yield is the normal peak edible forage production times the forage production multiplier minus the estimated forage consumption by grasshoppers (from the grasshopper model). In other words, the generic model calculates potential forage consumption by grasshoppers, but the ranch models calculate yield based on the interaction of forage growth with concurrent grasshopper forage consumption.

Hopper's recommendations are derived from the best scientific and field data available (including your own responses). However, remember that there is great

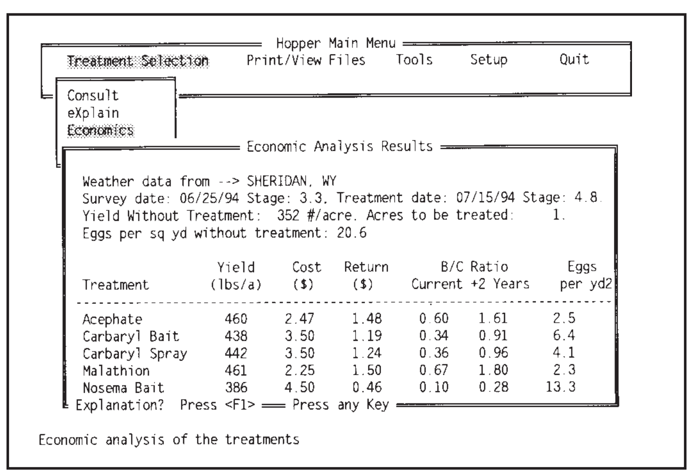


Figure VI.2–20—Final results from the generic economic analysis.

variability in any biological system. Also, future events, such as drought or changes in the cattle market, cannot be quantified accurately and are not included here. Therefore, you should evaluate the strength of your decision by running Hopper and changing some of the values you enter. For example, decrease the grasshopper density by 20 percent. If BC is greater than 1.0 (assuming it was greater than 1.0 in the first run), then you can have greater confidence in the decision to use the specified treatment. However, if BC drops below 1.0, you should suspect that a decision to use the given treatment is not very robust (not a decision that can be made with much confidence). Gaming with the program in this way can be very informative and is one of the strengths of using computer models.

Weather.—Hopper uses simulation models to predict forage production and grasshopper phenology and oviposition. These models use temperature and precipitation information to make the predictions as accurate as possible. The *Weather* module allows you to retrieve, modify, and save temperature data that are used by Hopper. Currently, precipitation and temperature are generated and stored in a file. Both can be edited or updated for each day of the year in the Temperature Editor provided in the *Weather* module.

You can create average weather (using the weather generator provided with your copy of Hopper, fig. VI.2–21) or provide your own weather files. The files may have any filename but must have `.WTR` as the *file extension*

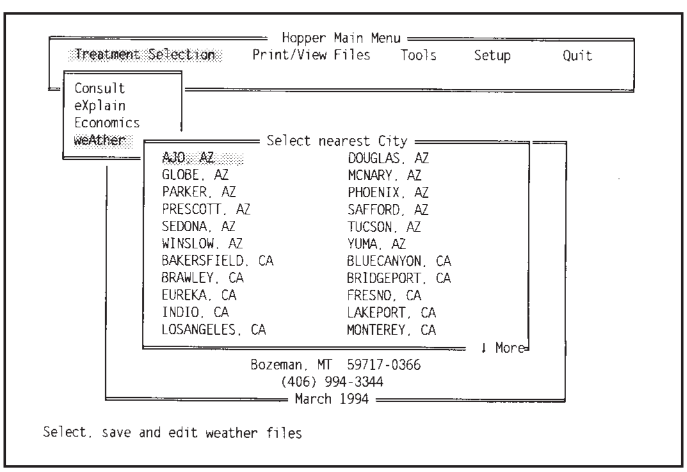


Figure VI.2–21—Weather generator submenu to select the weather station nearest your site.

(e.g., `mytemps.wtr`). For example, `mytemps.wtr` might look like this:

1	14	–5	0.110
2	13	–3	0.090
3	17	0	0.000

etc.

Column 1 is day of the year (where 1 is January 1, 365 is December 31), column 2 is maximum temperature (°F), column 3 is minimum temperature (°F), and column 4 is precipitation (inches). Incomplete data sets are accepted (whole days can be missing). There must be at least one space between each column. In the Northern States, Hopper uses temperatures from April 1 through October 8. Make sure you have good data for these dates before running the *Consult* or *Economics* modules.

A spreadsheetlike Weather Editor is provided to allow you to edit temperatures and precipitation from several sources (average from sites in your area, created by the weather generator; weather files that you have previously edited or assembled using a text editor; or temperature data that are currently loaded into Hopper). Often you may want to evaluate the effect of generally warmer, cooler, wetter, or dryer conditions. The Weather Editor allows you to increase or decrease temperatures or precipitation for the entire year all at once. When you are finished editing, you may press `<F5>` to update the current temperatures in Hopper and, optionally, to save your changes to a file on the disk. Any file you save may be reloaded later for use by Hopper and/or more editing.

Print/View Files

Graphs.—The *Graphs* option will allow you to print any graphs that were saved during an economic analysis. Note that your graphics printer must have been configured correctly at the time the graphs were created. Your graph will not print correctly if it was created for a printer different than the one you would like to use to print the graph (see **Setup** for more information on graphics printer setup, page VI.2–16).

Reports.—All of the information needed to duplicate a scenario is stored in Hopper's reports. The *Reports* option includes information entered in the *Consult* module and the *Economics* module and identity of the source of weather data. Hopper always saves the last run in the file `results.rpt`, even if you declined to save the results when prompted in the *Economics* module. Print Reports will display any report file on the screen or print it to the current printer (see **Setup** for more information on text printer setup, page VI.2–16).

Forms.—You can create hard-copy data-entry forms that you can use to collect input data for Hopper. The forms contain default values from Hopper or values from any data you have saved during an economic analysis. These files have the ending `.ec3`. You can view the forms on the screen or print them. To create a form, see *Forms* in the **Tools** section, page VI.2–16.

Tools

Tutorial.—An automated *Tutorial* will show you a typical run through Hopper. After you modify some of the data files that arrived with Hopper, the tutorial may not run correctly. This problem happens because Hopper may require a different response based on the data that are entered. The tutorial cannot adjust to these changes in advance.

SimHop.—*SimHop* will simulate the general pattern of grasshopper development, forage consumption, and treatment mortality. This is useful for teaching or explaining why it may be too late or too early in the year to treat. The effects of long-lasting (long residual) treatments and timing of treatments can be demonstrated. Text and graphics are used to show the results (fig. VI.–22).

There are two modes of operation. First, a grasshopper population can be simulated from before spring egg hatch (preseason) to the end of season (fig. VI.2–23). You can set the timing, length and size of the hatch period. Second, *SimHop* can begin after egg hatch (midseason). In this case you can specify the density of each instar and starting date of the simulation (fig. VI.2–24). For each type of simulation, you can set the timing, length, and total mortality for a treatment. Therefore, via simulation, you can compare results of a slow-acting biological control applied early to results of a short-residual, fast-acting chemical spray applied later.

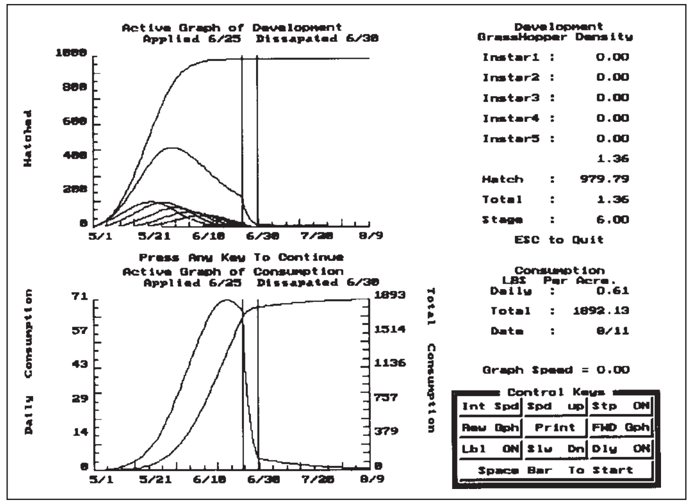
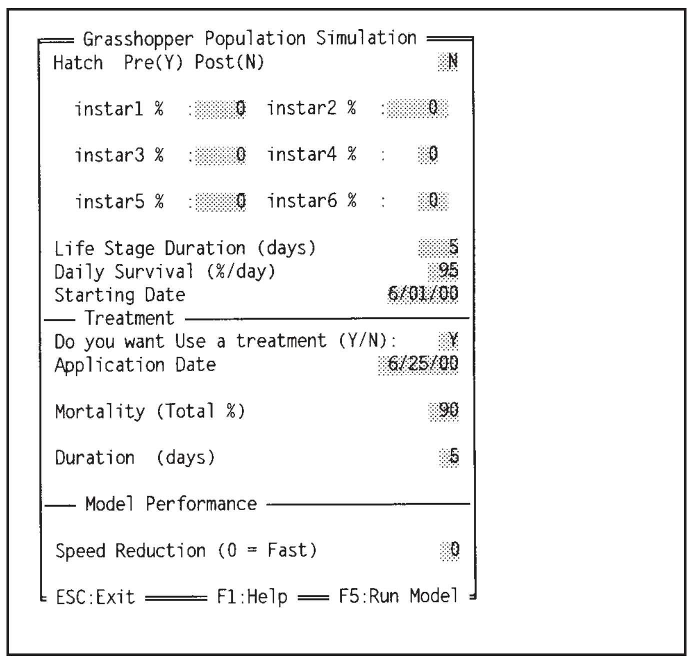


Figure VI.2–22—*SimHop* graphics display screen during a simulation beginning before egg hatch.


Grasshopper Population Simulation
Hatch Pre(Y) Post(N) N

instar1 % : 0 instar2 % : 0

instar3 % : 0 instar4 % : 0

instar5 % : 0 instar6 % : 0

Life Stage Duration (days) 5
Daily Survival (%/day) 95
Starting Date 6/01/00

Treatment
Do you want Use a treatment (Y/N): Y
Application Date 6/25/00

Mortality (Total %) 90

Duration (days) 5

Model Performance

Speed Reduction (0 = Fast) 0

ESC:Exit F1:Help F5:Run Model

Figure VI.2–23—Postegg-hatch onscreen data-entry form for *SimHop.*

```
== Grasshopper Population Simulation ==
Hatch             Pre(Y) Post(N) :     Y
Median Hatch Date                5/20/00

Start Hatch Date                 5/ 1/00

Total Expected Hatch (Eggs/yd²)     1000

Life Stage Duration (days)             5

Daily Survival (%/day)                95

— Treatment ——————————————————————————
Do you want Use a treatment (Y/N):     Y
Application Date                 6/25/00

Mortality (Total %)                   90

Duration  (days)                       5

— Model Performance ——————————————————

Speed Reduction (0 = Fast)             0

ESC:Exit ==== F1:Help == F5:Run Model
```

Figure VI.2–24—Pre-egg-hatch onscreen data-entry form for *SimHop*.

You can change between the prehatch model and the posthatch model by entering Y or N in the first field. The data-entry screen will switch so you can enter data for the model you chose. The last value on the screen is to slow the simulation so that the graph and data can be viewed in more detail. Press <F1> for more information on any current data value (where the cursor is flashing). Change any information on the screen; then press <F5> to run the simulation.

While *SimHop* is running, control keys in the lower right corner of the simulation results screen (fig. VI.2–22) can be used to slow, stop, reverse, or increment (step by step) the simulation. The layout of these keys represents the numeric keypad to the right on the computer keyboard. To use the numeric keypad during *Simhop*, turn off the Num-Lock. You could stop a simulation by pressing <SpaceBar> and then reverse the simulation by pressing the numeric keypad "4." <SpaceBar> will start and stop a simulation.

This tabulation explains the definitions of 1–9 on the numeric keypad:

Int Spd (7) Initial Speed	**Spd Up (8)** Increase speed	**Stp On (9)** Toggles step mode
Rev Gph (4) Reverse graph	**Print (5)** Print current screen to a file	**Fwd Gph (6)** Forward direction for graph
Lbl ON (1) Toggle numeric output to screen	**Slow Dn (2)** Decrease graph speed	**Dly ON (3)** Toggle delay for graph

The consumption rates used in *SimHop* are based on laboratory measurement for *Melanoplus sanguinipes.* Therefore, *SimHop* should be used to help with general understanding of grasshopper population dynamics, not to make precise estimates of forage loss.

Maps.—*Maps* allows you to select and view grasshopper hazard maps for several States. To select a State, move the highlighted bar to the State desired and press <ENTER>. When you are finished viewing the map, press <ENTER> to continue. To exit the *Maps* module, press <ESC> at the State selection submenu.

Economic Threshold.—Hopper can estimate the density of grasshoppers for a specified BC ratio. This estimate is also dependent on grasshopper life stage and species composition and current economic variables. The grasshopper density that corresponds to the BC ratio can be considered an economic threshold. In some situations, you might specify a BC ratio that cannot be achieved—one that is either too high or too low. Hopper will inform you when this situation occurs.

The *Economic Threshold* calculator will first run *Consult* to develop a list of treatments and then allow you to select one of those treatments and enter a BC ratio. Remember that BC ratios greater than 1.0 indicate a treatment profit for the single-year analysis. Next, an economic analysis will begin similar to the analysis in the **Treatment Selection** module. Generic models cannot be used for the *Economic Threshold* calculator. You can enter or modify any of the data to match your situation.

Hopper will run the analysis several times to find the economic threshold. This may take 3 minutes on a 486 computer. However, no intervention is required until the final results are presented. Results can be saved to a report file.

Forms.—You can create and print hard-copy data-entry forms that you can use to collect input data for Hopper. The forms will contain default values from Hopper or values from any data you have saved during an economic analysis. These can be a handy way to prepare to run Hopper because you will have at hand all the information Hopper requests. Select *Forms* and a submenu of items will be presented. You can create, view, or print a form. When you select "Create," a list of economic data files in your Hopper directory is displayed. These files have the ending `.ec3`. Highlight a file and press <ENTER> to create the form for those data. Next, you could view the new form on the screen or print it.

Setup

Printers.—Hopper uses the printer type (text and graphics) you select here to format properly the documents it prints. The printer information is stored in a file. Therefore, you need only select a printer once, unless you change printers. Select both a text printer and a graphics printer.

Text Printers.—Hopper will print existing reports and information in *eXplain* to your text printer. With Text Printers highlighted on the menu, press <ENTER> and a list of printers will appear (fig. VI.2–25). Use the arrow

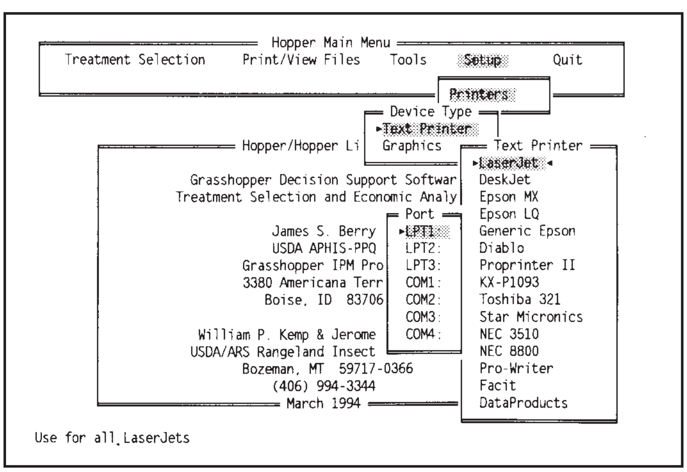


Figure VI.2–25—Setup submenu selected and Text Printer highlighted.

keys to highlight your text printer (or a similar model). If your printer is not listed, check to see if it is compatible with any other printers listed. The Epson printer is very common, and many printers are compatible with it. If your actual printer-model is not listed in Hopper, try selecting Epson instead. The text printer and graphics printer are often the same. However, you need to set up both types of printers in Hopper if the default printers are not acceptable. The text printer must be connected to a printer port (e.g., LPT). If your printer is connected to a COM port, you can place a Mode command in the file `autoexec.bat` to route the printer data through LPT1. For example, if your printer is attached to the serial port COM1, you should place this line in the `autoexec.bat` file:

```
mode lpt1=com1
```

Graphics Printers.—Hopper does not print graphics information directly to a printer. Instead, graphics are "printed" to a file. The format of the graphics file is determined by the graphics printer you select here. The advantage of having the graphics in a file is that they can be imported into a word processor or graphics software. For example, you can import Hopper's graphics (from the simulation models and *SimHop)* into your word processor document. The Hewlett–Packard Pen Plotter is the default graphics printer. Graphics files for this graphics printer consist of lines and end points (vector graphics), and the format is HPGL/2. Therefore, with this format, graphics can be reproduced at the maximum resolution of the printer device, and most graphics editors (such as Lotus Freelance™ and Harvard Graphics®) can import and edit them. Laser-printer or dot-matrix printer output cannot be imported into these graphics editors. Hopper prints only graphics from the **Print/View Files** submenu (see Graphs, page VI.2–13). Therefore, the graphics printer port is not used if you will only import graphics files into other software without ever printing directly. **Note:** Remember that if you select a dot matrix or laser printer, you will need at least 512 to 1024 KB of expanded memory (EMS). See the Installation section at the front of this manual for instructions for configuring your computer's memory.

To change the graphics printer, highlight “Graphics” on the menu and press <ENTER>; a list of printers will appear (fig. VI.2–26). Use the arrow keys to highlight your printer (or similar model) and press <ENTER>. If your printer is not listed, check to see if it is compatible with any other printers listed. Again, select “Epson” as first try if your printer-model is not listed. Next, a menu of ports for the graphics printer will be displayed. The normal port is LPT1. Select the correct port; then press <ENTER>. The text printer and graphics printer are often the same. However, you need to set up both types of printers in Hopper if the default settings are not acceptable. **Note:** Some graphics printers (dot matrix and some laser printers) will not work in Hopper unless the computer has about 512 KB of EMS (expanded) memory available.

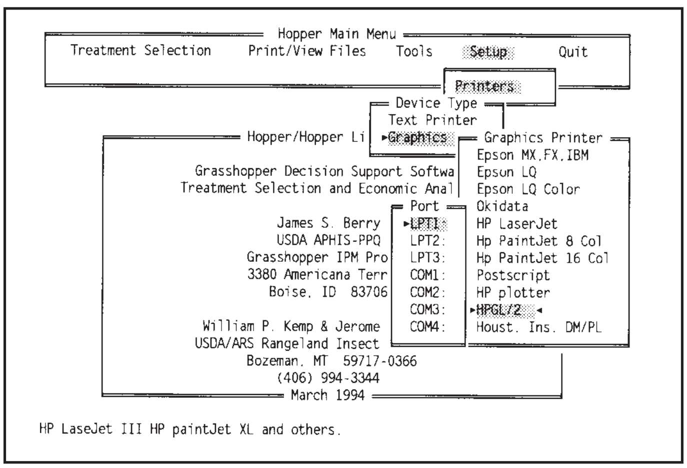


Figure VI.2–26—Setup submenu selected and Graphics selected with the Hewlett–Packard Pen Plotter highlighted (HPGL/2).

Selected References

Berry, J. S.; Kemp, W. P.; Onsager, J. A. 1991. Integration of simulation models and an expert system for management of rangeland grasshoppers. AI Applications 5: 1–14.

Berry, J. S.; Hanson, J. D. 1991. A simple, microcomputer model of rangeland forage growth for management decision support. Journal of Production Agriculture 4: 491–499.

Berry, J. S.; Kemp, W. P.; Onsager, J. A. 1995. Within-year population dynamics and forage destruction model for rangeland grasshoppers (Orthoptera: Acrididae). Environmental Entomology 24: 212–225.

Davis, R. M.; Skold, M. D.; Berry, J. S.; Kemp, W. P. 1992. The economic threshold for grasshopper control on public rangelands. Journal of Agricultural and Resource Economics 17: 56–65.

Foster, R. N.; Reuter, K. C.; Gourd, J. M.; Enis, J.; Wooldridge, A. W. 1983. Field experiments on the toxicity of acephate for control of grasshoppers (Orthoptera: Acrididae) on rangeland. Canadian Entomologist 115: 1163–1168.

Hanson, C. L.; Cumming, K. A.; Woolhiser, D. A.; Richardson, C. W. 1994. Microcomputer program for daily weather simulation in the contiguous United States. Misc. Publ. 114. [Place of publication unknown]: U.S. Department of Agriculture, Agricultural Research Service. 22 p.

Kemp, W. P.; Onsager, J. A. 1986. Rangeland grasshoppers (Orthoptera: Acrididae): modeling phenology of natural population of six species. Environmental Entomology 15: 924–930.

Kemp, W. P.; Onsager, J. A.; Lemmon, H. A. 1988. Rangeland grasshopper treatment selection: application of expert system technology to decision support for resource based management. AI Applications in Natural Resource Management 2: 1–8.

Kemp, W. P.; Kalaris, T. M.; Quimby, W. F. 1989. Rangeland grasshopper (Orthoptera: Acrididae) spatial variability: macroscale population assessment. Journal of Economic Entomology 82: 1270–1276.

Onsager, J. A. 1978. Efficacy of carbaryl applied to different life stages of rangeland grasshoppers. Journal of Economic Entomology 71: 269–273.

Onsager, J. A. 1983. Relationships between survival rate, density, population trends, and forage destruction by instars of grasshoppers (Orthoptera: Acrididae). Environmental Entomology 12: 1099–1102.

Onsager, J. A. 1984. A method for estimating economic injury levels for control of rangeland grasshoppers with malathion and carbaryl. Journal of Range Management 37: 200–203.

Onsager, J. A. 1988. Assessing effectiveness of *Nosema locustae* for grasshopper control. Montana AgResearch. 5(3): 12–16.

Onsager, J. A.; Henry, J. E.; Foster, R. N. 1980. A model for prediction efficacy of carbaryl bait for control of rangeland. Journal of Economic Entomology 73: 726–729.

Software Credits

Borland Pascal 7.0, Borland International, Inc., Scotts Valley, CA. Pascal Compiler.

Object Professional®, TurboPower Software, Scotts Valley, CA. User interface and general programmer's software toolbox for Turbo Pascal.

Turbo Analyst™, TurboPower Software, Scotts Valley, CA. Analytical tools in an integrated development environment, including Pascal formatter, cross referencer, execution timer, execution profiler, program indexer, and program lister.

Tlib Version Control™, Burton Systems Software, Cary, NC. Source code librarian.

PCX Programmer's Toolkit™, Genus Microprogramming, Houston, TX. Routines to display, save, scale, and print PCX images.

BLP88, Eastern Software Products, Alexandria, VA. Linear programming with bounded variables for the IBM-PC, used for the economic analysis.

INGRAF 6.0™, Integrated Graphics Library for Pascal, SutraSoft, Sugar Land, TX. Routines for scientific plotting and graphs.

INSTALIT™, Helpful Programs, Inc., Huntsville, AL. Hopper installation program.

USCLIMAT.BAS, Weather generator, U.S. Department of Agriculture, Agricultural Research Service, Northwest Watershed Research Center, Boise, ID. (Contact: C. L. Hanson.)

RanchMod, Economics Module, M. Skold and R. Davis, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO.

Appendix A How Hopper Works and Why

By Larry Zaleski

Why You Should Know How Hopper Works.—You should know how Hopper works to help accomplish your treatment responsibilities skillfully and accurately.

Whether you're a rancher or government official, professional and financial considerations demand that you work skillfully and accurately. Applying pesticides when *not* needed may threaten the environment and waste money. Conversely, failure to apply pesticides when conditions warrant may jeopardize native rangeland and potentially threaten the local ranching economy.

Hopper helps you decide objectively whether to treat or *not.* But you must use Hopper correctly for good results. And to use Hopper correctly, you must know how the program works.

What You Should Know.—You should be familiar with the following:
- How Hopper can save time, improve accuracy, and save money
- What the economic research shows
- How Hopper's components work together
- What the expert system (Consult) does
- What the forage model (RangeMod) does
- What the grasshopper model (HopMod) does
- What the economics model (RanchMod) does
- Your role

As you become familiar with Hopper, you will become more knowledgeable about treatment technology, rangeland ecology, and ranching economics.

How Hopper Can Save Time, Improve Accuracy, and Save Money.—Hopper saves time, improves accuracy, and saves money by
- Automating expensive and time-consuming tasks, and
- Using ecological and economic information previously unavailable to decisionmakers.

Automating Expensive and Time-Consuming Tasks.— Hopper automates many tasks that require time, money, and personnel to accomplish. You still collect information about local conditions, but with Hopper, your treatment decisions are greatly *improved* with little additional effort. To understand the value of automation, you should know

- What Hopper does automatically,
- How Hopper automates tasks, and
- How automation improves treatment decisionmaking.

What Hopper Does Automatically.—Hopper automatically

- Estimates the average instar of a grasshopper population (for integration with field data);
- Estimates the effects of precipitation on forage production;
- Estimates forage production and, then, forage loss to grasshoppers;
- Chooses treatments based on local conditions; and
- Determines if treatment is cost effective.

Without automation and computer simulation, many of these tasks are impractical or more likely to be completed with errors.

How Hopper Automates Tasks.—Hopper automates tasks by integrating an expert system with simulation and economic models (Berry et al. 1991, 1992).

Hopper's expert system is rule-based. Rule-based expert systems are computer programs consisting of rules. These rules are the same as those used by human experts, but the expert system uses the computer's ability to apply logic, instead. For example, an expert system program for reacting to a *traffic light* might look like this:

IF THE LIGHT IS RED: Stop and wait for the light to turn green.

IF THE LIGHT IS GREEN: Go on.

IF THE LIGHT IS YELLOW: Slow down, and...

— If the light turns red, stop, wait for it to turn green, then go on.

— If the light doesn't turn red, go on.

The computer runs through the program until it encounters an "if statement" that matches the current condition. Then the program follows the programmed procedure. Hopper's expert system works similarly, but it's designed to select treatments. Hopper asks questions, matches your answers to its rule base, then lists treatments accordingly.

Models, on the other hand, are mathematical formulas that imitate events in the real world. Models allow you to make predictions and estimates about events in the real world. Previously, such models were too time-consuming and complicated for everyday use. Only scientists could use them. But the personal computer has changed that.

How Computer Automation Improves Decisionmaking.—Computer automation improves decisionmaking in two ways. First, automation is comprehensive. That is, Hopper requires that you answer questions needed to make accurate decisions, each time. Critical factors, including those you might *not* ordinarily consider, are routinely considered. Without this prompting, you might ignore some factors to save time or because you don't know how to evaluate them.

Second, automation is consistent. It's consistent because users answer critical questions each time and because Hopper evaluates data the same way each time—something that people seldom do. Consequently, two people independently entering the same data into Hopper achieve the same results each time. Thus, Hopper transforms treatment decisionmaking into a more objective and scientific process.

Simulation, completeness, and consistency result in improved accuracy at roughly the same cost.

Using Ecological and Economic Parameters Previously Unavailable to Decisionmakers.—Hopper achieves improved accuracy because it uses parameters and variables that were previously impractical or unavailable (Davis et al. 1992). Even though these parameters were important, they were often not used because they were too costly and time consuming to obtain or because they could not be analyzed fast enough to help. As a result, treatment decisions were based on partial information.

Recently, however, researchers have shown that many of these unused but critical variables can be simulated mathematically. Other variables have been determined by the Grasshopper Integrated Pest Management Project and cooperators.

Before Hopper, Treatment Decisions Were Based on Less Extensive Information.—Hopper estimates critical variables previously unavailable to decisionmakers. Biologists and economists knew these variables were important, but only well-funded research projects could collect and analyze the data. And the results of their analysis usually came too late to help.

But the economic basis for control of grasshoppers on rangeland depends on several variables, not just grasshopper density (Davis et al. 1992). These critical variables include

- Rangeland productivity,
- Soil moisture,
- Livestock prices,
- Accessibility and cost of alternative forage,
- Effectiveness and timing of treatments, and
- Grasshopper numbers and composition.

These variables, however, are difficult and expensive to measure. Many could not be analyzed quickly. And few scientists, ranchers, or government officers could measure and interpret all of the variables. Consequently, no one could integrate the critical variables into a practical decision support system.

Critical Variables Can Be Estimated Mathematically.—Recently, researchers demonstrated that many critical variables could be estimated mathematically (Berry and Hanson 1991, Berry et al. 1995, Dennis et al. 1986, Kemp and Onsager 1986). Therefore, for some variables, mathematical simulation provides an alternative to sampling and measurement.

When combined with a personal computer, mathematical simulations provide quick, reliable estimates of difficult-to-measure variables. For the first time, critical variables are routinely available to decisionmakers. What's more, estimated variables can be combined with economic calculations to determine if treatment is cost effective.

What the Economic Research Shows.—The economic research reveals three key facts (Davis et al. 1992):

1. Decisionmakers should use an economic threshold as their basis for applying treatment.
2. Economic justification for grasshopper control programs depends on several variables, *not* just grasshopper population density.
3. Economic justification for grasshopper control programs varies from place to place and year to year.

Decisionmakers Should Consider Economic Threshold in Their Decision About Applying Treatment.— Economics is a primary justification for treating grasshopper infestations. So ranchers should treat grasshoppers *not* to reduce their numbers but to improve the profitability of the ranch. Reducing grasshopper numbers is only a tactic for managing the rangeland resource.

From a ranching perspective, even rangeland management—a continuous effort which some use as a justification for grasshopper control—is simply an economic endeavor aimed at preserving rangeland productivity. Preserving productivity preserves profit. To illustrate the profit motive: one way to manage the land and prevent range damage during a grasshopper outbreak is to remove cattle. But this option is unprofitable, so ranchers tend to avoid cattle removal when possible. Generally, ranchers seek more profitable alternatives.

Environmental factors are important, too, and may *prevent* treatment. But in most cases, the basis for your decision to treat or not is economic.

To apply an economic threshold to treatment decisions confidently, you need to understand the concept of the economic threshold and the concept that treatment is an investment.

The Economic Threshold.—The economic threshold is the population density of a pest at which the cost of management intervention equals the resulting benefit from controlling it. The economic threshold varies with the benefits and the cost of treatment (Davis et al. 1992).

When Does Treatment Become Profitable?—The economic threshold is reached when the benefit–cost ratio equals 1 or more.

Hopper determines the economic threshold by calculating the benefits of treatment, then dividing the benefits by the cost. This measure is called the benefit–cost ratio (BC):

$$BC = \frac{\text{Benefits}}{\text{Cost}}$$

When the benefits equal the cost, the ratio is equal to 1 and the economic threshold is achieved. For example:
Benefits of treatment = $5,000
Cost of treatment = $5,000

$$BC = \frac{\text{Benefits}}{\text{Cost}} = \frac{\$5{,}000}{\$5{,}000} = 1$$

BC's greater than 1 are profitable, but BC's less than 1 are unprofitable. The economic threshold (BC = 1) is the break-even point.

The cost of grasshopper control includes wages and the cost of chemicals, baits, and equipment. The benefit of grasshopper control, on the other hand, is equal to the *value* of the forage saved by treating grasshoppers.

Treatment Is an Investment.—Treatment is an investment in the agricultural economy. You apply treatment to attain or improve profitability.

Typically, you expect a return on your investments. For example, if you invest $100 in a savings account, you expect to collect interest, which is a return. If the account pays 5 percent simple interest, then after a year you would have $105. The BC of your account would be $105 ÷ $100 = 1.05. Because the BC is greater than 1, the account is profitable.

You would *never* knowingly invest in a savings account that loses money (an account whose BC is less than 1). Investing when the BC is less than 1 is unprofitable, and thus, economically unjustified.

Treatment, too, should show a return. Treating when the BC is less than 1 is unprofitable, and thus, economically unjustified.

Variables Affecting Economic Justification of Grasshopper Control Programs.—At least seven variables determine the economic justification for grasshopper control programs on rangeland:

- Rangeland productivity and composition,
- Precipitation and soil moisture,
- Accessibility and cost of alternative forage,
- Effectiveness of treatment,
- Cost of treatment,
- Timing of treatment, and
- Grasshopper population density, life stage, and species composition.

Put simply, these variables determine the *value* of the forage grasshoppers eat (the damage grasshoppers cause) and how much damage can be prevented. The interaction between critical variables is complex.

For example, if rangeland produces too much or too little forage, you cannot economically justify treatment. If *excess* forage is produced, there is enough to feed both grasshoppers and livestock, so you cannot justify treatment. On the other hand, if too little forage is produced, there is no forage to protect, so again, you may not be able to justify treatment purely based on forage value.

Consequently, the effects of the variables below assume that there is forage to protect, but *not* too much or too little. Otherwise, some of the following information would contradict. In practice, Hopper accounts for the effects of forage production automatically.

Rangeland Productivity and Composition.—On *highly productive* rangeland, you can economically justify treatment at lower grasshopper population densities than you can on less productive rangeland (Davis et al. 1992). This is true because treatment saves more forage per acre on highly productive rangeland.

The more forage you save per acre, the lower the cost per unit of forage saved and the greater your benefit for a given per-acre treatment cost. Consequently, on productive rangeland, you can treat *fewer acres* and still get the same per-acre benefit. The fewer acres you treat, the lower the cost.

In addition, some forage species are more valuable than others. Generally, the more valuable the forage, the easier it is to justify treatment.

Precipitation and Soil Moisture.—During *dry years*, you can economically justify treatment at lower grasshopper population densities than in years of normal or high precipitation.

Precipitation is the most important factor affecting rangeland productivity (Berry et al. 1991). Obviously, if it doesn't rain or snow, forage won't grow. When forage is scarce, its value increases because you must supplement it by buying hay or leasing additional land. Remember that, although the value of the forage may increase in dry years, the amount that will be protected by controlling grasshoppers is reduced. Hopper considers both of these factors.

In contrast, during normal and wet years, when forage is plentiful, there is often enough forage to feed both livestock and grasshoppers—even at high grasshopper population densities.

Hopper evaluates the effect of precipitation by calculating soil moisture.

Accessibility and Cost of Alternative Sources of Forage.—When alternative sources of forage are *expensive* or *inaccessible*, you can justify treatment at lower grasshopper population densities than when prices are low and forage accessible. This is true because when alternative sources of forage are expensive, you pay more to supplement or replace your existing forage. Therefore, your existing forage is worth more, and you can justify paying more to protect it.

Effectiveness of Treatments.—Other things being equal, when treatment is highly effective, you can justify treatment at lower grasshopper population densities than when treatment is ineffective. The more effective treatments are, the greater their value, and the higher the benefit–cost ratio.

Cost of Treatment.—When treatment is inexpensive, you can justify treatment at lower grasshopper densities than when treatment is expensive. Several factors influence the cost of treatment, including the price of pesticides, biological control agents, equipment, and personnel. In addition, the cost of treatment varies with demand. In years with lots of spraying, sprayers demand higher fees. Clearly, you need higher grasshopper densities to justify treatment at $4 per acre than you do at $2.25 per acre.

Timing of Treatment.—Timing influences the effectiveness and value of treatment. If you treat too early or too late, you reduce effectiveness. If you treat too early, many grasshopper eggs are still unhatched and will be unaffected. And if you treat too late, the forage is already eaten and next year's eggs are laid. In either case, the benefits are reduced.

Grasshopper Population Density and Composition.— Clearly, you can more readily justify treatment at higher grasshopper population densities than you can at lower grasshopper population densities. The higher their population density, the more forage grasshoppers eat. If the grasshopper density reaches the economic threshold, then grasshoppers literally eat up your profits.

In addition, species composition is important. Some grasshopper species do more harm than others. You can justify treating more-harmful species at lower densities than less-harmful species.

But as you've seen, several factors, in addition to grasshopper population density and composition, determine the economic threshold.

The Economic Justification for Grasshopper Control Varies From Place to Place and Year to Year.— Because the variables affecting the cost effectiveness of treatment vary from place to place and year to year, the economic justification for grasshopper control varies, too.

Conditions vary from place to place. For example, one pasture is more productive than the next, or one county has normal precipitation, while another is dry. Consequently, you may treat grasshoppers profitably at 1 location when densities reach 18 per square yard but not at another location until they reach 25 per square yard.

Similarly, conditions vary from year to year. Over time, a ranch may experience fluctuating precipitation, livestock prices, and lease costs. In 1 year grasshoppers may be worth treating at 30 per square yard; the following year, grasshoppers may be worth treating at 20 per square yard.

Normal variation of ranching conditions demands a flexible response to grasshopper treatment. Hopper provides flexibility by accounting for differences in conditions that vary with location and time.

How Hopper's Programs Work Together.—Hopper uses three kinds of software technology to assist you in making treatment decisions (fig. VI.2–27):

1. An expert system—to select treatments,
2. Simulation models—to estimate difficult-to-measure variables, and
3. An economic model (ranch model)—to determine if treatment is cost effective.

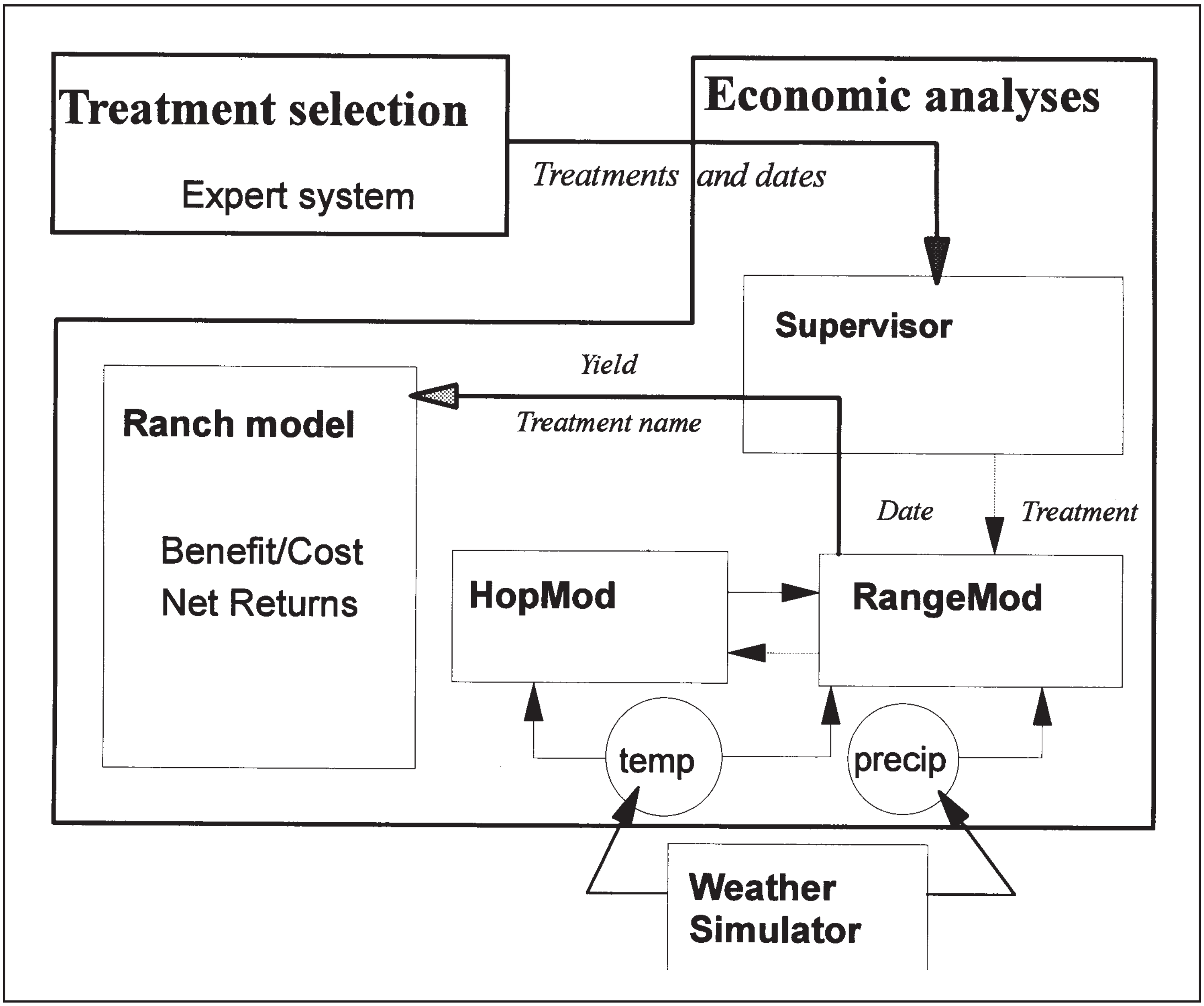


Figure VI.2–27—Overview of Hopper user interface and internal modules.

These technologies work together to provide decision support. Below is an overview of each class of technology. As each technology is introduced, you'll learn how it works with the others.

The Expert System.—The expert system (Consult) helps you choose grasshopper treatments as accurately as an expert. It does this by asking questions about the site, giving some of this information to simulation models to estimate grasshopper life stage, evaluating the data against an internal set of rules, and then providing you with a list of suggested treatments appropriate for the situation (Berry et al. 1991).

The Simulation Models.—The simulation models (HopMod and RangeMod) calculate values for critical variables that would otherwise require additional sampling and analysis.

Hopper uses simulation models to estimate the effects of precipitation, forage production, treatment mortality, grasshopper species composition and life stage (Berry et al. 1995). Information from the simulation models is used by the expert system and economics model.

Simulation models allow Hopper to respond to factors that change over time, like grasshopper life stage and forage production (Berry et al. 1991).

The Economics Model.—The economics model (RanchMod) is a linear programming model that does two things. First it determines if treatment is cost effective. Second, it determines which of the treatments listed by Consult is most cost effective. The economics model uses information from the expert system and simulation models to determine a benefit–cost ratio.

Hopper's models work together to provide reliable decision support. As a result, you can be more confident in your treatment decisions.

What the Expert System Does.—Hopper's expert system (Consult) provides you with a list of treatments appropriate for the conditions you specify. Consult uses internal rules to decide which treatment(s) to list (Berry et al. 1991). In addition, only treatments approved by the Environmental Protection Agency and the Environmental Impact Statement for the Cooperative Rangeland Grasshopper Program are considered.

Where Consult Gets Its Information.—Consult uses information from three sources. First, Consult asks you the following:

- Location?
- Species composition?
- Grasshopper census date?
- Treatment date?
- Presence or absence of managed bees?
- Should treatments harmful to beneficial insects be eliminated from consideration?
- Do conditions prohibit the use of toxic chemicals?
- Vegetation thickness?
- Current weather conditions?
- Percent of the hopper population already hatched (if known)?

Second, Consult uses Hopper's own weather model to enter weather data for the site.

Third, Consult uses the grasshopper model (HopMod) to calculate the average life stage at the time treatment will be applied and number of grasshopper eggs that will be deposited during the current year. This allows Consult to decide if it's too early or too late to treat the infestation economically.

What Consult Does With the Information.—Consult evaluates the information supplied against an internal set of rules. These rules allow Consult to choose treatments appropriate for local conditions.

Consult selects from five treatments approved by the Environmental Protection Agency and the final Environmental Impact Statement for use against grasshoppers on rangeland:

- Acephate spray,
- Carbaryl spray,
- Malathion spray,
- Carbaryl bait, or
- *Nosema locustae* bait (a pathogen of grasshoppers and Mormon crickets).

Depending on the conditions you specify, Consult may recommend none, one, or all of the treatments for economic evaluation. Carbaryl bait, for example, might be recommended when the presence of commercial bees or endangered species prohibit spraying in the area. *Nosema locustae* may be recommended for use near bodies of water, where chemicals are prohibited.

Consult considers species composition and development in making treatment recommendations because:

- Some species *don't* take baits, so you can't use baits.
- Some species *won't* eat the predominant local forage, so you *don't* have to control them.
- Some species develop faster or slower then the bulk of the population, so you should adjust treatment timing.

By accounting for these factors, Consult can alter its treatment list and, ultimately, the decision whether and when to treat.

What the Forage Model (RangeMod) Does.— RangeMod simulates growth of cool- and warm-season grasses and forbs on rangeland during a single growing season (Berry and Hanson 1991). Important features of the model include the following:

- Forage production depends on soil moisture and projected peak standing crop.
- Temperature starts and ends plant growth.
- Forage production occurs logistically (forming an S-shaped curve).

Forage Production Depends on Precipitation and Peak Standing Crop.—RangeMod determines forage production based on daily precipitation and an estimate of peak standing crop. The model uses either known precipitation averages from nearby cities or precipitation data that you supply. Forage consumption by wildlife is *not* estimated or considered by Hopper.

Precipitation directly affects soil moisture, which RangeMod calculates as a function of dry days (consecutive days without precipitation). The model causes soil to dry exponentially (quickly when wet but more slowly as moisture decreases–fig. VI.2–28) down to a minimum of 3 percent by weight. For comparison, the permanent wilting point for plants is reached when soil moisture is 10 percent (Berry and Hanson 1991).

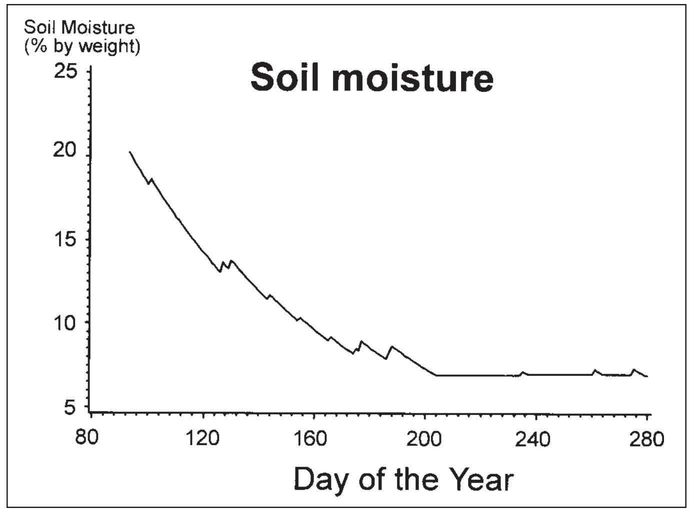


Figure VI.2–28—The effect of drying with occasional precipitation on soil moisture content. This pattern is typical for northern latitudes in the West.

Temperature Starts and Ends Plant Growth.— RangeMod uses a threshold temperature to begin growth in the spring, and to end growth in the fall. The model starts calculating growth when the temperature (the average of the daily high and low) exceeds 32 °F for 5 consecutive days. Growth occurs if daily minimum temperature is above the threshold for the plant type—44.6 °F for forbs and cool-season grasses, and 50 °F for warm-season grasses (Berry and Hanson 1991).

In RangeMod, temperature is *not* a factor in forage production except for its role in starting and ending growth (Berry and Hanson 1991).

Forage Production Occurs Logistically.—When graphed, forage production forms a logistic (S-shaped) curve (fig. VI.2–29). The logistic curve simulates forage production in pounds per acre over time. RangeMod simulates forage production for forbs, cool-season grasses, warm-season grasses, and total production, producing a logistic curve for each.

The *exact* shape of the logistic curve varies with precipitation and forage consumption by grasshoppers. Hopper simulates grasshopper forage consumption in the grasshopper model, HopMod.

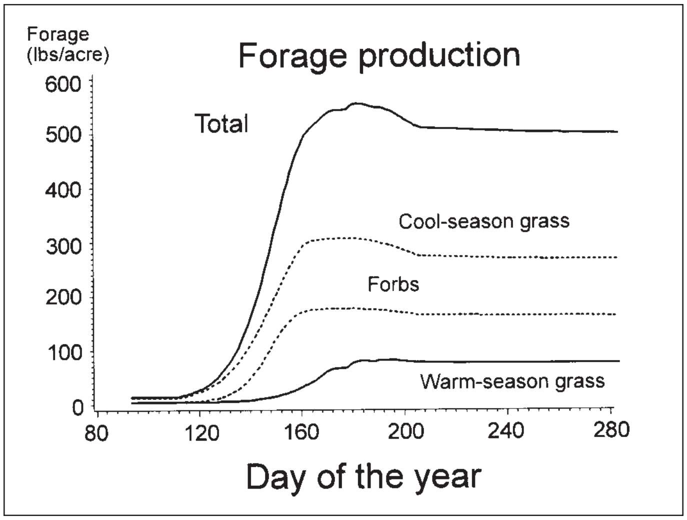


Figure VI.2–29—The logistic growth of forage appears S-shaped.

What the Grasshopper Model (HopMod) Does.— HopMod determines forage loss caused by grasshoppers and determines the loss that you can prevent by applying treatment (Berry et al. 1991).

HopMod simulates grasshopper development through time. Predicting development is important because the amount of forage eaten by grasshoppers per day varies greatly for each life stage. Early instars eat less than later instars. And because the proportion of each instar in the population changes daily, forage consumption changes daily, too.

HopMod's simulation of grasshopper development, in conjunction with the forage and economics models, allows you to decide whether or not to treat at a given time in the grasshopper's growing season.

To understand HopMod, you must understand the following:

- What the grasshopper phenology (growth and development) model does,
- How HopMod determines population size,
- How HopMod calculates forage consumption,
- How HopMod determines oviposition, and
- How accurate HopMod is.

What the Grasshopper Phenology Model Does.—Phenology is the study of the relationship between climate and recurring biological events, such as grasshopper life stage. The grasshopper phenology model estimates the *proportion* of the grasshopper population in each life stage on any given day as a function of time and temperature (fig. VI.2–30).

A proportion is a percentage divided by 100. For example, the proportion "0.8" is derived as follows: 0.8 = 80 percent ÷ 100. Most people use proportions frequently for various routine calculations.

How Development Is Calculated.—The model determines grasshopper development based on time and temperature, called development time (Kemp and Onsager 1986). Grasshopper development is controlled primarily by temperature, so development time is measured in degree-days.

Degree-Days Are Accumulated Heat.—A degree-day is a measure of accumulated heat. Degree-days accumulate in HopMod when the air temperature is between 40 °F (4.4 °C) and 100 °F (37.8 °C) (Berry et al. 1995).

For example, when the daily minimum and maximum temperatures are between 40 °F and 100 °F, HopMod calculates degree-days like this: If the air maximum temperature is 70 °F and the minimum is 40 °F, then there are 70–40 = 30 degree-days of development.

HopMod averages degree-days over a day–night cycle. The program adds degree-days when the temperature is

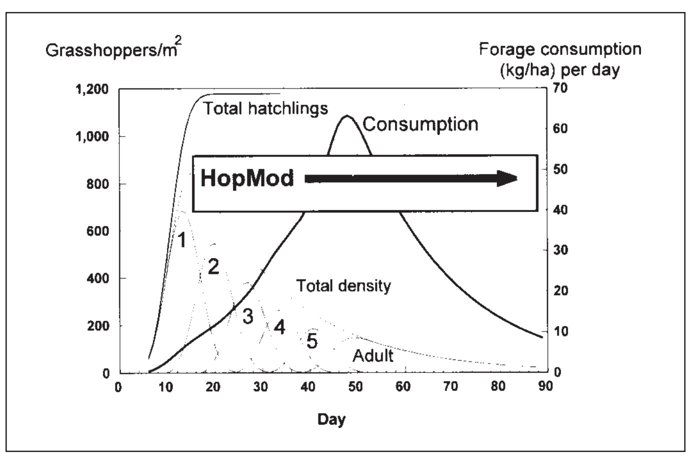


Figure VI.2–30—General progression of a grasshopper population during the spring and summer. HopMod begins when the population has peaked and egg hatch has finished.

within the thresholds. HopMod uses a modified sine-wave formula to adjust and accumulate degree-days as the value changes during the day–night cycle. (A sine-wave formula creates a curve similar to the wave pattern you'd see on an oscilloscope. The wave fluctuates above and below a line. In this case, above the line represents daylight; below the line represents night.) In this way, HopMod calculates the average instar, which is displayed in Consult.

When necessary, you can change Hopper's estimate of the average instar. For example, if you measure an average instar that is different than HopMod's estimate, you can replace Hopper's estimate with your measurement, and HopMod will adjust.

Development Is Based on Accumulated Increments of Development Time.—HopMod assumes that the development rate of a grasshopper depends on accumulated increments of development time (Kemp and Onsager 1986). The process is defined as the amount of development time that a grasshopper has accumulated by a given actual time.

HopMod uses Hopper's weather data base to calculate degree-days. Then HopMod calculates grasshopper development for each calendar day of the growing season. The result is a list of proportions for each life stage for each day. For example, on a given day, you might see the following: instar 1 = 0.1 (10 percent), instar 2 = 0.3 (30 percent), and so on. The proportions must add up to 1.00 (representing 100 percent of the grasshopper population) for the day.

How HopMod Determines Population Size.—HopMod gets the grasshopper population size from you. For example, you count 20 grasshoppers per square yard and type in that number. HopMod, however, adjusts over time for natural grasshopper mortality itself.

HopMod calculates average natural grasshopper mortality using a density-dependent model. The larger the grasshopper population, the faster grasshoppers die.

HopMod, however, does *not* have an egg-hatch model. Consequently, HopMod *cannot* add newly hatched grasshoppers to the population. The program assumes all eggs have hatched by the census date.

How HopMod Calculates Forage Consumption.—
HopMod calculates forage consumption in five steps:

1. HopMod determines the *proportion* of grasshoppers in each instar (life stage), each day. For example, instar 1 = 0.1, instar 2 = 0.3, instar 3 = 0.4, instar 4 = 0.15, instar 5 = 0.05. Remember, the total must add up to 1.00, meaning 100 percent of the population. The proportions in each instar change each day but always add up to 1.

2. HopMod determines the *number* of grasshoppers in each instar by multiplying the proportion in each instar by the population density of first grass feeders, then mixed feeders (usually, grass feeders won't eat forbs, so forbs are protected from grass feeders without treatment). You supply the data on population density and composition.

   For example, if the grasshopper population density is 20 per square yard and is 80 percent grass feeders, then—assuming the proportion of instar 2 = 0.4 —the number of grass-feeding grasshoppers in instar 2 is: $20 \times 0.4 \times 0.8 = 6.4$ per square yard.

3. HopMod determines *how much* forage each instar consumes by multiplying the feeding rate of grasshoppers in each instar (supplied by Hopper and based on scientific measurement) by the number of grasshoppers in the instar.

4. HopMod determines *total* forage consumption by adding the consumption of each instar for each day of the growing season. This value is passed to RangeMod and subtracted for each forage type from the amount of forage for the day. If conditions are favorable, forage continues to grow, and forage loss is usually less than the total consumption by grasshoppers.

5. Finally, HopMod *repeats* the process (steps 1–4) after applying simulated treatments. For example, if there are 20 grasshoppers per square yard, and the treatment is 92 percent effective (only 8 percent survive), then *after treatment* the population is $20 \times 0.08 = 1.6$ grasshoppers per square yard.

HopMod calculates forage consumption by grasshoppers on both treated and untreated rangeland to determine the difference in consumption. This difference is the *benefit* to the ranch.

HopMod repeats the process for each treatment selected by Consult. Available forage is used in the economics model (RanchMod) to determine the benefit–cost ratio for each treatment.

How Oviposition Is Determined.—HopMod assumes that grasshoppers lay eggs at a constant rate. The rate is different for grass feeders and mixed feeders. For grass feeders, the rate is 0.6550 eggs/adult female/day; and for mixed grass feeders, the rate is 0.4564 eggs/adult female/day (Berry et al. 1995).

How Accurate Is HopMod.—HopMod has been field validated (Berry et al. 1995). HopMod correctly simulates the general patterns of rangeland grasshopper population dynamics within a given year (Berry et al. 1991).

Comparison of Field Data and the Grasshopper Model.—Figure VI.2–31 shows a comparison between field data and the phenology model's plots. As you can see, the calculated values closely match the field values. In addition, the estimates of forage consumption by the different grasshopper instars are based on scientific measurement. Therefore, you can expect HopMod to produce reasonable approximations of grasshopper forage consumption.

Steps You Can Take To Improve Accuracy.—You can improve accuracy in two ways:

1. Conduct the grasshopper census as close to the treatment date as possible.
2. Enter actual measurements of the average instar instead of accepting calculated values.

Remember, HopMod does *not* have an egg-hatch model. Consequently, HopMod cannot add newly hatched grasshoppers to the population. As a result, the greater the time between field measurement and treatment the greater the error in estimating average instar and density. So for best results, use current data.

Also, observed measurements are the best estimate of reality. Therefore, whenever possible, enter observed measurements instead of relying on Hopper's initial life-stage estimates.

What the Economics Model (RanchMod) Does.—RanchMod determines the value of the forage. With this information, and with information from the other Hopper models, RanchMod can determine if a treatment is cost effective. In addition, RanchMod compares the cost effectiveness of each treatment listed by Consult, so you can decide which treatment is *most* cost effective. The model reports cost-effectiveness as a benefit–cost ratio.

To understand RanchMod, you must know the following:

- How RanchMod determines the benefit–cost ratio,
- What information you may supply, and
- How reliable RanchMod is.

How RanchMod Determines the Benefit–Cost Ratio.—Using the forage and grasshopper models, RanchMod estimates the *value* of forage consumed by grasshoppers when treatment is applied and when treatment is *not* applied. The difference is the damage avoided by treatment, called the benefit. RanchMod assumes that the forage saved (less the forage set aside by the proper use factor) is available to livestock. The proper use factor is the proportion of the forage that will *not* be consumed by livestock, to prevent overgrazing.

The model divides the *value* of the forage saved (benefit) by the *cost* of treatment to determine the benefit–cost ratio.

RanchMod combines information from the forage and grasshopper models within its economic model to determine the value of forage. The value of forage directly affects the benefit–cost ratio.

What Information You May Supply.—The economics model asks you for information on the arrangement, and operation of the local ranch(es). This information includes the following:

- Lease costs,
- Cost and availability of hay,
- Livestock prices, and
- Herd information–size and composition.

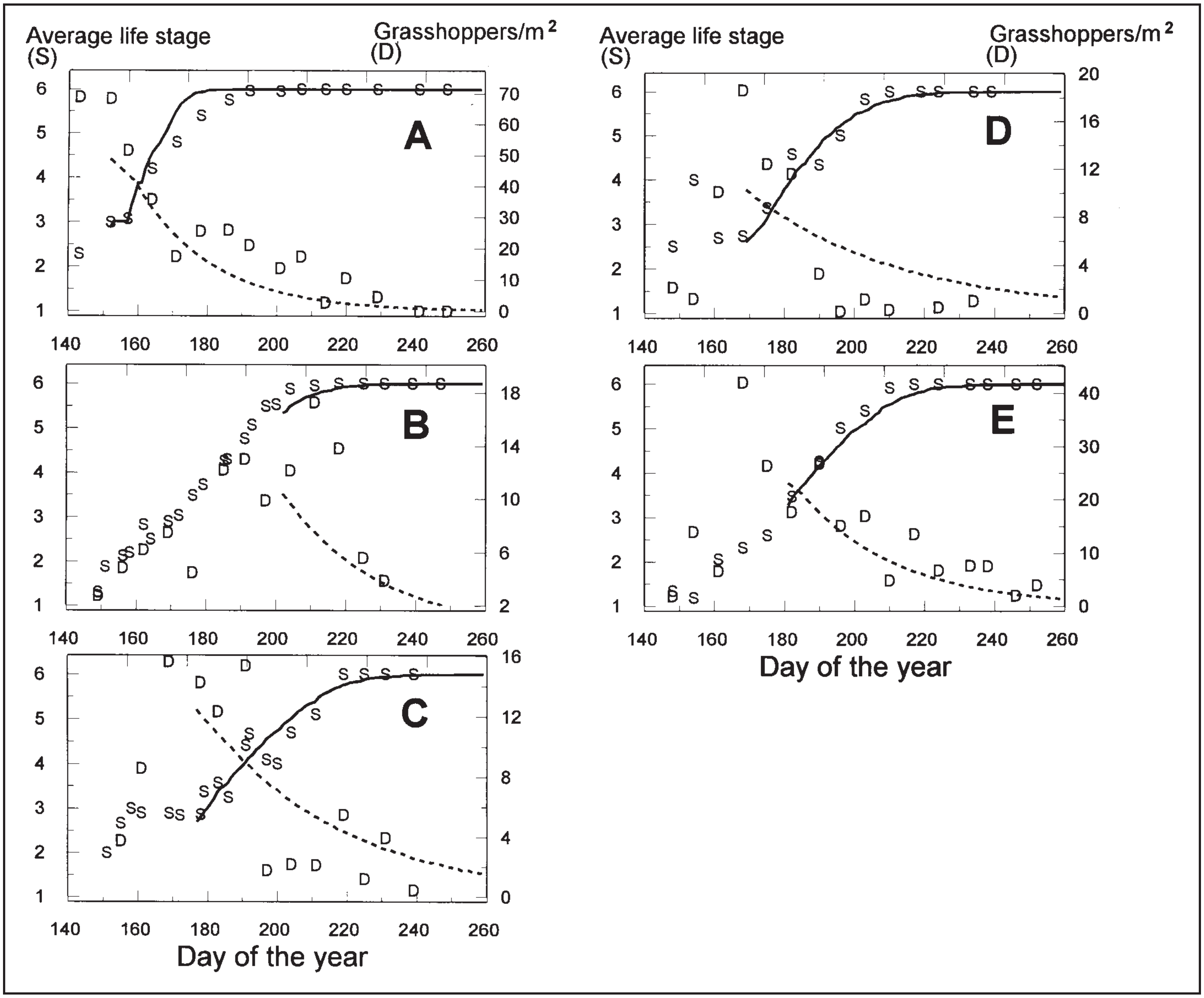


Figure VI.2–31—Validation runs showing average life stage (S, field data; solid line, model) and density (D, field data; dashed line, model) for GHIPM sites in North Dakota.

Hopper provides default values for most of these variables. Default values are averages. When you don't know the actual value, you can use the default value to get a reasonable approximation.

Do not, however, use default values for grasshopper population size and species composition. These values are so variable that your results will be useless. So, for grasshopper density and composition, always use field data. Supply the best information you can for other values as well.

Remember, Hopper is only as accurate as the information you supply. The closer this information matches reality, the more reliable Hopper's recommendation is. Use default values when you must, but supply the best information you can.

How Reliable RanchMod Is.—RanchMod is both reliable and justifiable. RanchMod uses factors previously unavailable to decisionmakers. These factors allow you to account for variation in the ranching environment and to justify your treatment decisions based on economic criteria.

RanchMod's accuracy depends on the accuracy of the data. The closer the data are to reality, the more reliable the benefit–cost ratio. During average years and on the average ranch, the default values will produce good results. But the more conditions stray from average, the more critical that you enter factual data instead of allowing the program to use default values. With accurate data, expect reliable results.

Remember, RanchMod's results are *not* exact. Rather, RanchMod gives you a "ball-park figure," an estimate. RanchMod's estimate, however, is more accurate and more reliable than any you get by other means.

Your Role.—Your role (the role of ranchers, ranching committees, and government officials) in making treatment decisions with Hopper is twofold:
1. To provide accurate data to Hopper.
2. To make the final decision.

Providing Accurate Data to Hopper.—Hopper's recommendation relies on the data you enter. Therefore, to ensure reliability, you must enter the best data available. Collecting this data, however, requires skill, professionalism, and discipline.

Give Hopper the best data you can—it's worth the effort.

Making the Final Decision.—You must make the decision to treat or not. Hopper supplies you with benefit–cost ratios and other useful information. You must decide whether to treat based on the benefit–cost ratio, and other factors *not* accounted for by Hopper, that you judge important. Hopper is a decision support tool, *not* APHIS policy.

Remember, under normal circumstances, treating when the benefit–cost ratio is less than 1 is economically unjustifiable. Failure to treat when the benefit–cost ratio is greater than 1 threatens the ranching economy.

Hopper provides support for your treatment decisions based on scientific and economic research. If you use Hopper's benefit–cost ratio to make your decision, you can claim Hopper's support. But if you use another criteria, you cannot.

References Cited

Berry, J. S.; Hanson, J. D. 1991. A simple, microcomputer model of rangeland forage growth for management decision support. Journal of Production Agriculture 4: 491–499.

Berry, James S.; Kemp, William P.; Onsager, Jerome A. 1992. Hopper decision support system: rangeland grasshopper management for the 1990's. In: Proceedings, 4th international conference: computers in agricultural extension programs; 28–31 January 1992; St. Joseph, MI. St. Joseph, MI: American Society of Agricultural Engineers: 610–615.

Berry, James S.; Kemp, William P.; Onsager, Jerome A. 1991. Integration of simulation models and expert system for management of rangeland grasshoppers. AI Applications in Natural Resource Management 5: 1–14.

Berry, James S.; Kemp, William P.; Onsager, Jerome A. 1995. Within-year population dynamics and forage destruction model for rangeland grasshoppers (Orthoptera: Acrididae). Environmental Entomology 24: 212–225.

Davis, Robert M.; Skold, Melvin D.; Berry, James S.; Kemp, William P. 1992. The economic threshold for grasshopper control on public rangelands. Western Journal of Agricultural and Resource Economics 17: 56–65.

Dennis, Brian; Kemp, William P.; Beckwith, Roy C. 1986. Stochastic model of insect phenology: estimation and testing. Environmental Entomology 15: 540–546.

Kemp, William P.; Onsager, Jerome A. 1986. Rangeland grasshoppers (Orthoptera: Acrididae): modeling phenology of natural populations of six species. Environmental Entomology 15: 924–930.

Appendix B Descriptions of Hopper's Ranch Models

By Melvin Skold, Rob Davis, and James S. Berry

Recent definitions of economic thresholds (ET's) and economic injury levels (EIL's) by economists and entomologists have shown that these concepts are dynamic in nature and must be evaluated for each site under consideration for treatment. Key economic parameters to evaluate include ranch type, rangeland productivity, cost of alternative sources of forage for livestock, and nontreatment options available to the rancher. Biological parameters for evaluating an ET or EIL depend on density of grasshopper species, life stage at time of treatment, mix of economic and noneconomic species, and presence of beneficial insects. Other factors of importance are proximity to waterways and presence of rare or endangered species.

The Grasshopper Integrated Pest Management (GHIPM) Project has provided economic models for eight important range ecosystems in the Western States. Within these range ecosystems, typical ranches are defined which characterize the predominant ranching practices of the area. Between range types, ranches vary considerably with respect to amounts, types, and costs of forages used. Livestock production and management strategies also differ between range types. An evaluation of these typical ranches through Hopper shows how the economic justification for treating rangeland grasshoppers changes between locations and ranching systems.

List of Existing Model Names and Descriptions (Range Types).—The range ecosystems included in Hopper are those identified by APHIS, PPQ personnel as having recurring grasshopper infestations. The selected areas characterize seven range ecosystems and eight typical ranch types. For one area, the Northern Highland Prairie, both beef cow–calf ranches and beef–sheep ranches are common; consequently, two typical ranches were defined to analyze the impacts from grasshoppers infestations more fully.

Generic.—The generic model can be used for any area in the United States or Canada. This model does not use the detailed economic model nor forage production model. Therefore, you will need to use the default value of a replacement AUM ($11.00) or enter a different value (calculated in the other, more detailed models). An AUM (animal unit month) is defined as the amount of forage a cow and calf consume in 1 month (about 800 lb of air-dry forage).

Northern Great Plains.—The rangeland is located within the Northern Great Plains range type, and about 2.2 to 3.3 acres are required to produce 1 AUM. The grazing season is approximately 8 months long; cattle are placed on grazing lands about May 1 and continue to graze until December 31. About half the forage needed on the ranch comes from public land, a quarter from private grazing lands, and the remaining quarter from hay and crop residue.

Located in western North Dakota on the Little Missouri National Grassland, the typical ranch in this model can be used for all of the Little Missouri National Grassland and extrapolated to eastern Montana with changes to rangeland productivity, herd size, leases, weather-generation models, etc. The rangeland is characterized as a northern mixed prairie and is predominantly cool-season grasses, forbs, and shrubs.

Northern Highland Prairie.—About 4 acres are required to produce 1 AUM of forage on this range type. Because elevations in the morthern Highland Prairie are somewhat higher than in the northern Great Plains, the grazing season is shorter. Grazing begins about May 1 and continues through early September.

There are two typical ranches defined for this region. The first is a cow–calf ranch that is supplied 23 percent of forage needs by public grazing lands. Hay stocks are produced for winter feeding needs, and private rangeland supplies the balance of forage AUM's (56 percent) for the livestock. A calf crop of 85 percent is achieved, with the calving season starting in March.

The second ranch has both a cow–calf enterprise and a range sheep enterprise. This ranch receives 41 percent of forage AUM's from public rangeland, no hay is produced, and private grazing lands supply the balance of forage needs. Lambing begins about May 15; a lambing crop of 122 percent is the norm. The calving season for this ranch starts in March, with a calving percentage of 80 percent.

Located in Johnson County, WY, this typical operation is a large cow–calf ranch; these model parameters can be used for ranches throughout eastern Wyoming, south-central Montana, and possibly northeastern Colorado (assuming the weather, rangeland productivity, herd size, leases, etc., are changed when data are input). This rangeland, is characterized as Northern Mixed Prairie, is predominantly cool-season grasses, forbs, and shrubs.

Central Great Plains.—This region is characterized by highly productive rangelands of predominantly warm-season grass species. The typical ranch of about 2,200 acres of grazing land is a cow—calf operation with a 6-month summer grazing season. Grazing land can support approximately 1 AUM/acre. Hay is fed in the winter to supplement crop-residue grazing and supplies 14 percent of the total AUM's of forage. Public grazing land is available to only a portion of these ranches. Livestock graze on rangeland owned by the rancher and rangeland leased from other landowners.

This typical ranch is located in western Nebraska, and its parameters can be extrapolated to ranches located in southeastern Wyoming, north-central Colorado, and the Nebraska panhandle.

Southern Great Plains.—The typical southern Great Plains ranch has both cow–calf and sheep enterprises. There is an 8-month grazing season, with 34 percent of the total AUM's of forage coming from public rangelands. The typical ranch includes about 15,600 acres. Privately owned rangelands supply 26 percent of total needed AUM's, and raised hay stocks supply the remaining 40 percent of forage needs.

Almost 53 acres are required to produce 1 AUM of forage. The grass and forb species in this area are predominantly warm season, and most vegetative growth occurs in July, when the monsoon rains come.

The typical ranch in this model is located in eastern New Mexico.

Mexican Highland Scrub.—The typical ranch for this region is a cow–calf operation. Total forage comes from public grazing land (34 percent), from privately owned grazing land (13 percent), private rangeland (10 percent), and from raised hay stocks (43 percent). The elevation is low, and summers are very hot. Most vegetative growth occurs in late summer, when monsoon rains occur. Almost all plant species present are warm season. The grazing season is 9 months long, and hay is fed to supplement the grazing.

Located in southeastern Arizona, this typical operation is a smaller cow–calf ranch operating in the "hot desert" environment. About 64 acres are required to produce 1 AUM of forage. Results from the Mexican Highland Scrub typical ranch profile can be extrapolated to ranches in southwestern New Mexico.

Gila Mountains.—Grazing needs are satisfied for this cow–calf ranch with a year-round grazing season. About 6.5 acres are required to produce 1 AUM of forage. There are no hay stocks produced. The split between public and private grazing lands is about 50–50. The grass species in this region have high percentages of both warm- and cool-season grasses. Most vegetative growth occurs in late July with the onset of summer monsoon rains.

Located in central Arizona in the Chino Valley near Prescott, this typical ranch is a very large cow–calf operation in a transition zone next to a hot desert zone.

Eastern Intermountain Basin.—The typical ranch for the southeastern Great Basin region is a cow–calf ranch that receives about 7 percent of its total forage supplies from public rangelands, 32 percent from leased private rangelands, 41 percent from owned rangeland, and 20 percent from hay produced on the ranch. About 12 acres are required to produce 1 AUM of forage. The grazing season is year-round, with hay stocks supplementing the rangeland forage supplies during the winter. Public rangelands are used during the spring months.

This typical ranch is located in western Utah, and results from this ranch profile can be extrapolated to ranches in southern Idaho and eastern Nevada.

Northern Intermountain Basin.—A cow–calf ranch was defined for this region. The grazing season starts in mid-April and runs until early November. About 9 to 10 acres are required to produce 1 AUM of forage. Public rangelands supply 44 percent of the total forage needs of the cow herd. Raised hay stocks supply 22 percent of the forage and are used in the winter months. Privately owned rangelands and leased private rangelands supply the remainder of forage needs (34 percent).

Located in Harney County, OR, this typical ranch is a cow–calf operation in the Great Basin Desert, which is dominated by big sagebrush. Results from this ranch profile can be extrapolated to operations in southern Idaho and northern Nevada.

Model Names in Hopper
(CC = cow–calf, CS = cow–sheep enterprise)

NGP	=	Northern Great Plains (western North Dakota)
NHP	=	Northern Highland Prairie (north-central Wyoming)
CGP	=	Central Great Plains (southeastern Wyoming, north-central Colorado, Nebraska panhandle)
SGP	=	Southern Great Plains (eastern New Mexico)
MHS	=	Mexican Highland Scrub (southeastern Arizona, southwestern New Mexico)
GM	=	Gila Mountain (central Arizona)
EIB	=	Eastern Intermountain Basin (western Utah, southern Idaho, eastern Nevada)
NIB	=	Northern Intermountain Basin (eastern Oregon, western Idaho)
Generic	=	Any area in the United States or Canada. This model does not use the detailed economic model nor forage model. Therefore, you will need to enter the value of replacement AUM's (calculated in the other, more detailed models). These files will have the extension `*.gn3` (e.g., `generic.gn3`).

VI.3 Applying Economics to Grasshopper Management

Melvin D. Skold and Robert M. Davis

Economic considerations are a major part of grasshopper management. Rangeland grasshopper control programs, as well as other pest management strategies, use the concepts of economic threshold (ET) and economic injury level (EIL). The ET is defined as the pest population (density) that produces incremental damage which is just equal to the incremental cost of control (Headley 1972). Pedigo and Higley (1992) advance an identical definition. Viewed from this perspective, the damage caused by the pest must be at least as great as the cost of treatment before the ET is reached. The EIL and ET are related concepts. For some pests, observations of earlier life stages can define an ET for an EIL density of a subsequent life stage. For grasshoppers, however, density surveys are completed and ET evaluations are made based on those surveys.

For many years, grasshopper control programs followed an administrative guideline intervention level of 8 grasshoppers/yd^2 as suggested by Parker in 1939. However, the Grasshopper Integrated Pest Management (GHIPM) Project found the ET to vary, depending on a number of conditions in the range forage, grasshopper, and ranch system. Because the ET for rangeland grasshoppers varies with conditions, the GHIPM Project developed a microcomputer-based decision-support system (Hopper) to help those responsible for grasshopper control programs make realistic estimates of the ET. This chapter discusses the physical, biological, and economic rationale that determines the ET.

Evaluating Benefits

There is a long history of public support for control of rangeland grasshoppers. Individual efforts cannot control widespread grasshopper outbreaks. However, there also is a public benefit from protecting rangelands from serious outbreaks of grasshoppers. Public rangeland has many uses. Ranchers lease rangeland for domestic livestock grazing, the traditional economic use. Rangeland also supports a diverse population of wildlife, provides recreation and open space, protects soil from erosion, and contributes to the watershed for rivers and streams. Rangeland grasshoppers eat and destroy forage that livestock and range-consuming wildlife could use. When grasshopper infestations occur on rangelands, ranchers relying on those lands for livestock grazing incur economic losses. Reducing the density of grasshoppers reduces losses to ranchers. The difference in ranch net returns with and without grasshopper treatments is the basis for the benefits calculation. If grasshoppers exceed the ET and land managers or agencies apply treatments, those treatments can limit the reduction in the ranchers' net returns.

The GHIPM Project's decision-support system, Hopper, includes an economics component that evaluates damage reduction (limiting the decrease in net returns for ranchers) for each of the approved grasshopper treatment alternatives. The damages abated are the benefits resulting from the treatment program. The estimate of damages abated likely is unique for a typical ranch and makes use of the type of range being considered for grasshopper control programs.

Typical Ranches

Because it would be very costly to estimate the damage caused by grasshoppers for each ranch using a grasshopper-infested rangeland, we estimated benefits from grasshopper treatments for "typical ranches" on the major range types for which a version of Hopper is available.

Typical ranches reflect the characteristics of ranches in an area. They are typical with respect to rangeland productivity, livestock on the ranch, grazing management practices, and livestock management practices. To define typical ranches, we interviewed ranchers in an area to identify the common practices. The typical ranch became the barometer to evaluate benefits of grasshopper treatment programs for a given range type. Consequently, typical ranches could be indicators of the extent of the economic impact of grasshoppers on the net incomes of ranchers using that range-type.

Suppose that, as a land manager, you are responsible for making the decision about whether or not to conduct a grasshopper control program in a given area. You know the typical ranch in your area is a cow–calf operation that uses public grazing land along with intermingled deeded rangeland. An economic decision model for the typical ranch is available to show the options you can choose among for dealing with an infestation of grasshoppers.

Here are some management strategies you may consider.

- Have a reserve of hay to supplement grazed forage, which may vary with climate or grasshoppers;
- Find additional grazing land to lease;
- Use crop residues to replace forage lost to grasshoppers;
- Change livestock management practices to reduce forage requirements (such as shift from a cow–yearling to a cow–calf marketing strategy, purchase rather than raise herd replacements, or reduce the size of the cow herd through culling);
- Purchase hay; and/or
- Initiate grasshopper control programs.

The economic decision model lets you consider simultaneously which of these options will result in the least reduction in the expected net returns from the ranch. You choose the option least costly to the ranch, based on your current expectations about prices and costs.

The economic decision model for the nine typical ranches is incorporated into Hopper. In Hopper, the decision model for the typical ranch works with two other components that consider the physical and biological systems present on the ranch. One component estimates the growth of rangeland forage, given soil type(s), temperature, precipitation, and related climatic variables. A second component estimates grasshopper population dynamics and the amount of forage that grasshoppers eat and destroy on the ranch.

The grasshopper population dynamics component of Hopper works with the rangeland forage growth model to predict how much forage will be available for grazing animals. Because some types of wildlife also use rangeland forage, the amount of grazable forage available to livestock depends on how much forage grew and how much remains after grasshoppers and wildlife have eaten.

The grasshopper population dynamics component of Hopper also lets you consider each of the approved treatment options available. Treatment options are determined by physical and biological conditions as well as by the cost effectiveness of the options. Each option comes at a different cost and behaves differently in its timing and effectiveness on grasshoppers. The economic decision model for the typical ranch uses these other two components of Hopper to evaluate the nontreatment adjustments available to the rancher along with the cost and effectiveness of alternative treatments.

To evaluate the benefits, Hopper compares the ranch net returns with no treatment to the ranch net returns for a given treatment at various grasshopper densities. Treatment benefits are the difference in ranch net returns between a treatment option at a given grasshopper density and ranch net returns with the no-treatment option. At low grasshopper densities, ranchers may adjust their grazing or livestock herd management to the loss of forage from grasshoppers. As grasshopper densities increase, losses in net returns also increase. At some point, the density of grasshoppers approaches the ET, and the use of treatments becomes economically justified (fig. VI.3–1).

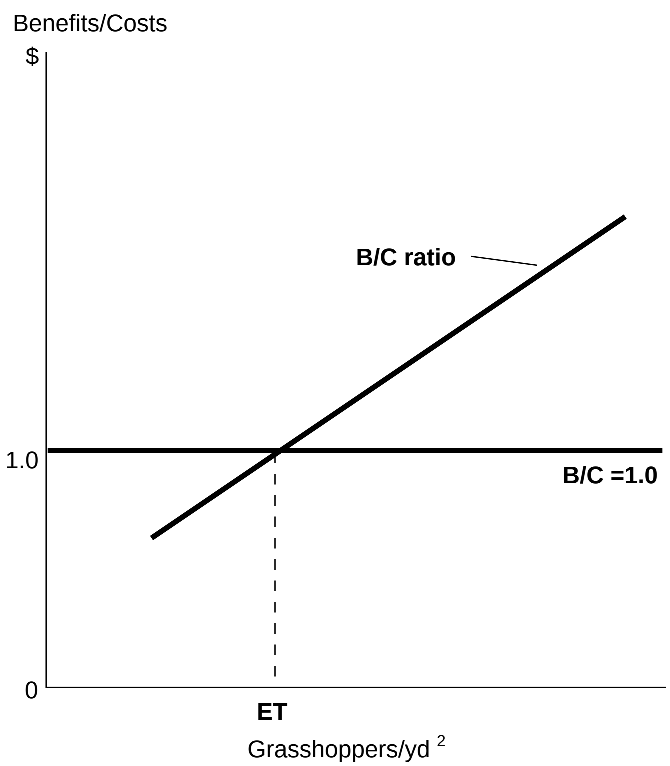


Figure VI.3–1—Determining the benefit–cost (B/C) ratio and the economic threshold (ET), based on grasshopper density per square yard and the cost of treatments.

Cost of Treatments

Hopper determines the costs in addition to the benefits for each treatment at varied densities of grasshoppers. Costs include materials and application expenses per acre, based on recent experience. The costs to apply a given treatment on the typical ranch in your area vary directly with number of acres in the ranch. If you expect the per-acre costs for the treatment(s) considered to differ from those specified in Hopper, you can change the costs to your current best estimate.

Hopper includes expected mortality (grasshopper kill) from each treatment. If dosage, treatment strategy, plant cover, or terrain is likely to change treatment effectiveness, the effective cost of treatment also will change. The benefits (damages abated) will not be as great from a treatment that is less effective (kills fewer grasshoppers) than a treatment that kills more grasshoppers.

The treatment costs reflected in Hopper are the total cost of treatments regardless of who pays. Through its Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ) staff, the U.S. Department of Agriculture pays treatment costs for controlling grasshoppers on Federal lands. The Department also pays a portion of the cost of treating intermingled and adjacent private lands. Some States also cost-share in the treatment programs. States may pay a portion of the cost of treating leased State land and a portion of the cost of treating private land. While the cost share may affect the out-of-pocket costs that a given rancher must pay, cost-sharing is not a part of the benefit and cost calculations of Hopper. Rather, in Hopper, benefits are directly compared to total costs, regardless of who pays.

Benefit–Cost Ratios

The ET is defined by a ratio of the per-acre benefits (B) and costs (C), or B/C (B ÷ C). When B/C = 1.0, the ET is reached (fig. VI.3–1). The B/C = 1.0 when the benefits line crosses the treatment cost line. At that grasshopper density, the ET is reached. At grasshopper densities less than where B/C = 1.0, damages (net return reductions) are occurring but are less than the cost of treatment. At densities greater than where B/C = 1.0, benefits (damages abated) are greater than treatment costs, and economic losses occur in the absence of treatments.

The B/C calculations in Hopper initially compare the costs of treatments to the benefits that result in the year of treatment. Many ranchers believe the benefits from effective treatments can last for several years. Consequently, with Hopper you can specify the expected duration (number of years) of control. If that number is >1, Hopper automatically takes it into account when calculating the B/C ratio.

Analysis with Hopper under varied conditions shows that the long-applied intervention level of 8 grasshoppers/yd^2 is not appropriate. Rather than a fixed ET, the ET in Hopper varies depending on rangeland productivity, the cost of replacing forage lost to grasshoppers, treatment costs, and treatment efficacy. Other physical, biological, and economic factors can affect the ET, too. By running Hopper, you can determine the grasshopper densities necessary to reach the ET on parcels like yours and the sensitivity of the ET to various conditions.

By using Hopper to define the ET, the ET is dynamic and may change from year to year at a given location. Further, the ET is different from location to location in any given year. The ET is determined by running Hopper for a typical ranch such as exists on a major range type. The typical ranch reflects the most common practices for the range type.

To characterize the ranches incorporated into Hopper, a ranch of a given size is described. Size is measured by the number of livestock as well as the amount of land available. The amount of grazing land is determined and for the deeded land, the amount that is owned and the amount that is leased are both specified. Public grazing land is divided by management agency between Federal and State. Grazing practices are also reflected in the economics component of Hopper. The use specifies the length of the grazing season, the time during which the different grazing land types are used, and the time when other sources of feed are fed. If some grazed forage is obtained from crop residue, that fact is reflected in Hopper. If harvested forage is fed, the time of its feeding and its source are also important.

The livestock management systems practiced and viable alternative livestock systems also are built into Hopper. Thus, the herd culling practices, typical calf crop, and disposition of steer and heifer calves must be accurately represented in Hopper.

As Hopper is used to evaluate a treatment decision and to determine the grasshopper density at which the ET is reached, several nontreatment management adjustments are automatically considered. The options available to each typical ranch are built into Hopper. Thus, if a grasshopper invasion occurs, the relevant changes in forage management and livestock herd management are considered simultaneously with the authorized treatment options. If leasing grazing land to replace grasshopper damaged grazing land is an option and leasing is less costly than any treatment, leasing other grazing land will occur before any treatment is applied. The availability of alternative forage and livestock management options affects the position of the benefits line and the grasshopper density at which the ET is reached.

Upon running Hopper, you can determine a separate benefits line for each approved treatment. Because treatments vary as to their cost and efficacy, Hopper calculates different ET's for each treatment. Of course, some treatments may not be possible because of environmental and biological circumstances present. In such cases, Hopper determines the ET only for the treatment options consistent with the conditions that prevail. Changes in treatment costs and efficacy also are important to the position of the B/C line. If treatments can be obtained at a reduced cost, the line shifts left and the ET is reached at lower grasshopper densities than for higher treatment costs.

Applying economic analysis to estimate the ET's for grasshopper treatments provides information-based decisions. Hopper defines typical ranches for important range ecosystems in which recurring grasshopper problems occur. We discuss these ranches in chapter VI.4.

References Cited

Headley, J. C. 1972. Defining the economic threshold. In: Pest control strategies for the future. Washington, DC: National Academy of Sciences: 100–108.

Parker, J. R. 1930. Some effects of temperature and moisture upon *Melanoplus mexicanus* Sanssure and *Camnula pellucida* (Orthoptera). Bull. 233. Bozeman, MT: Montana Agricultural Experiment Station. 132 p.

Pedigo, L. P.; Higley, L. G. 1992. The economic injury level concept and environmental quality: a new perspective. American Entomologist 38: 12–21.

VI.4 Regional Economic Thresholds in Grasshopper Management

Robert M. Davis and Melvin D. Skold

Rangeland grasshopper treatment programs traditionally have started when an economic threshold (ET) was reached. In 1939, Parker defined 8 grasshoppers/yd^2 as the density of grasshoppers at which economic damage to the rangeland begins. Therefore, this density became a "trigger" for beginning consideration of a treatment program. Until recently, the 8 grasshoppers/yd^2 intervention level was used for evaluating grasshopper treatment programs on public rangelands throughout the Western United States.

Recent definitions of ET's and economic injury levels (EIL's) by economists and entomologists have shown that these concepts are dynamic in nature and must be evaluated for each site under consideration for treatment. Key economic parameters to evaluate include ranch type, rangeland productivity, cost of alternative sources of forage for livestock, and nontreatment options available to the rancher. Biological parameters for evaluating an ET and/or EIL depend on density of grasshopper species, life stage at time of treatment, mix of economic/noneconomic species, and presence of beneficial insects. Other factors of importance are closeness to waterways and presence of rare and endangered species.

The Grasshopper Integrated Pest Management Project has provided estimates of ET's for eight important range-type regions in the Western States. Within these range-types, typical ranches are defined—ranches that characterize the predominant ranching practices of the area, as discussed in chapter VI.3. Between range-types, ranches vary considerably with respect to amounts, types, and costs of forage used. Livestock production and management strategies also differ between range ecoregions. An evaluation of these typical ranches through Hopper shows how the economic justification for treating rangeland grasshoppers changes between locations and ranching systems.

Range-Type Regions

The range-type regions included in Hopper are those identified by U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ) personnel as having recurring grasshopper infestations. Nine typical ranches are defined for the eight generalized range-type regions. While county lines were used to designate the range-type regions, the regions should be considered to represent a general area. Similarly, local variation may cause some ranches within the defined area to be different from the typical ranches used to characterize ranching in the eight areas. See figure VI.4–1 for details.

Northern Great Plains.—Rangelands within the Northern Great Plains range-type vary between 2.2 and 3.3 acres per animal unit month (AUM). The grazing season is approximately 8 months long; cattle are placed on grazing lands about May 1 and continue to graze until December 31. On the typical ranch, half the forage comes public land, a quarter from private grazing lands, and the remaining quarter from hay and crop residue.

Ranchers are typically cow–calf operators. Calving begins in March. Most ranchers raise their own herd replacements. On average, about 86 percent of the cows bear a calf each spring.

Northern Highland Prairie.—Here grazing lands average about 4 acres per AUM. Since elevations in the Northern Highland Prairie are somewhat higher than in the Northern Great Plains, the grazing season is shorter. Grazing begins about May 1 and continues through early September.

There are two typical ranches defined for this range-type. One is a cow–calf ranch that gets 23 percent of needed forage from public grazing lands. Hay stocks are produced for winter feeding needs, and private rangeland supplies the balance of forage AUM's (56 percent) for the livestock. A calf crop of 85 percent is achieved, with the calving season starting in March.

Another typical ranch has both a cow–calf enterprise and a range sheep enterprise. This ranch receives 41 percent of forage AUM's from public rangeland, no hay is produced, and private grazing lands supply the balance of forage needs. Lambing begins about May 15; a lambing crop of 122 percent is the norm. The calving season for this ranch starts in March, with a calving percentage of 80 percent.

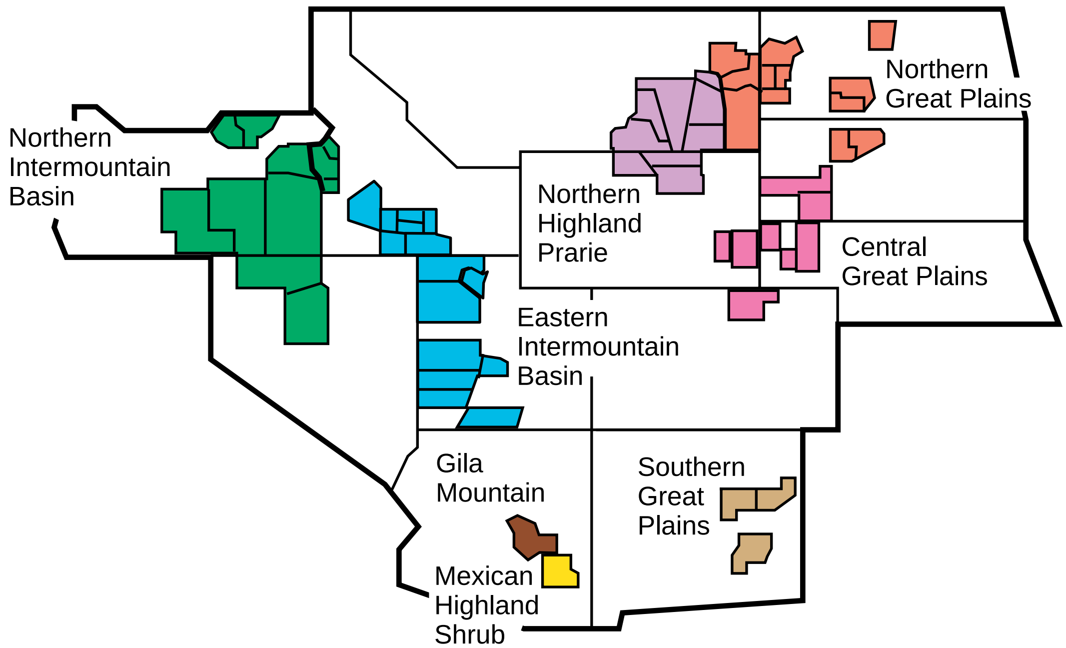


Figure VI.4–1—Map of the Western United States showing the eight generalized range-type regions.

Central Great Plains.—This region is characterized by highly productive rangelands of predominantly warm-season grass species. The typical ranch of about 2,200 acres of grazing land is a cow–calf operation with a 6-month summer grazing season. Grazing land can support approximately 1 animal unit (AU) per acre. Ranchers feed hay (supplying 14 percent of the total AUM's of forage) in the winter to supplement crop residue grazing. Public grazing land is available to only a portion of the ranches. Livestock graze on rangeland owned by the rancher and rangeland leased from other landowners.

Southern Great Plains.—The Southern Great Plains ranch has both cow–calf and sheep enterprises. There is an 8-month grazing season, with 34 percent of the total AUM's of forage coming from public rangelands. The typical ranch includes about 15,600 acres. Privately owned rangelands supply 26 percent of needed forage, and raised hay stocks supply the remaining 40 percent. The rangeland has a productivity rating of about 12 AU's per section (640 acres). The grass and forb species in this area are predominantly warm season, and most vegetative growth occurs in July, when the monsoon rains come.

Mexican Highland Shrub.—The typical ranch for this region is a cow–calf operation. Of total forage needed, 34 percent comes from public grazing land and 13 percent from privately owned grazing land. Another 10 percent is supplied by leasing private rangeland from other landowners. Raised hay stocks furnish the remaining 43 percent of forage. The elevation is low, and summers are very hot. Vegetative growth occurs when the monsoon rains come in late summer. Almost all plant species present are warm season. The grazing season is 9 months long.

Gila Mountains.—Grazing needs are satisfied for this cow–calf ranch with a year-round grazing season. Grazing land provides enough grazable forage to support an

AU for each 6.5 acres. There are no hay stocks produced. The split between public and private grazing lands is about 50–50. The grass cover in this region has high percentages of both warm- and cool-season grasses. Most vegetative growth occurs in late July with the onset of summer monsoon rains.

Eastern Intermountain Basin.—The typical ranch for the Eastern Intermountain Basin region is a cow–calf ranch that receives about 7 percent of its total forage supplies from public rangelands, 32 percent from leased private rangelands, 41 percent from owned rangeland, and 20 percent from hay produced on the ranch. Rangelands carry about 1 AUM/12 acres. The grazing season is year-round, with hay stocks supplementing the rangeland forage supplies during the winter. Public rangelands are used during the spring months.

Northern Intermountain Basin.—A cow–calf ranch was defined for this region. The grazing season starts in mid-April and runs until early November. Rangelands carry 1 AUM/9–10 acres. Public rangelands supply 44 percent of the total forage needs of the cow herd. Raised hay stocks supply 22 percent of the forage and are used in the winter months. Privately owned rangelands and leased private rangeland supply the remainder of forage needs (34 percent).

Results

The ET is the point at which the incremental damage caused by rangeland grasshoppers becomes equal to the incremental cost of applying treatment programs (see chapter VI.3). The ET varies from year to year at a given site; during a given year, it varies between sites. Benefits are measured in terms of the prevention of grasshopper-caused reductions in net returns from rangeland (forage production). Costs are the dollars required to conduct a grasshopper treatment program.

In figure VI.4–2, how the ET is determined is illustrated by ET_0. The ET is reached when the ratio of benefits (B) to costs (C) is equal to 1; B/C = 1.0. At grasshopper densities that are less than where B/C = 1.0, damages are occurring but the cost of applying a treatment exceeds the amount of damage experienced. Only when the ratio of B to C reaches 1.0 or higher does treatment become economically justified.

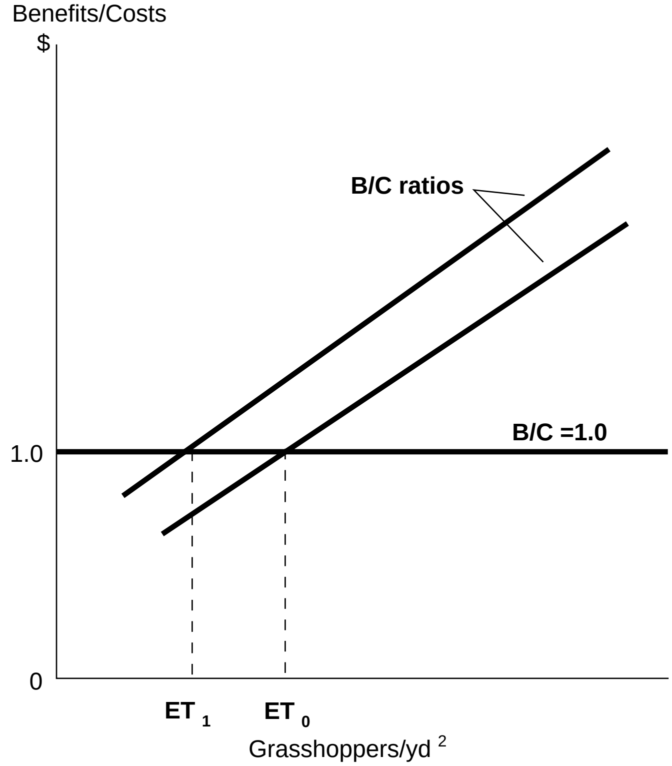


Figure VI.4–2—The relationship of benefit–cost ratios to economic thresholds.

Several factors may cause the ET to vary between years on any of the range-types shown on the map. A drought year will make grazable and harvested forage more valuable; the B/C line shown in figure VI.4–2 will shift to the left, indicating that the ET is reached at a lower grasshopper density (ET_1) than would occur during a year with normal precipitation. The cost and sources of forage to replace that destroyed by grasshoppers will also cause the ET to vary from year to year. If the cost of hay or leased grazing land decreases, the ET at which the B/C = 1.0 will shift to the right or to greater grasshopper densities.

Within a given year, variation in the productivity of rangeland results in a different ET for each range-type. The mix of cool- and warm-season forages and the emergence and maturing of grasshoppers relative to the growth of grasses also causes variation between sites. Further, the species mix of grasshoppers between grass feeders and mixed-forage feeders results in between-site variation in the grasshopper density at which the ET is reached. The ET is quite sensitive to the species composition of grasshoppers so it becomes very important to identify the species of grasshoppers present in the nymphal survey (fig. VI.4–3).

The ET is a dynamic number which changes from year to year and place to place. The conditions may be such that a given grasshopper density is sufficient to reach the ET one year; conditions may have changed by the next year to where that density of grasshoppers does not meet the ET. The ET also can be expected to be different among each of the range types represented in Hopper.

Figure VI.4–3—Monitoring and identifying grasshopper populations while the insects are in the nymph (young) stage allows pest managers to make timely decisions. Knowing species composition is important for calculating the economic threshold. (APHIS photo by Mike Sampson.)

VI.5 Field Guide to Common Western Grasshoppers

R. Nelson Foster and Mike W. Sampson

For many years, personnel who deal with survey and control of grasshoppers have voiced the need for a practical and comprehensive grasshopper identification and informational field guide. Numerous taxonomic keys exist, but most generally are designed only for adult grasshopper species, are for a single State, and are designed for laboratory use.

A wealth of information on certain grasshopper species can be found in the literature; however, information on many other species is scarce. When information does exist, it is scattered throughout numerous scientific journals, State and Federal publications, and textbooks.

When the Grasshopper Integrated Pest Management (GHIPM) Project began in 1987, one of the first needs identified by survey and control personnel was a field guide to the grasshopper species most commonly encountered on rangeland. The project asked Robert E. Pfadt, professor emeritus of entomology at the University of Wyoming, to prepare the field guide. Pfadt's grasshopper experience spans more than 50 years and includes more than 50 publications and several books. The general format of the guide was developed by Pfadt and the U.S. Department of Agriculture, Animal and Plant Health Inspection Service's (USDA, APHIS) Phoenix, AZ, Methods Development unit, and GHIPM Project personnel working collaboratively.

The guide was designed around a four-page factsheet on each selected grasshopper species. A shrink-wrapped collection of all the factsheets, grouped under the title "Field Guide to Common Western Grasshoppers," follows this chapter.

Color photographs of grasshoppers in the immature stages, the adult male and female, and the eggs and egg-pod of each species are shown on the inner pages of each factsheet. Here also appear the diagnostic characteristics used to distinguish the identity of the species. The layout is organized so readers can examine all photos and read the diagnostic descriptions without turning any more pages.

Each factsheet contains other important information, such as distribution and habitat, economic importance, food habits, dispersal and migration, hatching, nymphal development, adults and reproduction, population ecology, and daily activities. The information is a collection of existing published information and Pfadt's own personal observances.

Pfadt has color coded the factsheets to educate the user subtly in the taxonomic grouping of the grasshopper species to the subfamily level. The common name, distribution map, and subheadings are green for the slantfaced species (Gomphocerinae), tan for the spurthroated species (Melanoplinae), and blue for the bandwinged species (Oedipodinae). The Mormon cricket, which is really a longhorned grasshopper (Tettigoniidae), is color coded lavender.

Each factsheet is designed as a stand-alone publication so users in different States and regions may organize these field guides in an order most useful for individual needs. The factsheets, following a 41-page introductory publication, presently are arranged alphabetically for easy location of species.

Originally intended to take only 2 years, Pfadt's project eventually expanded to 4 years so he could complete descriptions and photographs of some 40 grasshopper species. Under a cooperative agreement between the GHIPM Project and the University of Wyoming, Pfadt produced his field guide, released as Bulletin 912, in September 1988 with the first four-page species factsheets in color.

Each year since 1988, Pfadt has added additional factsheets to his field guide. Finding all of the instars of some species has meant working in remote locations and being at the mercy of the up's and down's of grasshopper populations. To produce the required photographs of common grasshopper species has been a time-consuming, and sometimes frustrating, endeavor.

In April 1995, Pfadt and the University of Wyoming issued a second edition of Bulletin 912, with more detailed information about grasshopper identification and new and better photographs. The April 1995 revision contains factsheets describing 39 grasshopper species, and Pfadt continues to work on additional factsheets.

During the GHIPM Project, the field guide has become a valuable asset for land managers charged with grasshopper identification. Field guide users now include not only APHIS personnel but also Federal, State, and private land managers, pest control specialists, and scientists.

The knowledge of the most commonly encountered species in each State contained in Pfadt's "Field Guide" will promote a better understanding of grasshopper populations. In turn, that understanding will provide the foundation for making good management and pest-treatment decisions involving rangeland grasshoppers.

Additional free copies of Pfadt's revised "Field Guide to Common Western Grasshoppers" are available on a first-come, first-served basis from USDA, APHIS, Plant Protection and Quarantine; Operational Support Staff; 4700 River Road, Unit 134; Riverdale, MD 20737-1236. You may request a copy by telephone as well (301 734-8247). Once APHIS' supply is exhausted, you may write to the University of Wyoming Bulletin Room, P.O. Box 3313, Laramie, WY 82071-3313 for information on buying the factsheets.

VI.6 Relative Importance of Rangeland Grasshoppers in Western North America: A Numerical Ranking From the Literature

Richard J. Dysart

Introduction

There are about 400 species of grasshoppers found in the 17 Western States (Pfadt 1988). However, only a small percentage of these species ever become abundant enough to cause economic concern. The problem for any rangeland entomologist is how to arrange these species into meaningful groups for purposes of making management decisions. The assessment of the economic status of a particular grasshopper species is difficult because of variations in food availability and host selectivity. Mulkern et al. (1964) reported that the degree of selectivity is inherent in the grasshopper species but the expression of selectivity is determined by the habitat. To add to the complexity, grasshopper preferences may change with plant maturity during the growing season (Fielding and Brusven 1992). Because of their known food habits and capacity for survival, about two dozen grasshopper species generally are considered as pests, and a few other species have been called beneficials (Watts et al. 1989).

Between these extremes are more than 350 grasshopper species that are of little or no economic concern. However, while most species alone never cause serious economic loss, together an assemblage of minor species can inflict serious damage to rangeland. Through the years, the pest grasshoppers have received the greatest attention. Grasshoppers of the family Acrididae surpass all other arthropods in their destructiveness to rangeland (Watts et al. 1982). Although few in number, the pest grasshoppers cause losses to western rangeland estimated at $393 million per year, based on 1977 dollars (Hewitt and Onsager 1983).

Reviewing the Literature

Several authors have made estimates of the relative importance of the major pest grasshoppers on western rangeland, but the work by Hewitt (1977) is probably the most thorough and the most cited. To my knowledge, however, no estimates have been made on the relative importance of the minor, occasional, and nonpest grasshoppers. The purpose of this chapter is to score and rank the western grasshopper species, in terms of relative economic importance, on the basis of remarks made by many grasshopper experts in their reports and publications. It is important to point out that these estimates represent merely the opinions of those involved, not conclusive proof. By including a large number of articles and authors that cover most of the literature on the subject, I hope that the resulting compilation will be a consensus from the literature, without introduction of bias on my part.

This review is restricted to grasshoppers found in 17 Western United States (Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming) plus the 4 western provinces of Canada (Alberta, British Columbia, Manitoba, and Saskatchewan). Furthermore, only grasshoppers belonging to the family Acrididae are included here, even though many research papers reviewed mentioned species from other families of Orthoptera.

In my evaluation, I have emphasized the impact of grasshoppers on rangeland rather than on cropland. In cases where authors made comparative remarks, such as “this species is of major importance to crops, but only of minor importance to range ...,” I used only the rangeland remarks to assign a pest-status category to that species.

For my review of the North American grasshopper literature, I selected only articles in which the authors had grouped or characterized a number of grasshopper species according to their importance. Because of this limitation, several important taxonomic analyses (Brooks 1958, Handford 1946, and Otte 1981 and 1984) could not be used for my purposes.

Pest-Status Categories

Grasshoppers are important herbivores, and any pest classification is based on whether they compete with or benefit human activities. Many articles I reviewed contained proof that a species actually caused measurable injury to rangeland, but many did not. Also, most articles which claimed that certain grasshopper species were beneficial presented no data to support the claim.

In my review, I have used the authors’ remarks regardless of the evidence presented. In most instances, it was not difficult to assign species to one of my pest-status categories because the authors had made clear statements concerning the relative importance of grasshopper species in a study. However, it was sometimes necessary to make an interpretation from somewhat vague statements, such as "... occasionally common on rangeland." After reviewing each article, I translated the authors' remarks on a particular grasshopper species into one of five categories:

Serious pest species (S) Authors usually made clear statements about grasshoppers in this category, such as "... frequently causes major damage to rangeland," or "... one of the 10 most destructive species in our study."

Minor pest species (M) Authors categorized such species with phrases like "... this species occasionally causes injury to forage grasses," or "... populations may require control treatment in specific areas."

Innocuous species (I) Authors' remarks often contained phrases like "... of no economic importance," or "... this species was rarely encountered in the study area." Also, if an author categorized 10 grasshopper species as "serious pests" and another 10 species as "minor pests" but then discussed 10 additional species without mention of economic importance, I classified the latter species as "innocuous."

Possibly beneficial species (b?) In this and the next category I included grasshoppers that feed to some extent on undesirable rangeland plants, such as the perennial snakeweeds *(Gutierrezia* spp.). I also assigned species to the "possibly beneficial" category when the authors' remarks were either uncertain or intentionally ambiguous, for example "... possibly beneficial since it feeds on noxious forbs."

Beneficial species (B) In these cases the author's remarks were clear and unequivocal: "... this grasshopper is a beneficial insect."

Scientific Names

In this chapter, grasshopper names follow the usage recognized by the following sources, by subfamily:
Acridinae—Otte (1981)
Cyrtacanthacridinae—Arnett (1985), Helfer (1987)
Gomphocerinae—Otte (1981)
Melanoplinae—Arnett (1985), Helfer (1987)
Oedipodinae—Otte (1984)
Also the scientific names of all grasshoppers discussed were checked for proper usage by Dan Otte (Academy of Natural Sciences, Philadelphia) while this chapter was still in manuscript form. However, I am responsible for the accuracy of all names as printed here. In general, I have tried not to use names of subspecies, but in several instances that was unavoidable.

My Findings

My review of the literature yielded 69 articles (table VI.6–1) in which the authors provided opinions of the relative pest status for the grasshopper species in their studies. In the articles selected, a total of 377 different grasshopper species were discussed by 77 different authors and coauthors over a period of 70 years (1924–93). When these authors' opinions were translated into my five pest-status categories, there were a total of 2,731 rankings on the 377 species. The 2,731 rankings broke down into the five categories as follows:

	Percent
Serious pest species	17.4
Minor pest species	15.7
Innocuous species	65.7
Possibly beneficial species	0.5
Beneficial species	0.7

The 377 grasshoppers (table VI.6–2) included species in the following five acridid subfamilies: Acridinae (1), Cyrtacanthacridinae (8), Gomphocerinae (63), Melanoplinae (185), and Oedipodinae (120). Also listed in table VI.6–2 are the status category tally counts for each species. In order to make calculations, I assigned points for each status category, as follows:
Serious = +2, Minor = +1, Innocuous = 0, Possibly beneficial = –1, and Beneficial = –2.

The total score for each grasshopper species was calculated by multiplying the category tally count times the respective point values for each pest-status category. The rank number was determined by the magnitude of the total score for each species. In cases of tie scores, the species with the highest frequency of mentions as a "serious" and "minor" pest was given the higher rank.

Table VI.6–1—Summary of pest-status rankings of 377 western rangeland grasshoppers from 69 articles

Literature citation	Geographic region	Number of grasshopper species in each status[1] "S"	"M"	"I"	"b?"	"B"	Total species
Arnett (1985)	17 Western States	10	1	59	0	0	70
Ball (1936)	Arizona	0	0	10	0	13	23
Ball et al. (1942)	Arizona	13	27	99	1	1	141
Banfill and Brusven (1973)	Idaho	3	4	19	0	0	26
Bird (1961)	Western Canada	3	2	0	0	0	5
Brusven (1967)	Kansas	1	6	15	0	0	22
Brusven (1972)	Idaho	4	9	2	1	0	16
Brusven and Lambley (1971)	Idaho	2	13	13	0	0	28
Buckell (1936a)	Western Canada	5	1	0	0	0	6
Buckell (1936b)	Western Canada	6	0	0	0	0	6
Capinera (1987)	17 Western States	25	0	0	0	0	25
Capinera and Sechrist (1982)	Colorado	16	11	99	3	0	129
Capinera and Thompson (1987)	Colorado	2	4	3	0	0	9
Coppock (1962)	Oklahoma	10	5	97	1	0	113
Ewen and Mukerji (1984)	Western Canada	4	0	0	0	0	4
Fielding and Brusven (1990)	Idaho	3	4	0	0	0	7
Gibson (1938)	Western Canada	7	6	0	0	0	13
Hagen (1970)	Nebraska	4	8	62	0	0	74
Harper (1952)	California	4	19	1	0	0	24
Hauke (1953)	Nebraska	8	8	97	0	0	113
Hebard (1936)	North Dakota	6	3	59	0	0	68
Hebard (1938)	Oklahoma	10	15	36	0	0	61
Helfer (1987)	17 Western States	19	16	234	0	0	269
Henderson (1924)	Utah	4	8	26	0	0	38
Henderson (1931)	Utah	6	5	1	0	0	12
Hewitt (1977)	17 Western States	26	0	0	0	0	26
Hewitt and Barr (1967)	Idaho	1	5	30	0	0	36
Hewitt et al. (1974)	17 Western States	26	0	0	0	0	26
Isely (1938)	Texas	2	0	36	0	0	38
Kemp and Dennis (1991)	Montana	6	0	0	0	0	6
Kemp and Onsager (1986)	Montana	6	0	0	0	0	6
Kevan (1979)	Western Canada	5	0	1	0	0	6
Knowlton and Janes (1932)	Utah	6	21	0	0	0	27
La Rivers (1948)	Nevada	4	9	63	0	0	76
Middlekauff (1958)	California	2	2	0	0	0	4
Mitchener (1953)	Manitoba	3	2	0	0	0	5
Mulkern (1980)	North Dakota	2	10	25	0	0	37
Mulkern et al. (1962)	North Dakota	7	0	19	0	0	26
Mulkern et al. (1969)	17 Western States	7	11	40	3	0	61
Nerney (1960)	Arizona	3	1	0	0	0	4

Table VI.6–1—Summary of pest-status rankings of 377 western rangeland grasshoppers from 69 articles (Continued)

Literature citation	Geographic region	Number of grasshopper species in each status[1] "S"	"M"	"I"	"b?"	"B"	Total species
Nerney (1961)	Arizona	2	3	0	0	0	5
Nerney and Hamilton (1969)	Arizona	2	6	0	0	0	8
Newton et al. (1954)	Montana and Wyoming	12	0	52	0	0	64
Parker (1952)	17 Western States	19	3	0	0	0	22
Parker (1957)	17 Western States	3	9	2	0	0	14
Parker and Connin (1964)	17 Western States	3	9	1	0	0	13
Pfadt (1949)	17 Western States	8	2	0	4	0	14
Pfadt (1977)	17 Western States	4	8	15	0	0	27
Pfadt (1982)	Arizona	2	1	14	0	0	17
Pfadt (1984)	Colorado	1	12	11	0	0	24
Pfadt (1988)	17 Western States	13	17	5	0	1	36
Pfadt and Hardy (1987)	17 Western States	13	0	0	0	0	13
Putnam (1962)	British Columbia	2	1	0	0	0	3
Richman et al. (1993)	New Mexico	19	23	122	0	1	165
Scoggan and Brusven (1972)	Idaho	4	12	21	0	0	37
Scoggan and Brusven (1973)	Idaho	1	9	38	0	0	48
Shewchuk and Kerr (1993)	Alberta	3	0	0	0	0	3
Shotwell (1938a)	Northern Great Plains	5	0	4	0	0	9
Shotwell (1938b)	17 Western States	10	16	13	0	0	39
Shotwell (1941)	17 Western States	2	10	0	0	0	12
Strohecker et al. (1968)	California	11	9	146	1	0	167
Turnock (1977)	Western Canada	3	0	0	0	0	3
Van Horn (1972)	Colorado	5	10	19	0	0	34
Vickery and Scudder (1987)	Western Canada	7	3	91	0	0	101
Wakeland (1951)	17 Western States	5	11	0	0	0	16
Watts et al. (1989)	17 Western States	25	0	0	0	2	27
White and Rock (1945)	Alberta	5	5	66	0	0	76
Wilbur and Fritz (1940)	Kansas	4	8	18	0	0	30
Woodruff (1937)	Kansas	0	7	11	0	0	18
Totals		474	430	1,795	14	18	2,731
Percent of total rankings		17.4	15.7	65.7	0.5	0.7	100.0

[1] S = serious, M = minor, I = innocuous, b? = possibly beneficial, B = beneficial.

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks

Grasshopper species	Sub-family[2]	Number of rankings[1] “S”	“M”	“I”	“b?”	“B”	Total	Score	Rank
Acantherus piperatus Scudder & Cockerell	G	0	0	4	0	0	4	0	163
Achurum sumichrasti (Saussure)	G	0	0	5	0	0	5	0	148
Acrolophitus hirtipes (Say)	G	0	0	16	0	0	16	0	113
Acrolophitus maculipennis (Scudder)	G	0	0	5	0	0	5	0	149
Acrolophitus nevadensis (Thomas)	G	0	0	7	0	0	7	0	133
Aeoloplides chenopodii (Bruner)	M	0	0	3	0	1	4	–2	374
Aeoloplides elegans (Scudder)	M	0	0	1	0	0	1	0	264
Aeoloplides fratercula (Hebard)	M	0	0	1	0	0	1	0	265
Aeoloplides fuscipes (Scudder)	M	0	0	1	0	0	1	0	266
Aeoloplides minor (Bruner)	M	0	0	2	0	0	2	0	214
Aeoloplides rotundipennis Wallace	M	0	0	1	0	0	1	0	267
Aeoloplides turnbulli (Caudell)	M	0	3	9	1	0	13	2	65
Aeoloplus californicus Scudder	M	0	0	1	0	0	1	0	268
Aeoloplus tenuipennis (Scudder)	M	0	0	7	0	1	8	–2	368
Aeropedellus clavatus (Thomas)	G	6	2	13	0	0	21	14	32
Ageneotettix brevipennis (Bruner)	G	0	0	1	0	0	1	0	269
Ageneotettix deorum (Scudder)	G	27	7	11	0	0	45	61	5
Ageneotettix salutator (Rehn)	G	0	0	2	0	0	2	0	215
Agnostokasia sublima Gurney & Rentz	M	0	0	2	0	0	2	0	216
Agroecotettix modestus Bruner	M	0	0	2	0	0	2	0	217
Agymnastus ingens (Scudder)	O	0	0	3	0	0	3	0	183
Aidemona azteca Saussure	M	0	0	3	0	0	3	0	184
Amblytropidia mysteca (Saussure)	G	0	0	5	0	0	5	0	150
Amphitornus coloradus (Thomas)	G	18	12	12	0	0	42	48	8
Anconia hebardi Rehn	O	0	0	2	0	0	2	0	218
Anconia integra Scudder	O	0	0	5	0	1	6	–2	370
Argiacris militaris (Scudder)	M	0	0	1	0	0	1	0	270
Argiacris rehni Hebard	M	0	0	2	0	0	2	0	219
Arphia behrensi Saussure	O	0	0	3	0	0	3	0	185
Arphia conspersa Scudder	O	0	2	22	0	0	24	2	66
Arphia pseudonietana (Thomas)	O	1	8	20	0	0	29	10	36
Arphia ramona Rehn	O	0	0	1	0	0	1	0	271
Arphia saussureana Bruner	O	0	0	1	0	0	1	0	272
Arphia simplex Scudder	O	0	0	8	0	0	8	0	128
Arphia sulphurea (Fabricius)	O	0	0	5	0	0	5	0	151
Arphia xanthoptera (Burmeister)	O	0	0	8	0	0	8	0	129
Asemoplus hispidus (Bruner)	M	0	0	1	0	0	1	0	273
Asemoplus montanus (Bruner)	M	0	1	3	0	0	4	1	105
Asemoplus sierranus Hebard	M	0	0	1	0	0	1	0	274
Aulocara elliotti (Thomas)	G	39	7	3	0	0	49	85	2

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Aulocara femoratum (Scudder)	G	12	8	6	0	0	26	32	12
Aztecacris gloriosus (Hebard)	M	0	0	4	0	0	4	0	164
Barytettix cochisei Gurney	M	0	0	1	0	0	1	0	275
Barytettix humphreysii (Thomas)	M	0	0	3	0	0	3	0	186
Booneacris glacialis (Scudder)	M	0	0	2	0	0	2	0	220
Boopedon auriventris McNeill	G	0	0	6	0	0	6	0	142
Boopedon flaviventris (Bruner)	G	2	1	0	0	0	3	5	54
Boopedon gracile Rehn	G	0	0	5	0	0	5	0	152
Boopedon nubilum (Say)	G	4	6	11	0	0	21	14	31
Bootettix argentatus Bruner	G	0	0	6	0	1	7	–2	369
Bradynotes obesa (Thomas)	M	0	1	8	0	0	9	1	91
Buckellacris chilcotinae (Hebard)	M	0	0	1	0	0	1	0	276
Buckellacris hispida (Bruner)	M	0	0	1	0	0	1	0	277
Buckellacris nuda (Walker)	M	0	0	3	0	0	3	0	187
Camnula pellucida (Scudder)	O	35	7	5	0	0	47	77	3
Campylacantha olivacea (Scudder)	M	1	0	9	0	0	10	2	80
Chimarocephala elongata Rentz	O	0	0	1	0	0	1	0	278
Chimarocephala pacifica (Thomas)	O	0	0	3	0	0	3	0	188
Chloealtis abdominalis (Thomas)	G	0	0	9	0	0	9	0	125
Chloealtis aspasma (Rehn & Hebard)	G	0	0	1	0	0	1	0	279
Chloealtis conspersa (Harris)	G	0	0	14	0	0	14	0	116
Chloealtis dianae (Gur., Stro. & Helf.)	G	0	0	2	0	0	2	0	221
Chloealtis gracilis (McNeill)	G	0	0	2	0	0	2	0	222
Chloroplus cactocaetes Hebard	M	0	0	2	0	0	2	0	223
Chorthippus curtipennis (Harris)	G	6	7	15	0	0	28	19	19
Chortophaga mendocino Rentz	O	0	0	1	0	0	1	0	280
Chortophaga viridifasciata (DeGeer)	O	0	3	17	0	0	20	3	58
Chrysochraon petraea (Gur., Stro. & Helf.)	G	0	0	2	0	0	2	0	224
Cibolacris parviceps (Walker)	G	0	0	8	0	0	8	0	130
Cibolacris samalayucae Tinkham	G	0	0	1	0	0	1	0	281
Circotettix carlinianus (Thomas)	O	0	1	13	0	0	14	1	84
Circotettix crotalum Rehn	O	0	0	2	0	0	2	0	225
Circotettix maculatus Scudder	O	0	0	3	0	0	3	0	189
Circotettix rabula Rehn & Hebard	O	0	0	14	0	0	14	0	117
Circotettix shastanus Bruner	O	0	0	2	0	0	2	0	226
Circotettix stenometopus (Stro. & Buxt.)	O	0	0	2	0	0	2	0	227
Circotettix undulatus (Thomas)	O	0	2	9	0	0	11	2	72
Clematodes larreae Scudder	M	0	0	4	0	0	4	0	165
Conalcea huachucana Rehn	M	0	0	3	0	0	3	0	190
Conozoa carinata Rehn	O	0	1	2	0	0	3	1	109

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] “S”	“M”	“I”	“b?”	“B”	Total	Score	Rank
Conozoa hyalina (McNeill)	O	0	0	1	0	0	1	0	282
Conozoa rebellis (Saussure)	O	0	0	4	0	0	4	0	166
Conozoa sulcifrons (Scudder)	O	0	6	10	0	0	16	6	46
Conozoa texana (Bruner)	O	0	0	12	0	0	12	0	121
Cordillacris crenulata (Bruner)	G	4	7	11	0	0	22	15	29
Cordillacris occipitalis (Thomas)	G	13	4	14	0	0	31	30	15
Cratypedes lateritius (Saussure)	O	0	0	6	0	0	6	0	143
Cratypedes neglectus (Thomas)	O	0	5	12	0	0	17	5	51
Dactylotum bicolor pictum (Thomas)	M	0	1	12	0	0	13	1	86
Dactylotum bicolor variegatum (Scudder)	M	0	0	3	0	0	3	0	191
Dendrotettix hesperus (Hebard)	M	0	0	2	0	0	2	0	228
Derotmema delicatulum Scudder	O	0	0	4	0	0	4	0	167
Derotmema haydeni (Thomas)	O	0	1	20	0	0	21	1	83
Derotmema laticinctum Scudder	O	0	0	3	0	0	3	0	192
Derotmema saussureanum Scudder	O	0	0	2	0	0	2	0	229
Dichromorpha elegans (Morse)	G	0	0	1	0	0	1	0	283
Dichromorpha viridis (Scudder)	G	0	0	7	0	0	7	0	134
Dissosteira carolina (Linnaeus)	O	3	11	18	0	0	32	17	24
Dissosteira longipennis (Thomas)	O	8	2	3	0	0	13	18	23
Dissosteira pictipennis Bruner	O	0	2	2	0	0	4	2	75
Dissosteira spurcata Saussure	O	3	8	6	0	0	17	14	30
Encoptolophus californicus (Bruner)	O	0	0	1	0	0	1	0	284
Encoptolophus costalis (Scudder)	O	5	3	7	0	0	15	13	34
Encoptolophus pallidus Bruner	O	0	0	3	0	0	3	0	193
Encoptolophus robustus Rehn & Hebard	O	0	0	1	0	0	1	0	285
Encoptolophus sordidus (Burmeister)	O	2	3	6	0	0	11	7	43
Encoptolophus subgracilis Caudell	O	0	3	6	0	0	9	3	60
Eritettix abortivus (Bruner)	G	0	0	2	0	0	2	0	230
Eritettix simplex (Scudder)	G	7	3	15	0	0	25	17	26
Esselenia vanduzeei Hebard	G	0	1	3	0	0	4	1	106
Eupnigodes megacephala (McNeill)	G	0	1	2	0	0	3	1	110
Eupnigodes sierranus Rehn & Hebard	G	0	0	2	0	0	2	0	231
Hadrotettix magnificus (Rehn)	O	0	0	5	0	0	5	0	153
Hadrotettix trifasciatus (Say)	O	0	3	22	0	0	25	3	57
Hebardacris albida (Hebard)	M	0	0	3	0	0	3	0	194
Hebardacris excelsa (Rehn)	M	0	0	2	0	0	2	0	232
Hebardacris mono Rehn	M	0	0	2	0	0	2	0	233
Heliastus benjamini Caudell	O	0	0	4	0	0	4	0	168
Heliaula rufa (Scudder)	G	0	0	11	0	0	11	0	124
Hesperotettix curtipennis Scudder	M	0	0	1	0	1	2	–2	375

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Hesperotettix nevadensis Morse	M	0	0	1	0	0	1	0	286
Hesperotettix pacificus Scudder	M	0	0	1	0	0	1	0	287
Hesperotettix speciosus (Scudder)	M	1	0	7	2	0	10	0	112
Hesperotettix viridis (Thomas)	M	0	2	17	5	5	29	–13	377
Hippiscus ocelote (Saussure)	O	0	2	12	0	0	14	2	69
Hippopedon capito (Stal)	O	0	0	3	0	0	3	0	195
Hippopedon gracilipes (Caudell)	O	0	0	3	0	0	3	0	196
Horesidotes cinereus Scudder	G	0	0	5	0	0	5	0	154
Hypochlora alba (Dodge)	M	0	0	13	2	1	16	–4	376
Hypsalonia merga Gurney & Buxton	M	0	0	1	0	0	1	0	288
Hypsalonia miwoki Gurney & Eades	M	0	0	1	0	0	1	0	289
Hypsalonia petasata Gurney & Eades	M	0	0	1	0	0	1	0	290
Hypsalonia rentzi Gurney & Eades	M	0	0	1	0	0	1	0	291
Hypsalonia satur (Scudder)	M	0	0	1	0	0	1	0	292
Hypsalonia tioga Gurney & Eades	M	0	0	1	0	0	1	0	293
Karokia blanci (Rehn)	M	0	0	1	0	0	1	0	294
Lactista aztecus (Saussure)	O	0	2	2	0	0	4	2	76
Lactista gibbosus Saussure	O	0	0	3	0	0	3	0	197
Leprus intermedius Saussure	O	0	0	9	0	0	9	0	126
Leprus wheeleri (Thomas)	O	0	1	6	0	0	7	1	97
Leptysma marginicollis (Serville)	M	0	0	6	0	0	6	0	144
Leuronotina ritensis (Rehn)	O	0	0	3	0	0	3	0	198
Ligurotettix coquilletti McNeill	G	0	0	4	0	1	5	–2	372
Ligurotettix planum (Bruner)	G	0	0	2	0	0	2	0	234
Melanoplus ablutus Scudder	M	0	0	1	0	0	1	0	295
Melanoplus alpinus Scudder	M	0	1	7	0	0	8	1	95
Melanoplus angustipennis (Dodge)	M	4	4	12	0	0	20	12	35
Melanoplus aridus (Scudder)	M	0	2	4	0	0	6	2	73
Melanoplus arizonae Scudder	M	0	3	4	0	0	7	3	61
Melanoplus artemesiae (Bruner)	M	0	0	1	0	0	1	0	296
Melanoplus ascensus Scudder	M	0	0	1	0	0	1	0	297
Melanoplus aspasmus Hebard	M	0	0	1	0	0	1	0	298
Melanoplus beameri Hebard	M	0	0	1	0	0	1	0	299
Melanoplus bernardinae Hebard	M	0	0	1	0	0	1	0	300
Melanoplus bispinosus Scudder	M	0	2	3	0	0	5	2	74
Melanoplus bivittatus (Say)	M	2	14	6	0	0	47	68	4
Melanoplus bohemani (Stal)	M	0	0	1	0	0	1	0	301
Melanoplus borealis (Fieber)	M	2	1	8	0	0	11	5	53
Melanoplus bowditchi Scudder	M	1	0	13	1	0	15	1	82
Melanoplus bruneri Scudder	M	3	1	6	0	0	10	7	44

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] “S”	“M”	“I”	“b?”	“B”	Total	Score	Rank
Melanoplus buxtoni Strohecker	M	0	0	1	0	0	1	0	302
Melanoplus caroli Gurney & Helfer	M	0	0	2	0	0	2	0	235
Melanoplus chimariki Gurney & Buxton	M	0	0	1	0	0	1	0	303
Melanoplus chiricahuae Hebard	M	0	0	1	0	0	1	0	304
Melanoplus cinereus Scudder	M	0	1	5	0	0	6	1	99
Melanoplus complanatipes Scudder	M	0	1	5	0	0	6	1	100
Melanoplus confusus Scudder	M	1	4	17	0	0	22	6	48
Melanoplus daemon Strohecker	M	0	0	1	0	0	1	0	305
Melanoplus dawsoni (Scudder)	M	2	5	11	0	0	18	9	39
Melanoplus desultorius Rehn	M	1	0	1	1	1	4	–1	366
Melanoplus devastator Scudder	M	9	1	0	0	0	10	19	20
Melanoplus differentialis (Thomas)	M	13	11	4	0	0	28	37	10
Melanoplus discolor (Scudder)	M	0	0	7	0	0	7	0	135
Melanoplus dodgei (Thomas)	M	0	0	3	0	0	3	0	199
Melanoplus elaphrus Strohecker	M	0	0	1	0	0	1	0	306
Melanoplus elater Strohecker	M	0	0	1	0	0	1	0	307
Melanoplus eremitus Strohecker	M	0	0	1	0	0	1	0	308
Melanoplus fasciatus (Walker)	M	0	0	7	0	0	7	0	136
Melanoplus femurnigrum Scudder	M	0	0	2	0	0	2	0	236
Melanoplus femurrubrum (DeGeer)	M	18	19	3	0	0	40	55	7
Melanoplus flabellatus Scudder	M	0	0	1	0	0	1	0	309
Melanoplus flavidus Scudder	M	0	2	11	0	0	13	2	70
Melanoplus foedus Scudder	M	2	9	13	0	0	24	13	33
Melanoplus franciscanus Scudder	M	0	0	2	0	0	2	0	237
Melanoplus fricki Strohecker	M	0	0	1	0	0	1	0	310
Melanoplus frigidus (Boheman)	M	0	0	1	0	0	1	0	311
Melanoplus fultoni Hebard	M	0	0	1	0	0	1	0	312
Melanoplus gladstoni Scudder	M	8	3	11	1	0	23	18	21
Melanoplus glaucipes (Scudder)	M	0	1	4	0	0	5	1	102
Melanoplus gracilipes Scudder	M	0	0	1	0	0	1	0	313
Melanoplus gracilis (Bruner)	M	0	0	3	0	0	3	0	200
Melanoplus harperi Gurney & Buxton	M	0	0	1	0	0	1	0	314
Melanoplus herbaceus Bruner	M	0	0	5	0	1	6	–2	371
Melanoplus hesperus Hebard	M	0	0	1	0	0	1	0	315
Melanoplus hupah Strohecker & Helfer	M	0	0	1	0	0	1	0	316
Melanoplus huporeus Hebard	M	0	0	1	0	0	1	0	317
Melanoplus huroni Blatchley	M	0	0	5	0	0	5	0	155
Melanoplus immunis Scudder	M	0	0	1	0	0	1	0	318
Melanoplus impudicus Scudder	M	0	0	2	0	0	2	0	238
Melanoplus inconspicuous Caudell	M	0	0	2	0	0	2	0	239

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Melanoplus indigens Scudder	M	0	1	3	0	0	4	1	107
Melanoplus infantilis Scudder	M	12	7	11	0	0	30	31	13
Melanoplus islandicus Blatchley	M	0	0	1	0	0	1	0	319
Melanoplus keeleri (Thomas)	M	0	2	14	0	0	16	2	67
Melanoplus keiferi Gurney & Buxton	M	0	0	1	0	0	1	0	320
Melanoplus kennicotti Scudder	M	0	0	5	0	0	5	0	156
Melanoplus lakinus (Scudder)	M	0	1	7	0	0	8	1	96
Melanoplus lemhiensis Hebard	M	0	0	1	0	0	1	0	321
Melanoplus lepidus Scudder	M	0	0	2	0	0	2	0	240
Melanoplus ligneolus Scudder	M	0	0	1	0	0	1	0	322
Melanoplus lithophilus Gurney & Buxton	M	0	0	1	0	0	1	0	323
Melanoplus magdalenae Hebard	M	0	0	2	0	0	2	0	241
Melanoplus marginatus (Scudder)	M	1	3	0	0	0	4	5	52
Melanoplus microtatus Hebard	M	0	0	1	0	0	1	0	324
Melanoplus montanus (Thomas)	M	0	0	3	0	0	3	0	201
Melanoplus muricolor Strohecker	M	0	0	1	0	0	1	0	325
Melanoplus nanus Scudder	M	0	0	1	0	0	1	0	326
Melanoplus occidentalis (Thomas)	M	7	7	10	0	1	25	19	18
Melanoplus oklahomae Hebard	M	0	0	2	0	0	2	0	242
Melanoplus olamentke Hebard	M	0	0	1	0	0	1	0	327
Melanoplus oregonensis (Thomas)	M	0	0	4	0	0	4	0	169
Melanoplus pacificus (Scudder)	M	0	0	1	0	0	1	0	328
Melanoplus packardii Scudder	M	23	12	5	0	0	40	58	6
Melanoplus payettei Hebard	M	0	0	1	0	0	1	0	329
Melanoplus pictus Scudder	M	0	2	1	0	0	3	2	78
Melanoplus pinaleno Hebard	M	0	0	1	0	0	1	0	330
Melanoplus platycercus Hebard	M	0	0	1	0	0	1	0	331
Melanoplus plebejus (Stal)	M	0	0	3	0	0	3	0	202
Melanoplus ponderosus Scudder	M	0	0	7	0	0	7	0	137
Melanoplus punctulatus (Scudder)	M	0	0	3	0	0	3	0	203
Melanoplus regalis (Dodge)	M	0	0	7	0	0	7	0	138
Melanoplus rileyanus Scudder	M	0	0	2	0	0	2	0	243
Melanoplus rugglesi Gurney	M	5	0	3	0	0	8	10	38
Melanoplus rusticus (Stal)	M	0	0	1	0	0	1	0	332
Melanoplus saltator Scudder	M	0	0	1	0	0	1	0	333
Melanoplus sanguinipes (Fabricius)	M	53	7	1	1	0	62	112	1
Melanoplus scudderi (Uhler)	M	0	0	7	0	0	7	0	139
Melanoplus siskiyou Strohecker	M	0	0	1	0	0	1	0	334
Melanoplus snowii (Scudder)	M	0	0	2	0	0	2	0	244
Melanoplus sonomaensis Caudell	M	0	0	2	0	0	2	0	245

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Melanoplus splendidus Hebard	M	0	0	4	0	0	4	0	170
Melanoplus stonei Rehn	M	0	0	1	0	0	1	0	335
Melanoplus texanus (Scudder)	M	0	0	4	0	0	4	0	171
Melanoplus thomasi Scudder	M	0	2	1	0	0	3	2	79
Melanoplus tristis Bruner	M	0	0	2	0	0	2	0	246
Melanoplus truncatus Scudder	M	0	0	1	0	0	1	0	336
Melanoplus tuberculatus Morse	M	0	0	1	0	0	1	0	337
Melanoplus tunicae Hebard	M	0	0	1	0	0	1	0	338
Melanoplus viridipes Scudder	M	0	0	1	0	0	1	0	339
Melanoplus walshii Scudder	M	0	0	1	0	0	1	0	340
Melanoplus warneri Little	M	0	0	1	0	0	1	0	341
Melanoplus washingtonius (Bruner)	M	0	0	1	0	0	1	0	342
Melanoplus wilsoni Gurney	M	0	0	1	0	0	1	0	343
Melanoplus wintunus Strohecker & Helfer	M	0	0	1	0	0	1	0	344
Melanoplus yarrowii (Thomas)	M	0	4	1	0	0	5	4	55
Mermiria bivittata (Serville)	G	6	12	10	0	0	28	24	17
Mermiria picta (Walker)	G	0	1	8	0	0	9	1	92
Mermiria texana Bruner	G	0	0	6	0	0	6	0	145
Mestobregma impexum Rehn	O	0	0	4	0	0	4	0	172
Mestobregma plattei (Thomas)	O	0	1	8	0	0	9	1	93
Mestobregma terricolor Rehn	O	0	0	3	0	0	3	0	204
Metaleptea brevicornis (Johannson)	A	0	0	2	0	0	2	0	247
Metator nevadensis (Bruner)	O	0	0	5	0	0	5	0	157
Metator pardalinus (Saussure)	O	4	9	15	0	0	28	17	25
Microtes helferi (Strohecker)	O	0	0	3	0	0	3	0	205
Microtes occidentalis (Bruner)	O	0	0	3	0	0	3	0	206
Microtes pogonata (Strohecker)	O	0	0	1	0	0	1	0	345
Netrosoma nigropleura Scudder	M	0	0	1	0	0	1	0	346
Nisquallia olympica Rehn	M	0	0	2	0	0	2	0	248
Oedaleonotus borckii (Stal)	M	0	1	4	0	0	5	1	103
Oedaleonotus enigma (Scudder)	M	7	4	4	0	0	15	18	22
Oedaleonotus orientis Hebard	M	0	0	1	0	0	1	0	347
Oedaleonotus pacificus (Scudder)	M	0	0	1	0	0	1	0	348
Oedaleonotus phryneicus Hebard	M	0	0	1	0	0	1	0	349
Oedaleonotus pictus (Scudder)	M	0	0	1	0	0	1	0	350
Oedaleonotus tenuipennis (Scudder)	M	0	0	1	0	0	1	0	351
Oedomerus corallipes Bruner	M	0	0	1	0	0	1	0	352
Opeia atascosa Hebard	G	0	0	2	0	0	2	0	249
Opeia obscura (Thomas)	G	13	5	11	0	0	29	31	14
Orphulella pelidna (Burmeister)	G	0	3	10	0	0	13	3	59

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1]					Total	Score	Rank
		"S"	"M"	"I"	"b?"	"B"			
Orphulella speciosa (Scudder)	G	3	3	14	0	0	20	9	40
Paraidemona mimica (Scudder)	M	0	0	1	0	0	1	0	353
Paraidemona punctata (Stal)	M	0	0	1	0	0	1	0	354
Paratylotropidia brunneri Scudder	M	0	0	4	0	0	4	0	173
Paratylotropidia morsei Rehn & Rehn	M	0	0	2	0	0	2	0	250
Pardalophora apiculata (Harris)	O	0	0	12	0	0	12	0	122
Pardalophora haldemani (Scudder)	O	0	1	13	0	0	14	1	85
Pardalophora phoenicoptera (Burmeister)	O	0	0	3	0	0	3	0	207
Pardalophora saussurei (Scudder)	O	0	0	5	0	0	5	0	158
Paropomala pallida Bruner	G	0	0	7	0	0	7	0	140
Paropomala virgata (Scudder)	G	0	0	4	0	0	4	0	174
Paropomala wyomingensis (Thomas)	G	1	1	13	0	0	15	3	62
Paroxya atlantica Scudder	M	0	0	2	0	0	2	0	251
Paroxya clavuliger (Serville)	M	0	0	1	0	0	1	0	355
Phaedrotettix dumicola palmeri (Scudder)	M	0	0	1	0	0	1	0	356
Phaulotettix compressus Scudder	M	0	0	1	0	0	1	0	357
Phaulotettix eurycercus Hebard	M	0	0	1	0	0	1	0	358
Phlibostroma quadrimaculatum (Thomas)	G	13	11	6	0	0	30	37	9
Phoetaliotes nebrascensis (Thomas)	M	8	11	10	0	0	29	27	16
Poecilotettix longipennis (Townsend)	M	0	0	1	0	0	1	0	359
Poecilotettix pantherinus (Walker)	M	0	0	4	0	1	5	–2	373
Poecilotettix sanguineus Scudder	M	0	0	4	0	0	4	0	175
Prorocorypha snowi Rehn	M	0	0	3	0	0	3	0	208
Prumnacris rainierensis (Caudell)	M	0	0	2	0	0	2	0	252
Pseudopomala brachyptera (Scudder)	G	0	0	15	0	0	15	0	114
Psinidia amplicornis Caudell	O	0	0	1	0	0	1	0	360
Psinidia fenestralis (Serville)	O	0	0	3	0	0	3	0	209
Psoloessa delicatula (Scudder)	G	1	4	20	0	0	25	6	47
Psoloessa texana Scudder	G	1	1	8	0	0	10	3	63
Rhammatocerus viatorius (Saussure)	G	0	0	3	0	0	3	0	210
Schistocerca alutacea albolineata (Thomas)	C	0	1	4	0	0	5	1	104
Schistocerca alutacea rubiginosa (Harris)	C	0	0	1	0	0	1	0	361
Schistocerca alutacea shoshone (Thomas)	C	2	6	3	0	0	11	10	37
Schistocerca americana (Drury)	C	2	2	5	0	0	9	6	50
Schistocerca damnifica (Saussure)	C	0	0	2	0	0	2	0	253
Schistocerca emarginata Scudder	C	1	4	11	0	0	16	6	49
Schistocerca nitens (Thunberg)	C	2	4	1	0	1	8	6	45
Schistocerca obscura (Fabricius)	C	0	0	5	0	0	5	0	159
Shotwellia isleta Gurney	O	0	0	3	0	0	3	0	211
Spharagemon bolli Scudder	O	0	0	7	0	0	7	0	141

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Spharagemon campestris (McNeill)	O	0	0	15	0	0	15	0	115
Spharagemon collare (Scudder)	O	1	5	20	0	0	26	7	42
Spharagemon cristatum (Scudder)	O	0	0	2	0	0	2	0	254
Spharagemon equale (Say)	O	0	7	17	0	0	24	7	41
Spharagemon superbum Hebard	O	0	0	2	0	0	2	0	255
Stenobothrus brunneus Thomas	G	1	1	7	0	0	9	3	64
Stenobothrus shastanus (Scudder)	G	0	2	2	0	0	4	2	77
Stethophyma gracile (Scudder)	G	0	0	6	0	0	6	0	146
Stethophyma lineata (Scudder)	G	0	0	4	0	0	4	0	176
Sticthippus californicus (Scudder)	O	1	2	2	0	0	5	4	56
Syrbula admirabilis (Uhler)	G	0	1	10	0	0	11	1	88
Syrbula montezuma (Saussure)	G	0	1	3	0	0	4	1	108
Tomonotus ferruginosus Bruner	O	0	0	4	0	0	4	0	177
Trachyrhachys aspera Scudder	O	0	1	5	0	0	6	1	101
Trachyrhachys coronata Scudder	O	0	0	4	0	0	4	0	178
Trachyrhachys kiowa (Thomas)	O	13	10	13	0	0	36	36	11
Trepidulus hyalinus (Scudder)	O	0	0	2	0	0	2	0	256
Trepidulus rosaceus (Scudder)	O	0	0	5	0	0	5	0	160
Trimerotropis agrestis McNeill	O	0	0	13	0	0	13	0	118
Trimerotropis albescens McNeill	O	0	0	3	0	0	3	0	212
Trimerotropis arenacea Rehn	O	0	0	6	0	0	6	0	147
Trimerotropis arizonensis Tinkham	O	0	0	2	0	0	2	0	257
Trimerotropis barnumi Tinkham	O	0	0	2	0	0	2	0	258
Trimerotropis bifaciata Bruner	O	0	1	1	0	0	2	1	111
Trimerotropis californica Bruner	O	0	1	10	0	0	11	1	89
Trimerotropis cincta (Thomas)	O	0	0	9	0	0	9	0	127
Trimerotropis cyaneipennis Bruner	O	0	1	9	0	0	10	1	90
Trimerotropis diversellus Hebard	O	0	0	1	0	0	1	0	362
Trimerotropis fontana Thomas	O	0	2	10	0	0	12	2	71
Trimerotropis fratercula McNeill	O	0	0	4	0	0	4	0	179
Trimerotropis gracilis (Thomas)	O	0	1	11	0	0	12	1	87
Trimerotropis inconspicua Bruner	O	0	0	8	0	0	8	0	131
Trimerotropis koebelei (Bruner)	O	0	0	3	0	0	3	0	213
Trimerotropis latifasciata Scudder	O	0	2	13	0	0	15	2	68
Trimerotropis maritima (Harris)	O	0	1	8	0	0	9	1	94
Trimerotropis melanoptera McNeill	O	0	0	4	0	0	4	0	180
Trimerotropis modesta Bruner	O	0	0	4	0	0	4	0	181
Trimerotropis occidentalis (Bruner)	O	0	0	2	0	0	2	0	259
Trimerotropis pacifica Bruner	O	0	0	2	0	0	2	0	260
Trimerotropis pallidipennis (Burmeister)	O	1	13	9	0	0	23	15	27

Table VI.6–2—Alphabetical list of 377 western rangeland grasshoppers with pest-status scores and ranks (Continued)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Trimerotropis pistrinaria Saussure	O	0	0	13	0	0	13	0	119
Trimerotropis pseudofasciata Scudder	O	0	1	6	0	0	7	1	98
Trimerotropis salina McNeill	O	0	0	4	0	0	4	0	182
Trimerotropis saxatilis McNeill	O	0	0	2	0	0	2	0	261
Trimerotropis sparsa (Thomas)	O	0	0	13	0	0	13	0	120
Trimerotropis thalassica Bruner	O	0	0	2	0	0	2	0	262
Trimerotropis titusi Caudell	O	0	0	1	0	0	1	0	363
Trimerotropis tolteca (Saussure)	O	0	0	1	0	0	1	0	364
Trimerotropis verruculata (Kirby)	O	1	0	5	0	0	6	2	81
Trimerotropis verruculata suffusa Scudder	O	0	0	12	0	0	12	0	123
Tropidolophus formosus (Say)	O	0	0	9	0	1	10	–2	367
Xanthippus aquilonius Otte	O	0	0	1	0	0	1	0	365
Xanthippus corallipes (Haldeman)	O	3	9	17	0	0	29	15	28
Xanthippus montanus (Thomas)	O	0	0	8	0	0	8	0	132
Xanthippus olancha (Caudell)	O	0	0	2	0	0	2	0	263
Xeracris minimus (Scudder)	G	0	0	5	0	0	5	0	161
Xeracris snowi (Caudell)	G	0	0	5	0	0	5	0	162

[1] S = serious, M = minor, I = innocuous, b? = possibly beneficial, B = beneficial.
[2] A = Acridinae, C = Cyrtacanthacridinae, G = Gomphocerinae, M = Melanoplinae, O = Oedipodinae.

Each of the 377 species is represented (in order of overall score and rank) in the bar graph shown in figure VI.6–1. From left to right, it displays 111 grasshopper species with scores above zero ("pests"), 254 species with a score of zero ("innocuous"), and 12 species with scores below zero ("possibly beneficial" or "beneficial").

Pest Species.—A total of 114 different grasshoppers were categorized as either a serious or a minor pest in at least one paper, but only 111 species had total scores above zero. In table VI.6–3, I have listed 38 of the highest ranked "pest" species, those with scores of 10 and above. As expected, the migratory grasshopper *(Melanoplus sanguinipes)* was ranked as the number 1 pest, with the highest total score (112 points) of the 377 grasshopper species.

Innocuous Species.—There were 254 grasshopper species with a total score of zero. Within this group, higher rank numbers were assigned to species having the highest frequency of mention. Several species, including *Acrolophitus hirtipes, Pseudopomala brachyptera,* and *Spharagemon campestris,* were mentioned frequently but were never described as either a pest or a beneficial. For innocuous species with only a single ranking, the rank number has no significance; it was assigned due to the alphabetical arrangement of scientific names.

Beneficial Species.—Overall, 19 different grasshoppers were categorized by at least one author as either beneficial or possibly beneficial, but only 12 species had total scores below zero. The highest ranked "beneficial" grasshoppers are listed in table VI.6–4. Although 12 spe-

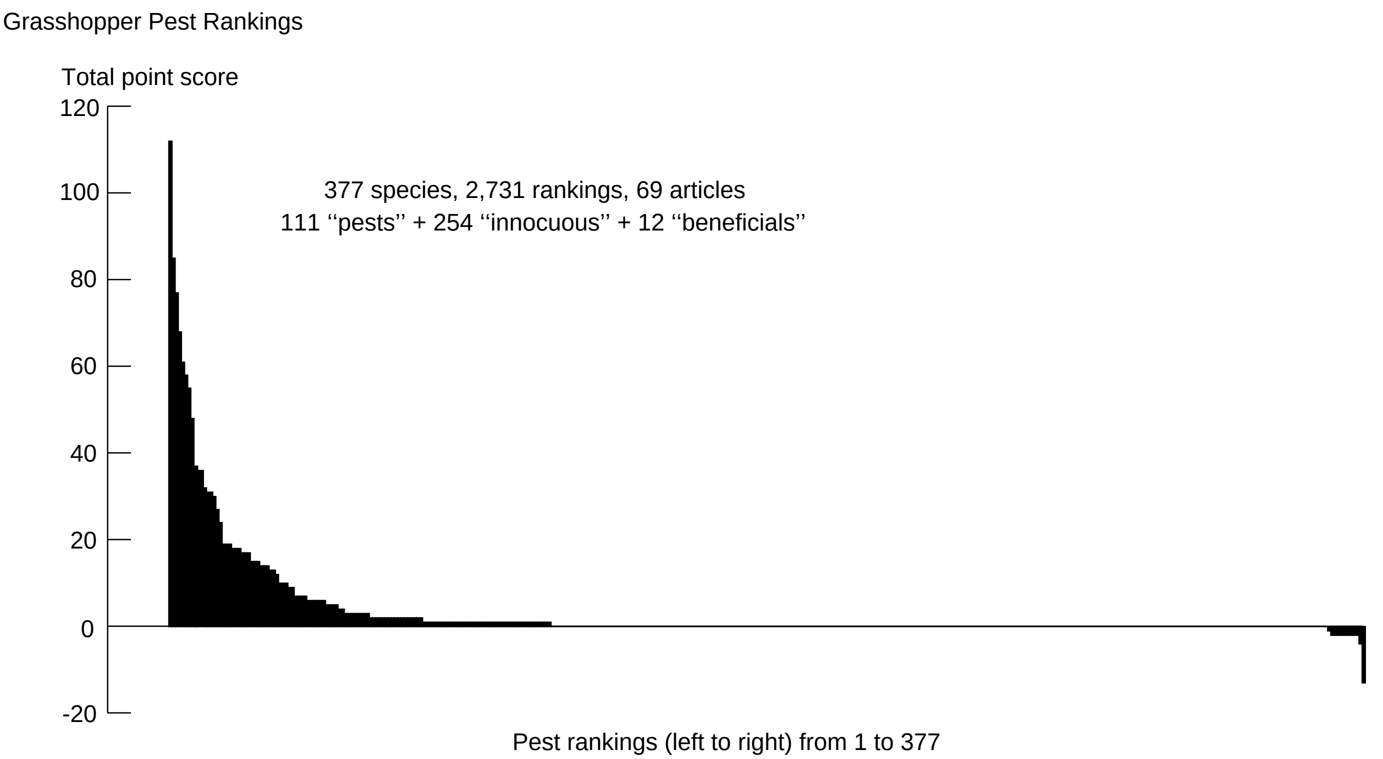


Figure VI.6–1—Graphic display of total scores of 377 western range grasshoppers arranged (left to right) by pest-status rank number. Graph is plotted from data shown in table VI.6–2.

cies were scored as “beneficial,” only 2 were mentioned as such with any frequency: *Hesperotettix viridis* Thomas, a grasshopper commonly associated with snakeweed *(Gutierrezia* spp.), and *Hypochlora alba* Dodge, which prefers to feed on sagebrush *(Artemisia* spp.).

Conclusions

In his 1977 review, Hewitt divided the western rangelands into three different regions: Great Plains, Intermountain, and Pacific Coastal. The literature I reviewed covered a cross section of these same regions, but the reader should be aware that not all of the 377 grasshoppers listed here are common to all regions. Indeed, one limitation of my scoring scheme is that widespread species are cited more frequently and thus accumulate higher total scores than species with a more restricted distribution. A serious pest that occurs in a small geographic area would not be such a pest in the big picture. Three such species, listed in table VI.6–3, are *Dissosteira longipennis, Melanoplus devastator,* and *Oedaleonotus enigma.*

The graph in figure VI.6–1 offers a view of the whole spectrum of western grasshoppers and should provide some perspective when evaluating their relative importance as pests and as beneficials. From the graph it seems clear that nearly one-third (111) of the western grasshopper species are at least occasionally classified as pests. Again I must stress that damage to rangeland is rarely caused by only a single pest species but usually by an assemblage of several grasshopper species.

About two-thirds (254) of the western grasshoppers are thought to be of no economic importance, and only 12 species are considered to be of possible benefit to the

Table VI.6–3 —List of the 38 most serious “pest” grasshoppers on western rangeland (those listed have scores of 10 and above)

Grasshopper species	Sub-family[2]	Number of rankings[1]					Total	Score	Rank
		“S”	“M”	“I”	“b?”	“B”			
Melanoplus sanguinipes (Fabricius)	M	53	7	1	1	0	62	112	1
Aulocara elliotti (Thomas)	G	39	7	3	0	0	49	85	2
Camnula pellucida (Scudder)	O	35	7	5	0	0	47	77	3
Melanoplus bivittatus (Say)	M	27	14	6	0	0	47	68	4
Ageneotettix deorum (Scudder)	G	27	7	11	0	0	45	61	5
Melanoplus packardii Scudder	M	23	12	5	0	0	40	58	6
Melanoplus femurrubrum (DeGeer)	M	18	19	3	0	0	40	55	7
Amphitornus coloradus (Thomas)	G	18	12	12	0	0	42	48	8
Phlibostroma quadrimaculatum (Thomas)	G	13	11	6	0	0	30	37	9
Melanoplus differentialis (Thomas)	M	13	11	4	0	0	28	37	10
Trachyrhachys kiowa (Thomas)	O	13	10	13	0	0	36	36	11
Aulocara femoratum (Scudder)	G	12	8	6	0	0	26	32	12
Melanoplus infantilis Scudder	M	12	7	11	0	0	30	31	13
Opeia obscura (Thomas)	G	13	5	11	0	0	29	31	14
Cordillacris occipitalis (Thomas)	G	13	4	14	0	0	31	30	15
Phoetaliotes nebrascensis (Thomas)	M	8	11	10	0	0	29	27	16
Mermiria bivittata (Serville)	G	6	12	10	0	0	28	24	17
Melanoplus occidentalis (Thomas)	M	7	7	10	0	1	25	19	18
Chorthippus curtipennis (Harris)	G	6	7	15	0	0	28	19	19
Melanoplus devastator Scudder	M	9	1	0	0	0	10	19	20
Melanoplus gladstoni Scudder	M	8	3	11	1	0	23	18	21
Oedaleonotus enigma (Scudder)	M	7	4	4	0	0	15	18	22
Dissosteira longipennis (Thomas)	O	8	2	3	0	0	13	18	23
Dissosteira carolina (Linnaeus)	O	3	11	18	0	0	32	17	24
Metator pardalinus (Saussure)	O	4	9	15	0	0	28	17	25
Eritettix simplex (Scudder)	G	7	3	15	0	0	25	17	26
Trimerotropis pallidipennis (Burmeister)	O	1	13	9	0	0	23	15	27
Xanthippus corallipes (Haldeman)	O	3	9	17	0	0	29	15	28
Cordillacris crenulata (Bruner)	G	4	7	11	0	0	22	15	29
Dissosteira spurcata Saussure	O	3	8	6	0	0	17	14	30
Boopedon nubilum (Say)	G	4	6	11	0	0	21	14	31
Aeropedellus clavatus (Thomas)	G	6	2	13	0	0	21	14	32
Melanoplus foedus Scudder	M	2	9	13	0	0	24	13	33
Encoptolophus costalis (Scudder)	O	5	3	7	0	0	15	13	34
Melanoplus angustipennis (Dodge)	M	4	4	12	0	0	20	12	35
Arphia pseudonietana (Thomas)	O	1	8	20	0	0	29	10	36
Schistocerca alutacea shoshone (Thomas)	C	2	6	3	0	0	11	10	37
Melanoplus rugglesi Gurney	M	5	0	3	0	0	8	10	38

[1] S = serious, M = minor, I = innocuous, b? = possibly beneficial, B = beneficial.
[2] G = Gomphocerinae, M = Melanoplinae, O = Oedipodinae.

Table VI.6–4 —List of the 12 highest ranked "beneficial" grasshoppers on western rangeland (those listed all have scores below zero)

Grasshopper species	Sub-family[2]	Number of rankings[1] "S"	"M"	"I"	"b?"	"B"	Total	Score	Rank
Hesperotettix viridis (Thomas)	M	0	2	17	5	5	29	–13	377
Hypochlora alba (Dodge)	M	0	0	13	2	1	16	–4	376
Hesperotettix curtipennis Scudder	M	0	0	1	0	1	2	–2	375
Aeoloplides chenopodii (Bruner)	M	0	0	3	0	1	4	–2	374
Poecilotettix pantherinus (Walker)	M	0	0	4	0	1	5	–2	373
Ligurotettix coquilletti McNeill	G	0	0	4	0	1	5	–2	372
Melanoplus herbaceus Bruner	M	0	0	5	0	1	6	–2	371
Anconia integra Scudder	O	0	0	5	0	1	6	–2	370
Bootettix argentatus Bruner	G	0	0	6	0	1	7	–2	369
Aeoloplus tenuipennis (Scudder)	M	0	0	7	0	1	8	–2	368
Tropidolophus formosus (Say)	O	0	0	9	0	1	10	–2	367
Melanoplus desultorius Rehn	M	1	0	1	1	1	4	–1	366

[1] S = serious, M = minor, I = innocuous, b? = possibly beneficial, B = beneficial.
[2] G = Gomphocerinae, M = Melanoplinae, O = Oedipodinae.

rangeland. This small number of "beneficial" grasshoppers, amounts to only 3 percent of the 377 species involved in this review, which is several orders of magnitude less than the recent estimate of 10 percent claimed by Lockwood (1993). The grasshopper most frequently called a beneficial is *Hesperotettix viridis.* Although often seen feeding on snakeweed, it also feeds on more than 30 other rangeland plants (Pfadt 1988). Another grasshopper, *Hypochlora alba,* is highly ranked as a beneficial because of its preference for sagebrush. But the value of sagebrush on rangeland is widely debated. As a strong competitor with desirable forage plants for domestic livestock, it is considered by some as an undesirable weed. Others consider sagebrush a beneficial plant because it comprises an important portion of the diet of mule deer, antelope, and the sage grouse (Watts et al. 1982).

Concerning the relative importance of the major pest grasshoppers, I believe that the rankings shown in table VI.6–3 represent a good concensus of opinions from the North American literature. Although experts differ over the ranking of individual species, most agree that there are about 2 dozen western grasshoppers that should be categorized as pests. I believe that a statement by Watts et al. (1989) summarized the pest issue quite well: "About a dozen species frequently occur in high densities, and . . . an additional 12 species occasionally occur in high densities." Readers are free to compare their own opinions with the species listed and the pest-status rankings shown.

References Cited

Arnett, R. H. 1985. Orthoptera (grasshoppers, crickets, and katydids), Order 11. In: American insects, a handbook of the insects of America north of Mexico. New York: Van Nostrand Reinhold: 116–138.

Ball, E. D. 1936. Food plants of some Arizona grasshoppers. Journal of Economic Entomology 29: 679–684.

Ball, E. D.; Tinkham, E. R.; Flock, R.; Vorhies, C. T. 1942. The grasshoppers and other Orthoptera of Arizona. Tech. Bull. 93. Tucson, AZ: Arizona Agricultural Experiment Station. 373 p.

Banfill, J. C.; Brusven, M. A. 1973. Food habits and ecology of grasshoppers in the Seven Devils Mountains and Salmon River breaks of Idaho. Melanderia 12: 1–21.

Bird, R. D. 1961. Ecology of the aspen parkland of western Canada in relation to land use. Res. Branch Publ. 1066. Ottawa, ON: Canada Department of Agriculture: 89–92.

Brooks, A. R. 1958. Acridoidea of southern Alberta, Saskatchewan, and Manitoba (Orthoptera). Canadian Entomologist 90, Suppl. 9: 1–92.

Brusven, M. A. 1967. Differentiation, ecology and distribution of immature slant-faced grasshoppers (Acridinae) in Kansas. Tech. Bull. 1490. Manhattan, KS: Kansas Agricultural Experiment Station: 1–59.

Brusven, M. A. 1972. Differentiation and ecology of common Catantopinae and Cyrtacanthacridinae nymphs (Orthoptera: Acrididae) of Idaho and adjacent areas. Melanderia 9: 1–31.

Brusven, M. A.; Lambley, J. D. 1971. Part I. The food habits and ecology of grasshoppers from southern Idaho rangeland. Coop. Proj. Rep. 12-14-100-9726 (33). Moscow, ID: University of Idaho and U.S. Department of Agriculture. 85 p., 46 tables.

Buckell, E. R. 1936a. Part 1. The influence of man on the distribution of grasshoppers in Canada. In: Proceedings of the 4th international locust conference, anti-locust research; March, 1936; Cairo, Egypt. [Place of publication and publisher unknown.] Appendix 12: 1–7.

Buckell, E. R. 1936b. Part 3. Summary of losses and expenditures due to grasshoppers in Canada 1925–1934. In: Proceedings of the 4th international locust conference, anti-locust research; March, 1936; Cairo, Egypt. [Place of publication and publisher unknown.] Appendix 1: 1–13.

Capinera, J. L. 1987. Population ecology of rangeland grasshoppers. In: Capinera, J. L., ed. Integrated pest management on rangeland: a shortgrass prairie perspective. Boulder, CO: Westview Press: 162–182.

Capinera, J. L.; Sechrist, T. S. 1982. Grasshoppers (Acrididae) of Colorado: identification, biology and management. Bull. 584S. Fort Collins, CO: Colorado State University and Colorado Agricultural Experiment Station. 161 p.

Capinera, J. L.; Thompson, D. C. 1987. Dynamics and structure of grasshopper assemblages in shortgrass prairie. Canadian Entomologist 119: 567–575.

Coppock, S. 1962. The grasshoppers of Oklahoma (Orthoptera: Acrididae). Processed Ser. P-399. Stillwater, OK: Oklahoma Agricultural Experiment Station. 143 p.

Ewen, A. B., Mukerji, M. K. 1984. *Melanoplus* spp., *Camnula pellucida* (Scudder), and other grasshoppers (Orthoptera: Acrididae). In: Kelleher, J. S.; Hulme, M. A., eds. Biological control programs against insects and weeds in Canada 1969–1980. Slough, UK: Commonwealth Agricultural Bureaux: 61–62.

Fielding, D. J.; Brusven, M. A. 1990. Historical analysis of grasshopper (Orthoptera: Acrididae) population responses to climate in southern Idaho. Environmental Entomology 19: 1786–1791.

Fielding, D. J.; Brusven, M. A. 1992. Food and habitat preferences of *Melanoplus sanguinipes* and *Aulocara elliotti* (Orthoptera: Acrididae) disturbed rangeland in southern Idaho. Journal of Economic Entomology 85: 783–788.

Gibson, A. 1938. Report on the grasshopper situation and organization for grasshopper control in Canada, Rep. 4. In: Proceedings of the 5th international locust conference, anti-locust research; [dates of meeting unknown]; Brussels, Belgium. [Place of publication and publisher unknown]: 10–107.

Hagen, A. F. 1970. An annotated list of grasshoppers (Orthoptera, Acrididae) from the eleven panhandle counties of Nebraska. Res. Bull. 238. Lincoln, NE: Nebraska Agricultural Experiment Station. 60 p.

Handford, R. H. 1946. The identification of nymphs of the genus *Melanoplus* of Manitoba and adjacent areas. Scientific Agriculture 26(4): 147–180.

Harper, R. W. 1952. Grasshoppers of economic importance in California. Sacramento, CA: California Department of Agriculture Bulletin 41(3): 153–175.

Hauke, H. A. 1953. An annotated list of the Orthoptera of Nebraska, part II, the Tettigidae and Acrididae. Lincoln, NE: Bulletin of the University of Nebraska State Museum 3(9): 1–79.

Hebard, M. 1936. Orthoptera of North Dakota. Tech. Bull. 284. Fargo, ND: North Dakota Agricultural Experiment Station. 69 p.

Hebard, M. 1938. An ecological survey of the Orthoptera of Oklahoma. Tech. Bull. 5. Stillwater, OK: Oklahoma Agricultural Experiment Station. 31 p.

Helfer, J. R. 1987. How to know the grasshoppers, crickets, cockroaches and their allies, 2d edition. New York: Dover. 363 p.

Henderson, W. W. 1924. A taxonomic and ecological study of the species of the subfamily Oedipodinae (Orthoptera—Acrididae) in Utah. Bull. 191. Logan, UT: Utah Agricultural Experiment Station. 150 p.

Henderson, W. W. 1931. Crickets and grasshoppers in Utah. Circ. 96. Logan, UT: Utah Agricultural Experiment Station. 38 p.

Hewitt, G. B. 1977. Review of forage losses caused by rangeland grasshoppers. Misc. Publ. 1348. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 24 p.

Hewitt, G. B.; Barr, W. F. 1967. The banded-wing grasshoppers of Idaho (Orthoptera: Oedipodinae). Res. Bull. 72. Moscow, ID: University of Idaho and Idaho Agricultural Experiment Station. 64 p.

Hewitt, G. B.; Onsager, J. A. 1983. Control of grasshoppers on rangeland in the United States—a perspective. Journal of Range Management 36: 202–207.

Hewitt, G. B.; Huddleston, E. W.; Lavigne, R. J.; Ueckert, D. N.; Watts. J. G. 1974. Rangeland entomology. Range Sci. Ser. 2. Denver, CO: Society for Range Management. 99 p.

Isely, F. B. 1938. The relations of Texas Acrididae to plants and soils. Ecolological Monographs 8(4): 551–604.

Kemp, W. P.; Dennis, B. 1991. Toward a general model of rangeland grasshopper (Orthoptera: Acrididae) phenology in the steppe region of Montana. Environmental Entomology 20: 1504–1515.

Kemp, W. P.; Onsager, J. A. 1986. Rangeland grasshoppers (Orthoptera: Acrididae): modeling phenology of natural populations of six species. Environmental Entomology 15: 924–930.

Kevan, D.K.McE. 1979. Orthoptera (s. str.). In: Danks, H. V., ed. Canada and its insect fauna. Memoirs Entomol. Soc. Can. 108. Ottawa, ON: Entomological Society of Canada: 321–323.

Knowlton, G. F.; Janes, M. F. 1932. The 1931 grasshopper outbreak in Utah. Proceedings of the Utah Academy of Science 9: 105–108.

La Rivers, Ira. 1948. A synopsis of Nevada Orthoptera. American Midland Naturalist 39(3): 652–720.

Lockwood, J. A. 1993. Environmental issues involved in biological control of rangeland grasshoppers (Orthoptera: Acrididae) with exotic agents. Environmental Entomology 22: 503–518.

Middlekauff, W. W. 1958. Biology and ecology of several species of California rangeland grasshoppers (Orthoptera: Acrididae). Pan-Pacific Entomologist 34: 1–11.

Mitchener, A. V. 1953. A history of grasshopper outbreaks and their control in Manitoba, 1799–1953. Ann. Rep. 84. Ottawa, ON: Entomological Society of Ontario: 27–35.

Mulkern, G. B. 1980. Population fluctuations and competitive relationships grasshopper species (Orthoptera: Acrididae). Transactions of the American Entomological Society 106: 1–41.

Mulkern, G. B; Anderson, J. F.; Brusven, M. A. 1962. Biology and ecology of North Dakota grasshoppers. I. Food habits and preferences of grasshoppers associated with alfalfa fields. Res. Rep. 7. Fargo, ND: North Dakota Agricultural Experiment Station. 26 p.

Mulkern, G. B.; Toczek, D. R.; Brusven, M. A. 1964. Biology and ecology of North Dakota grasshoppers. II. Food habits and preferences of grasshoppers associated with the sandhills prairie. Res. Rep. 11. Fargo, ND: North Dakota Agricultural Experiment Station. 59 p.

Mulkern, G. B.; Pruess, K. P.; Knutson, H.; Hagen, A. F.; Campbell, J. B.; Lambley, J. D. 1969. Food habits and preferences of grassland grasshoppers of the North Central Great Plains. Bull. 481. Fargo, ND: North Dakota Agricultural Experiment Station. 32 p.

Nerney, N. J. 1960. Grasshopper damage on short-grass rangeland of the San Carlos Apache Indian Reservation, Arizona. Journal of Economic Entomology 53: 640–646.

Nerney, N. J. 1961. Effects of seasonal rainfall on range condition and grasshopper population, San Carlos Apache Indian Reservation, Arizona. Journal of Economic Entomology 54: 382–385.

Nerney, N. J.; Hamilton, A. G. 1969. Effects of rainfall on range forage and populations of grasshoppers, San Carlos Apache Indian Reservation, Arizona. Journal of Economic Entomology 62: 329–333.

Newton, R. C.; Esselbaugh, C. O.; York, G. T.; Prescott, H. W. 1954. Seasonal development of range grasshoppers as related to control. Rep. E-873. Billings, MT: U.S. Department of Agriculture, Agricultural Research Service, Bureau of Entomology and Plant Quarantine. 18 p.

Otte, D. 1981. The North American grasshoppers. Vol. I. Acrididae: Gomphocerinae and Acridinae. Cambridge, MA: Harvard University Press. 275 p.

Otte, D. 1984. The North American grasshoppers. Vol. II. Acrididae: Oedipodinae. Cambridge, MA: Harvard University Press. 366 p.

Parker, J. R. 1952. Grasshoppers. In: Insects, the yearbook of agriculture 1952. Washington, DC: U.S. Department of Agriculture: 595–605.

Parker, J. R. 1957. Grasshoppers, a new look at an ancient enemy. Farm. Bull. 2064. Washington, DC: U.S. Department of Agriculture. 40 p.

Parker, J. R.; Connin, R. V. 1964. Grasshoppers, their habits and damage. Agric. Inf. Bull. 287. Washington, DC: U.S. Department of Agriculture. 28 p.

Pfadt, R. E. 1949. Range grasshoppers as an economic factor in the production of livestock. Wyoming Range Management 7: 1–7.

Pfadt, R. E. 1977. Some aspects of the ecology of grasshopper populations inhabiting the shortgrass plains. In: Kulman, H. M.; Chiang, H. C., eds. Insect ecology. Tech. Bull. 310. St. Paul, MN: University of Minnesota and Minnesota Agricultural Experiment Station: 77–79.

Pfadt, R. E. 1982. Density and diversity of grasshoppers (Orthoptera: Acrididae) in an outbreak on Arizona rangeland. Environmental Entomology 11: 690–694.

Pfadt, R. E. 1984. Species richness, density, and diversity of grasshoppers (Orthoptera: Acrididae) in a habitat of the mixed grass prairie. Canadian Entomologist 116: 703–709.

Pfadt, R. E. 1988. Field guide to common western grasshoppers. Bull. 912. Laramie, WY: University of Wyoming and Wyoming Agricultural Experiment Station. [Species factsheets nos. 1–37, dated through Sept. 1993.]

Pfadt, R. E.; Hardy, D. M. 1987. A historical look at rangeland grasshoppers and the value of grasshopper control programs. In: Capinera, J. L., ed. Integrated pest management on rangeland: a shortgrass prairie perspective. Boulder, CO: Westview Press: 162–182.

Putnam, L. G. 1962. The damage potential of some grasshoppers (Orthoptera: Acrididae) of the native grasslands of British Columbia. Canadian Journal of Plant Science 42: 596–601.

Richman, D. B.; Lightfoot, D. C.; Sutherland, C. A.; Ferguson, D. J. 1993. A manual of the grasshoppers of New Mexico, Orthoptera: Acrididae and Romaleidae. Handbk. 7. Las Cruces, NM: New Mexico State University and New Mexico Cooperative Extension Service. 112 p.

Scoggan, A. C.; Brusven, M. A. 1972. Differentiation and ecology of common immature Gomphocerinae and Oedipodinae (Orthoptera: Acrididae) of Idaho and adjacent areas. Melanderia 8: 1–76.

Scoggan, A. C.; Brusven; M. A. 1973. Grasshopper—plant community associations in Idaho in relation to the natural and altered environment. Melanderia 12: 22–33.

Shewchuk, B. A.; Kerr, W. A. 1993. Returns to grasshopper control on rangelands in southern Alberta. Journal of Range Management 46(5): 458–462.

Shotwell, R. L. 1938a. Some problems of the annual grasshopper survey. Journal of Economic Entomology 31: 523–533.

Shotwell, R. L. 1938b. Species and distribution of grasshoppers responsible for recent outbreaks. Journal of Economic Entomology 31: 602–610.

Shotwell, R. L. 1941. Life histories and habits of some grasshoppers of economic importance on the Great Plains. Tech. Bull. 774. Washington, DC: U.S. Department of Agriculture. 47 p.

Strohecker, H. F.; Middlekauff, W. W.; Rentz, D. C. 1968. The grasshoppers of California (Orthoptera: Acridoidea). Bull. 10. Berkeley, CA: California Insect Survey. 177 p.

Turnock, W. J. 1977. Adaptability and stability of insect pest populations in prairie agricultural ecosystems. In: Kulman, H. M.; Chiang, H. C., eds. Insect ecology. Tech. Bull. 310. St. Paul, MN: University of Minnesota and Minnesota Agricultural Experiment Station: 89–101.

Van Horn, D. H. 1972. Grasshopper population numbers and biomass dynamics on the Pawnee site from fall of 1968 through 1970. Tech. Rep. 148. Colorado Springs, CO: U.S. International Biological Program, Grassland Biome. 70 p.

Vickery, V. R.; Scudder, G.G.E. 1987. The Canadian orthopteroid insects summarized and updated, including a tabular check-list and ecological notes. Proceedings of the Entomological Society of Ontario 118: 25–45.

Wakeland, C. 1951. Changing problems and procedures in grasshopper and Mormon cricket control. Journal of Economic Entomology 44: 76–82.

Watts, J. G.; Hewitt, G. B.; Huddleston, E. W.; Kinzer, H. G.; Lavigne, R. J.; Ueckert, D. N. 1989. Rangeland entomology, 2d edition. Range Sci. Ser. 2. Denver, CO: Society for Range Management. 388 p.

Watts, J. G.; Huddleston, E. W.; Owens, J. C. 1982. Rangeland entomology. Annual Review of Entomology 27: 283–311.

White, R. M.; Rock, P.J.G. 1945. A contribution to the knowledge of the Acrididae of Alberta. Scientific Agriculture 25: 577–596.

Wilbur, D. A.; Fritz, R. F. 1940. Grasshopper populations (Orthoptera, Acrididae) of typical pastures in the bluestem region of Kansas. Journal of the Kansas Entomological Society 13: 86–100.

Woodruff, L. C. 1937. A grasshopper survey for eastern Kansas, 1936. Journal of the Kansas Entomological Society 10: 75–83.

VI.7 Hopper Helper

By Wendal Cushing

Preface

This reference was developed as a resource for personnel after years of observing them struggle to identify the life stages and species of grasshoppers while in the field. Although many resource tools are available, they often are too technical or too bulky to be used in survey operations.

Data for this reference were based on studies done in the Grasshopper Integrated Pest Management (GHIPM) Project demonstration area in McKenzie County, ND. Pocket Hopper Helper, which fits in a shirt pocket, provides necessary information about grasshoppers that will aid the user in identifying different species found in southwestern North Dakota and on western rangelands.

Acknowledgments

The production of Pocket Hopper Helper and Hopper Helper has entailed the efforts and expertise of many coworkers. I wish to acknowledge their valued contributions which made this publication possible.

In particular, I wish to thank three employees of the Animal and Plant Health Inspection Service's (APHIS) Plant Protection and Quarantine (PPQ) Phoenix Methods Development Center: Nelson Foster, for facilitating the production of this aid to be used in conjunction with factsheets for field identification of common grasshoppers; K. Chris Reuter, who provided assistance with identification characters of immature and adult grasshoppers and review of the manuscript; and Lonnie Black, who prepared final drawings from my originals and representative specimens of individual species.

Introduction

Hopper Helper provides field personnel with an easy-to-use guide for survey operations. Data gained through direct observation in field operations in southwestern North Dakota provided the basis for this guide. Please observe the following seven additional facts in applying this field guide:

1. The data in the Seasonal Life History Chart (see next chapter) are based on each instar stage, which lasts about 7 days. In other words, it takes about 35 days, from the day it hatches, for the average grasshopper to become an adult. Changing weather conditions can lengthen or shorten this process.

2. When applying the Seasonal Life History Chart to your operation, for every 100 miles south of latitude 47°46'N (Watford City, ND), instar stages will be ahead of schedule by about 7 days (one instar stage).

3. To improve readability, words and symbols used to represent approximate size are defined as:
   Small = approximately 11 mm.
   Average = approximately 22 mm.
   Large = approximately 33 mm.
   Robust = approximately 44 mm.

   G, M, and F indicate preferred food sources for grasshoppers. A "G" appearing next to a grasshopper's name indicates the species' preferred food is grass. "M" stands for mixed food sources (grass and forbs). "F" stands for forbs.

   * = the particular characteristic mentioned is the primary identification characteristic of the grasshopper species.

4. For quick reference, all grasshopper species are numbered 1–44.

5. To make the most effective use of this guide, become familiar with the external morphological structures (physical characteristics) most often used in identification.

6. To make full use of the color description in this outline, use fresh specimens when possible.

7. Have available a copy of Robert Pfadt's "Field Guide to Common Western Grasshoppers."

Physical Characteristics Used To Identify Grasshoppers

The following drawings are useful in pinpointing physical characteristics (morphology) of nymphal and adult grasshoppers. Learning the morphology of grasshoppers will speed identification in the field.

Figure A—Lateral view of an adult female.

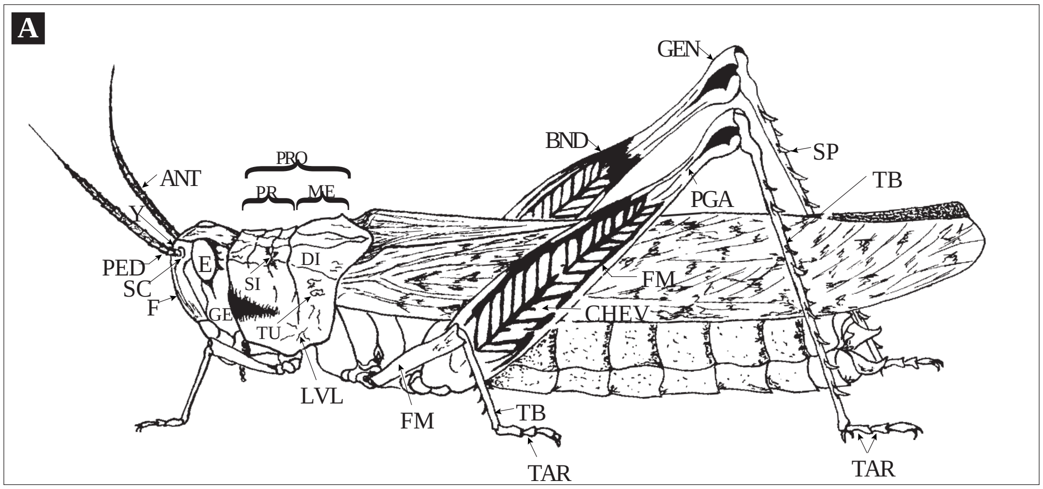


Figure B—Anterior view of head of adult female.

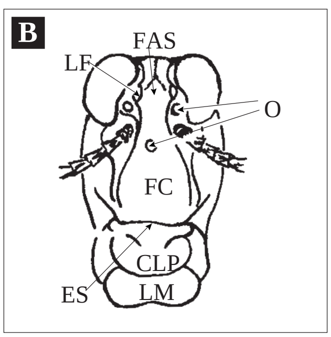
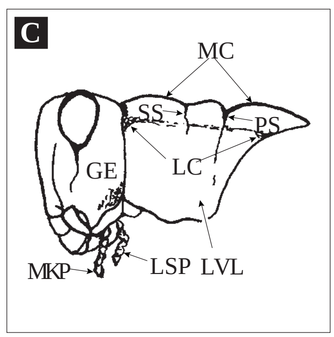


Figure C—Lateral view of head and pronotum of adult female.

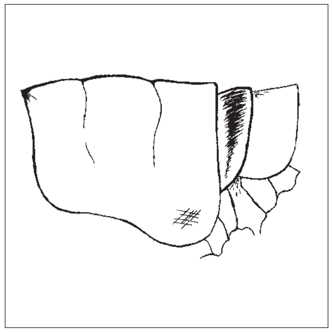


*ANT	Antenna	GEN	Genicular area	*PR	Prozona
*BND	Band	LSP	Labial palpus	*PRO	Pronotum
CHEV	Chevrons	LM	Labrum	*PS	Primary sulcus
CLP	Clypeus	*LC	Lateral carina	SC	Scape
DI	Disk of pronotum	*LF	Lateral foveolae	SCU	Scutellum
*E	Compound eye	*LVL	Lateral ventral lobe of pronotum	Si	Sinus
ES	Epistomal suture	*MC	Median carina	SP	Spines
*F	Frons	*ME	Metazona	SS	Secondary sulcus
FAS	Fastigium	MKP	Maxillary palpus	TAR	Tarsus
*FC	Frontal costa	O	Ocelli	*TB	Tibia
*FM	Femur	PED	Pedicel	*TU	Tubercule
*GE	Gena	PGA	Pregenicular area	V	Vertex

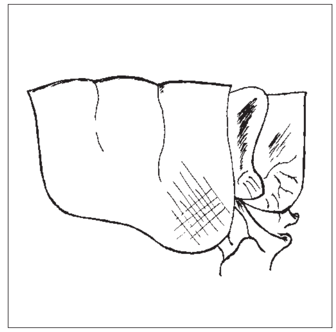
* = characteristics most used in identification.

Key to Normal Nymphal Instars

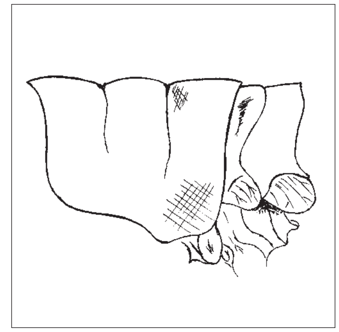
(From Handford 1946)



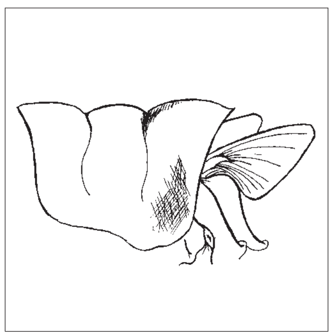
Wing pads rounded with no visible bulge at apex ..... first instar



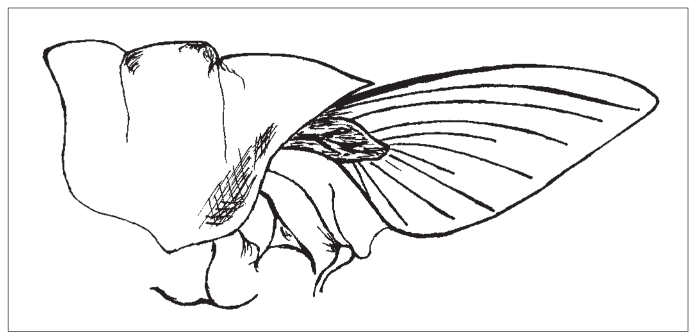
Wing pads rounded with visible bulge at apex ..... second instar



Wing pads more sharply triangular and showing slight venation ..... third instar



Wing pads short, not extending beyond first abdominal segment, more truncated ..... fourth instar



Wing pads elongated, extending beyond the second but hardly beyond the third abdominal segment, more pointed at the apex ..... fifth instar

Several of the adult grasshoppers possess wings that are not of the typical form and are sometimes confused with the wing pads of immatures. Examples of some short-winged species are shown below.

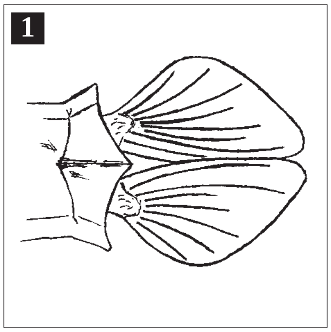


Figure 1—Immature wing pads.

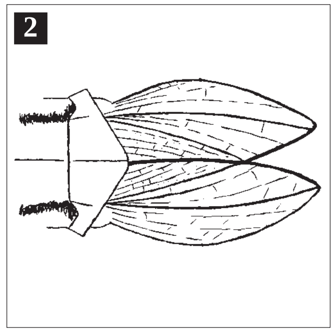


Figure 2—
Hypochlora alba
Melanoplus dawsoni
Phoetaliotes nebrascensis
Both sexes

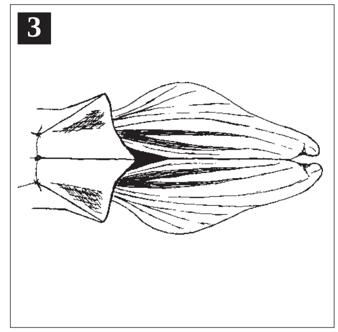


Figure 3—*Aeropedellus clavatus*
Females only

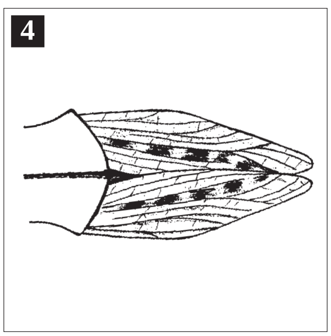


Figure 4—*Boopedon nubilum*
Females only

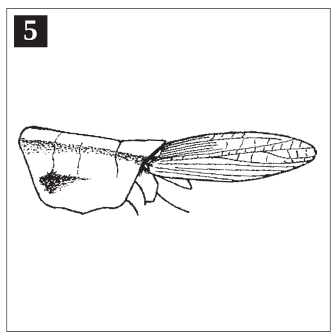


Figure 5—*Pseudopomala brachyptera*
Both sexes

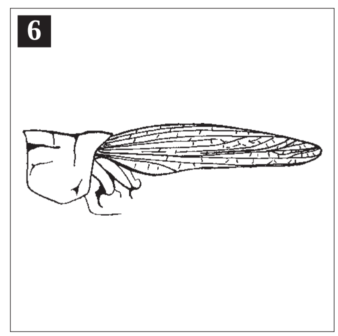


Figure 6—*Chorthippus curtipennis*
Females only

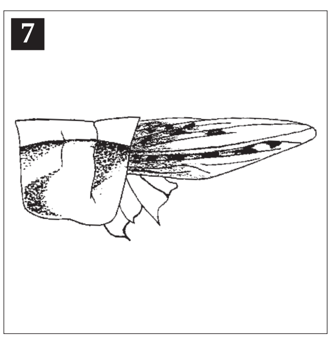


Figure 7—*Chloealtis conspersa*
Females only

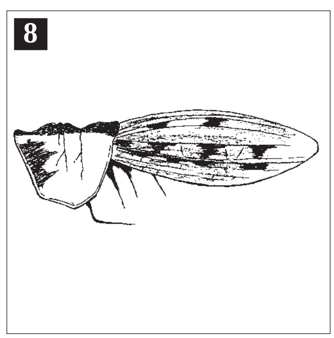
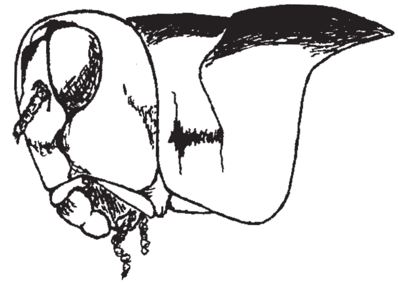


Figure 8—*Oedaleonotus enigma*
Both short- and long-winged forms are common in both sexes.

Overwintering Species

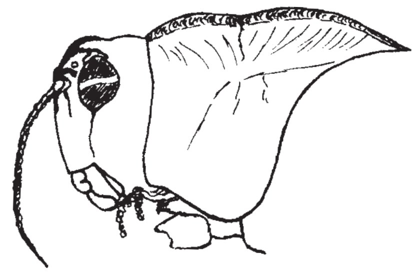
(To be adults at spring greenup.)

Arphia conspersa *1–G*



Adult: A large brown grasshopper with red or yellow wings. Lower abdomen and hind tibia yellowish. This species often will flush before you get close enough to catch them in a net.
Immature: Usually dark brown and having many of the adult morphological characteristics, *two light bands on inner face of femur.

Chortophaga viridifasciata *2–G*



Adult: A large grasshopper with smoke-colored wings, greenish-yellow at base. Color usually green, antennae red with the pronotum slightly arched. *A visible band through the compound eye.
Immature: Body color may range from green to brown speckled with white, but the median carina is always high and sharp. First instars usually appear near mid-July.

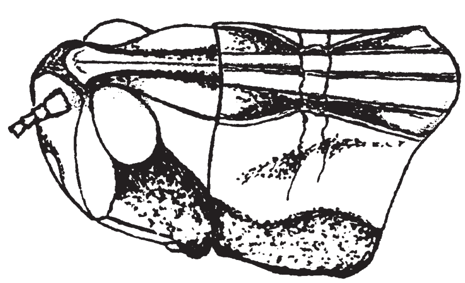
Pardalophora haldemanii *3–G*

Adult: A large, robust grasshopper with one sulcus cutting the pronotum. *Inner surface of the hind femora usually a greenish yellow. Dark spots on forewing, rough pronotum.
Immature: Later instars are large with one sulcus cutting the pronotum. Very similar to *Xanthippus*, can have two sulci on pronotum.

Xanthippus corallipes *4–G*

Adult: A large, robust grasshopper with *two sulci cutting the pronotum. Inner surface of the hind femora and tibiae a bright reddish pink. Dark spots on forewing, rough pronotum.
Immature: Overwinter in the later instar stages. *Usually dark blue on inner femur in first four instars, becoming more reddish pink instars five and six. A slight “X” is sometimes visible on the dorsal area of the pronotum. First instars appear in early July.

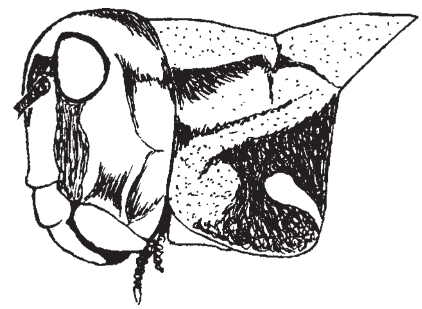
Eritettix simplex *5–G*



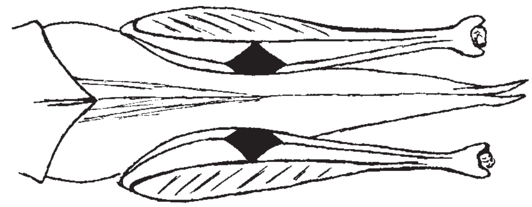
Adult: An average-sized grasshopper. Colors range from a bright green to a light tan. Adults normally begin to appear in early May. *Adults and immatures share tricarinate feature on head and pronotum.
Immature: Apparently overwinter in the fourth and fifth instar stage and can be found from fall to early spring. First instars usually appear around the first week of July.

Psoloessa delicatula ***6–G***

Adult: A small, drab grasshopper with a *diamond visible on the hind femora. Posterior dorsal area of pronotum very flat. Lateral carinae strongly constricted in the middle for immatures and adults.



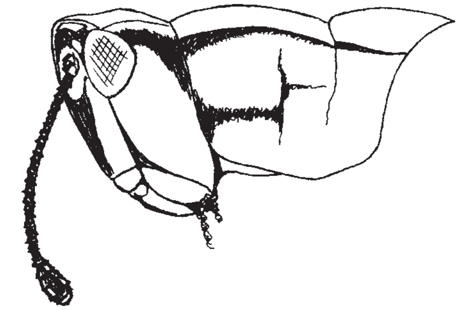
Immature: Color somewhat darker than *Eritettix* sp. with an evident white mark on the pronotum. Face not as slanted as *Eritettix* sp. First instars usually appear around the first week of July. Diamond on hind femora often visible in immatures.



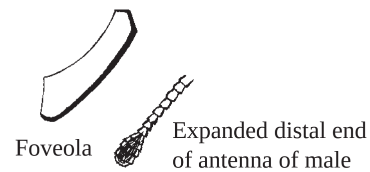
Early-Hatching Species

Aeropedellus clavatus *7–G*

Adult: Females have short wings, white cheeks, and a line ahead of the eye. The drawing shows an early summer adult. The lateral carinae constrict near the middle.

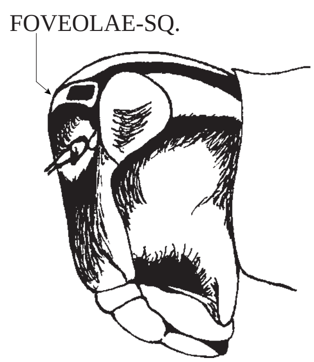


Immature: Lateral foveolae evident in all instars. First instars usually appear by the first week of June.

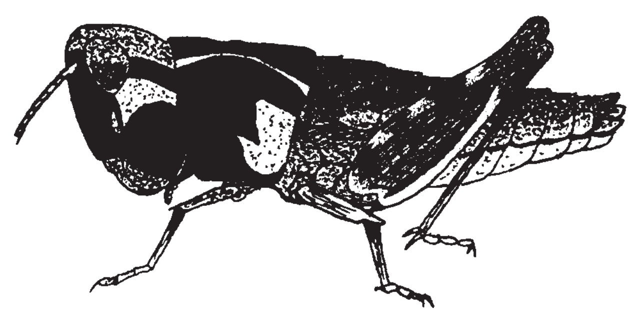


Ageneotettix deorum *8–G*

Adult: *Face usually dark, body color speckled, knee black with an orange tibia. Dorsal pronotum with an hourglass shape. *Whitish antennae while grasshopper is alive. Foveolae appear almost square. Inner hind tarsal claw unusually long.

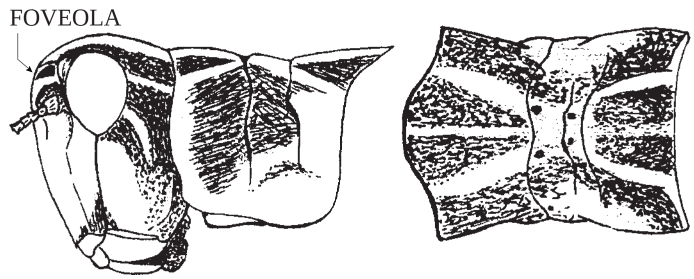


Immature: Face usually dark with lateral foveolae evident. First instars usually appear by mid-May.

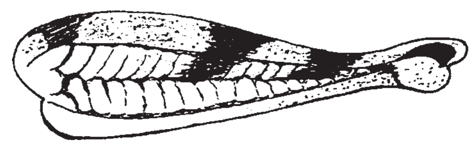


Aulocara elliotti *9–G*

Adult: *Banding of the inner surface of hind femora and "X" mark on the top of the pronotum. Lateral foveolae usually teardrop shaped or triangular.



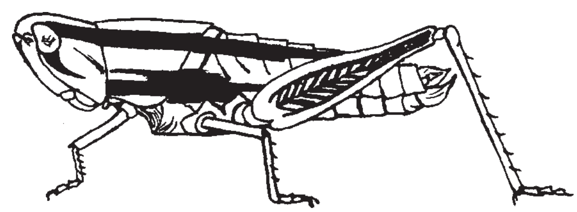
Immature: Banding of the inner surface femora. Lateral foveolae evident. First instars usually appear by the second week in May.



Amphitornus coloradus *10–G*

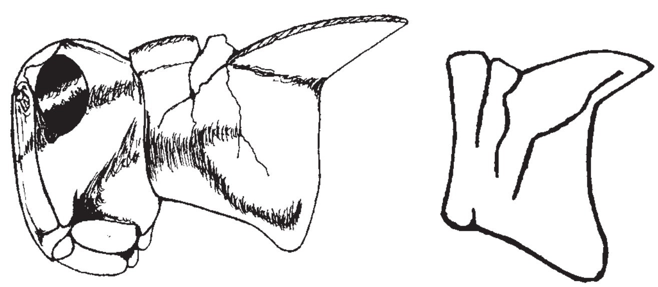
Adult: *Pair of brown stripes running from the head to the end of the pronotum. Hind femora with very visible bands on the outer surface and having a blue tibia.

Immature: A small version of the adult. First instars normally appear by mid-May.

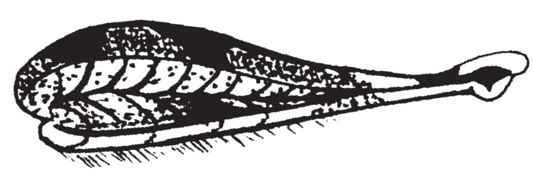


Trachyrhachys kiowa *11–G*

Adult: *A small- to medium-sized grasshopper with bands on the forewing. Banding on the inner surface of femora and having a blue tibia. *Rough pronotum with a lateral ventral flange.

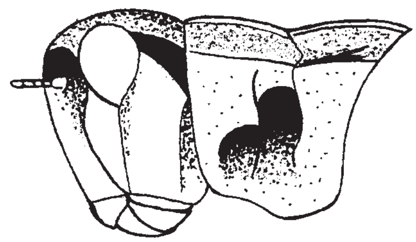


Immature: Body size small and stout. Pronotum rough and the lower hind femora is hirsute (hairy). First instars normally appear by late May.

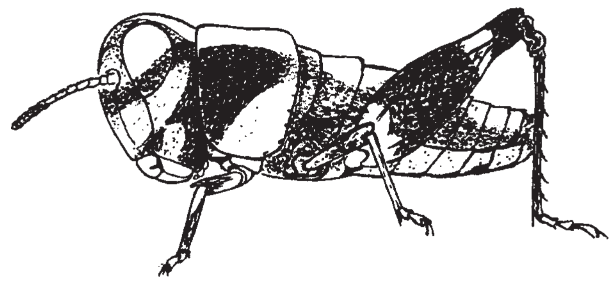


Camnula pellucida *12-G*

Adult: Both sexes a straw yellow. Lateral carina continuous to posterior end of the pronotum. Spotted forewing and clear hindwings. *Population usually found in hatching beds, hay yards, etc. *Continuous lateral carina.



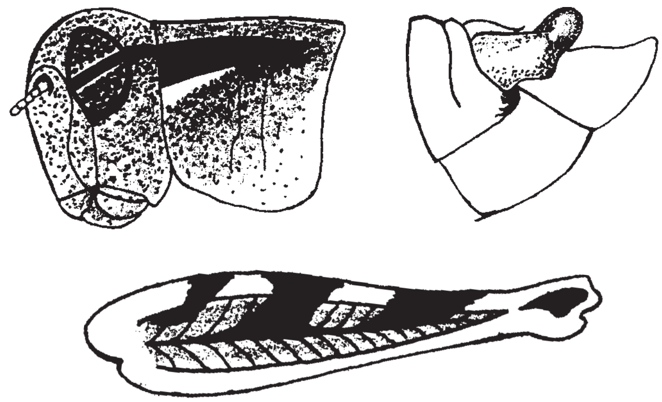
Immature: First instars distinctive with a tan saddle. All later instars have a tan color. First instars normally appear by mid-May.



Problem *Melanoplus* Species

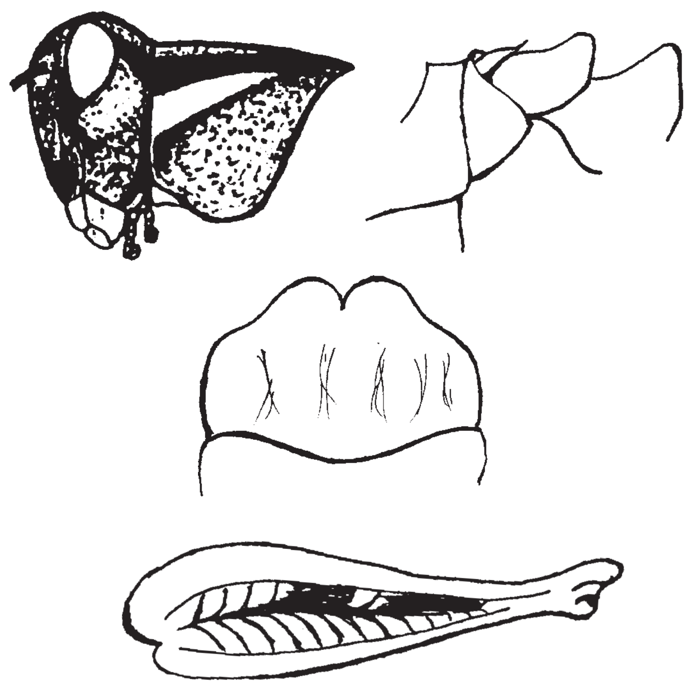
Melanoplus confusus *13-G*

Adult: *Side of pronotum with a patent leather shine and a definite line through the eye.
Immature: *Diagonal dark stripe bordered by narrow light lines through the eye. Cercus evident in later instars. First instars usually appear by early May.



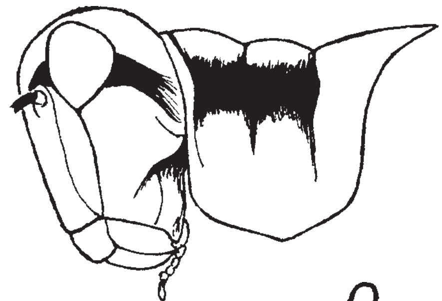
Melanoplus sanguinipes *14-F*

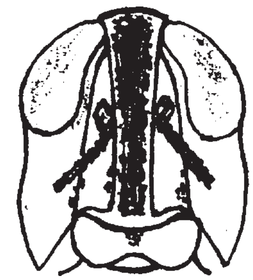
Adult: *Distinctive hump between the second pair of legs in males. The male subgenital plate distinctive.
Immature: First instars usually appear in late May, about 2 weeks later than *M. confusus.* *Early instars have speckled appearance.

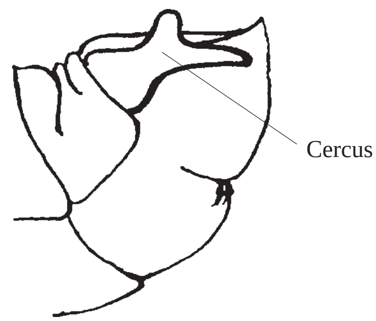


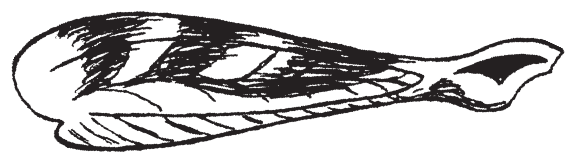
Melanoplus infantilis *15–G*

Adult: *Size small with a beelike striping on the abdomen. *Frontal costa dark, sometimes with spots along the margins. The cheek area is usually cream-colored. Most are adults by the end of June. Cercus boot shaped.
Immature: First instars usually appear by mid-May.









Melanoplus gladstoni *16–M*

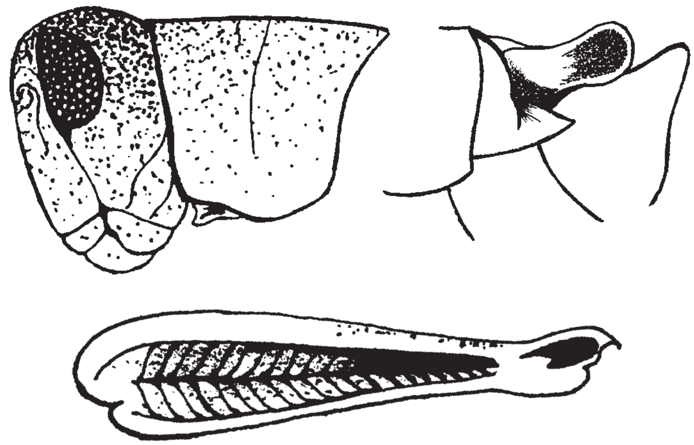
Adult: *Hind femora banding. *Hind femora flattened below base.
Immature: Look much like *M. infantilis* except *gladstoni* are usually adults by the end of June. This species lacks the frontal costal spots but has a very "dark" clypeus.

Dorsal view

Outer face

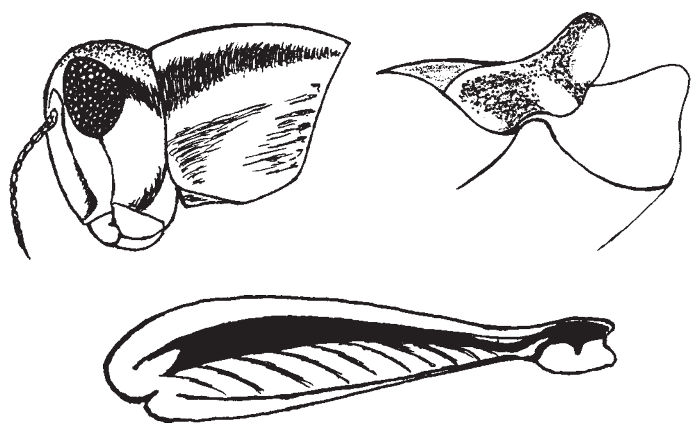
Melanoplus packardii *17–M*

Adult: Most resemble *M. bivittatus* but are smaller. *Two light stripes down the pronotum.
Immature: *Generally tan or green and covered with brown spots over the whole body.



Melanoplus bivittatus *18–M*

Adult: *Compound eye uniformly spotted. *Two clear yellow stripes from the head to the wing tips. Size large. Color usually an olive green with yellow.
Immature: *Bright green or tan is the general body color. The definite black band on the femur and large size usually aid in this species' identification. First instars usually appear by mid-May.



Melanoplus femurrubrum *19–M*

Adult: *Black band on outer face of femur. A pronounced crest and usually a large cream-colored cheek. Strongly contrasting black and white color is similar to *M. dawsoni.* *Underside of abdomen and inner surface of femur bright yellow with red tibia. Tip of male abdomen swollen.
Immature: First instars usually appear by early June.

Melanoplus dawsoni *20–M*

Adult: *General body color a shiny patent leather look.

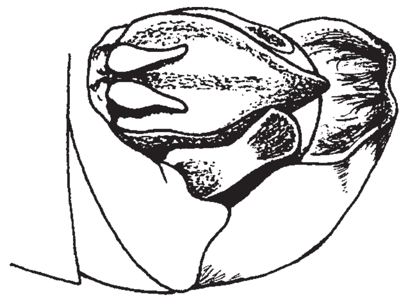
Compound eye with up to 10 white spots. *Both sexes usually have reduced wings. See fig. 2 on p. 4, description of wings. Underside bright yellow.
Immature: First instars usually appear by early July.

Melanoplus keeleri *21–G*

Adult: Hind femora yellow below. Hind tibia red with a black spot or band at its base.
Immature: *Two distinct white lines running parallel through the compound eye. *Large cream-colored area covers the cheek and extends to cover the whole side of the pronotum (pattern may vary). First instars usually appear by mid-June.

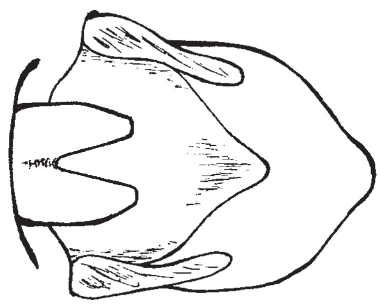
Intermediate-Hatching Species

Melanoplus angustipennis *22-G*



Adult: Markings inconspicuous. It may look much like the *M. sanguinipes* male except for the cercus and furcula. *This species is associated with sandy or "blow out" (windswept) land. No noticeable femoral markings. Cercus spoon shaped.
Immature: Tan or green with fine brown spots over most of the body. No banding evident on the outer femur.

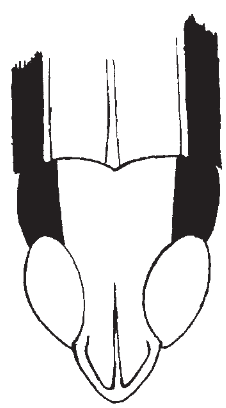
Melanoplus bowditchi *23–F*

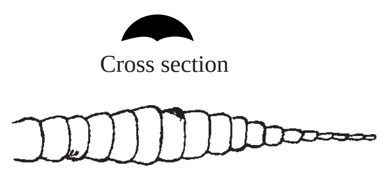


Adult: Markings inconspicuous. Body color usually a brownish olive with a spattering of brown. *Associated with sagebrush or near the base of steep eroded banks. *No noticeable femoral markings.
Immature: Pale gray with dark markings and generally a speckled appearance.

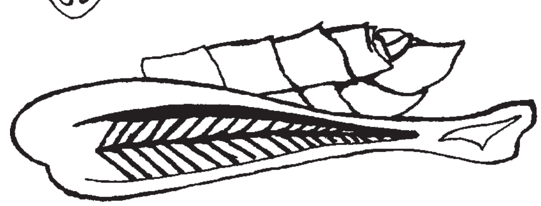
Opeia obscura *24–G*

Adult: Females larger than males. Size small to average. Parallel lateral carina evident. Forewing usually with some green. Forewing with a dark longitudinal stripe. Below the stripe there is a white line in the marginal field. Antennae triangular in cross section, swordshaped (ensiform).





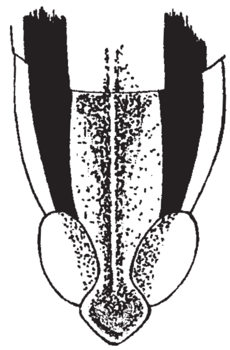
Immature: Resembles *Amphitornus* sp. except without external bands on the hind femora, and does not have brown stripes above eyes. *Hind femora long.

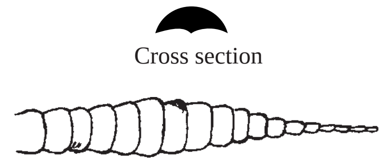


Mermiria bivittata *25–G*

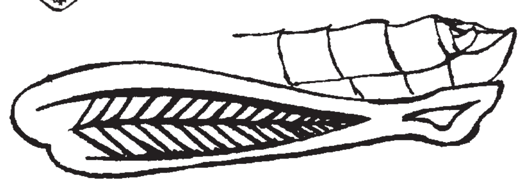
Adult: *Body yellow to greenish. Yellow underneath.

Size large. *No lateral carina evident. Brown stripes behind eye and onto the pronotum. Strongly slanted face. *Depression of vertex without a median carina. Associated with tall, coarse grass.



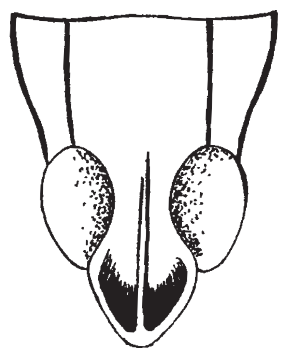


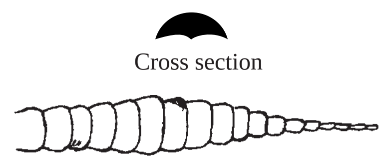
Immature: Quite large and generally green or tan. Fine brown spots cover the body. Antennae triangular in cross section, swordshaped.



Pseudopomala brachyptera *26–G*

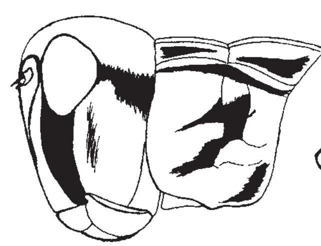
Adult: *Abdomen extending beyond the hind femora in adults. Size large. Lateral carina well developed. Body color light brown. Fastigium divided by a median carina. Both sexes short winged. Antennae triangular in cross section, swordshaped.

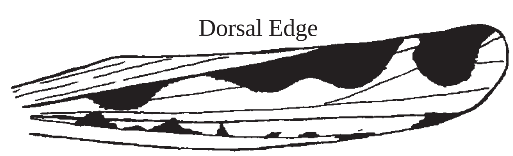




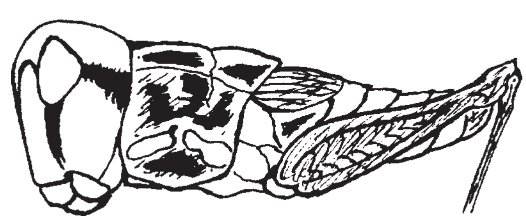
Phlibostroma quadrimaculatum *27–G*

Adult: *Forewing with four spots. Tibia reddish orange. Color brownish olive with some green. Size: Females large, males small. Distinct constricted lateral carinae, vertical white stripe below eye.



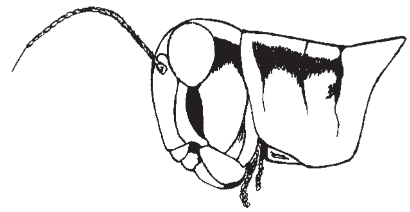


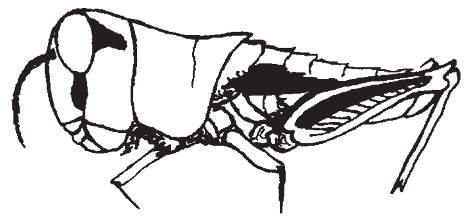
Immature: *Usually a lateral carina and some green color. Hind femora a light brown. No noticeable banding. *Two white areas are usually visible on the lower pronotum.



Phoetaliotes nebrascensis *28–M*

Adult: *Both sexes usually with reduced forewing. (See fig. 2, description of wings.) *Head larger than pronotum. Black teardrop below compound eye.

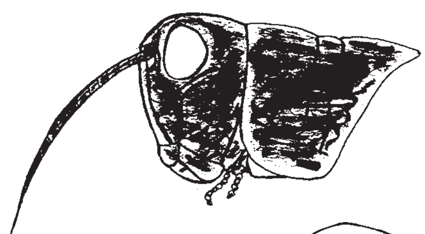


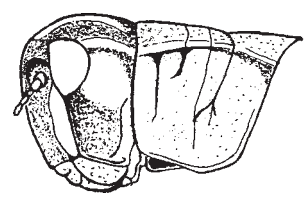


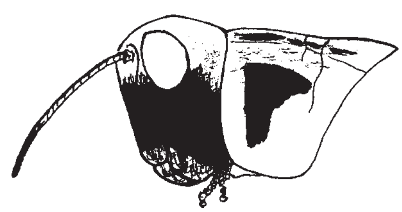
Immature: *No visible lateral carina. *The hind femora with noticeable band on the upper half. Immatures appear to be soft and delicate.

Boopedon nubilum *29–G*

Adult: Males are jet black and with fully developed wings. Females are large and have an olive green and brown color and short wings.



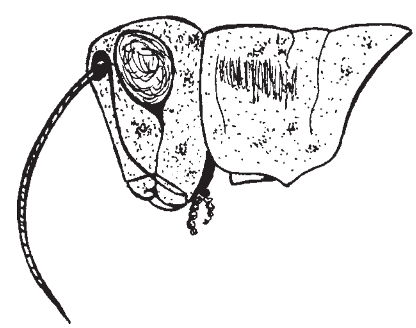




Immature: Pronotum is very distinctive with a dark saddle area.

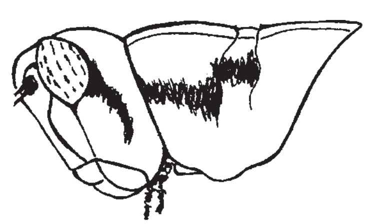
Hypochlora alba *30–F*

Adult: *Both sexes with pointed, reduced forewing. (See fig. 2, description of wings.) *Color a sage-gray green that resembles the host plant (Mulkern et al. 1969). *The entire body is covered with small rust-colored dots.
Immature: A small version of the adult.



Hesperotettix viridis *31–F*

Adult: Pronotum green with a pale white middorsal stripe. *A reddish orange band around the femur near the knee. Compound eye with vertical rows of spots.
Immature: Compound eyes with light spots. Antennae dark with light colored rings. A light-colored line running from the head to the posterior tip of the pronotum. In later instars, hind femoral chevrons are dark.

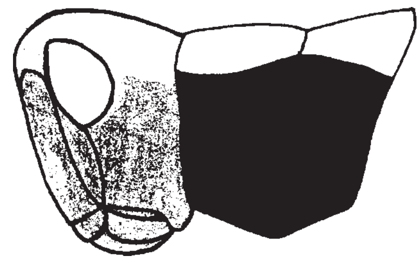


Late-Hatching Species

(To be adults by late summer.)

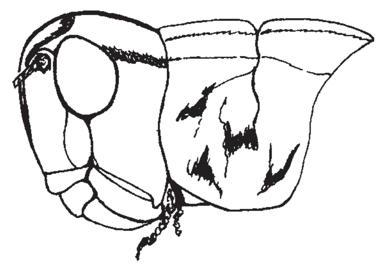
Chloealtis conspersa *32–G*

Adult: Lateral pronotal area of male entirely black. Female with reduced wings. (See fig. 7, p. 4, description of wings.) Sides of female pronotum lighter colored. Black knee in both sexes.



Encoptolophus costalis *33–M*

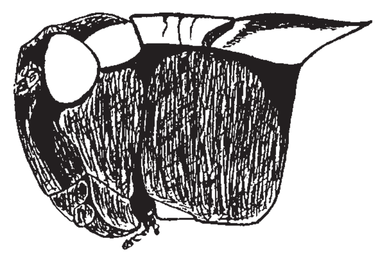
Adult: Corresponding bands on forewing and femur. A small late bandwing. Inner surface of hind femora dark bluish-black on the basal half and with a dark band toward the apex.



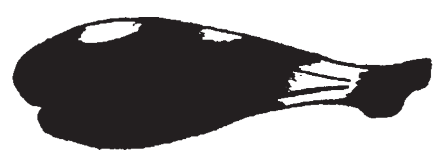
Immature: Similar to *Chortophaga* sp. in color and morphology, but this species is in an advanced instar stage when *Chortophaga* hatches.

Arphia pseudonietana *34–M*

Adult: A late-season adult bandwing. Color bronze, almost black. Color varies from grayish-brown to black, mottled appearance. Usually a red wing disk with a black band.

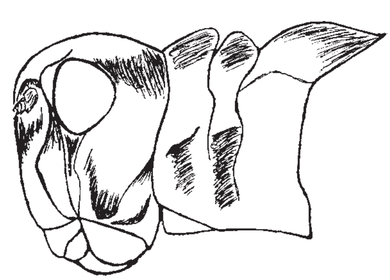


Immature: This species is usually at least two instars ahead of *Arphia conspersa* near the middle of July.



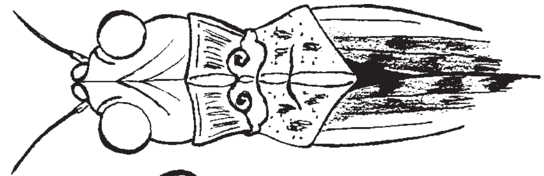
Metator pardalinus *35–M*

Adult: A large bandwing grasshopper. Females are almost robust. Males are smaller and have dark blue abdomen, tibia, and inner femur. Dark spots on forewing.
Immature: Early instars resemble *Trachyrhachys,* but this species does not have any dense hair on the femora.

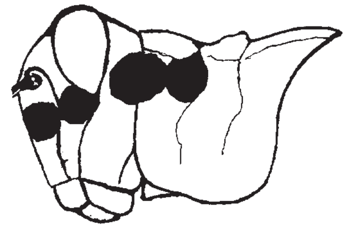


Derotmema haydeni *36–M*

Adult: A small- to medium-sized bandwing grasshopper with large, bulbous eyes and a very wrinkled pronotum and speckled spots quite evident in the forewing.

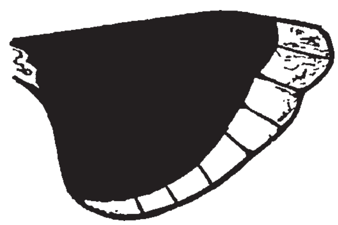


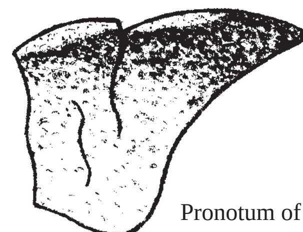
Immature: Early instars have four shiny black spots on the front of the head and two on the pronotum. All instars have two rust spots on each ventral abdominal segment.



Dissosteira carolina *37–M*

Adult: Adults are known as “road dusters.” The hind wing is black with a pale yellow border. This species has the largest wingspan of our grasshoppers. Mimics local soil coloration.
Immature: Early instars possess a morphology much like *Arphia* sp. except the body color is like wet beach sand. Later *Dissosteira* instars are much larger, and the pronotum is shaped like a buffalo’s hump.

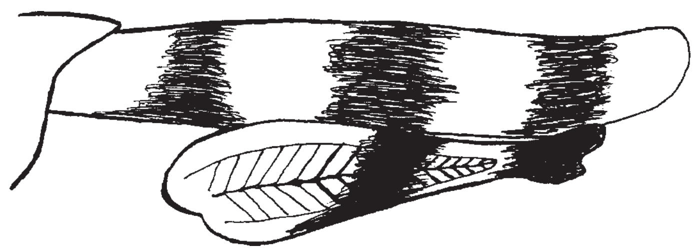




Pronotum of an immature

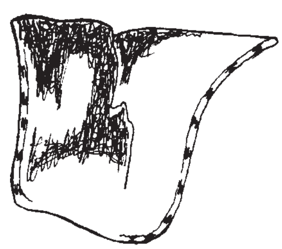
Hadrotettix trifasciatus *38–M*

Adult: *Forewing reddish-brown with conspicuous dark crossbands; apex clear. *Inner surface of hind femora a deep blue color on the basal two-thirds followed by a white band and a dark apex. Hind tibia orange.
Immature: All later instars exhibit the above femoral coloration. Stout appearance.



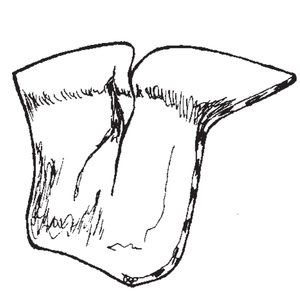
Spharagemon equale *39–M*

Adult: *General body color is a speckled, sandy look with a bright orange inner femora and tibia. *Pronotum with the median carina slightly elevated, usually cut once. Forewing banded.
Immature: *All later instars exhibit the basic adult coloration. On first instars, hind tibia dark.



Spharagemon collare *40–G*

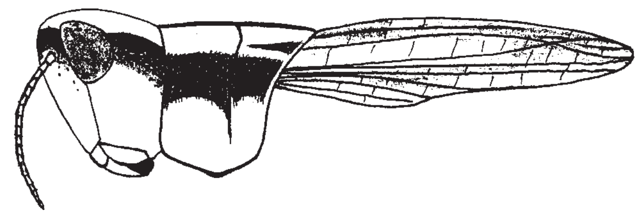
Adult: *General body color is a speckled, sandy look with a yellowish femora and orange tibia. *Pronotum with the median carina raised into a high crest and cut deeply by one sulcus. Forewing not noticeably banded.
Immature: *All later instars exhibit the basic adult coloration. On first instars, hind tibia dark.



Chorthippus curtipennis *41–G*

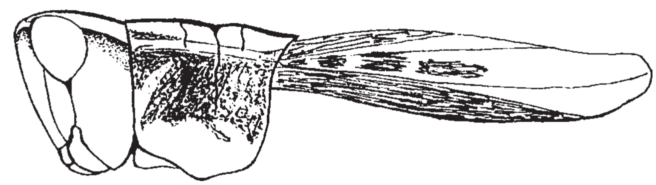
Adult: Body color usually varies from green to a yellowish brown with the ventral portion yellowish. The hind femora of the males have a black knee and are longer

than the abdomen. The lateral foveolae are visible from above. Female wings short. Male wings reach end of abdomen.
Immature: Quite variable in body striping and color. First and second instars have distinct brown stripe from eye well onto the abdomen.



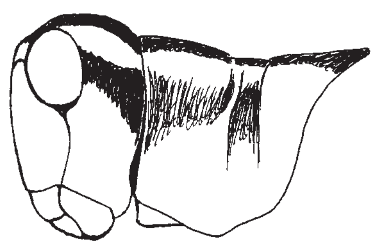
Orphulella speciosa *42–G*

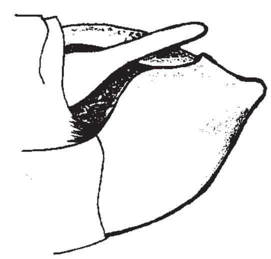
Adult: *Body color variable, greens and browns with a dark band extending from behind the compound eye to the pronotum. *A dark triangular area inside the rear portion of the lateral carina. Hind femora a brownish tan in color and longer than the abdomen in the males. *A visible depression on the point of the head. Lateral carinae of pronotum cut by one sulcus.
Immature: Possess many of the adult morphological characters.



Aeoloplides turnbulli *43–F*

Adult: *Stout body with a greenish yellow color. Body widest at the posterior end of the pronotum. Hind tibia blue. Male subgenital plate with a subapical tubercle. Distinctive stripe on head and pronotum. Outer femur distinctively marked with dark chevrons.





Oedaleonotus enigma *44–M*

Adult: Not found in North Dakota. *Found in California, Nevada, Utah, Idaho, Washington, and Oregon. The anterior edge of the pronotum has a conspicuous cream-colored band giving the appearance of wearing a clergyman's collar. The lower portion of the femora has a thin orange line. The cercus is drumstick shaped. An early hatching species in Idaho.
Immatures: Robust appearance. Distinctive white stripe on middle of pronotum, extends onto abdomen.

Selected References

Brooks, A. R. 1958. Acridoidea of southern Alberta, Saskatchewan and Manitoba (Orthoptera). Suppl. 9. Canadian Entomologist 90: 1–92.

Capinera, J. L., ed. 1987. Integrated pest management on rangeland, a shortgrass prairie perspective. Boulder, CO: Westview Press.

Handford. R. H. 1946. The identification of nymphs of the genus *Melanoplus* of Manitoba and adjacent areas. Scientific Agriculture 26: 147–180 and 12 plates.

Hewitt, G. B.; Barr, W. F. 1967. The banded-wing grasshoppers of Idaho. (Orthoptera: Oedipodinae). Sta. Bull. 72. Moscow, ID: Idaho Agricultural Experiment Station.

Mulkern, G. B.; Pruess, K. P.; Knutson, H.; Hagen, A. F.; Campbell, J. B.; Lanbley, J. D. 1969. Food habits and preferences of grassland grasshoppers of the north central Great Plains. Sta. Bull. 481. Fargo, ND: North Dakota Agricultural Experiment Station.

Newton, R. C.; Esselbaugh, C. O.; York, G. T.; Prescott, H. W. 1954. Seasonal development of range grasshoppers as related to control. Bull. E-873. Division of Cereal and Forest Insect Investigations: U.S. Department of Agriculture, Agricultural Research Service, Bureau of Entomology and Plant Quarantine. 18 p.

Pfadt, R. E. 1988. Field guide to common western grasshoppers. Sta. Bull. 912. Laramie, WY: U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wyoming Agricultural Experiment Station. 25 p.

Selected References—Unpublished

Cushing, W. J. 1970. Characteristics of the immature stages of North Dakota bandwinged grasshoppers with a key for their identification. M.S. thesis. Fargo, ND: North Dakota State University.

Turley, D. M. 1964. Acridinae nymphs of North Dakota. National Science Foundation final report.

VI.8 Seasonal Occurrence of Common Western North Dakota Grasshoppers

By W. J. Cushing, R. N. Foster, K. C. Reuter, and Dave Hirsch

Several authors have compiled excellent taxonomic keys for identifying various grasshopper groups in North America: slantfaced and bandwinged adults by Otte (1981), spurthroated adults by Brooks (1958), and the identification of nymphs of the genus *Melanoplus* by Hanford (1946). Others have used hatching dates and developmental charts to aid in grasshopper identification. For Wyoming and Montana, excellent examples are the charts developed by Newton (1954) and the charts modified for use in Colorado by Capinera (1981).

Many of the identification aids are not commonly available and are technical and difficult to use in a field situation because of bulk and terminology. Also, the field person attempting to use such identification aids usually is a temporary summer employee with little or no background in entomology.

Although scientists have computer mapping technology and sophisticated methods of conducting grasshopper surveys, grasshoppers still need to be identified at each survey stop. A small, easy-to-use reference such as this one will help in the identification process.

Used in combination, the seasonal occurrence chart (table 1) and the Pocket Hopper Helper can help a field person identify grasshopper species in the field. In a year with average grasshopper populations, a field person using the two aids in combination can identify an unknown grasshopper of known life stage (instar) in western North Dakota.

In 1987, the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) funded a multiyear Grasshopper Integrated Pest Management (GHIPM) Project to investigate ways to control rangeland grasshoppers in the West. The GHIPM Project set up a study area in McKenzie County, ND, with a demonstration area and several study sites. At each treatment location, there were 10 or more treatment-evaluation sites. Approximately one-half mile outside the treatment areas, 10 untreated sites were also monitored.

Field personnel collected data on pretreatment and posttreatment grasshopper densities, species composition, and age structure at permanent sampling sites on treated and untreated plots. To determine density, each site had a circular transect of 40 0.1-m^2 rings placed 5 m apart (Onsager and Henry 1977). Rings were in place for the duration of the season.

To sample, field personnel took 400 sweeps, 200 high and fast and 200 low and slow, with standard sweep nets during the grasshopper season. Samples were sacked, frozen, and later identified in the laboratory by species and age class for each site and sampling date.

During a 7-year period from 1987 to 1993, the GHIPM Project studied 25 separate demonstration areas. Laboratory personnel examined and recorded data on approximately 250,000 individual grasshoppers comprising 57 species (table 2).

Of the 57 species, no more than 38 are typical in western North Dakota rangeland samples. Of the 50 species listed in the seasonal history chart, surveyors in western North Dakota commonly find the 15 noted in table 3.

The seasonal history chart is divided into four developmental time periods of 4 months each. These four time periods are subdivided into approximately three 10-day periods. The numbers 1 through 5 represent a grasshopper's instar stage, and the letter "A" stands for adulthood. The placement of the numbers and letter A's in the chart represents the time a certain species has reached a stage of development. These data come from 7 years of observing and recording thousands of individual grasshoppers.

Several species listed on the seasonal chart have almost no early dates of occurrence indicated. This void results from a lack of basic identification tools available on important bandwinged and *Melanoplus* species and from the small number of these species examined.

The arrangement of grasshopper-hatch time periods in order by type of species are (1) overwintering, (2) early-hatching, (3) intermediate-hatching, and (4) late-hatching.

Overwintering Species

North Dakota has six species that commonly pass the winter in various instar stages, and others occasionally overwinter as adults. Ranchers and survey personnel usually find these species early in the season. Although damage caused by most of the six species is below the threshold of economic significance, their appearance can cause concern because many lay persons are unaware of this group and may think the season's hatch of genuinely threatening species has begun.

Early-Hatching Species

This group of grasshoppers, whose eggs hatch from about late May to mid-June, probably is the most important. Many of the species that cause economically unacceptable levels of damage begin to develop at this time. Most agencies and Cooperative Extension Service personnel advise ranchers and farmers to check their fields and rangeland for possible infestations at this time. Late spring is the critical time to be able to differentiate among overwintering, noneconomic, and problem species. Most grasshopper control decisions take increased numbers of problem species into account.

Intermediate-Hatching Species

This group includes a number of species that hatch over an extended period of time, mainly because of a number of environmental conditions. Most species in this group begin appearing in late May or early June.

Late-Hatching Species

This group includes several late-hatching species and many that could fall into the intermediate-hatching group. Grasshopper species in this group appear slightly later than intermediate-hatching species and reach adulthood late. Both the intermediate- and late-hatching species need further study.

Acknowledgments

We would like to thank Phil Mazuranich for furnishing an unpublished personal copy of the life history chart of the grasshoppers of Montana.

The technical assistance of the following colleagues has been most helpful: Robert E. Pfadt, Richard J. Dysart, Jim Jeske, Terry Reule, and Selene Gaffri. We received special assistance from Jeff Transtrom, Ryan Nordoven, Ryan Endrud, Denise Anderson, Wade Marmon, Dan Wingenbach, Mike Smith, A. and S. Battaglia, Matt Morgans, Tom Lorang, Dan Kahler, Paul Stohr, and David R. Walgenbach.

Selected References

Brooks, A. R. 1958. Acridoidea of southern Alberta, Saskatchewan and Manitoba (Orthoptera). Suppl. 9. Canadian Entomologist 90: 1–92.

Capinera, J. L.; Sechrist, T. S. 1981. Grasshoppers (Acrididae) of Colorado, identification, biology and management. Exp. Stn. Bull. 584s. Fort Collins, CO: Colorado State University.

Handford, R. H. 1946. The identification of nymphs of the genus *Melanoplus* of Manitoba and adjacent areas. Scientific Agriculture 26: 147–178.

Newton, R. C.; Esselbaugh, C. O.; York, G. T.; Prescott, H. W. 1954. Seasonal development of range grasshoppers as related to control. Bull. E-873. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service, Bureau of Entomology and Plant Quarantine.

Onsager, J. A.; Henry, J. E. 1977. A method for estimating the density of rangeland grasshoppers (Orthoptera: Acrididae) in experimental plots. Acrida 6: 231–237.

Unpublished Reference

Mazuranich, Philip. 1987. Seasonal history of common Montana grasshoppers. (Mimeo, 4 p.)

Table 1—Seasonal history of common western North Dakota grasshoppers

Overwintering species	April			May			June			July			August		
	E[1]	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Arphia conspersa[2]			A	A	A[3]	A	A				[4]1	2	3	4	
Chortophaga viridifasciata		5 A	A	A	A	A	A			1	2	3	4	5	
Eritettix simplex		5 A	A	A	A	A	A	A	A		1	2	3	4	
Psoloessa delicatula		5 A	A	A	A	A	A	A			1	2	2	2 3	—[5]
Pardalophora haldemani		—	—	—	4	5		A	A						
Xanthippus corallipes		4 5	A	A	A	A	A	A	A		1	2	2 3		
Early-hatching species															
Aeropedellus clavatus				1	2	3	—	4 A	A	A	A	A	A	A	
Acrolophitus hirtipes					1	2	3	—	4	5 A	A	A	A	A	
Ageneotettix deorum					1	—	2	3	4	5 A	A	A	A	A	
Amphitornus coloradus[6]						1	2	—	3 4	5	A	A	A	A	
Aulocara elliotti					1	2	3	4	5	A	A	A	A	A	
Camnula pellucida						1	2	3 4	—	5 A	A	A	A	A	
Circotettix carlinianus						1	2	3	4	5 A	A	A	A	A	
Chloealtis conspersa					—	—	—	—	5	A	A	A	A	A	
Melanoplus bivittatus						1	2	3	4	5 A	A	A	A	A	
Melanoplus confusus				1	2	3	4	5 A	A	A	A	A	A	A	
Melanoplus infantilis						1	2 3	4	5 A	A	A	A	A	A	
Melanoplus occidentalis				—	1	2	3	4	5 A	A	A	A	A	A	

Table 1—Seasonal history of common western North Dakota grasshoppers (continued)

Early-hatching species (cont'd.)	April			May			June			July			August		
	E[1]	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Melanoplus packardii						1	2	—	3	4	5 A	A	A	A	
Melanoplus sanguinipes						1	—	2	3	4	5 A	A	A	A	
Trachyrhachys kiowa						1	—	—	2	3	4	5	A	A	
Intermediate-hatching species															
Aeoloplides turnbulli						1	2	3	4	5	A	A	A	A	
Aulocara femoratum								1	2	3	4	5	A	A	
Boopedon nubilum						1	—	2	3	4	—	5 A	A	A	
Chorthippus curtipennis							1	2	3	4	—	—	A		
Derotmema haydeni								1	2	3	4 A	A	A	A	
Hesperotettix viridis						1	—	2	3	4	5 A	A	A	A	
Melanoplus femurrubrum						1	—	1	2	—	3 4		5 A	A	
Melanoplus bowditchi							1	2	3	4	5	A	A	A	
Metator pardalinus							1	2	3	4	5 A	A	A	A	
Spharagemon equale						—	2	3	—	4	—	5 A	A	A	
Stenobothrus brunneus					—	1	2	3	4	5	A	A	A	A	
Late-hatching species															
Dissosteira carolina							—	2	3	4	5 A	A	A	A	
Hadrotettix trifasciatus						—	2	—	—	3	4	5	A	A	

Late-hatching species (cont'd.)	April			May			June			July			August		
	E[1]	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Hypochlora alba								1	2	—	3	4	5	A	
Melanoplus dawsoni									1	2	3	4	5	A	
Phlibostroma quadrimaculatum									1	2	3	4 5	A		
Spharagemon collare								1	2	3	4	5	A		
Arphia pseudonietana									1	2 3	4	5	A		
Encoptolophus costalis									1	2	3	4	5	A	
Melanoplus keeleri								1	2	—	2	—	3	4 5 A	
Mermiria bivittata							1	—	2	3	—	4	5	A	
Opeia obscura[6]							1	2	3	4		5	A		
Orphulella speciosa								1	—	2 3	4	5	A		
Phoetaliotes nebrascensis									1	2	3 4	5	A		
Melanoplus gladstoni								1	2	—	3 4	5	A		
Dactylotum pictum									1	2 3	4		A		
Schistocerca lineata								—	—	—	—		5	A	
Melanoplus angustipennis							1	2	3	4	5		A		

[1] E = early part of month, M = midmonth, L = latter part of month.
[2] Overwintering immatures of *Arphia conspersa* and *Chortophaga viridifasciata* usually hatch near the second week of July.
[3] A = adult grasshopper.
[4] Numerals 1 through 5 refer to grasshopper instar.
[5] — = little or no data about instar stage.
[6] *Amphitornus coloradus* and *Opeia obscura* exhibit like early instar characteristics and colors, but *Amphitornus coloradus* usually hatches at least 10 days before *Opeia obscura*.

Table 2—Species collected in northwestern North Dakota, 1987–93

Acrolophitus hirtipes (Say)	*Hadrotettix trifasciatus* (Say)	*Pardalophora haldemani* (Scudder)
Aeoloplides turnbulli (Candell)	*Hesperotettix viridis* (Thomas)	*Phlibostroma quadrimaculatum* (Thomas)
Aeropedellus clavatus (Thomas)	*Hypochlora alba* Dodge	*Phoetaliotes nebrascensis* (Thomas)
Ageneotettix deorum (Scudder)	*Melanoplus angustipennis* (Dodge)	*Pseudopomala brachyptera* (Scudder)
Amphitornus coloradus (Thomas)	*Melanoplus bivittatus* (Say)	*Psoloessa delicatula* (Scudder)
Arphia conspersa (Scudder)	*Melanoplus bowditchi* (Scudder)	*Schistocerca lineata* Scudder
Arphia pseudonietana (Thomas)	*Melanoplus confusus* Scudder	*Spharagemon collare* (Serville)
Aulocara elliotti (Thomas)	*Melanoplus dawsoni* (Scudder)	*Spharagemon equale* (Say)
Aulocara femoratum (Scudder)	*Melanoplus femurrubrum* (DeGeer)	*Stenobothrus brunneus* Thomas
Boopedon nubilum (Say)	*Melanoplus foedus* Scudder	*Trachyrhachys kiowa* (Thomas)
Camnula pellucida (Scudder)	*Melanoplus gladstoni* Scudder	*Trimerotropis agrestis* McNeill
Chloealtis conspersa (Harris)	*Melanoplus infantilis* Scudder	*Trimerotropis campestris* McNeill
Chorthippus curtipennis (Harris)	*Melanoplus keeleri* (Thomas)	*Trimerotropis gracilis* (Thomas)
Chortophaga viridifasciata (DeGeer)	*Melanoplus occidentalis* (Thomas)	*Trimerotropis latifasciata* Scudder
Circotettix carlinianus (Thomas)	*Melanoplus packardii* Scudder	*Trimerotropis pallidipennis* (Burmeister)
Dactylotum pictum (Thomas)	*Melanoplus sanguinipes* (Fabricius)	*Trimerotropis sparsa* (Thomas)
Derotmema haydeni (Thomas)	*Mermiria bivittata* (Serville)	*Xanthippus corallipes* (Haldeman)
Dissosteira carolina (L.)	*Metator pardalinus* (Saussure)	
Encoptolophus costalis (Scudder)	*Opeia obscura* (Thomas)	
Eritettix simplex (Scudder)	*Orphulella speciosa* (Scudder)	

Table 3—The 15 most abundant grasshopper species encountered on rangeland during the study in North Dakota, in alphabetical order

Aeropedellus clavatus (Thomas)	Clubhorned grasshopper
Ageneotettis deorum (Scudder)	Whitewhiskered grasshopper
Amphitornus coloradus (Thomas)	Striped grasshopper
Aulocara elliotti (Thomas)	Bigheaded grasshopper
Camnula pellucida (Scudder)	Clearwinged grasshopper
Melanoplus bivittatus (Say)	Twostriped grasshopper
Melanoplus confusus Scudder	Pasture grasshopper
Melanoplus femurrubrum (De Geer)	Redlegged grasshopper
Melanoplus gladstoni Scudder	Gladston grasshopper
Melanoplus infantilis Scudder	Little spurthroated grasshopper
Melanoplus packardii Scudder	Packard grasshopper
Melanoplus sanguinipes (Fabricius)	Migratory grasshopper
Metator pardalinus (Saussure)	Bluelegged grasshopper
Phlibostroma quadrimaculatum (Thomas)	Fourspotted grasshopper
Trachyrhachys kiowa (Thomas)	Kiowa grasshopper

VI.9 Geographic Information Systems (GIS) and Integrated Pest Management of Insects

W. P. Kemp, D. McNeal, and M. M. Cigliano

Space and Pests

An understanding of the geographic variability in distributions and densities of pests is required for any integrated pest management (IPM) program. Pest densities influence the intensity of sampling required to define the area infested and the timing and economics of various control options. However, until recently there has been a general lack of analytical and data management tools that pest managers and researchers could use in IPM planning and execution.

Among several new technologies evaluated and demonstrated by Grasshopper Integrated Pest Management (GHIPM) Project participants, the geographic information system (GIS) and Global Positioning System (GPS) technologies appear to be sufficiently well developed to be integrated into existing IPM programs for rangeland grasshoppers in the Western United States. Although the primary focus of this chapter is GIS, we have chosen to include additional information on GPS because of the obvious link between the two technologies.

First Consider GPS

GPS refers to an advanced navigational system that was developed primarily for military applications. GPS consists of a number of satellites orbiting the Earth. These satellites have the ability to communicate with any appropriately equipped plane, ship, vehicle, or individual and indicate the geographic position on the face of the Earth and the elevation of the receiver. Position accuracy within feet may be obtained with appropriate equipment.

Because of the obvious improvements in guiding or tracking for commercial uses, some portions of the GPS have been made available to the public. Hand-held GPS receivers (fig. VI.9–1) are finding wide usage throughout

Figure VI.9–1—One of the newest tools to aid pest managers is a hand-held Global Positioning System (GPS) instrument. GPS provides accurate latitude and longitude coordinates, aiding the process of mapping locations of grasshopper populations. (APHIS photo by Mike Sampson.)

the public and private sectors. For the purposes of IPM, the GPS offers several capabilities. The most highly developed aspect of GPS that has been exploited by the participants of the GHIPM Project is aircraft guidance (see II.22). We focus the following discussion of GPS application on field scouting and the obvious link to the GIS.

Those involved with pest management of rangeland grasshoppers have struggled with the problem of locating their position on a map. Agencies often use the U.S. Geological Survey 7.5 Minute Quadrangle Series Maps, frequently referred to as simply "topo maps" or "quad sheets," where 2 inches on the map represents 1 mile on the surface of the Earth. Using 2 inches = 1 mile map scale as an example, consider what a scouting activity frequently involves. Whether sampling for Mediterranean fruit fly in California or for grasshoppers in Montana, the problem is the same—how to mark a place on a map that represents the location of a sample site?

Over the years, most scouts develop experience, which helps them locate their position on a map quickly and accurately. Scouts usually become good "mappers." However, learning to read maps is an acquired skill, and new scouts cannot be expected to be able to locate their position at all times quickly and accurately (accuracy is possible, but most novices cannot work quickly). Furthermore, scouts vary in their ability to read maps. As with any human activity, some scouts are simply better mappers than others.

Currently, a number of GHIPM Project participants use hand-held GPS receivers (some of which are about the size of a large pocket calculator), which can provide positional accuracies of plus or minus 100 feet in normal operational mode or plus or minus a few feet when operating in an optional mode. The positional accuracy possible in point location and block location (for example, the location of an infestation of insect A) via GPS goes a long way toward reducing errors and helps minimize the differences between scouts in mapping activities. Furthermore, many of the currently available GPS receivers can be connected directly to microcomputers or field data recorders. These can manage data in standard GIS formats, so scouting information can be examined very rapidly and thoroughly.

On to GIS

A GIS is a set of computer programs that can store, use, and display information about places of interest. Examples of places of interest to a grasshopper pest manager might be a 20-acre field, a 20,000-acre watershed, or the 2 million square miles of rangeland in a particular State. Examples of information for any place of interest are soil types, rainfall and temperature patterns, land use, ownership patterns, roads, vegetation types, and topography (landform). A GIS stores two types of data that are found on a map, the geographic definitions of Earth's surface features (spatial reference) and the attributes or qualities that those features possess. It is generally agreed that a true GIS is capable of several characteristic activities: (1) the storage and retrieval of information with a spatial reference (point A is located in Section 20 of Township 5, Range 8 and has soil type B), as well as (2) the input, (3) analysis, and (4) reporting of spatially referenced information in digital form.

GIS Storage and Retrieval

A basic feature of any of the hundreds of GIS products available today is the ability to represent map information in a form that a computer can use. In the world of information management, people generally reserve the term "map" for paper, acetate, or Mylar™ maps, whereas the representation of the map in the GIS is called a "coverage" or "map layer." For the sake of simplicity, we will use "coverage" throughout for the GIS representation of a paper map. Of the approaches used by various GIS products, the two most often heard about are "raster" and "vector."

A GIS that uses a raster approach is similar to observing an attribute such as soil type through a grid or to the view that one has of the world through a screen door. With raster-based GIS products, a coverage of the frequency of grasshopper outbreaks in Montana consists of hundreds of tiny cells each with only one value for the number of years when outbreaks were observed (fig. VI.9–2). Raster-based GIS products keep track of the arrangement of each cell. Each cell and its unique outbreak frequency value have one and only one correct location on the coverage, so when pest managers want to view the grasshopper outbreak frequency coverage of Montana, the GIS always displays the same arrangement of the cells.

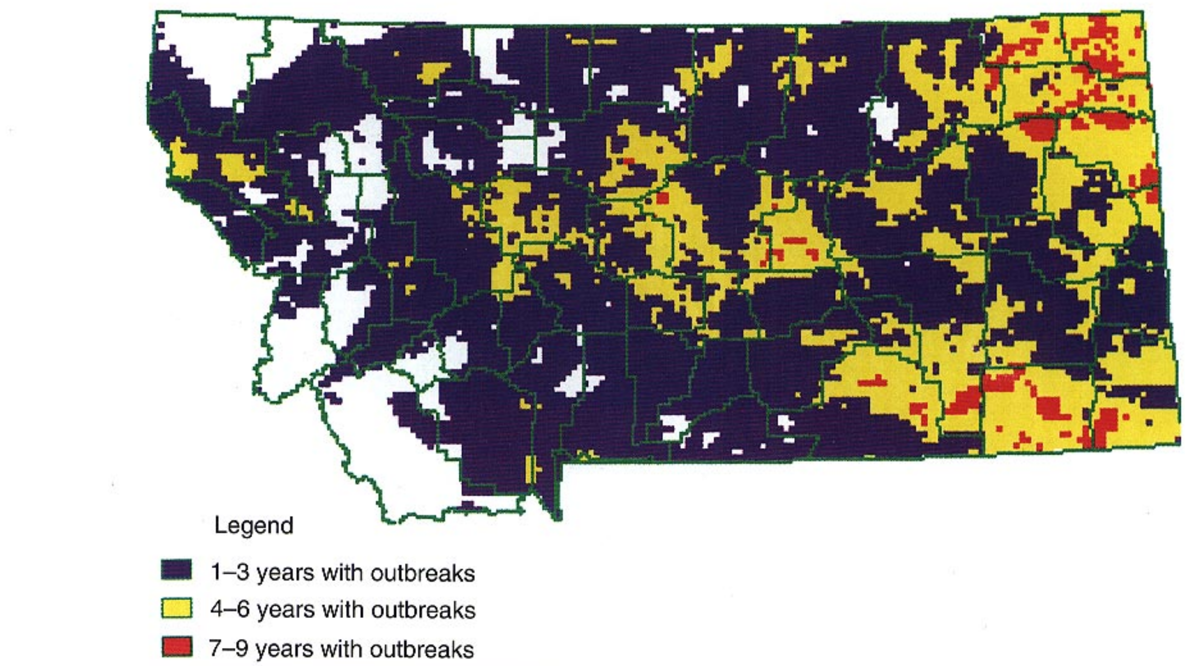


Figure VI.9–2—Rangeland grasshopper outbreak frequency in Montana, an example of a raster-based GIS product.

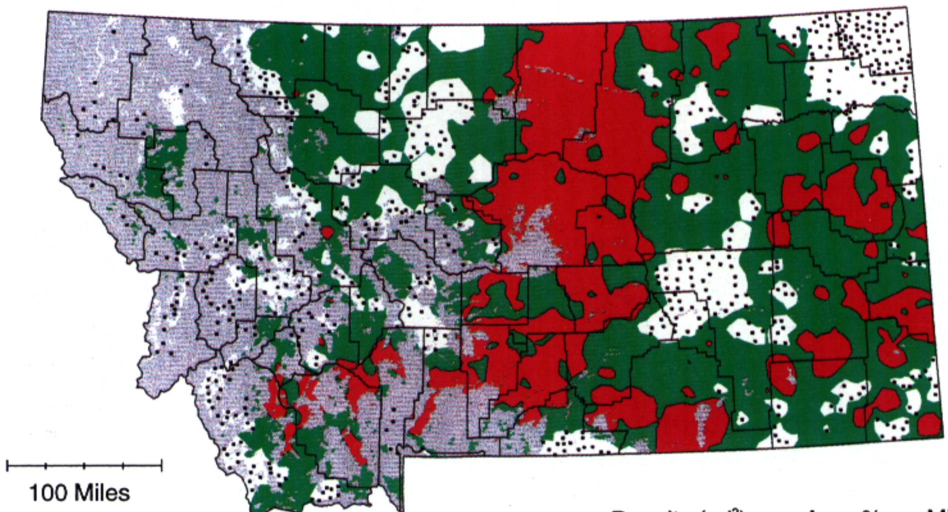
A GIS that uses a vector approach stores information in a somewhat different manner. For example, rather than viewing grasshopper densities as a collection of discrete cells that, when taken together, make up the entire image (the raster-based GIS approach), vector-based GIS products keep track of borders. Vector-based GIS products then associate a particular density to each unique area or polygon area found on the coverage (fig. VI.9–3). With vector representation, the boundaries of the features are defined by a series of points that, when joined with straight lines, form the graphic representation of that feature. The attributes (information) of features are then stored within a standard data-base management software program. The vector-based method is similar to what pest managers do when they draw insect-infested areas on a map in pencil.

Although some applications are more logically approached with either a raster or vector GIS product, in reality it is possible to convert map coverages from raster to vector format and vice versa. If one has purchased a raster-based GIS, he or she is not limited from obtaining a coverage from a vector-based GIS. Whether the basic unit of a coverage is a raster or a polygon, it is not uncommon to have more than one attribute (for example, soil type, vegetation type, or elevation) associated with it. The way that this task is accomplished varies from one GIS product to another.

Data Input and Spatial Analyses

An obvious, yet underappreciated (see more on this below in GIS—The Growth Years), GIS activity is getting the information on the map that you have in front of you into the GIS. In reality, there are a variety of data types that GIS products (paper maps showing point samples or infested areas, digital line graphs, or remotely sensed data) can use. With, for example, a soil type map resting on your desk, you have two logical ways, either "digitizing" or "scanning," of getting the information from that map into the GIS that resides on your desktop microcomputer or workstation.

1994 Montana Rangeland Adult Grasshopper Survey



Data source:
USDA Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Billings, MT 59101

Prepared by:
USDA Agricultural Research Service
Rangeland Insect Laboratory
Bozman, MT 59717-0366

	Density (yd^2)	Area %	Million acres
Uninfested	<3	16.4	15.4
Threatened	3–8	35.8	33.7
Infested	>8	18.5	17.5
Forested		29.3	27.6
Sample locations in uninfested areas			

Figure VI.9–3—The 1994 annual adult grasshopper survey for Montana, an example of a vector-based GIS product used in integrated pest management.

A digitizer device connected directly to your GIS by a cable from your computer may be as small as the blotter on your desk or as big as a draftsman's table. The digitizer has a device, called a "puck," that looks like the mouse on your PC (personal computer), but has more buttons as well as a set of cross hairs to allow you to trace the outlines of soil types on your paper map. The tracing process and some additional steps taken with your GIS successfully convert the information from your paper map into an electronic version or coverage, as we explained above. This process should sound a lot like the vector-based GIS approach we discussed above.

A scanner, on the other hand, performs a task much like a facsimile machine in a home or office and may range in size from a small hand-held device to the large-format photocopy machines that you have seen in photocopy shops. A scanner simply performs a raster (grid) scan of the map that you insert and senses and records the light reflectance of each raster cell. This information is stored in a file format the GIS on your computer can read and convert into a desired coverage. As mentioned, although digitizing and scanning are two commonly used methods for getting map data into a GIS, digital line graphs (DLG), published electronically by government agencies such as the U.S. Geological Survey, provide information in GIS-ready formats. Formats include attributes like elevation, political boundaries, highways, soils, land use, and more.

As mentioned, when people discuss GIS applications or the potential of the technology, they frequently gloss over the "minor details" of getting data into a GIS and concentrate on what we call the spatial analysis capabilities of GIS. Perhaps the most important process common to all true GIS products is the "overlay." An overlay is simply a GIS procedure where two or more coverages (perhaps vegetation type, river courses, and primary highways) are combined and the result is a new coverage that represents a combination of the originally separate coverages. In another example, one coverage (environmentally sensitive areas, for example) may be used to mask out portions of a second coverage. Lastly, it is possible to compute the sum of specific attributes from a series of yearly coverages to compute, for example, the number of years each county in Utah has seen problem populations of rangeland grasshoppers or Mormon crickets.

In addition to the overlay, most GIS products offer a variety of spatial measurement techniques or area analyses. Examples include calculating the area of rangeland in a particular county with more than 20 grasshoppers/yd^2, estimating the area of a lake, or computing the proportion of a chemical control block devoted to buffer zones. All true GIS products also offer solutions to people interested in overlaying coverages of different scales (and projections—although we have chosen for the sake of simplicity to discuss only different scales). Consider, for example, a situation where you want to identify those vegetation types in a particular county where grasshopper densities exceeded 20 grasshoppers/yd^2. If scouts collected density data on maps with a scale of 2 inches = 1 mile (a 7.5-minute quad) and vegetation data was mapped at a scale of 1 inch = 1 mile (a 15-minute quad), you can use the capabilities of a GIS to rescale one map or the other. You could produce a correct overlay to depict only those vegetation types with more than 20 grasshoppers/yd^2.

Maps, Graphs, and Tables

GIS products offer a bewildering array of report types. Reports can consist of paper maps, tables, charts, graphs, or computer images. Selecting which report type is the most useful will depend on your particular application (see Cigliano et al. 1995). For viewing an overlay consisting of vegetation type, land use, rivers, and roads, you would likely choose a simple paper map presentation. If you wanted to forecast grasshopper densities throughout a State for next year, you could select options that would produce a contour map (for example, fig. VI.9–3). In short, GIS offers pest managers a great deal of flexibility in the presentation of information.

GIS Applications and IPM of Insects

Liebhold et al. (1993) described GIS's as "enabling technology." As previously stated, a GIS provides pest managers with the capabilities to store, retrieve, process, and display spatially referenced data. It seems only logical that GIS technology will be rapidly embraced because so many questions from insect ecology to pest management have a spatial component. Whether studying the patch dynamics of host and herbivore or predicting multi-State pest hazards, GIS technology provides today's researchers and pest managers with the ability to answer questions that frustrated their predecessors.

Now it is possible to identify two general areas where GIS technology has been used in entomology—applied insect ecology research and insect pest management. Within the general area of applied insect ecology, perhaps the major use of GIS is in the relation of insect outbreaks to environmental features of the landscape. Using grasshoppers as an example, investigators in Canada used GIS products to examine the relationship between historical grasshopper outbreaks and soil characteristics (Johnson 1989a) and between weather and survey counts (Johnson and Worobec 1988). From these geographically referenced data, Johnson (1989a) found that grasshopper abundance in Alberta was related to soil type but not to soil texture. Furthermore, a significant association was found between rainfall levels and grasshopper densities. Populations tended to decline in areas receiving above average rainfall (Johnson and Worobec 1988).

Future efforts to characterize habitat susceptibility probably will use remotely sensed data extensively because of its high spatial resolution and its availability in virtually every portion of the globe (for a complete review of remote sensing in entomology, see Riley 1989). For example, Bryceson (1989) used Landsat satellite data to determine areas in New South Wales, Australia, that were likely to have egg beds of the Australian plague locust. Through the use of an index that indicated the general greenness levels of local vegetation, Bryceson was able to identify resulting nymphal bands geographically through changes in the greenness index that resulted from rains during March (nymphal bands tend to be associated with "green" areas that result from rain).

Similar "greenness mapping" exercises have been conducted in Africa for grasshoppers and locusts (Tappan et al. 1991). In addition to illustrating the apparent ecological association between nymphal bands of grasshoppers or locusts in Australia and Sahelian Africa and changes in greenness indices, studies of Bryceson (1989) and Tappan et al. (1991) have immense practical utility because they produce rapid estimates of the location and extent of potential pest problems. Through such methods, it has been possible to improve sampling efficiency vastly for detection of problems as well as to reduce the guesswork involved with planning and execution of pest management programs.

The second major area where GIS products have been used is for compilation and analysis of insect census data that are collected regularly by U.S. Department of Agriculture, Animal Plant Health Inspection Service (USDA, APHIS). One example of this application for rangeland insects in the United States is the use of a GIS for developing a distribution atlas for grasshoppers and Mormon cricket in Wyoming (Lockwood et al. 1993). Additionally, Kemp et al. (1989) and Kemp (1992 unpubl.) provide methods for the development of rangeland grasshopper GIS coverages and hazard forecasts, using annual survey data collected on adult grasshoppers in Montana. (See Johnson [1989b] for similar studies for grasshoppers in Canada.)

The compilation and interpretation of spatially referenced insect and habitat data is a complex process, if for no other reason than the sheer volume of information. Although GIS software is designed to handle this complexity successfully, these systems often are not easy to use. In order to make a GIS more accessible to applied problems, GIS is increasingly being linked as a part of a larger decision support system (DSS). These systems typically use a GIS to manage habitat, geophysical, political, and census data. The DSS uses these data, along with other data, as input to mathematical models and other modeling methods to produce useful abstractions or recommendations (Power 1988). These outputs might be maps of high damage hazard or even maps of proposed control areas. Hopper, the DSS for rangeland grasshoppers being developed by the GHIPM Project (Berry et al. 1991; see chapter VI.2), currently has the ability to display density coverages. Future plans include a closer link to GIS procedures. Coulson et al. (1991) use the term "intelligent geographical information system" (IGIS) to describe systems that use a GIS and rule-based models to combine landscape data and knowledge from a diversity of scientific disciplines.

GIS—The Growth Years

GIS brings a great deal of analytical horsepower to the complex tasks associated with managing America's natural resource base. However, expectations frequently associated with bringing GIS activities into the IPM realm frequently result in frustration for both pest managers and GIS professionals. Two major reasons why frustrations develop already have been mentioned: (1) People generally underestimate the resources required to get information into a GIS, and (2) GIS products are, at present, frequently complex enough to require specialized training. Another confounding problem that we should add is communication. Pest managers frequently lack indepth familiarity with computer systems and at times may distrust all the apparent complexity involved with GIS activities. GIS technicians, on the other hand, frequently lack the biological expertise necessary to assist the pest managers with creative solutions to a particular problem. These communication problems can be frustrating to those on both sides of the table and may result in little advancement toward the solution to the current pest management problem.

At this time, to expect pest management professionals, for example APHIS, Plant Protection and Quarantine (PPQ) plant health directors, to be trained as GIS technicians is no more realistic than expecting them to be able service their personal computers. Rather, it indeed is logical to provide plant health directors or similar professionals with general training that highlights GIS capabilities, so they can in turn direct the activities of GIS technicians or cooperators. At present, the revamped APHIS, PPQ Cooperative Agriculture Pest Survey (CAPS) is being used by a number of plant health directors from individual States to contract small GIS projects, frequently involving rangeland grasshoppers. This is a way of exploring the uses of GIS products with minimal investment and an attempt to become more knowledgeable about potential GIS applications in other pest management problems.

In general, GIS–pest management activities coordinated through the CAPS program have received good reviews from the participants largely because of the ability of plant health directors from individual States to specify the types of GIS products best suited to their particular needs. For the future of GIS and rangeland grasshopper IPM, today's interactions among plant health directors, GIS technicians, and researchers will be the basis for tomorrow's creative solutions.

References Cited

Berry, J. S.; Kemp, W. P.; Onsager, J. A. 1991. Integration of simulation models and an expert system for management of rangeland grasshoppers. AI Applied Natural Resource Management 5: 1–14.

Bryceson, K. P. 1989. Use of Landsat MSS data to determine the distribution of locust egg beds in the Riverina region of New South Wales, Australia. International Journal of Remote Sensing 10: 1749–1762.

Cigliano, M. M.; Kemp, W. P.; Kalaris, T. M. 1995. Spatiotemporal characteristics of rangeland grasshopper (Orthoptera: Acrididae) regional outbreaks in Montana. Journal of Orthoptera Research 4: 111–126.

Coulson, R. N.; Lovelady, C. N.; Flamm, R. O.; Spradling, S. L.; Saunders, M. C. 1991. Intelligent geographic information systems for natural resource management. In: Turner, M. G.; Gardner, R. H., eds. Quantitive methods in landscape ecology. New York: Springer Verlag: 153–172.

Johnson, D. L. 1989a. Spatial analysis of the relationship of grasshopper outbreaks to soil type. In: McDonald, L. L., et al., eds. Estimation and analysis of insect populations: proceedings of a conference; 25–29 January 1988, Laramie, WY. New York: Springer Verlag: 347–359.

Johnson, D. L. 1989b. Spatial autocorrelation, spatial modeling, and improvements in grasshopper survey methodology. Canadian Entomologist 121: 579–588.

Johnson, D. L.; Worobec, A. 1988. Spatial and temporal computer analysis of insects and weather: grasshoppers and rainfall in Alberta. Memoirs of the Entomological Society of Canada 146: 33–48.

Kemp, W. P.; Kalaris, T. M.; Quimby, W. F. 1989. Rangeland grasshopper (Orthoptera: Acrididae) spatial variability: macroscale population assessment. Journal of Economic Entomology 82: 1270–1276.

Liebhold, A. M.; Rossi, R. E.; Kemp, W. P. 1993. Geostatistics and geographic information systems in applied insect ecology. Annual Review of Entomology 38: 303–327.

Lockwood, J. A.; McNary, T. J.; Larsen, J. C.; Cole, J. 1993. Distribution atlas for grasshoppers and the Mormon cricket in Wyoming 1988–92. Misc. Rep. B-976. Laramie, WY: University of Wyoming and Wyoming Agricultural Experiment Station. 117 p.

Power, J. M. 1988. Decision support systems for the forest insect and disease survey and for pest management. Forestry Chronicle 64: 132–135.

Riley, J. R. 1989. Remote sensing in entomology. Annual Review of Entomology 34: 247–271.

Tappan, G. G.; Moore, D. G.; Knausenberger, W. I. 1991. Monitoring grasshopper and locust habitats in Sahelian Africa using GIS and remote sensing technology. International Journal of Geographical Information Systems 5: 123–135.

Reference Cited—Unpublished

Kemp, W. P. 1992. Annual report for grasshopper population dynamics. In: Cooperative Grasshopper Integrated Pest Management Project, 1992 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 39–44.

VI.10 Assessing Rangeland Grasshopper Populations

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Introduction

Land managers need accurate and comprehensive methods for assessment of rangeland grasshopper populations to make appropriate management decisions and to support research. Some of the needed information at known locations includes grasshopper density, developmental stage, and species composition.

One option is to count and identify every grasshopper in an area. This procedure is called a census. Obviously, a complete census of grasshoppers in a State, a county or even a small ranch is impossible. Therefore, managers must have methods to sample a limited number of the grasshoppers in order to estimate the status of entire grasshopper populations over large and often remote geographic areas where rangeland grasshoppers occur. The result of sampling large areas to estimate grasshopper populations is called a survey. In this chapter, we will explore techniques and issues related to sampling and surveying rangeland grasshoppers.

Overview of Types and Purposes of Surveys

Nymphal Survey.—This is an early season survey to identify areas with high densities of grasshoppers. The nymphal survey notes grasshopper density, species, and developmental stages at recorded sites on all rangeland areas where grasshoppers may be a problem in a State. Developmental stage data are useful for timing the adult survey later in the year (discussed later in this chapter). In years when resources and time are limited for the nymphal survey, areas associated with a greater risk of grasshopper outbreak (such as a potential treatment block) should receive a greater priority for survey. Priority can be determined using previous year adult survey maps, other historical data, and cooperator reports, including requests from and discussions with local people. Other considerations include current conditions, weather (drought or above normal precipitation), cattle prices, range conditions, economics (benefit–cost), species composition, and politics.

Nonoutbreak Years/Areas.—In general, survey sites should be 5 miles (7.65 km) apart on accessible routes. Another alternative is to use sentinel sites (fixed locations) that have been proven as predictive indicator locations. All areas will have uniform priority.

Outbreak Years/Areas.—Deploy survey sites first to high-priority areas as discussed above. Within a potential treatment block (highest priority), survey sites may be a quarter to a half mile (0.4–0.8 km) apart (an area probably less than the entire infestation). These data can be used to establish density estimates for management decisions for the block, including use in the Hopper Decision Support System (Hopper). Grasshopper populations that lie outside but near the potential treatment block are of secondary priority. These areas may not be sampled, but you can collect data in them later during the adult survey.

Proposed Treatment Areas.—A proposed treatment area is one where grasshopper densities exceed the economic threshold (ET, determined by Hopper) for a given treatment, or where land owners or managers have indicated a desire for their lands to be treated (escrow accounts established, letters of request on file, and cooperative agreements in place). For management purposes, a single average grasshopper density is needed for the proposed treatment block. You can combine estimated grasshopper densities over all sample stops within the proposed treatment block to obtain this single average grasshopper density. This average density is useful for the decision-support process, which may include economic analysis with Hopper.

Delimiting Survey.—The purpose of a delimiting survey is to determine the perimeter of the area infested with economically important densities of grasshoppers. (The economic density can be estimated using Hopper.) Often, delimiting surveys are a continuation of the nymphal survey, and they also may be used in the adult survey to collect additional data for forecasting. These data also should be sufficient to support a single density estimate for a proposed treatment area for use in Hopper (to determine the ET). Surveyors can record key grasshopper species composition and developmental stages during the delimiting survey. Survey sites may be one-quarter to one-half mile apart. Concentrate sampling effort in the transition between high-density areas and lower density areas to delineate the perimeter of a treatment block.

Adult Survey.—This is a midseason forecasting survey timed to evaluate *economic species* (5 to 10 in each State) in prime reproductive stage (fifth instar through early adult stage) to predict hazard for the following season. Record grasshopper density, species composition, and developmental stages at survey sites. Determine priorities for survey areas to sample by using nymphal survey maps and other historical data and cooperator concerns (requests from and discussions with local people). In general, survey sites should be 5 miles apart on accessible routes. Sample areas containing grasshopper densities of the greatest concern should be sampled with more survey sites (delimit high-density areas) to provide more information for hazard prediction.

Common Data Set Survey.—These data are used to provide regional- and national-level hazard maps. A data base can be developed (and saved) for improving existing models for predicting hazard. For example, while trained surveyors frequently refer to differences in vegetation and grasshopper dynamics throughout the 17 Western United States, so far surveyors have collected little data to confirm these impressions. In an effort to describe just how different outbreak dynamics can be throughout the West, it is necessary to collect data on both density and grasshopper species composition. These data will be used to develop a better understanding of grasshopper dynamics in different ecoregions (biologically similar areas) throughout the West and provide a mix of strategic planning maps that will be valuable at regional and national scales.

These data are collected as part of the normal adult survey. In general, sample sites are at least 5 miles apart on accessible routes with uniform priority. For States that survey more than 1,000 sites, 10 percent of the sites are used for the common data set. All other States should provide data for about 100 sites.

General Guidelines for Surveying Large Areas

Each year, the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA, APHIS) conducts the preceding surveys of grasshopper populations throughout the rangelands of the Western United States. The surveys are managed within each State to meet local, State, and Federal needs for the information. Planning begins each fall for the surveys to be conducted the next summer. The survey manager determines the areas that need to be surveyed, when to begin and end each survey, survey site intervals, method of determining population, and logistics of completing the survey.

Area To Be Surveyed.—The criteria for deciding what areas to survey vary from State to State. Historical and recent information on the outbreaks of grasshopper and control activities provide the best guide to the areas that need to be surveyed. Priority is given to areas that have frequent outbreaks that tend to persist over several years. These are the areas where control is most likely to be requested.

Nymphal survey concentrates on areas that had high grasshopper densities the preceding fall and on areas that cooperators indicate may need treatment during the current season. Information from the nymphal survey is useful for making management decisions during the current season. Adult grasshopper surveys cover the general area where grasshoppers occur because information from these surveys is targeted for predicting future trends and recording historical information.

Survey managers consider many other factors when determining what areas within a State to survey. The amount of rangeland versus cropland is important in some States. Likewise, the amount of rangeland versus forested or mountainous areas is important. In recent years, Conservation Reserve Program (CRP) land is included as part of the surveyed area in some States.

The survey in Nevada targets areas where large parcels of the rangeland have burned, removing much of the sagebrush. Much of the rangeland in southwestern Wyoming is not surveyed because historical records show that, even if an outbreak occurs, it is usually short lived and grasshopper populations collapse on their own. Other States may concentrate surveys on rangeland that is sufficiently productive so that the costs of treatment can be recovered and leave out areas of low forage productivity.

Survey Timing.—The objectives of each survey are considered while planning the surveys. Weather strongly influences when each species of grasshopper will hatch. Nymphal surveys are timed to occur after the majority of the potential pest species hatch but must be completed in a timely manner, allowing management decisions to be made for effective management and forage protection. Adult surveys are timed to include the period when most individuals of the potential pest species are nearing reproductive maturity but before the seasonal population decline. This timing gives results that yield the best indication of the reproductive potential of the grasshopper populations.

Survey Site Interval.—The standard interval between survey sites used in APHIS grasshopper surveys is 5 miles, but each State office adjusts this distance to meet its own needs. When habitat or populations are homogeneous (similar) over large expanses the distance between sites can be lengthened beyond 5 miles without detriment to survey quality. If the rangeland is interrupted by crops, forest, river, or other features or the habitat or grasshopper population are localized, then shorter survey site intervals may become necessary. Often the availability of roads dictates the interval between sites.

Method of Estimating Grasshopper Density.—The 18-ft^2 sample method used by many APHIS offices in the Western United States is a simple and quick way of determining the density of grasshoppers on rangelands. (A few States use a less reliable method correlating the number of grasshoppers caught in a sweep net to a population density.) At each survey site, choose a sample area typical of the rangeland to be surveyed. Next, look ahead and determine the approximate route you will walk (fig. VI.10–1). Pick a spot on the ground about 10 paces in front of you. Choose the spot before you determine if any grasshoppers are actually present there.

Visualize a sample area surrounding the spot that is equal to 1 ft^2 on the ground. You can use landmarks such as a stick, pebble, tuft of grass, or flower to help keep your eye focused on the sample area chosen. Once the area is set in your mind, walk slowly toward the area and determine the number of grasshoppers that are in the area by counting the grasshoppers as they flush out of the visualized sample area.

Do not count individuals that hop into the sample area while counting. When you reach the spot, probe the area with the handle of your insect net or other suitable object to make sure all individuals have flushed and been

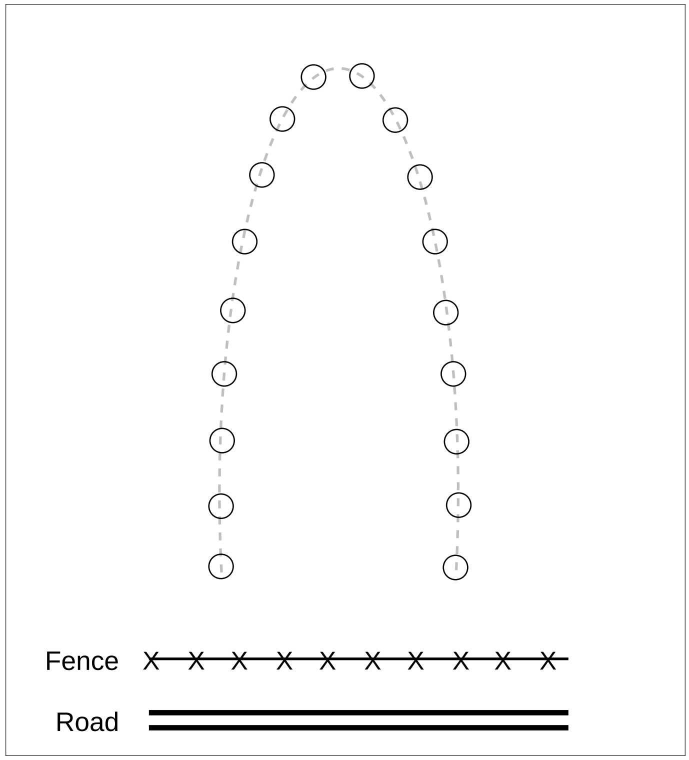

Figure VI.10–1—Configuration of the 18 1-ft^2 sample areas counted during a grasshopper surver on rangeland.

Figure VI.10–2—Using a prod can help flush grasshoppers out of the 0.1-m^2 counting rings. (APHIS photo.)

counted (fig. VI.10–2). Record the number counted and repeat the count at a total of 18 sample areas. The total number of grasshoppers counted in the 18 1-ft^2 sample areas, divided by 2, gives you the number of grasshoppers per square yard.

Logistics of Completing a Survey

After determining the area to be surveyed, survey timing, survey site interval, and the method to determine grasshopper density, you can decide the logistics for completing the survey. A combination of the size of the area to be surveyed and the site interval determines the total number of sites to be visited. For example, if the area to be surveyed is 30 million acres and the site interval is 5 miles, you will need approximately 1,875 survey sites. Plan 10 percent more survey sites for a delimiting survey where needed. For this example, the total number of survey sites is now 2,062.

Next, calculate the time it takes to sample each survey site. Include the time to actually complete the count at a survey site, plus time to record the data, travel between sites, travel to the area, contact cooperators and landowners, time lost to bad weather, and vehicle servicing and repair. This time ranges from 45 minutes to an hour and 15 minutes per site in the States surveyed by APHIS. For example, if you allot 1.1 hours for each site, to complete a survey of 2,062 sites takes 2,268 hours. If the time window to complete the survey is 6 weeks (240 work hours), 10 surveyors are needed to complete the survey. Other examples are outlined in table VI.10–1.

Issues Related to Sampling Error

Sample Accuracy, Precision, and Bias.—There are two broad criteria for evaluating sampling procedures: accuracy and precision. Both are important, and both must be present in some degree of balance.

To illustrate accuracy, imagine a person shooting a rifle at a target. If all hits are in the bull's-eye, these hits are accurate. If, however, the sights are not properly aligned, the hits will be outside of the bull's-eye. In statistical language, these hits are inaccurate, and the degree to which they miss the bull's-eye is called bias. Specifically, bias is the distance from where hits should fall to where they do fall. In terms of grasshopper sampling, accurate counts are those that include all grasshoppers that are within the correctly envisioned area. If the sampler consistently counts fewer or more grasshoppers than what are there, and/or if the sampler is envisioning an area that is smaller or larger than it should be, then the counts will be biased.

Notice that accuracy requires hits to fall in the bull's-eye, but is not concerned with size of the bull's-eye. In order to hit a very small bull's-eye consistently, surveyors need very high precision. In terms of grasshopper sampling, low precision might allow one to accurately estimate an infestation at 10–50 grasshoppers/yd^2, but high precision could accurately fine-tune the estimate to 28–32/yd^2.

Table VI.10–1—Example of logistics for completing a grasshopper survey over a large area

Survey type	Thousand acres surveyed	Stop interval (miles)	Acres represented per stop	+ 10% No. of stops	Hours to for delimiting	Hours for each stop	complete survey	Survey window	Surveyors needed
Adult	30,000	5	16,000	1,875	2,062	1.1	2,268	6 wk	10
Adult	10,000	3	5,760	1,736	1,909	1.0	1,909	5 wk	10
Nymphal	5,000	5	16,000	313	344	1.1	278	3 wk	3
Nymphal	25,000	10	64,000	390	430	1.2	516	2 wk	7
Delimiting	25	0.5	160	156	N/A	0.5	78	3 d	4
Delimiting	100	2	2,560	39	N/A	0.75	30	2 d	2

Land managers realistically can desire both accuracy and a certain minimum level of precision. Accuracy of grasshopper sampling can be affected by a number of factors will be discussed here. As far as we know, however, there is only one way to increase precision (estimate density within a narrower range), and that will be the subject of the next two paragraphs.

Rangeland grasshoppers generally appear to be distributed at random, with predictable probabilities of occurrence within samples taken at reasonably homogeneous sites. In mathematical terms, grasshoppers follow a "Poisson" distribution (a probability function which offers a description of a number of possible outcomes), which is not typical of most insects. Therefore, grasshopper sampling requires some atypical rules.

For all practical purposes, surveyors can increase sampling precision only by accurately counting more grasshoppers. This can be accomplished only by taking more samples in an accurate manner because an individual sample area cannot be increased without an accompanying loss in accuracy. In 1981 Onsager published a simple relationship between the counts and precision. In general, rapid gains in precision are made by continuing to examine samples until at least 40–60 total grasshoppers have been counted. On the other hand, there is little to be gained in precision by sampling after 150–200 grasshoppers have been counted.

Estimated (Visualized) Versus Delineated Samples.— For all but the most experienced persons, samples that are mechanically delineated (by wire frames or hoops) should yield greater accuracy and consistency between different individuals than visualized or estimated samples (fig. VI.10–3). Delineated samples are inconvenient in that templates should be placed about a day before they are examined (necessitating two trips to each survey site) and they require investment in bulky, single-purpose equipment. However, during the training process or when high accuracy is very important, the extra effort associated with delineated samples is worthwhile.

Sample Area Size.—Experiments have shown that examination of sample areas as large as 1.08 ft^2 (0.1 m^2) tends to detect only about 90 percent of the true density estimated by less subjective but more labor-intensive methods of sampling. Successively larger sample areas

Figure VI.10–3—One of the most valuable tools in field surveys is the 0.1-m^2 counting ring. Counting the number of grasshoppers in a series of rings provides an accurate count of grasshoppers per square meter or square yard. (USDA photo.)

detect successively lower percentages of the true density, so the 1-ft^2 sample area is about as large as even a well-experienced sampler should attempt to examine. Experiments found that persons with moderate experience were able to count grasshoppers accurately in 0.06-ft^2 (0.05-m^2) rings, even when densities exceeded 125/yd^2. That area is approximately the size of a 9-inch pizza pan (about 1/20 of a square yard) or an 8 1/2- × 8 1/2-inch square (about 1/18 of a square yard).

Bias in Selecting a Site.—Sample sites must be representative of the general area. Atypical vegetation or topography could influence grasshopper density and species composition. For example, surveyors should avoid sites near roads, cattle trails, ditchbanks, fencelines, or any features not representative of the general habitat in the area.

Bias in Selecting a Visualized Sample Area.—Even a slight bias may seriously affect the outcome of the survey. If a sampler counted only 1 more grasshopper per sample than was actually present, the density estimate would be increased by 9 grasshoppers/yd^2 (assuming that

9 samples/yd^2 are taken at each survey site). Subconsciously, a sampler may choose movement by a grasshopper to be the center or edge of the area that will be visually delimited and counted. To demonstrate the potential for bias, one need only consistently use the last grasshopper movement as the edge of the visualized area and not include that grasshopper in the count. Such counts are obviously low estimations of actual densities. To prevent inaccuracy, exercise great care to select a point, patch of vegetation, pebble, or small topographic feature from which to base the boundaries of the visualized sample area. These boundaries must be established before the counting begins.

Sample Area Shape.—Most experienced samplers agree that the best sample area shape is the one they were taught to use. Some prefer squares while others prefer circles, and both can defend their viewpoint. Advantages of squares are that standard areas are easily visualized, and a variety of standard templates are easily found or constructed. For example, the suggested 8 1/2- × 8 1/2-inch square template can be made from a standard sheet of writing paper. However, a visualized square entails keeping mental track of four 90-degree corners that are equidistant from each other and connected by straight lines.

The advantage of circles is that a sampler can concentrate on one central point plus a constant omnidirectional radius without shifting focus. However, a circular standard area is not easy to visualize without studying a standard template, and round templates usually are not available in a variety of convenient dimensions. For example, a 0.5-ft^2 circular template would require a diameter of 9.57 inches.

Effects of Weather.—Variations in daily weather conditions probably contribute more to sampling error than any other single factor like size or shape of typical samples, visualized versus delineated sample areas, or total area sampled. Cool temperatures reduce grasshopper mobility, and lack of mobility can make smaller grasshoppers inconspicuous and larger ones relatively easier to spot before they flush. Cool weather most often occurs during the nymphal stages, when their small size makes grasshoppers most difficult to see. Under such conditions, additional prodding with a stick or pole is required to provoke movement and ensure that all grasshoppers in the sample area are counted.

Under extreme conditions, the sampler will have to stoop and brush the ground with a hand to ensure a more accurate count. Warm temperatures are generally the best condition for conducting surveys because of the increased activity of grasshoppers and ease with which they are seen. However, because of this increase in activity, the sampler must begin concentrating on the sample area from a greater distance. Higher temperatures are usually associated with sunny conditions, which can cause the sampler's own shadow to become a factor. The sampler must approach the sample so the shadow will not flush grasshoppers prematurely.

Cloudy conditions reduce general visibility and can make some inconspicuous grasshopper species even more difficult to detect. Rain or mist may reduce the activity of grasshoppers even more than cool temperatures. In addition, rain or mist causes grasshoppers to hide and may prevent movement even when prodded. When counts are conducted in the rain, even with extra care, they are generally lower than the actual density of grasshoppers. Therefore, grasshopper surveys should not be conducted under these conditions.

Wind can be particularly troublesome when it is strong enough to provide a lot of background movement within the plant canopy, to alter the normal trajectory of grasshoppers that hop in the vicinity of the sample, or to whisk away grasshoppers that take flight. Under these conditions, probing with a stick to flush grasshoppers may also dislodge seeds or other dry pieces of vegetation, which blow in the same direction as most disturbed grasshoppers. When this happens, some seeds (those that appear to be grasshoppers) will need to be followed and probed again to determine if they were grasshoppers.

In itself, wind can become a major distraction to the concentration of the sampler. Wind moves clothing, equipment, and other items near the site and/or the sampler. If collections of grasshoppers are required in addition to the count, the consistent operation of a sweep net sometimes may become almost impossible. Wind generally is accompanied by other adverse conditions and tends to further aggravate less-than-ideal conditions already present. Walking at an angle to the wind is helpful, but going slower, concentrating harder, and spending more time at each sample are requirements for achieving accurate counts under windy conditions.

When weather conditions become increasingly unfavorable, it is critical that a sampler apply an increasing level of concentration if survey data are to have meaning. Nevertheless, in spite of the highest degree of concentration, if foul-weather sampling should yield high densities near some pivotal action threshold, it would be wise to verify some of the results later during favorable weather.

Effects of Habitat.—The nature of the vegetative canopy can affect sampling results. A short, sparse, and uniform canopy is easiest to sample accurately. A classic example would be crested wheatgrass that has been mowed or subjected to moderate grazing pressure. As vegetation becomes taller, the vertical dimension increases the volume you must examine simultaneously for grasshoppers. When vegetation becomes more dense, as when the sampler goes from bunchgrass to sod, it becomes easier to overlook smaller nymphs or species.

Where vegetation is strongly clumped, it becomes more difficult to apply representative sampling intensity to occupied and unoccupied portions. Habitats dominated by tall, thick, well-spaced clumps of shrubs are the most difficult to sample. Sample areas with dense vegetation require thorough probing with a stick, even under the best weather conditions.

Other Insects.—You may confuse other insects with grasshoppers as the other insects move from a sample area when the sampler approaches, probes, or brushes the area by hand. Most often, these insects are leafhoppers. During nymphal surveys, leafhoppers can be about the same size as very young grasshoppers. At low densities, you can follow these small insects and flush them again to determine if they are grasshoppers. Grasshoppers and other insects that move ahead of the sampler may land and flush new grasshoppers from a sample area before they can be counted. Be aware of this possibility, especially during the adult survey.

Disturbance of Sample Area.—Sample areas undisturbed for 24 hours before survey can produce accurate counts. Disturbance of sample areas just prior to or during counting can reduce the density estimate significantly. Cattle grazing or moving through the site are the most frequent source of direct disturbance. Vehicles driven by the sampler or others through or near the site also can affect the count. Nearby farming activity, such as harvesting or irrigation, may cause local movement of grasshoppers, and that can affect the counts. If densities at sites near these activities yield results that are of concern, additional counts at a later date may be required.

Dense Grasshopper Populations.—When finding grasshoppers at densities of 1 per square foot or fewer, counting is relatively easy. In denser populations where you flush several grasshoppers from each sample area, take greater care. When this happens, the sampler should take a mental picture of the action in the sample area to estimate the number of grasshoppers.

Concentration of the Sampler.—Concentration plays the central role in dealing with all factors that affect survey and can become critical at the end of a long day for a tired sampler. Many of the factors that complicate surveying are uncontrollable, but you can practice and improve concentration. A sampler may take several actions to maintain good concentration. A sampler continually using visualized sample areas can recalibrate by frequently referring to a physical template the size of the visualized area to be counted.

Removal of as many distractions as possible during the actual counting can help greatly. Wearing a billed hat or cap not only shades the eyes from the sun but can help focus the attention toward the ground and reduce distraction. The use of a long probing stick helps flush grasshoppers from the sample area. By simply slowing down while approaching and counting sample areas, you can reduce or eliminate many problems.

Training New Scouts

In the past, it was common practice for an experienced sampler to line up a class of novices, have everyone count grasshoppers in a certain number of visualized sample areas, compare results, and repeat the process until counts by the novices approximated those by the expert. There are three major disadvantages to this system. First, the expert may have unknown biases that are then passed on to the trainees. Second, a trainee cannot verify or recalibrate density estimates in the absence of an expert. Third, the system cannot be used for self-instruction.

A novice must learn to overcome two major tendencies that contribute to sampling error. The first is a tendency to overestimate size of the sample area. The second is a tendency to count all grasshoppers that are moving in the general vicinity of the sample area, even though there is uncertainty whether the movement originated inside or outside of the sample area. Both of these negative tendencies can be minimized by starting trainees out with delineated samples (all sample areas marked with wire rings or squares). When the trainees show proficiency with that setup, they can advance to using visualized sample areas and then carry one standard template along for periodic confirmation or recalibration of proper sample area size. To obtain accurate counts, sample areas should be small enough to be totally comprehended without shifting the focus of attention (preferably about 0.5 ft^2 each, but not over about 1 ft^2; see Issues Related to Sampling Error, Sample Area Size in this chapter).

The Importance of Species Composition and Developmental Stage

Information on species composition and average stage of development is necessary to take maximum advantage of biological relationships that are considered in Hopper (see VI.2). Useful information may include proportions and developmental stage of grasshopper infestations made up of known pest species, grass feeders, mixed feeders, forb feeders, or bait feeders. Environmental assessments of proposed management activities also may require such documentation.

Determine species composition by collecting with a sweep net (fig. VI.10–4) and identifying at least 50 grasshoppers from what is judged to be representative habitat. Other chapters in section VI of the User Handbook provide help in identifying grasshoppers. Because issues about habitat representation are beyond the scope of this chapter, our concern is largely reduced to the question, "How many grasshoppers do we need to identify?" We can develop some intuitive guidelines through examination of binomial confidence limits (mathematical description of confidence associated with an estimate) if we can agree on some useful examples of proportions that we will regularly encounter.

Figure VI.10–4—Catching grasshoppers in a sweep net is the first step in determining which of many species are active in a given area. (APHIS photo.)

In our experience, three to six pest species usually dominate extensive outbreaks of grasshoppers. As troublesome infestations build up over a time scale of several seasons, sweep-net samples tend to recover an increasing total number of species. Nevertheless, the proportion of individuals in the samples that are known pest species also tends to increase. Let's consider two normal examples. First, assume that 90 percent of the grasshoppers are pest species. Second, assume that 50 percent of these grasshoppers are bait feeders (bait treatment probably will not be effective under these conditions).

Figure VI.10–5 shows 95 percent confidence limits for composition of 50 percent and 90 percent based on sample sizes ranging from 50 to 800 total grasshoppers. Notice that the highest proportion obviously is the easiest one to estimate precisely. For example, if 90 percent of a sample of 50 grasshoppers (45 of them) from 1 sample site are pest individuals, figure VI.10–5 suggests that the true proportion likely is somewhere between 78 percent and 97 percent, a range of 19 percentage points. If half of them (25) are bait feeders, the figure suggests that the true proportion is somewhere between 36 percent and 64 percent, a range of 28 percentage points.

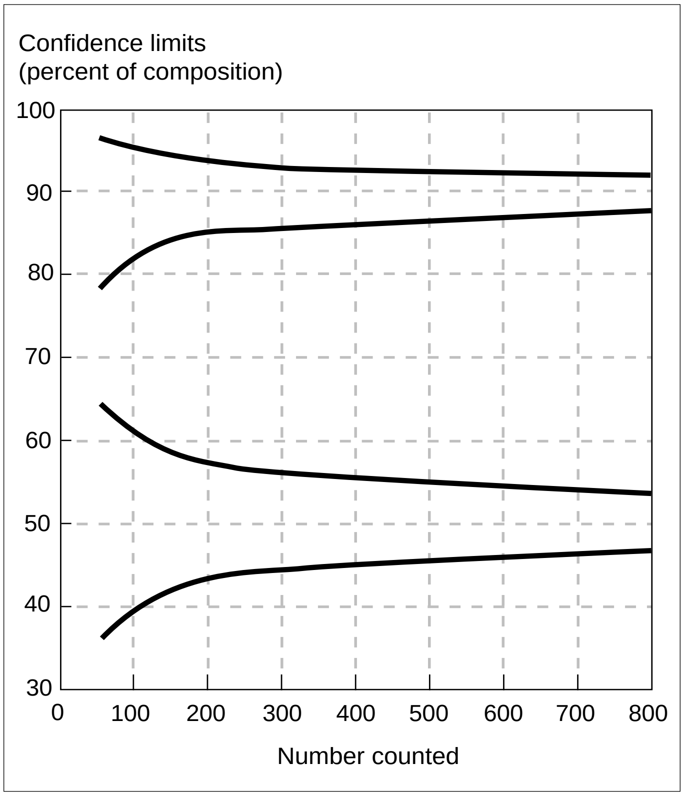

Figure VI.10–5—Confidence limits in relation to numbers of grasshoppers counted.

If those broad ranges do not inspire sufficient confidence to support a management decision, then we need to examine a larger sample or sample more sites. If our estimate of 90 percent pest species was from examination of 50 grasshoppers from each of 16 sites (720 out of 800), then the true composition is likely between 88 percent and 92 percent, a range of only 4 percentage points. Notice in figure VI.10–5 that our confidence intervals improve rapidly as sample size increases to about 200–300 grasshoppers. Notice also that minor improvements require major increases in effort when counts exceed about 400 grasshoppers.

Average stage of development usually is estimated as the summation of each observed instar number (adults are considered sixth instar for this purpose) divided by the number of individuals. Thus, for 20 fifth instars and 30 adults, the average stage is

$$\frac{(20 \times 5) + (30 \times 6)}{(20 + 30)} = \frac{100 + 180}{50} = 5.6.$$

During the nymphal survey, the stage of development is important for at least four major reasons. First, it is an indication of whether egg-hatch is completed. When very early instars predominate, it is possible that continued hatch will cause future increases in density. Second, knowing the stage of development helps to establish viable action windows. For example, if average life stage is 5.0, we know we have about 24 days until egg laying seriously begins to negate the opportunity for reducing next year's population. Third, the developmental stage is used to estimate the amount of forage destruction that can be prevented by a treatment. For any given treatment, application early in the action window should be more economical than late in the action window. Fourth, ascertaining the developmental stage correctly makes it possible to time the adult survey accurately.

In certain cases, it may be advisable to exclude particular species from the calculation of average stage of development. For example, in predicting the expected short-term response to a bait treatment, the developmental stage of grasshopper species that do not eat bait is irrelevant. Similarly, in estimating the economic benefits of a spray treatment, the developmental stage of nontarget species is not a consideration.

Future Considerations: The Potential for Sequential Sampling

Sometimes the number of grasshoppers per square foot is so low or so high that taking the full complement of required samples is a ridiculous waste of time. Under these circumstances, ranchers, university Cooperative Extension personnel, weed and pest district supervisors, and even USDA, APHIS grasshopper scouts could spend more of their sampling time on other tasks. Further, some scouts might intuitively leave a survey site before examining all samples when grasshopper densities are very low or extremely high. This is could be a perfectly valid thing to do for very busy people; in fact, it represents a crude form of something we call sequential sampling.

What is sequential sampling and how can it be used to sample grasshoppers? Well, it is the process of classifying grasshopper infestations into “high,” “low,” or “too close to call” categories, in sequence, from one sample to the next. Sequential sampling can save a lot of time by allowing you to stop sampling at a site when it has been determined, by a sequential sampling plan, that grasshopper densities are very low or extremely high. The technology for developing and using sequential sampling has been around for a long time, but is just now being proposed for use in grasshopper sampling.

Lower and upper grasshopper densities levels must be specified to use a sequential sampling plan. For example, we could specify grasshopper densities below which infestations are of no economic concern and above which economic concern may be justified. The computer program Hopper will allow you to calculate economic thresholds so that you can generate these upper and lower density levels.

Using sequential sampling, three possibilities exist after each sample: (1) density could be declared less than a lower level, say, 8/yd^2; (2) density could be declared greater than an upper level, say, 16/yd^2; or (3) no such decision may be concluded. When the first or second decision is made, sampling can stop because the infestation has been classified. When the third situation occurs, examination of another sample is mandated.

If a classification is not made within some arbitrary number of samples (say, within 18 samples), then sampling can stop and the grasshopper infestation is declared as being between the two levels. If this third decision occurs at most survey sites, use sequential sampling at a later date to determine whether the population has changed. Note that the total number of sample areas at 1 survey site can range from 1 to 18 in our example.

The advantages sequential sampling are several:
- It will save time when actual densities are either well above or well below the upper and lower levels.
- It reduces the number of samples at most survey sites.
- It allows the sampler to predetermine the proportions of decisions that will be correct. For example, a person could specify that at least 9 of 10 sites be correctly classified.
- It can be used to delimit the borders of grasshopper infested areas.

But sequential sampling also has some disadvantages:
- Density estimates will be less precise if sequential sampling is used and a classification is reached with a low number of samples.
- Some erroneous classifications cannot be avoided.
- A table must be consulted to know when to stop sampling.

How To Conduct a Sequential Sampling Effort.— Sequential sampling can be conducted by either counting all grasshoppers or by simply noting their presence or absence (presence–absence sequential sampling) in successive samples. Here, we offer an example of the presence–absence method.

In Wyoming, there is a need to develop a grasshopper sampling plan for use by ranchers, Cooperative Extension system personnel, and weed and pest district employees. The objective is to help these individuals rapidly decide if grasshopper densities are less than 8/yd^2 (no cause for concern), greater than 16/yd^2 (potential cause for concern), or in between (worth watching). These levels of grasshopper densities may be referred to as the lower and upper thresholds, respectively. Also, we can set these thresholds to any values that are appropriate for a specific situation.

In this example, we will use a visualized sample area defined by folding a sheet of 8 1/2- × 11-inch paper into an 8 1/2- × 8 1/2-inch square (0.5 ft^2). Once you have calibrated your eyes to the 8 1/2- × 8 1/2-inch square, take a copy of table VI.10–2 and examine the first sample at a survey site. If it contains no grasshoppers, write a zero in the “Running total” slot opposite sample number 1 (as shown in table VI.10–3, example A).

If there are no grasshoppers present in the second sample area, then add zero to the previous running total and enter zero in the “Running total” slot for “Sample area” number 2, as shown in table VI.10–3, example A. However, if at least one grasshopper is present in the second sample area, then add 1 to the previous running total and enter 1 in the “Running total” slot for “Sample area” number 2, as shown in table VI.10–3, example B. This new running total is then compared to the lower and upper stop values. Each time a sample area contains at least one grasshopper, add 1 to the running total. A minimum of four

Table VI.10–2—Presence–absence sequential sampling stop values for levels of 8 and 16 grasshoppers/yd², assuming samples areas are 0.5 ft² each. Note that other sample area sizes cannot be used with this table.

Sample number	Lower stop value	Running total	Upper stop value
1	—	_____	3
2	—	_____	3
3	—	_____	4
4	0	_____	4
5	0	_____	5
6	1	_____	5
7	1	_____	6
8	1	_____	6
9	2	_____	7
10	2	_____	7
11	3	_____	8
12	3	_____	8
13	4	_____	8
14	4	_____	9
15	5	_____	9
16	5	_____	10
17	6	_____	10
18	6	_____	11

samples is needed in this case to yield a running total that is potentially less than or equal to the lower stop value or is greater than or equal to the upper stop value. If either case is true, you can stop sampling and declare the infestation as being 8 or fewer per square yard or 16 or more per square yard, respectively. Thus, the sampling process repeats itself until one of the following occurs:

- The running total is equal to or less than the lower stop value (table VI.10–3, example A),
- The running total is equal to or greater than the upper stop value (table VI.10–3, example B), or
- A density classification has not been made after the 18 samples have been examined (table VI.10–3, example C).

Corresponding decisions about grasshopper infestations for this example may be found at the bottom of table VI.10–3.

As mentioned, you also can do sequential sampling by counting each grasshopper in each sample area. If this is done, the sampler must keep a running total of the number of grasshoppers counted, and the stop values used are different from those shown in table VI.10–2. This kind of sequential sampling would be useful in delimiting surveys where grasshopper density estimates are needed.

If sequential sampling is to be used throughout a State or region, then flexible methods for choosing realistic lower and upper thresholds must be developed.

Future Considerations: Electronics

Electronic mapping, using geographic information systems (GIS) (see VI.9) may be very useful for grasshopper survey. For example, maps produced using GIS are useful for historical perspectives, analyses of ecological correlates (such as topography, vegetation, and soil), planning surveys, and allocating limited resources. GIS also will allow maps to be updated daily during a survey. We can use these maps to focus the survey effort on the most important areas as the season unfolds.

Computer-interpolated maps of grasshopper densities can be combined with land-use maps, ecological buffer zone maps, and land ownership maps to produce final treatment area maps. GIS software also can calculate the size of any defined area on an electronic map. These maps can be printed on paper to be used in the field or for display at meetings.

Economical battery-powered, hand-held computers hold much promise for grasshopper surveys. Scouts recently have used these types of computers in the field to enter and store data. These data can be transmitted through normal telephone lines to a computer centrally located in each State. Sequential sampling protocols, described earlier in this chapter, could be programmed into these computers. The user would simply enter the number of grasshoppers in each sample area, and the computer could store and analyze the data and notify the user when to stop sampling.

Other types of electronic data-collection equipment being used at some sites store environmental data important for

Table VI.10–3—Three examples of using a presence–absence sequential sampling plan

Example A				**Example B**				**Example C**			
Sample area	Lower stop value	Running total	Upper stop value	Sample area	Lower stop value	Running total	Upper stop value	Sample area	Lower stop value	Running total	Upper stop value
1	—	0	3	1	—	0	3	1	—	0	3
2	—	0	3	2	—	1	3	2	—	0	3
3	—	0	4	3	—	2	4	3	—	0	4
4	0	0	4	4	0	3	4	4	0	1	4
5	0	[quit]	5	5	0	4	5	5	0	2	5
6	1		5	6	1	5	5	6	1	2	5
7	1		6	7	1	[quit]	6	7	1	2	6
8	1		6	8	1		6	8	1	3	6
9	2		7	9	2		7	9	2	4	7
10	2		7	10	2		7	10	2	4	7
11	3		8	11	3		8	11	3	4	8
12	3		8	12	3		8	12	3	5	8
13	4		8	13	4		8	13	4	5	8
14	4		9	14	4		9	14	4	6	9
15	5		9	15	5		9	15	5	6	9
16	5		10	16	5		10	16	5	7	10
17	6		10	17	6		10	17	6	7	10
18	6		11	18	6		11	18	6	8	11
Decision: Infestation is less than 8 grasshoppers/yd^2.				Decision: Infestation is greater than 16 grasshoppers/yd^2.				Decision: Infestation is between 8 and 16 grasshoppers/yd^2.			

grasshopper research and management. These devices automatically log information, such as temperature and precipitation, for weeks at a time without human intervention. Technology that allows a computer to read hand-written data directly from data sheets is also becoming available. A scout could use a standard pen and clipboard to record the data on a printed data sheet in the field. The data sheet could then be faxed directly to a waiting computer or delivered to a site with a page scanner and scanned into a computer. In both cases, software could read the image made from the data sheet, interpret the information, and automatically store it in a data base that corresponds to the specific data sheet. Paper data sheets would be inexpensive, familiar, and highly reliable for field data entry. Data still could be rapidly acquired and distributed for use in management decisions.

Another technology that is already showing usefulness for rangeland grasshopper management is Global Positioning System (GPS). With GPS, hand-held units receive information from navigational satellites and calculate the location coordinates of the unit. Surveyors can obtain latitude and longitude coordinates even for the most remote sites where there are no distinguishing landmarks. A computer can use these coordinates to map any data collected at the site. Also, the hand-held units help a person navigate back to a site.

High-quality survey data always will be the basis for sound management decisions. Most of these data will be collected by humans working under various conditions in the field. This chapter provides reference for current survey activities and a starting place for future innovations in survey technology.

VI.11 Major Grasshopper Species of the Western Rangeland States and Alaska

R. Nelson Foster

On rangeland, the number of grasshopper species that occur across an area of several thousand acres typically ranges from about 15 to 40. Assemblages of grasshopper species in each of the western rangeland States can differ considerably. The makeup of these assemblages also can vary between locations within a State and from year to year at the same location.

To make wise management and treatment decisions requires a knowledge of the species that make up the populations of concern. To aid land managers and pest managers in making their decisions, the Animal and Plant Health Inspection Service plant health directors in the rangeland States recently provided a listing of major grasshopper species in the States.

The listing is a combination of responses to two questions asked of each plant health director on separate occasions: (1) What are the 10 most important grasshopper species in your State? and (2) what are the top 10 pest species of grasshoppers in your State? Species are listed alphabetically in table VI.11–1 with full names, and listed by occurrence in States in table VI.11–2. The listings will be especially useful in combination with Pfadt's "Field Guide to Common Western Grasshoppers" (described in VI.5) and Hopper Helper (VI.7).

The two species that occurred most frequently (16 out of 18 States) in responses are *Ageneotettix deorum* and *Melanoplus sanguinipes.* Next in terms of frequency are *Aulocara elliotti* (in 14 out of 18 States) and *Camnula pellucida* (13 out of 18 States). Four other species—*Melanoplus bivittatus* and *Melanoplus femurrubrum* (both 11 out of 18 States) and *Amphitornus coloradus* and *Phlibostroma quadrimaculatum* (both 10 out of 18 States)—are of concern in a majority of rangeland States. All other species in these surveys were of concern in fewer than 10 States.

The lists are not limited to species that cause economically unacceptable levels of damage. Grasshoppers noted on the lists include the most commonly encountered species in each State, some of which may not be considered economically damaging to rangelands.

Some species usually considered nonpests are included because they may occur in significant numbers at some

Table V.11–1—Grasshopper species most frequently encountered and pest species (with full names), listed alphabetically

Aeropedellus clavatus (Thomas)
Ageneotettix deorum (Scudder)
Amphitornus coloradus (Thomas)
Arphia conspersa Scudder
Aulocara elliotti Thomas
Aulocara femoratum (Scudder)
Camnula pellucida Scudder
Campylacantha olivacea (Scudder)
Conozoa sulcifrons Scudder
Cordillacris crenulata (Bruner)
Cordillacris occipitalis (Thomas)
Eritettix simplex (Scudder)
Hesperotettix viridis (Scudder)
Melanoplus angustipennis (Dodge)
Melanoplus bivittatus (Say)
Melanoplus borealis (Fieber)
Melanoplus confusus Scudder
Melanoplus cuneatus Scudder
Melanoplus devastator Scudder
Melanoplus differentialis (Thomas)
Melanoplus femurrubrum (DeGeer)
Melanoplus foedus Scudder
Melanoplus gladstoni Scudder
Melanoplus infantilis Scudder
Melanoplus marginatus (Scudder)
Melanoplus occidentalis (Thomas)
Melanoplus packardii Scudder
Melanoplus rugglesi Gurney
Melanoplus sanguinipes (Fabricius)
Mermiria bivittata (Serville)
Metator pardalinus (Saussure)
Oedaleonotus enigma (Scudder)
Oedaleonotus pacificus (Scudder)
Opeia obscura (Thomas)
Orphulella speciosa (Scudder)
Phlibostroma quadrimaculatum (Thomas)
Phoetaliotes nebrascensis (Thomas)
Psoloessa delicatula Scudder
Schistocerca emarginata (Scudder)
Syrbula admirabilis Uhler
Trachyrhachys kiowa Thomas
Xanthippus corallipes Haldeman

Table VI.11–2—Major grasshopper species of the western rangeland States and Alaska

Species	AK	AZ	CA	CO	ID	KS	MT	NB	NV	NM	ND	OK	OR	SD	TX	UT	WA	WY
Gomphocerinae																		
Aeropedellus clavatus											x							
Ageneotettix deorum		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Amphitornus coloradus		x				x	x			x	x	x		x	x		x	x
Aulocara elliotti		x			x	x	x		x	x	x	x	x	x	x	x	x	x
Aulocara femoratum			x	x		x				x		x			x			
Cordillacris crenulata				x						x								
Cordillacris occipitalis				x						x								x
Eritettix simplex		x						x			x							
Mermiria bivittata		x																
Opeia obscura				x		x		x			x			x				
Orphulella speciosa						x												
Phlibostroma quadrimaculatum				x	x	x	x	x		x	x			x	x			x
Psoloessa delicatula		x						x										
Syrbula admirabilis						x												
Oedipodinae																		
Arphia conspersa			x															
Camnula pellucida	x	x	x	x	x		x		x	x	x		x			x	x	x
Conozoa sulcifrons																	x	
Metator pardalinus		x																
Trachyrhachys kiowa				x			x				x	x		x				x
Xanthippus corallipes			x													x		
Melanoplinae																		
Campylacantha olivacea								x										
Hesperotettix viridis										x			x					
Melanoplus angustipennis								x										
Melanoplus bivittatus			x	x	x		x		x	x		x	x		x	x	x	
Melanoplus borealis	x																	
Melanoplus confusus											x							
Melanoplus cuneatus		x								x								
Melanoplus devastator			x															
Melanoplus differentialis			x		x							x			x	x		
Melanoplus femurrubrum	x		x		x			x	x			x	x	x	x	x	x	
Melanoplus foedus					x							x	x		x		x	
Melanoplus gladstoni								x										
Melanoplus infantilis					x		x				x			x				x
Melanoplus marginatus			x															
Melanoplus occidentalis																		x
Melanoplus packardii			x		x	x	x		x	x			x			x	x	
Melanoplus rugglesi									x									
Melanoplus sanguinipes	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x

Table VI.11–2—Major grasshopper species of the western rangeland States and Alaska (Continued)

Species	AK	AZ	CA	CO	ID	KS	MT	NB	NV	NM	ND	OK	OR	SD	TX	UT	WA	WY
Oedaleonotus enigma			x		x				x				x			x	x	
Oedaleonotus pacificus			x															
Phoetaliotes nebrascensis						x		x						x				
Cyrtacanthacridinae																		
Schistocerca emarginata			x															

Note: The importance of some species in some States has changed over the years. For a comparison with a 1969 listing of species and their potential for damage by State, see: Grasshopper Survey: A Species Field Guide, published in 1969 by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine unit. Copies of the 1969 publication are available from the National Technical Information Service, U.S. Department of Commerce, P.O. Box 1425, Springfield, VA 22151. The publication, number P95241436, is available in print for $19.50 and on microfiche for $9.00.

sites during survey. For example, overwintering species such as *Psoloessa delicatula, Eritettix simplex, Xanthippus corallipes,* and *Arphia conspersa*—which rarely if ever cause concern—may occur in significant numbers late in the summer. The early hatching species, *Aeropedellus clavatus* and *Melanoplus confusus*, feed at a time of year when forage removal is generally irrelevant. These two species are included because they are common in some areas and signal the awakening of the grasshopper season.

Hesperotettix viridis, which feeds on broom snakeweed and burrowweed, is considered a beneficial species but is included because it can occur in high numbers at some locations. In addition, some species usually considered to be cropland species—such as *Melanoplus bivittatus, M. differentialis, M. femurrubrum,* and *M. packardii*—are frequently found on rangeland and hence are included.

The circumstances under which a species or a combination of species occurs is what determines the economic importance of a particular species at a particular time. By themselves, many of the species listed here would not be economic pests, but together with other species, the population may cause damage.

A knowledge of the most commonly encountered species in each State will promote a better understanding of the grasshopper populations and will provide the foundation for making good management and pest treatment decisions involving rangeland grasshoppers.