Show Me a Picture, Tell Me a Story:
An Introduction to Graphs for the Analysis of Ecological Data from Schoolyard Science Research Studies

Harvard Forest Schoolyard Ecology Program
Harvard Forest, Petersham, MA, USA

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This manual is a publication of the Harvard Forest Schoolyard Science Program. The text and most of the graphs of schoolyard science data in this manual were prepared by Dr. Betsy A. Colburn, Aquatic Ecologist. Pamela Snow, Harvard Forest Schoolyard Coordinator, compiled pertinent national and state education standards. Harvard Forest researchers and Schoolyard Science collaborators Dr. Emery Boose, Information Manager, Dr. John O'Keefe, Fisher Museum Director, and Dr. David A. Orwig, Forest Ecologist, contributed research graphs and provided valuable insights and feedback.

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We extend special thanks to the anonymous donor who provided the funds that made this educational project possible. Thank you.

Please Provide Feedback

We hope that you will find this material interesting and of practical use. Do give us feedback, so that the final manual will be as useful as possible to classroom teachers carrying out schoolyard ecology studies with their students. Whether your students are carrying out research according to protocols available through the Harvard Forest LTER program or are conducting other kinds of ecological studies, we would value your input. Please feel free to send us feedback if you run into difficulties or if you have suggestions for improvements or further refinements. You can send your comments by email to Pamela Snow, Harvard Forest's Schoolyard Coordinator, (psnow@fas.harvard.edu).

Dedication

This manual and the accompanying exercises are dedicated to all the classroom teachers who share their excitement and enthusiasm about science and the natural world with their students. Your work changes lives and makes the Earth a better place for all of its inhabitants. We salute you for it!

1. Introduction

Chapter Overview:

This chapter covers
- The approach we take to graphing in this manual
- How the manual is organized

You and your students are carrying out field studies on an ecological question. Once you have collected data, how do you look at and interpret the information? Graphs can be valuable tools for examining and interpreting research results.

Scientists regularly create graphs as a way of visualizing patterns in data, and of showing those patterns to others. We use pictures – graphs – to help us explain our research results – to tell the story we are learning about how some aspect of nature works.

Teachers involved in Harvard Forest’s Schoolyard Science Program have requested more information on ways that they and their students can work with data that they collect in field research studies. This manual is intended to introduce teachers to some options for organizing, manipulating, and graphing student data. It includes background information as well as multiple examples of graphs from data collected by teachers and students in the course of schoolyard research studies. The basic concepts and approach are applicable to many graphing programs available on computers, and also to graphing data by hand.

Our Approach to Understanding Graphing

Our intent in developing this manual is to introduce teachers to graphing in the broader context of how scientists analyze ecological data. We therefore approach graphing of Schoolyard Science data from several perspectives. This manual presents

- an overview of the ways scientists use graphs to help them understand their data,
- a discussion of how field data can be organized into different kinds of data sets, including specific examples pertinent to schoolyard ecology data,
- an explanation of the kinds of data manipulations and corrections that are usually necessary before data can be graphed or otherwise analyzed, using a schoolyard data set to illustrate key points,
- a review of different kinds of graphs,
- examples of graphs from Harvard Forest scientists’ research, and
- graphs of real field data collected by students whose teachers have been participating in Harvard Forest’s Schoolyard Science Program.

Some data are graphed several ways to illustrate how different kinds of graphs can provide different insights into research results. Each graph is discussed in terms of the data that it illustrates, and it is interpreted in relation to patterns that may be brought into focus, suggested trends that may be worth exploring, any potential anomalies or odd behaviors in the data that need to be accounted for, and/or other features that may be of particular interest.

What Information is Where?

This manual is divided into five chapters. Following this introductory chapter are chapters on educational goals and standards, data sets and kinds of graphs, preparing data for graphing, and examples of graphs prepared from schoolyard science data.

Chapter 2, Graphs in the Classroom, considers graphing in the broad context of Schoolyard Science, and of education in general. It includes some general thoughts about why teachers may want to teach their students about graphs and graphing. It also discusses ways that lesson plans that involve data analysis through graphs help meet formal educational goals in state curriculum frameworks. This section includes specific state and national educational goals that can be met through graphing instruction. Finally, it considers specific ways that graphs may contribute to, and enhance, science education, including but not restricted to Schoolyard Science programs.

Chapter 3, Understanding Data and Graphs, presents a broad overview of some topics that are key to understanding data, deciding how to present data in graphical form, and interpreting graphs. It first discusses how to organize and work with data files, including ways to organize and format data for graphing. Then, it presents an overview of different kinds of graphs, including pie charts, bar graphs, scatter plots, and line graphs. Examples of graphs developed from research data collected by Harvard Forest scientists and from Schoolyard Science data from participating classrooms are used to illustrate how different kinds of graphs can be used to obtain different kinds of information from a data set. Some data sets are graphed in several different ways.

Chapter 4, Preparing Data for Graphing, looks at the steps involved in getting data ready for graphing. It first considers sorting and checking data to find missing data and errors. It then discusses some indications that the data will need to be standardized or changed, and gives an example of converting raw data into a percentage. It also shows how you can extract additional data from a data set and organize the new information for analysis. The steps are illustrated with a set of fall phenology data collected over a four-year period by middle-school students in Athol, MA. The data show leaf fall over time for 11 trees studied each autumn from 2004-2007.

Chapter 5, Presenting Schoolyard Ecology Data in Graphs, presents and interprets 15 graphs illustrating schoolyard science studies. Most of the examples show data on leaf-fall phenology.

These graphs are based on the schoolyard leaf-fall data set used in Chapter 4. They include the following.

- Three simple graphs, a pie graph, a stacked bar graph, and a bar graph by species, showing the composition of the study tree population.
- Graphs showing the time course of leaf fall in a single tree over time, in a single year and over multiple years.
- A graph of leaf fall showing the percentage of leaves that remain on the tree over time, rather than the percentage of leaves that have fallen.
- Two graphs, a scatter plot and a bar graph, of the dates of initial and total leaf fall for a single tree over multiple years.
- A graph showing leaf fall in three trees of the same species over three years.

In addition, we include a bar graph that shows data on the abundance of hemlock woolly adelgid egg masses on three hemlock branches; two options for presenting data on changes in water depth at four locations in a stream; and two graphs comparing data on water depths and diameters in two vernal pools studied by classes in two different towns.

Comparable graphs can be made of a wide variety of other field ecological data.

2. Graphs in the Classroom

Chapter Overview:

This chapter covers
- Reasons for teaching graphing skills
- Education goals addressed
- Where to find related lesson plans
- Graphs and Schoolyard Science

Graphs let researchers see patterns in their data, and they can suggest ideas about what might be happening in the system that is being studied. Graphs are also useful for helping scientists explain data to other people, as pictures can combine a lot of information into a compact package. In fact, the applications and uses of graphs extend far beyond scientific research.

This manual has been prepared in the context of Harvard Forest's Schoolyard Science Program. Its overall focus is on the graphical presentation of scientific data collected by students involved in field research projects. In this chapter, we step back and look briefly at the value of graphing exercises in an educational context.

Reasons to Teach Graphing Skills

There are many reasons why graphing skills should be taught in schools. The ability to graph data is a valuable mathematical skill in its own right, and the evaluation of graphical data is an important adjunct to critical thinking.

The basic skills involved in looking at and interpreting graphs are useful in many contexts. In addition to being useful in scientific research, graphs are used in politics, medicine, economics, agriculture, business, sports, and almost every other aspect of daily life. They can be highly effective means for presenting information – we see them in magazines, on television news broadcasts, in financial reports, and in advertisements. Many people are visual thinkers and learn best when presented with pictures rather than words. People who have difficulty in reading and interpreting graphical information may be at a disadvantage, and in some situations they may find themselves less-well informed than people who understand graphs.

Students who have mastered the simple manipulations involved in preparing graphs by hand or with basic computer programs have the ability to examine many kinds of scientific, economic, and social information, on their own. They can create their own graphs and use them to evaluate whether conclusions that have been drawn by other people seem to be supported by the data. They can identify patterns and trends, observe inconsistencies, and draw their own conclusions. Further, they can use graphs to share information with other people.

State and National Frameworks and Standards Addressed by Graphing Exercises

Teachers may find that classroom activities and lesson plans that include graphing not only have a wide range of general educational benefits but also can be used to meet specific educational goals specified in federal recommendations and state curriculum guidelines. The list below identifies some specific national and state science and mathematics educational goals addressed by graphing exercises. The goals are taken from the following sources:

- **Massachusetts Department of Education. 2000, 2006**. *Mathematics Curriculum Framework.* (2000), *Massachusetts Science and Technology/Engineering Curriculum Framework* (2006). Malden, MA. ("Massachusetts Frameworks") Both are available online at http://www.doe.mass.edu/frameworks/current.html
- **National Committee on Science Education Standards and Assessment**, **National Research Council. 1996.** *National Science Education Standards.* National Academies Press, Washington, D.C. ("National Standards") Available online at http://www.nap.edu/openbook.php?record_id=4962&page=103

We have not explicitly identified life science standards addressed by graphing exercises. Note, however, that many standards and frameworks relating to the understanding of life histories, adaptations, and distributions of living organisms, and of environmental change and ecology, are encompassed in the research questions investigated as part of schoolyard science projects. The use of graphs to interpret study results can thus contribute to educational goals in the life sciences.

A complete list of Massachusetts Frameworks and National Science Standards addressed in Harvard Forest's Schoolyard projects can be found at: http://harvardforest.fas.harvard.edu/museum/data/k12/HF%20sLTER%20State%20Frameworks%20and%20National%20Standards.pdf.

Scientific Inquiry Skills Standards – Massachusetts Frameworks

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
- Represent data and relationships between and among variables in charts and graphs.
- Use appropriate technology (e.g., graphing software) and other tools.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Use results of an experiment [study] to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment [study] that may require further investigation.

SIS4. Communicate and apply the results of scientific investigations.

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (e.g., presentation software) and other tools to present findings.

<u>Science as Inquiry – National Standard A</u>

Grades K-4:

- Abilities necessary to do scientific inquiry:
  - Use Data to construct a reasonable explanation
    - This aspect of the standard emphasizes the students' thinking as they use data to formulate explanations. Even at the earliest grade levels, students should learn what constitutes evidence and judge the merits or strength of the data and information that will be used to make explanations. After students propose and explanation, they will appeal to the knowledge and evidence they obtained to support their explanations. Students should check their explanations against scientific knowledge, experiences, and observations of others.
  - Communicate investigations and explanations
    - Students should begin developing the abilities to communicate, critique, and analyze their work and the work of other students. This communication might be spoken or drawn as well as written.
- Understanding about scientific inquiry:
  - Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge).Good explanations are based on evidence from investigations.

Grades 5-8:

- Abilities necessary to do scientific inquiry
  - Conduct a scientific investigation
    - Students should develop general abilities, such as …interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures.

- Use appropriate tools and techniques to gather, analyze, and interpret data
    - The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, suing hardware and software designed for these purposes.
- Think critically and logically to make the relationships between evidence and explanations.
    - Thinking critically about evidence includes deciding what evidence should be used and accounting for anomalous data. Specifically, students should be able to review data from a simple experiment, summarize the data, and form a logical argument about the cause-and –effect relationships in the experiment.
- Use mathematics in all aspects of scientific inquiry
    - Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

Grades 9-12:

- Abilities necessary to do scientific inquiry
    - Conduct scientific investigations
        - The investigation may also require…student organization and display of data
    - Use technology and mathematics to improve investigations and communications.
        - The use of computers for the collection, analysis and display of data….charts and graphs are used for communicating results. Mathematics play an essential role in all aspects of an inquiry. For example,...formulas are used for developing explanations, and charts and graphs are used for communicating results.
    - Communicate and defend a scientific argument
        - Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, Developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments

Mathematics – Massachusetts Frameworks

Grades 1-2:

Data Analysis, Statistics, and Probability:

2.D.1 Use interviews, surveys, and observations to gather data about themselves and their surroundings.

2.D.2. Organize, classify, represent, and interpret data using tallies, charts, tables, bar graphs, pictographs, and Venn diagrams; interpret the representations.

2.D.3. Formulate inferences (draw conclusions) and make educated guesses (conjectures) about a situation based on information gained from data.

Grades 3-4, 5-6:

Exploratory Concepts and Skills:

- Select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatter plots.
- Compare different representations of the same data and evaluate how well each representation shows important aspects of the data.

Grades 3-4:

Data Analysis, Statistics, and Probability:

4.D.1 Collect and organize data using observations, measurements, surveys, or experiments, and identify appropriate ways to display the data.

4.D.2 Match a representation of a data set such as lists, tables, or graphs (including circle graphs) with the actual set of data.

4.D.3 Construct, draw conclusions, and make predictions from various representations of data sets, including tables, bar graphs, pictographs, line graphs, line plots, and tallies.

Grades 5-6:

Data Analysis, Statistics, and Probability:

6.D.1 Construct and interpret stem-and-leaf plots, line plots, and circle graphs.

6.D.2 Use tree diagrams and other models (e.g., lists and tables) to represent possible or actual outcomes of trials. Analyze the outcomes.

Grades 7-8:

Data Analysis, Statistics, and Probability:

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them
- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

8.D.1 Describe the characteristics and limitations of a data sample. Identify different ways of selecting a sample, e.g., convenience sampling, responses to a survey, random sampling.

8.D.2 Select, create, interpret, and utilize various tabular and graphical representations of data, e.g., circle graphs, Venn diagrams, scatterplots, stem-and-leaf plots, box-and-whisker plots, histograms, tables, and charts. Differentiate between continuous and discrete data and ways to represent them.

8.D.3 Find, describe, and interpret appropriate measures of central tendency (mean, median, and mode) and spread (range) that represent a set of data. Use these notions to compare different sets of data.

Grades 9-10:

Data Analysis, Statistics, and Probability:

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them
- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

10.D.1 Select, create, and interpret an appropriate graphical representation (e.g., scatterplot, table, stem-and-leaf plots, box-and-whisker plots, circle graph, line graph, and line plot) for a set of data and use appropriate statistics (e.g., mean, median, range, and mode) to communicate information about the data. Use these notions to compare different sets of data.

10.D.3 Describe and explain how the relative sizes of a sample and the population affect the validity of predictions from a set of data.

Grades 11-12:

Data Analysis, Statistics, and Probability:

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them
- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

12.D.1 Select an appropriate graphical representation for a set of data and use appropriate statistics (e.g., quartile or percentile distribution) to communicate information about the data.
12.D.2

Sample Lesson Plans

Several teachers participating in Harvard Forest's Schoolyard Science Program have developed lesson plans that include data analysis through graphing. These plans provide further discussion of educational goals and curriculum frameworks. The plans are available online on the Harvard Forest website.

http://harvardforest.fas.harvard.edu/museum/data/k12/lesson-plans.html

Why Graphs Are Useful for Schoolyard Science Investigations

With data collected in the Schoolyard Science Program, graphs are useful for several reasons.

1. They let students "see" their data.
2. They make it easy to observe the changes that occur between one sampling date and the next, as well as the overall pattern of changes throughout the course of the study.
3. They allow each student research team to look at differences between their results and those of other teams in the class.

4. They let students compare their results with those of students in other classes, whether in the same school at the same time, in other schools, or in past years.
5. They may stimulate students to suggest reasons for patterns of change, and for differences in different data sets.

3. Understanding Data and Graphs

Chapter Overview:

This chapter covers

- Kinds of data sets
- Examples from schoolyard studies
- Ways to organize schoolyard data
- Formatting data
- Kinds of graphs

It is relatively easy to make a graph from research data. And it can be easy to draw conclusions about trends and patterns in the data, and to infer relationships among sample variables from graphs. Before a graph is created, however, the researcher needs to have a basic understanding of the data, what graphs show, and how different kinds of graphs can influence the way the results appear.

This chapter begins with a discussion of data. We look at ways that field data can be organized, discuss pros and cons of different data formats, and suggest how schoolyard data might be organized in the classroom to simplify the preparation of graphs. We also discuss how individual kinds of data can – and should – be formatted in a data set, and how improper formatting can lead to problems when creating graphs.

The rest of the chapter looks at graphs. It starts with a brief overview of different kinds of graphs and what they show. This overview is followed by some examples of graphs developed as part of research carried out by Harvard Forest scientists or created from data sets collected by classrooms participating in Schoolyard Science studies. The examples are intended to show a range of options for graphing data. For specific graphs, we discuss some of the kinds of information that can be observed and look at ways that the graphs might be improved.

Organizing and Working With Field Research Data

The specific information included in a data set and the way that the data set is organized can have a great influence on the amount of work that will be needed to prepare the data for graphing. Field data-forms, spreadsheets, and computer data bases often contain many kinds of information. This information may include sampling locations, sampling dates, the researchers' names, specific plots or organisms that were sampled, and measured results for a number of study variables.

Often, data are stored in a way that makes it difficult for researchers to read the information, to observe patterns in the data, or even to identify errors and inconsistencies in the data set. It is also difficult to graph many kinds of data as they occur in spreadsheets and data bases.

Researchers routinely take subsets of data from the comprehensive spreadsheets and data bases where the data are stored, and reorganize the data into new formats that make it easier to carry out analyses, including quality control checks of the data, statistical testing, and graphing.

Kinds of Data Sets – Some Schoolyard Data Examples

We illustrate some different ways of organizing and presenting schoolyard research data, below. The data were collected by students at Athol-Royalston Middle School, Athol, MA, in 2004-2007 in accordance with the phenology protocols outlined in Harvard Forest's Schoolyard Science Program (see http://harvardforest.fas.harvard.edu/museum/phenology.html).

Comma-delimited data. The data from Schoolyard Science studies are collected on field forms, entered into spreadsheets, and submitted to Harvard Forest for archiving on the computer. The archived files are saved as a "comma-delimited" data set. Table 1 illustrates part of one of these data sets. It shows the first 19 rows of a 312-row data set that covers four years of fall phenology sampling (the ARM data set).

Table 1. An example of a Schoolyard Science phenology data set in comma-delimited text (.csv) format, as found on the Harvard Forest Schoolyard Science website. The table represents a subset of the fall phenology data set provided by teacher Judy Miller, Athol-Royalston Middle School, Athol, MA (ARM data set on Harvard Forest Schoolyard Science website). Data are described below.

```
School,Teacher,Date,Julian,TreeID,Species,Ltotal,Lfallen,Tcolor
ARM,Miller,2004-09-06,250,2,CH,5,0,NA
ARM,Miller,2004-09-22,266,1,YB,10,0,NA
ARM,Miller,2004-09-22,266,2,CH,10,0,NA
ARM,Miller,2004-09-22,266,3,RM,5,0,NA
ARM,Miller,2004-09-22,266,4,RM,5,0,NA
ARM,Miller,2004-09-22,266,5,CH,10,0,NA
ARM,Miller,2004-09-22,266,6,WH,10,0,NA
ARM,Miller,2004-09-22,266,7,RM,5,0,NA
ARM,Miller,2004-09-29,273,1,YB,10,0,NA
ARM,Miller,2004-09-29,273,2,CH,5,0,NA
ARM,Miller,2004-09-29,273,3,RM,5,0,NA
ARM,Miller,2004-09-29,273,4,RM,5,0,NA
ARM,Miller,2004-09-29,273,5,CH,10,0,NA
ARM,Miller,2004-09-29,273,6,WH,10,0,NA
ARM,Miller,2004-09-29,273,7,RM,5,0,NA
ARM,Miller,2004-10-06,280,1,YB,10,0,NA
ARM,Miller,2004-10-06,280,2,CH,10,0,NA
ARM,Miller,2004-10-06,280,3,RM,5,2,NA
```

The data in Table 1 represent the combined results of schoolyard sampling of seven trees in early fall of 2004 (the full data set covers four years and eleven trees). The data are stored in a form that is relatively efficient in its use of computer space, and at the same time is readily recognized by many computer programs that are used to store, manipulate, analyze, and graph data.

What does the data set include? Data sets stored in this format are organized very systematically. The data are presented in rows. The first row is a list of words or abbreviations, separated by commas. The words identify the data that follow in the rows that make up the rest of the data set.

In Table 1, the top row contains nine words. Each row that follows represents one sample and contains nine values, separated by commas, identifying (in order):

- the school,
- the teacher,
- the sampling date (entered in the order year-month-day),
- the day of the year (Julian day),
- the tree that was sampled,
- the tree's species,
- the total number of leaves that were sampled on the tree on the sampling date,
- the number of leaves that had fallen, and
- the average leaf-color condition of the sampled leaves.

Note that what most people would think of as the actual data of interest, the number of leaves studied and information on their condition, are found at the end of each row, after six separate pieces of identifying information!

What rules govern the data? Strict rules govern the data. The variables in each row must be entered in the order listed in the top row, and in a pre-determined format. Every row must contain an entry for every variable listed in the top row, with the entries separated by commas.

NOTE: In addition to the comma-delimited format shown in Table 1, data can be entered using other delimiters such as tabs, spaces, punctuation other than a comma, and other indicators selected by a researcher. The basic data structure remains the same.

If there are no data for one of the variables for a sample, a predetermined code is entered in the place where the data record would otherwise go. (In this data set, NA indicates no data. We can see that there are no color-change data available for the sampling dates shown in Table 1.)

How do you interpret the data? Without additional information, someone looking at the data set from the schoolyard phenology study would find it impossible to understand what the data set represents. The term "Metadata" (literally, "data about data") is used to describe explanatory information that is stored somewhere else and that allows researchers to understand each of the variables in a data set. Ideally, metadata should define each of the variables, identify measurement units, explain any codes that are used, specify formats used for data entry, and explain how data were collected. Sometimes, there are multiple layers of metadata, with some information needed for data interpretation and other information used for other purposes. For example, one level might list School Codes and identify the school that each code represents. At another level, a list of schools might provide information on the school location, grades taught, teacher(s), projects being carried out, and other details. A third level might include a list of participating teachers with contact information.

For the data shown in Table 1, the first-level metadata include:

- a list of school codes and the associated school names,
- a list of the teacher codes, with the name of each teacher, contact information, and other pertinent details,
- an explanation that the Date variable refers to the sampling date, formatted in the order Year-Month-Day
- an explanation that the Julian variable refers to the Julian date, or the consecutive day of the year starting with January 1
- an explanation that TreeID is a code that identifies each of the individual trees sampled by a classroom research team (additional information on each tree, including its location, its size, the student teams studying it, and other pertinent details, may be available in different metadata files)
- a list of codes describing tree species
- an explanation that Ltotal refers to the total number of leaves sampled for that tree on that date
- an explanation that Lfallen refers to the number of sampled leaves that had fallen from the tree on the sampling date
- an explanation that Tcolor represents an estimate of the color change for the entire tree on the sampling date

How do you read a comma-delimited data set? Although this kind of data set is efficient for data managers, uses computer space effectively, and is easy for computers to work with, the format is very difficult for most humans to read. Comma-delimited data sets can be especially hard to read if there are many items of data in each row, if there are many rows of data, and if the data do not line up evenly horizontally across the rows or vertically below the appropriate data labels. In fact, data sets in this format are not intended to be used directly. Instead, before working with data, researchers move the data into a format that is easier to read, such as a spreadsheet.

Spreadsheets. Many, if not most, researchers save their field data in spreadsheets. Table 2 presents the same 19 rows of data as Table 1, but the comma-delimited data set has been downloaded from the website and converted into a spreadsheet format (the commas do not appear in the spreadsheet). In the spreadsheet, the data are lined up in columns beneath the data labels, and it is much easier to look at the data – especially the results for leaf-fall – than in the delimited text list. Note that the data here look pretty much like the data that you submit to Harvard Forest at the end of sampling each year.

Table 2. The data in Table 1, converted into a spread-sheet.

School	Teacher	Date	Julian	TreeID	Species	Ltotal	Lfallen	Tcolor
ARM	Miller	9/6/2004	250	2	CH	5	0	NA
ARM	Miller	9/22/2004	266	1	YB	10	0	NA
ARM	Miller	9/22/2004	266	2	CH	10	0	NA
ARM	Miller	9/22/2004	266	3	RM	5	0	NA
ARM	Miller	9/22/2004	266	4	RM	5	0	NA
ARM	Miller	9/22/2004	266	5	CH	10	0	NA
ARM	Miller	9/22/2004	266	6	WH	10	0	NA
ARM	Miller	9/22/2004	266	7	RM	5	0	NA
ARM	Miller	9/29/2004	273	1	YB	10	0	NA
ARM	Miller	9/29/2004	273	2	CH	5	0	NA
ARM	Miller	9/29/2004	273	3	RM	5	0	NA
ARM	Miller	9/29/2004	273	4	RM	5	0	NA
ARM	Miller	9/29/2004	273	5	CH	10	0	NA
ARM	Miller	9/29/2004	273	6	WH	10	0	NA
ARM	Miller	9/29/2004	273	7	RM	5	0	NA
ARM	Miller	10/6/2004	280	1	YB	10	0	NA
ARM	Miller	10/6/2004	280	2	CH	10	0	NA
ARM	Miller	10/6/2004	280	3	RM	5	2	NA

Working with spreadsheets. Data in a spreadsheet are easy to read, and they can be sorted and manipulated by a variety of computer programs, as desired by the researcher. Observe, for example, that the format of the sampling date has been changed, so that the date is presented in M-D-Y order.

It is easy to insert new columns in a spreadsheet. For example, if you want to perform some calculations with the data and add the results to the existing data you can do so readily. In addition, subsets of the data that are of interest, such as the information on leaf fall over time, can be selected and copied for use in graphing, for statistical analysis, or for other purposes.

Describing data in spreadsheet data bases. Like the comma-delimited data set shown in Table 1, spreadsheets that contain complex data need to be linked to other data sets that explain the data. One or more metadata pages may list each of the column headings and provide information about the variables. Data can also be stored in "relational databases" in which variables are electronically linked between different data sets. Thus, you might have a database for the phenology data, similar to that in Table 1 or 2, and have it linked to a second database with information on each of the sampled trees. The tree code would allow you to move between the two data bases, to obtain information about the tree from the field-results data set, and to obtain data on the field data from the sample-tree data set.

<u>Simple data sets</u>. For many reasons, schoolyard data sets that teachers submit to Harvard Forest for long-term archiving include only part of the information collected by the student research teams. Additional field data recorded as part of schoolyard ecology research protocols can also contribute to long-term understanding of the research problem being studied, even if these results are not currently provided to Harvard Forest!

It is not practicable for many teachers, but for those who can manage it there can be great educational value – and potentially great scientific value – in having individual student research teams keep track of their own data in simple spreadsheets, and in looking at these data as well as at the combined summary results that are submitted for archiving.

This is particularly the case for phenology studies. For example, the data set illustrated in Tables 1 and 2 lists all of the variables that are measured on each sampling date for each study tree, as submitted to Harvard Forest for long-term archiving of Schoolyard Science data. It is a consolidated data set, with a combined whole-tree value for each variable based on the data from all of the branches sampled by the student research teams. It does not include the data from the individual branches or from individual leaves, and it does not include the one-time measurements that students make of leaf length. Similarly, archived data from spring phenology studies are a composite for the study trees, and they lack the results from the individual buds and branches.

To a greater or lesser extent, the same holds for other schoolyard ecology research projects. For example, the archived data for hemlock woolly adelgid abundance are the average of two (or more) branches on one date. Especially if your field research goes beyond the limited sampling specified in the protocols (e.g., if your students take multiple measurements, record information on plants or animals in or next to vernal pools or study streams, or track hemlock woolly adelgid over time during the school year), your students' field data are worth looking at in the classroom.

Table 3 shows a simple spreadsheet that might be kept by students, with autumn leaf-fall data for one of the trees in the larger ARM data set over the sampling period in fall, 2004. In this data table, information is provided on the tree, the (hypothetical) branch, the teacher, the name of a (hypothetical) student team collecting the data, and the year, but this information is at the top of the form and separate from the research data. The data table simply lists the sampling dates and provides the number of leaves that were sampled and the number of leaves that had fallen on each date. These data are the same as in the composite data set provided to Harvard Forest. (The example assumes that the hypothetical student research team collected all of the leaf-fall data for chestnut tree #5. If one research team sampled one branch on the tree, and another team sampled a second branch, then each team could keep track of the data for its branch.)

Table 3. A simple table showing leaf-fall data collected by a hypothetical student research team in 2004. Data from Athol-Royalston Middle School.

Research Team: CH5
Teacher: Mrs. Miller
Year: 2004
Branch: 1

Tree ID# 5
Tree Species: Chestnut

Date	# of Leaves Observed	# of Leaves Fallen
9/22	10	0
9/29	10	0
10/6	10	0
10/13	10	0
10/19	10	1
10/26	10	8
10/27	5	4
11/05	10	10

A similar data table could be prepared for the leaf-length data, with one column listing the leaves individually, and the second column providing the length of each listed leaf. A third column could provide the date on which the leaf was observed to have fallen. An example of how such a data table might be organized, with no data, is illustrated in Table 4. The students could then graph leaf size in relation to the leaf's position on the branch or look at the date of leaf fall vs. leaf size, to see if there are any relationships. This would be especially interesting for the data on all leaves from the whole class, separated by tree species, or not.

Data organized this way are easy to look at, are ready to be manipulated, and can be graphed with little additional modification. Individual students or research teams can track their own research results and make graphs or carry out other detailed analyses of their data. It is also easy for the students to compare their findings with other students' data.

For forest tree phenology data, comparisons might be across research teams, different individuals of the same tree species, different tree species, individual leaves or buds, or multiple branches. Students following the hemlock woolly adelgid might compare adelgid abundance on the different branches that are sampled on each tree, in different trees, and over time – or even variations in counts of the same branch by different teams or individuals. Students looking at streams or vernal pools could compare water levels in different parts of a stream, or measurements of pool water depth made by multiple teams on the same date, or pool diameters along different dimensions of a pool relative to water depth, or how observed animals differ among samples or over time, how water and air temperature vary over time, or how water temperature varies with water depth.

Table 4. An example of a simple spreadsheet showing how student research teams might record data they collect on individual leaves during fall phenology sampling.

School	
Teacher	
Year	
Research Team	
Tree Species	
Tree ID	
Branch ID	

Leaf #	Leaf length	Date of length measurement	Date when leaf had fallen from branch
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

NOTE: Individual Field Data Sets are Important! Field data recorded as part of schoolyard ecology research protocols can be very valuable for long-term understanding of the data, even if these results are not currently provided to Harvard Forest for long-term archiving. You may find that if you have your students keep track of their own data you will end up with the ability to document interesting patterns of variation. Some of the data may lend themselves to individual student research projects, especially for older students. When the class examines the individual data that are not submitted to Harvard Forest, but that are collected in accordance with the research protocols, they may find patterns and gain insights into the research questions that are not readily apparent from the combined data set.

Deciding How to Organize Your Data

So, what is the "Best" way to organize Schoolyard Science data? The answer to this question depends on the nature of the data, the kinds of uses the researcher hopes to make of the data, the amounts of data that are generated, and whether the data need to be archived for a long time.

From a teaching perspective, data formatted like the classroom data in Table 3 or the other options described above can be made ready for graphing more readily than the more complex Schoolyard Science data set shown in Tables 1 and 2. It is easy for students to put together a data set in this format, and it is easy to create simple graphs from data that are organized in this way. Individual student research teams might want to use a data file like this to record and track the results of their weekly sampling trips to a study tree. The combined data for a class, if several research teams are looking at branches on a tree, could also be organized using this kind of format. However, this format does not lend itself to complex data, especially when multiple trees or branches are being studied.

All of the long-term and short-term scientific data generated from research by Harvard Forest scientists, are archived in the comma-delimited format illustrated in Table 1. When scientists at the Forest, or researchers from outside, want to use a data set, they typically download the data and convert it to a format comparable to that illustrated in Table 2, and then work with the data to modify the results and extract the parts of the data set that they want to work with.

To the extent that schoolyard studies are intended to contribute to Harvard Forest's scientific research on the phenology of forest trees, expansion of the hemlock woolly adelgid, and water-level variations in vernal pools and headwater streams, and especially considering that we hope that some schoolyard data sets will end up providing long-term data, it is critical to have the Schoolyard Science data archived in a format that:

- is consistent across the many groups collecting data,
- allows data from multiple sources to be merged together readily,
- does not overload the computer's storage capacity, and
- can be worked with efficiently by data managers and researchers using a variety of computer programs.

This means that Harvard Forest needs to have data sets that include all of the codes for school, tree, and the like, organized for maximum efficiency – i.e., as comma-delimited data sets like Table 1.

The more complex data structures illustrated in Tables 1 and 2 allow the data sets to include information on many trees, and to include multiple years of data. It is easy to add more trees, and more sampling dates – and even to add data from other schools. Such data from other classes can be downloaded easily by teachers for comparison with their own students' results.

Data Formats

When you enter information into a computer, it has a format that the computer is instructed to recognize, and that has certain properties. Some formats for data include text, date (in various forms), percent, general number, currency, scientific notation, and fraction. The format used for some kinds of data is very important. For example, we noted on page 15 that in the data sets archived on the Schoolyard Science website, the sampling date is entered in the order Year-Month-Day. The computer has been instructed to recognize information entered into the Date column as a date, in that particular order. Sometimes, when research data are entered into spreadsheets, the formatting is not correct, and sometimes, when data are transferred from one location to another, the formatting can be lost. In either case, problems can arise when you try to graph data that are not formatted properly.

In general, numbers should be formatted as numbers, text as text, dates as dates, and so on. Most computers are quick to recognize text, numbers, and dates, but sometimes you will get strange results, with the computer changing the information you entered into something else. In such instances, you need to check the format using the procedures appropriate for the software you are using. Chapter 3 discusses of how to evaluate and manipulate data, and it addresses some potential formatting problems that may occur when you are preparing data for graphing.

Kinds of Graphs

There are many kinds of graphs. Most computer graphing programs provide many options. Some examples include bar graphs, pie graphs, scatter plots, box-and-whisker graphs, and line graphs. How do you decide what kind of graph is appropriate for your data?

The decision as to the type of graph to make depends on several factors. Graphs are designed to help you understand your data. The kind of graph to use depends, in part, on the nature of the data themselves, and in part on the kinds of questions you are asking.

First, you need to understand your data. Do you have categories of information, or numbers? Are you looking at individual components of a single whole, or do you have many separate measurements you need to display? Are your measured variables organized in relation to some kind of numerical scale, such as time, space, or the abundance of another variable?

Second, you need to think about your purpose in graphing the data. What are you trying to show with the graph? Are you looking at how an environmental or biological factor changed over time? Many of the data collected according to the Schoolyard Science protocols look at changes in a measured variable over time. Does your research examine how something varied along a gradient of distance, elevation, or other quantified variable? Do you have specific sets of data you are trying to compare with each other?

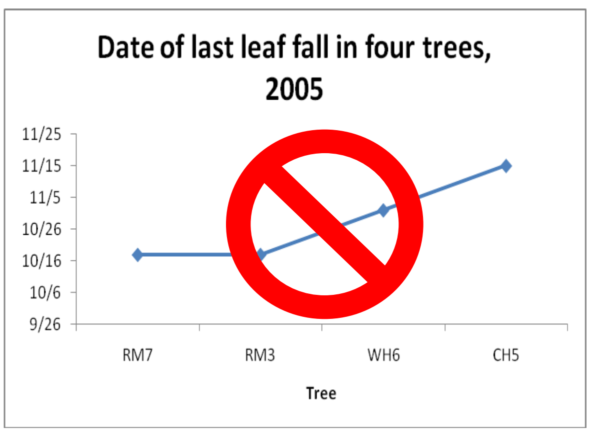
Different kinds of graphs are useful for presenting different kinds of information. Within most broad categories of graphs, researchers can choose details of how the data are displayed. The choice often comes down to a determination of which format shows the information most effectively, and is really a matter of personal preference.

Some kinds of graphs are not appropriate for presenting some kinds of data. For example, a line graph linking leaf-fall percentages in four different trees on the same date would not be appropriate, because the line suggests a trend or a relationship that does not exist. You might want to compare the trees using a bar graph, instead (see Figure 1).

Figure 1a shows the dates of last leaf fall in the four trees presented as points connected by a line. This suggests a trend or relationship between the trees. It is hard to think what such a relationship might be.

In Figure 1b, the same data on the last dates of leaf fall are compared using a bar graph. This graph illustrates a pattern (some trees dropped their leaves earlier than others) without suggesting that there is a connection between the data for the different trees.

a. Line graph – not appropriate



b. Bar graph – appropriate

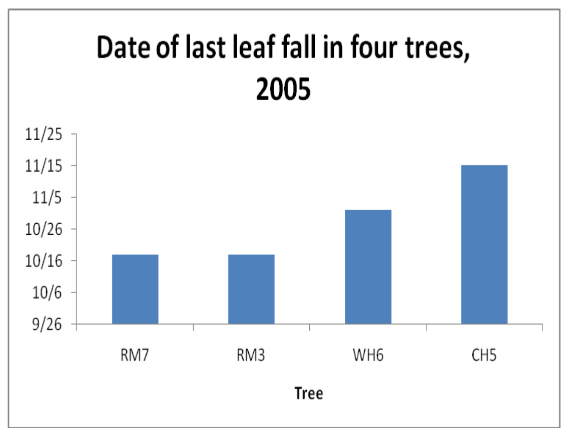


Figure 1. Two graphs showing the date when the last leaf fell for four study trees in 2005.

On the other hand, several of the examples and exercises presented later show lines connecting the leaf-fall results for an individual tree over time. This is entirely appropriate, because there is a finite number of leaves sampled in any given year, and they only fall in one direction (that is, there can't be an increase in the number of leaves on the tree or branch from one sampling date to the next within a single autumn season). Similarly, it may be useful to connect data showing measured phenology events, such as the date when all the leaves had fallen, for a single tree over multiple years, because one of the questions that the research study is asking is whether there is a long-term change in the timing of leaf fall.

We provide a brief summary of several different graphing options below. Examples are taken from research carried out by scientists at Harvard Forest. (Graphs of Schoolyard Science data are presented separately in Chapter 5). For more information on how different kinds of graphs are used, and for illustrations of the different graph types, you may want to check the following websites:

Choosing a graph:
http://www.graphicsserver.com/com_products/choosing_a_graph.aspx
How to choose which type of graph to use?
http://nces.ed.gov/nceskids/help/user_guide/graph/whentouse.asp

You may also find it both useful and interesting to look at the publications of Edward Tufte, who taught political science, computer science and statistics at Yale and has become known for his insightful publications on graphs and charts—and especially, on ways that poorly designed and presented graphics can lead to poor decision making and confusion (some key references are listed below). Among his recommendations are to include all the data, to integrate the graphics with the words, to make comparisons, to be clear about sources of the data, and to "tell the truth."

Some of Tufte's key publications include the following:

Tufte, Edward. 1983, 2001. *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, CT. ISBN 0961392142.

Tufte, Edward R. 1990. *Envisioning Information*. Graphics Press, Cheshire, CT. ISBN 0961392118.

Tufte, Edward R. 1997. *Visual Explanations: Images and Quantities, Evidence and Narrative*. Graphics Press, Cheshire, CT. ISBN 0961392126.

Simple Graphs

Some graphs simply break a data set into component parts. In such graphs, bars, circles ("pies"), or other shapes reflect the proportional relationships of the data that are being graphed.

The aquatic macroinvertebrate community in a vernal pool. Dr. Betsy Colburn has been carrying out long-term studies of the aquatic invertebrate communities in vernal pools – temporary ponds that are important habitats for a variety of aquatic animals that cannot withstand predation from fish. Figure 2 presents two examples of a pie graph illustrating the broad distribution of different groups of macroinvertebrates in a vernal pool sampled in April, 1996. The graphs show that in early spring the pool was dominated by crustaceans, with copepods, water fleas, and fairy shrimp accounting for more than 90 percent of the animals collected. Of the aquatic insects, only mosquito larvae were present in any numbers.

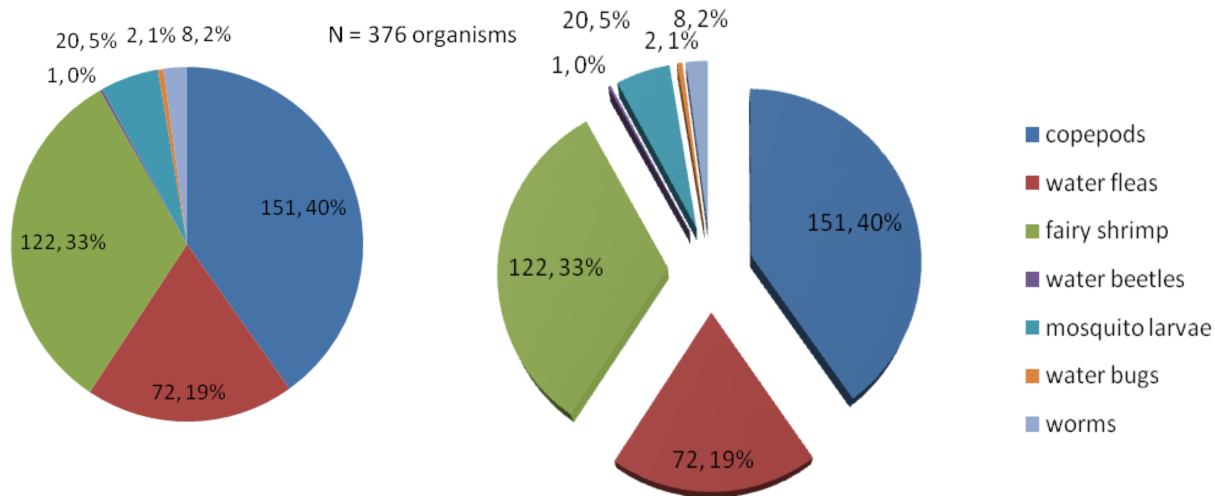


Figure 2. Two pie graphs illustrating the composition of the aquatic macroinvertebrate community in vernal pool #1, Eastham, MA, April, 1996. Source: Colburn, unpublished data.

The graphs are essentially identical, except that one is shown as an intact circle subdivided into segments or "pie slices." Each slice is proportional to the abundance of a different group of animals, but in the right-hand graph, the pie slices are separated slightly from one another. In the exploded pie on the right, the single water beetle and the two water bugs are more readily seen than in the intact pie to the left. Some people find it easier to visualize the parts of the whole in the intact chart.

In general, when graphing research data – whether in simple graphs or more complex graphs with multiple axes – the choice of graph details is up to the researcher and depends in part on personal preference and in part on the specific details that the graph is designed to illustrate.

Graphs With X and Y Axes

Most of the graphs used by researchers display data along two axes, a horizontal X axis and a vertical Y axis. Common kinds of graphs with more than one axis include scatter plots, line graphs, and many bar graphs. Each axis represents a variable of interest, and the graphed data show the intersections between the two variables. Every point on the graph represents one value of X and one value of Y.

NOTE: Sometimes graphs have a third axis, Z, which is perpendicular to the other two and represents a third variable. We do not discuss graphs with more than two axes in this manual.

The X axis. Variables shown on the X axis vary in a way that is consistent and predefined, and that researchers understand, define, or even control. For this reason, the X axis is sometimes described as representing the "independent variable(s)" in a study.

In some graphs, the X axis simply presents categories of samples. For example, in schoolyard data sets the X axis might be divided to show different schools or classes, student research teams, individual trees, tree species, branches, leaf-color classes, vernal pools, pest species, samples, and so on.

The X axis may also represent an independent variable that changes in some consistent way. In long-term research studies, including the schoolyard data sets, the X axis on graphs commonly represents time. Some other X-axis variables might include air or water temperature, elevation, sampling effort, level of hemlock woolly adelgid infestation, leaf size, water depth – it just depends on the questions being asked by the researchers.

The Y axis. The Y axis represents the range of values that were measured for the variable(s) of interest along the range of categories or values of X. It is possible to have multiple Y measurements for a given X-axis value, or there may be a single Y for each X.

You will sometimes see the term "dependent variable" used in reference to the Y axis. Although the Y variable is measured or presented in relation to the "independent" X axis variables, the measured Y variable is not necessarily dependent on the X axis variables in the sense of a cause-effect relationship. In fact, in ecological studies graphs showing such direct dependent relationships are not terribly common. We therefore prefer not to refer to the measured Y values as "dependent variables." More thoughts on how graphs show relationships between X and Y are provided in the next section.

In the schoolyard phenology studies, the Y values in different graphs might represent the number of leaves fallen, percent of leaf-color change, extent of bud opening in spring, length of leaves, number of days in growing season, date of first leaf fall, air temperature, and so on. In other studies, the Y variables might include water depth, pool diameter, needle infestation by woolly adelgids, branch growth, number of ants, amount of rainfall, number of kinds of plants or animals, and so on – there is a nearly infinite variety of variables that can be measured, depending on the study being conducted!

Interpreting the graph. In a graph with X and Y axes, the data points represent the intersection between the values on the X and Y axes. Ideally, by graphing the data we will be able to visualize patterns in the data. If the variable represented on the X axis and the measured variable(s) plotted along the Y axis are related to one another in some way, a pattern may be visible in the graph. In general, the amount of variability in the measured Y values relative to the X values can provide some information on how tightly the two variables may or may not be related.

There are no hard and fast rules about how much information to show on a given graph. However, consider the following.

1. Are there some logical or explainable relationships that justify putting different kinds of data together in the graph?
2. Are there patterns you want to illustrate with the graph?
3. Will other people who look at the graph to be able to make sense of the information?

In addition, you should be sure that you are presenting all of the data so that the data can speak for themselves.

There may be multiple values of Y for any X. For example, in a study of leaf-color change in forest trees, on a given sampling date X there is a value for leaf color, Y, for each branch that is sampled, and there is also a composite leaf-color value Y for each tree. A classroom could choose to make a graph that shows all of the individual values, the composite value, or the individual and composite values for each sampling date. The student research teams could also graph the data for their individual branches. A similar choice is available when graphing leaf-fall data – again, there is a measurement of leaf fall for each branch and a composite Y leaf-fall value for the whole tree. If several branches or trees are sampled on each date, there are likely to be multiple values for leaf color and/or leaf fall on at least some sample dates. Similar options are available for research teams looking at water levels in different reaches of a study stream; groups making multiple measurements of the depth, diameter, or temperature of a vernal pool; students studying hemlock woolly adelgid infestation on different hemlock branches, and so on.

In some cases, the values on the Y axis are "dependent" on the value on the X axis; that is, changes in Y are **caused by** changes in X. The simplest examples are seen in the physical sciences. For example, if you heat a container of water, the water temperature (the measured variable, which would be plotted on the Y axis) would be caused by – and would vary in a predictable way with – the amount of heat applied to the container (the independent variable, which would be shown on the X axis).

In ecology, relationships between measured variables and the independent variables are usually less clear. Often the X and Y variables may **<u>covary</u>** – that is, they both change in a consistent way in relation to each other in response to some external factor(s) – but neither variable is **<u>causing</u>** the changes in the other. It is often possible to test the strength of the relationship between the variables statistically. One of the great challenges in designing ecological research studies lies in trying to distinguish out cause-effect relationships.

In other cases, the Y values are "independent" of the values on the X axis. For example, if the X axis represents three different groups of students who are sampling leaf-color changes, and the Y axis represents the percent of leaves that have changed color, the observed changes in leaf color are not caused by differences in the students doing the sampling. (At least, we hope that is the case!)

Scatter Diagrams or Scatter Plots

Scatter diagrams plot two sets of data against each other. The data can be related to each other, or they can be independent. Scatter plots are useful if the data don't occur at regular intervals or if they don't belong to a single series. For example, most of the schoolyard data we collect look at changes in measured variables over time, with the sampling dates differing from one year to the next, and with the intervals between sampling dates in each year not always constant. Scatter plots allow the data to be graphed. Most of the graphs made through the hands-on exercises are scatter plots.

Scatter plots are very useful because they let you look at all of the actual data you collected. It is often possible to observe patterns and trends simply by looking at the way the data points are distributed in the graph. Depending on the kinds of measurements being made, you can sometimes connect the data points with a line to show the patterns in the data more clearly. This can be particularly useful when you are making repeated measurements over a period of time, because the lines connecting the data can help illustrate an overall trend – but it is important to be sure that the gaps between sampling dates do not hide information that would make the trend illustrated by the line incorrect.

Also, be sure not to confuse the patterns that may be illustrated by a line that connects data points, and cause-effect relationships between the X and Y variables.

Scatter plot of age and size of trees on Wachusett Mountain. Figure 3 is a straightforward example of a basic scatter plot. It presents some data from a study of the age of trees on Wachusett Mountain in Central Massachusetts.

Dr. David Orwig measured 63 trees, cored their trunks, and counted the growth rings. The graph plots the age thus determined against the tree diameter, and it uses different markers to distinguish individuals of the different species sampled.

This graph shows quite a bit of information in a tidy package. We can see that there was not a very large range of diameter in the study trees; that trees of the same diameter ranged in age from almost 300 years to about 125 years; that the youngest tree sampled was a c. 100-year old hemlock; that most of the trees were more than 150-years old (the analysis showed that 40% of the trees were older than 200 years); and that hemlocks and red oaks span a wide range of ages, while white pines show only about a 50-year variation in age.

Note that the units on the X axis represent the year when the tree started to grow, based on subtraction of the number of growth rings from the current year. The axis title, "Coring height age," also makes it clear that the age was determined from a core taken at a certain height (identified in the report as close to the ground at a height of approximately 30 cm). A researcher who counted growth rings in a stump cut off flush with the ground, or higher up the trunk, might get a slightly different result.

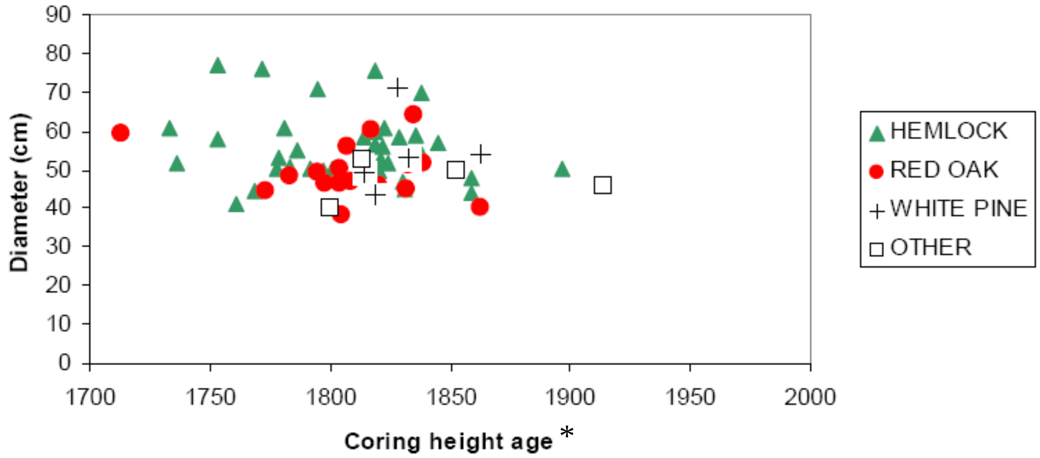


Figure 3. Coring height ages versus diameter relationship of trees sampled within the lower western slope of Wachusett Mountain (n = 63). Graph from Orwig, D. 2004. An evaluation of the western slope forests of Wachusett Mountain. Report submitted to the Massachusetts Department of Conservation and Recreation, Commonwealth of Massachusetts.

(* Ed. note: "Coring height age" is equivalent to the year that the tree started growing.)

A long-term study of spring and fall phenology. Dr. John O'Keefe has been studying leaf emergence and leaf drop in forest trees at the Harvard Forest for 18 years. His research follows individual trees, and his sampling protocols are similar to those described in the Schoolyard Science protocols. Figures 4 and 5 illustrate some of the data.

Figure 4 graphs phenology data from both fall and spring for four tree species. The year of sampling is on the X axis, and the date (presented as day of year, or Julian Day), is on the Y axis. The graph shows the fall dates when 50-percent of leaves had fallen, and the spring dates when 50-percent of buds had opened and when the leaves on the study trees had reached an average of 75-percent of their final size. Each data point is the average value for several trees.

Looking at the graph, we can see several patterns in the data. There is greater variability in the date of leaf development than in the timing of leaf fall – almost a month's variation in the date when leaves had reached 75 percent of their final size in all four species! The oaks have always lost their leaves later than the maple and birch, with red oak consistently losing its leaves later than white oak. In the spring, buds have started to break later in white oak than in the other three species, but the timing of bud break and leaf development in red oak relative to the other species is less consistent. There appears to be a slight trend in the leaf-fall data suggesting slightly later dates of leaf fall over time.

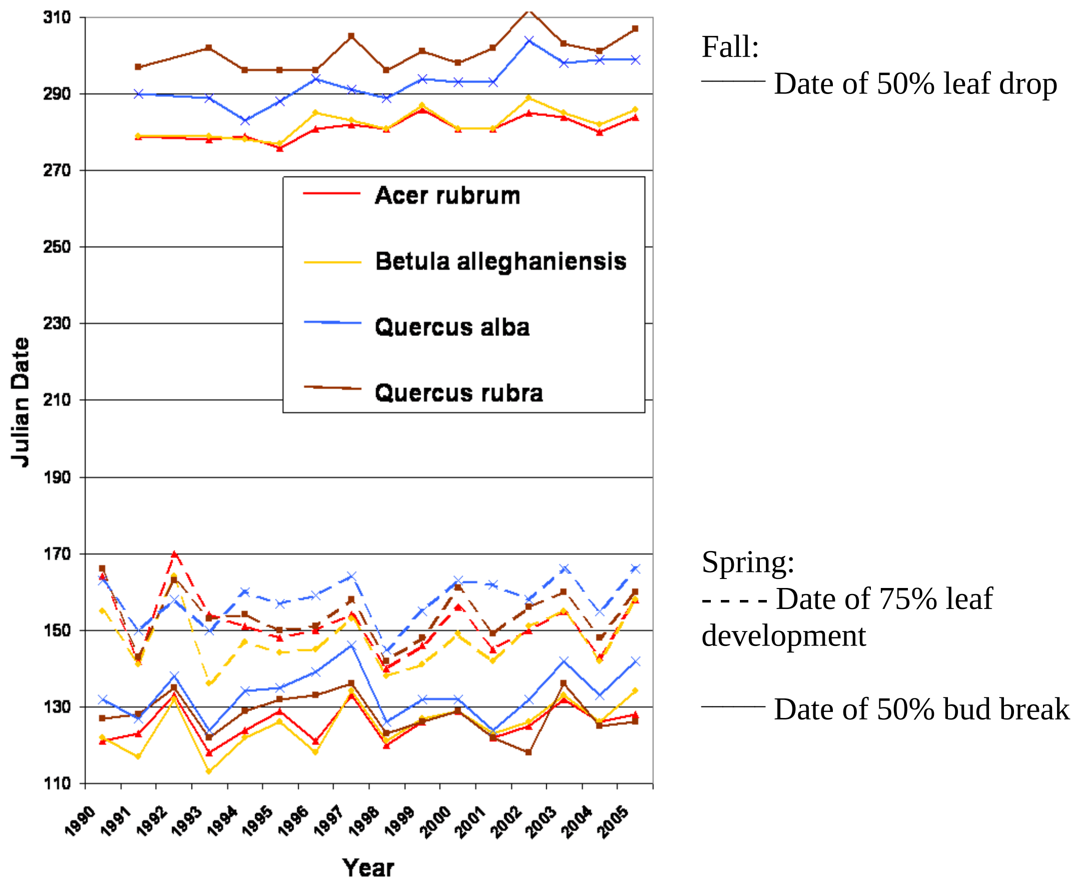


Figure 4. Patterns of spring leaf emergence and autumn leaf fall in four tree species at the Harvard Forest, Petersham, MA, USA, 1991-2006. Data points represent the mean of measurements from multiple individuals of each species: *A. rubrum*, N = 5; *Q. rubra*, N = 4; *Q. alba*, N = 3; *B. alleghaniensis*, N = 3. Graph courtesy of John O'Keefe, Harvard Forest.

Environmental information and the results of phenology measurements are plotted together in Figure 5. This allows leaf-fall data (the pink line) to be looked at in relation to the date when the first frost occurred each year (dark blue line). The graph differs from Figure 4 in that, instead of representing leaf fall in a single tree or a single species, the data are an average of all of the trees studied continuously over time. The graph also shows a five-year running average for the day of the year on which half of the leaves had fallen from the study trees (the yellow line). The running average helps to smooth out some of the year-to-year variation, and it can be helpful in evaluating whether there is a trend in the data toward earlier or later leaf fall. In this graph, the running average appears to show a general tilt upward from left to right. When Dr. O'Keefe carried out statistical analyses of the yearly data for leaf fall and date of first frost, the results indicated that there was a trend toward a later leaf drop of about five days over the course of the study.

Notice that in both of these graphs, the measured variable represented on the Y axis is the date when a certain environmental or phenological event occurred, presented as Day of the Year (Julian Date). This is in contrast to many of the graphs of schoolyard data for leaf fall and leaf-color change, in which the date is on the X axis as the independent variable.

Note: These graphs and some of the associated data, as well as additional information on the broader phenology research project, can be viewed on the Harvard Forest website: http://harvardforest.fas.harvard.edu/asp/hf/symposium/showsymposium.html?id=179&year=2006. A poster on this research, with additional graphs and explanations, can be found through http://harvardforest.fas.harvard.edu/museum/data/k12/presentations.html.

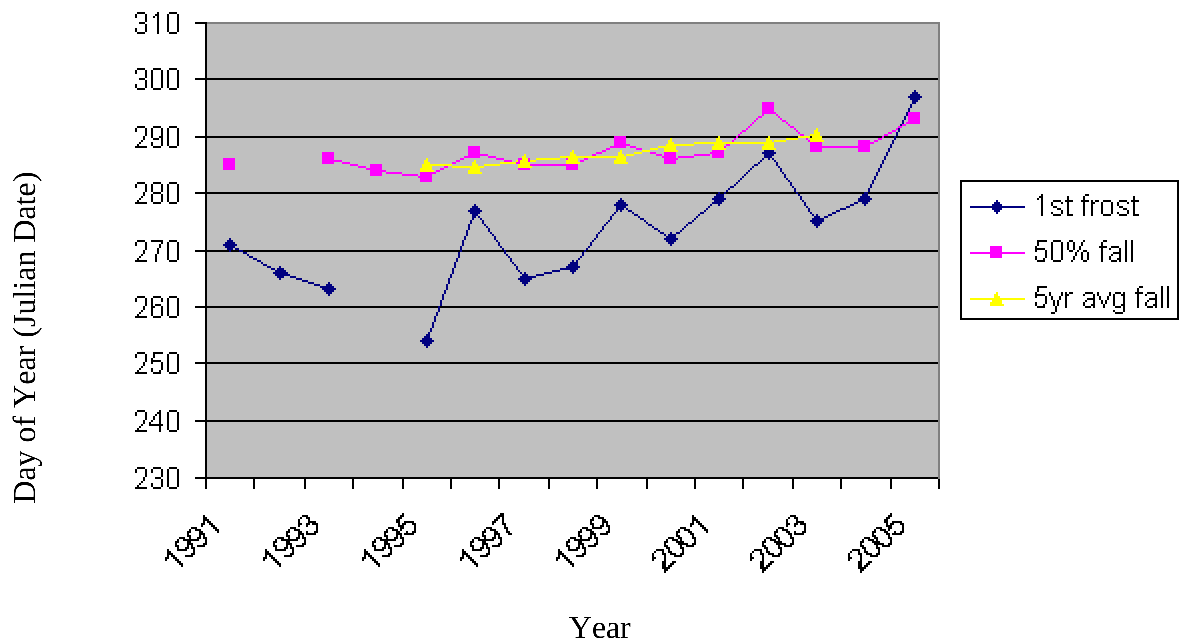


Figure 5. Long-term pattern of leaf fall in trees studied at Harvard Forest, Petersham, MA, 1991-2005. 1st frost = date when first frost of the year was recorded at the Harvard Forest meteorological station. 50 % fall = date when half of monitored leaves had fallen from study trees. 5yr avg fall = date when half of monitored leaves had fallen from study trees, averaged over the five-year period preceding and including the study year. Graph courtesy of John O'Keefe, Harvard Forest.

Variations in stream discharge over time. Dr. Emery Boose is investigating the hydrology of a small watershed at the Harvard Forest. This research includes a long-term study of discharge in Bigelow Brook, a small headwater stream, in relation to local weather, long-term climate patterns, and forest ecology. Automatic data recorders collect data at 15-minute intervals. Figure 6 shows variations in streamflow and air temperature from mid-March through the first week in August, 2008. Figure 7 shows a small subset of the stream discharge data from July 13-18, along with data on solar radiation, air temperature, and soil temperature.

The upper part of Figure 6 shows daily temperature fluctuations and the gradual trend of increasing temperatures from early spring to mid-summer. The lower part of Figure 6 presents stream discharge at the stream gauge on upper Bigelow Brook for the same time period. We can see that the base flow remains relatively constant at around 10 liters per second from March 10 to the middle of April, with occasional short-term increases in response to snowmelt and precipitation events (not shown on this graph), and then starts to decline around day 100 (April 9). The spring decline in base flow occurs at the same time that air temperatures go above freezing, a point when we know, from other research, that hemlock trees start photosynthesis. The forest is thus starting to withdraw more water from the soils, and less groundwater makes its way underground to the stream channel.

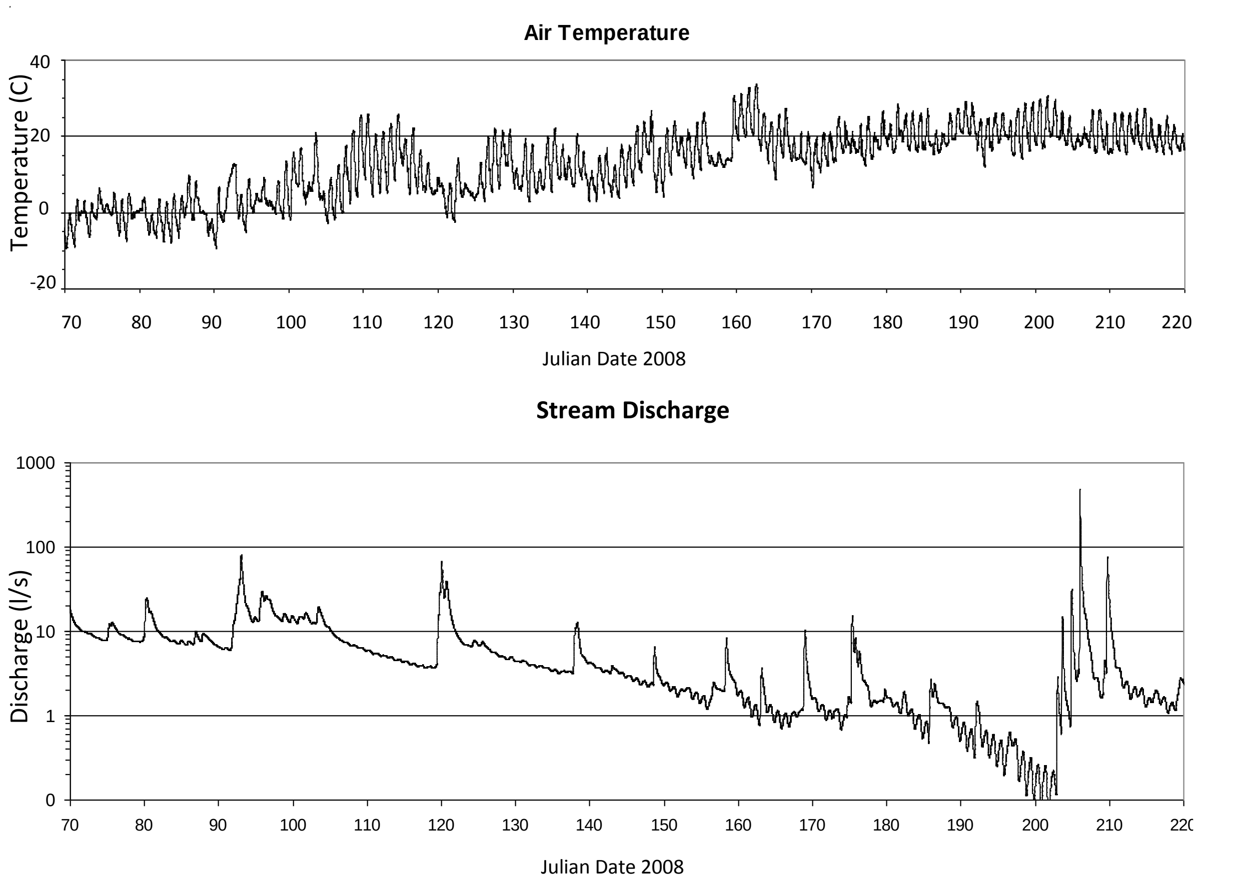


Figure 6. Stream discharge and air temperature at Upper Bigelow Brook, Harvard Forest, Petersham, MA, March 10 - August 7, 2008. Graph courtesy of Emery Boose.

Two other things should be noted on the graph. First, there are measurable daily fluctuations in flow, associated with the forest actively removing water by evaporation and transpiration. Second, the flow in this stream varies nearly a thousand-fold from the minimum to the maximum recorded, and the Y axis is shown on a logarithmic scale so that the patterns in low-flow discharge can be seen.

This graph is a typical example of how researchers can present long-term data on environmental variation over time. It also illustrates how the scale of the Y-axis may need to be varied to show certain kinds of data.

In Figure 7, five days of data are graphed in greater detail than in Figure 6. Stream discharge is shown in red, along with solar radiation (black), air temperature (blue), and soil temperature (green). Data are collected at 15-minute intervals. We see the daily patterns of temperature increasing and decreasing, the sunlight rising to a peak at midday and setting to a dark night, and streamflow increasing and decreasing in response to withdrawals by the forest and evaporation and to inputs of rainfall. We also see that the peaks of the different measured variables occur at different times of day. Note that solar radiation is decreased on day 196 (July 14), indicating a cloudy day. Temperatures are correspondingly depressed, with a greater effect in air than in soil. In contrast, stream discharge is higher on day 196 because (1) forest trees photosynthesize less under cloudy conditions, and hence they withdraw less water from the ground, (2) evaporation is lower due to the lower sunlight and lower temperatures, and, most importantly, (3) rainfall (not shown here) caused an initial increase in discharge followed by a higher-than-usual minimum daily flow, as the rain that had fallen gradually made its way to the stream.

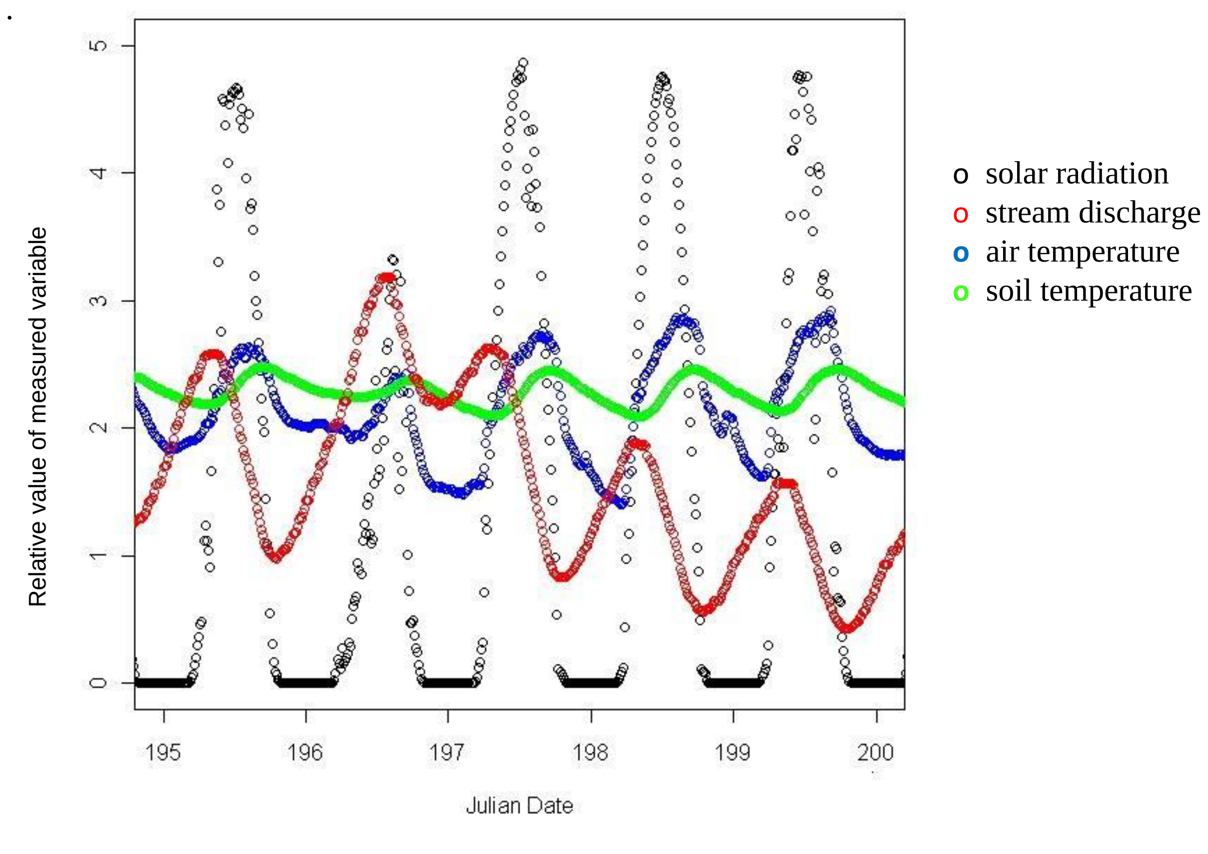


Figure 7. Relationships among solar radiation, air temperature, soil temperature, and stream discharge in upper Bigelow Brook, Harvard Forest, Petersham, MA, over five days in July, 2008. Graph courtesy of Emery Boose.

Note that the Y axis on this graph does not show units of measurement; it simply reflects relative scales for each of the four measured variables. A final version of the graph would provide axis scales for the different parameters shown.

Complex data such as those shown in this graph, along with information on precipitation, humidity, evaporation, and a host of other factors, are analyzed statistically by computer programs, but graphs are very useful in explaining the relationships among the many variables that influence discharge in forest streams.

Line Graphs

Strictly speaking, line graphs are used to illustrate trends. Scientists often use mathematical equations to “fit” a line to data, and they can then use statistical tests to figure out how close the data actually are to the line. This can be useful in figuring out whether the X and Y variables are related to each other. As noted above, though, you can connect data points together with a line to illustrate patterns in your data. Just be careful that the lines are not suggesting trends or causal relationships that are not really clear from the data (as illustrated in Figure 1a), and be careful as well not to infer causal relationships when the data do not allow you to draw those conclusions.

Bar Graphs

Bar graphs or bar charts are typically used to compare different values or amounts to one another. You might use a bar graph to compare the date of leaf fall for different trees, to compare leaf-fall dates for a single tree over time, to describe water levels in water bodies, or to display the abundance of hemlock wooly adelgids. Several examples of bar graphs of schoolyard science data are presented in Chapter 5. Bar graphs come in a variety of formats.

Aquatic macroinvertebrates in a vernal pool on different dates. Figures 8 and 9 use stacked bar graphs to compare the macroinvertebrate community composition of a vernal pool in April, shown above in Figure 2, with the community observed two months later, in June. Both figures start with the same data set, but Figure 8 uses the raw numbers of animals collected, and Figure 9 transforms the results into a percent of the total sample.

Although the same data are used in both graphs, the information we obtain from the two graphs is somewhat different. The bars in Figure 8 emphasize the decline in the number of animals collected – the June sample numbers were much lower than in April. The composition of the community also changed, but the details of this change are somewhat difficult to see in Figure 8.

The changes in the proportions of the different taxa are shown more clearly when the data are graphed as a percent of the total population, as in Figure 9. The crustaceans that dominated the pool in early spring were mostly absent in June. Aquatic insects made up the majority of the animals present in the June sample. Water bugs, dragonflies, and damselflies, which were rare or absent in April, had become an important part of the aquatic community in June.

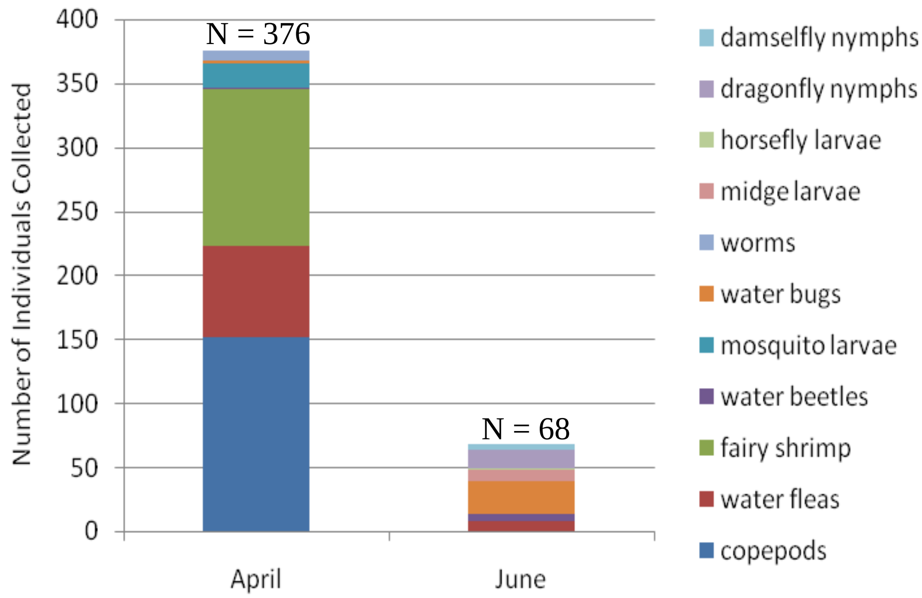


Figure 8. Stacked bar graphs comparing numbers of aquatic macroinvertebrates collected in vernal pool #1 in April and June, 1996. Source: Colburn, unpublished data.

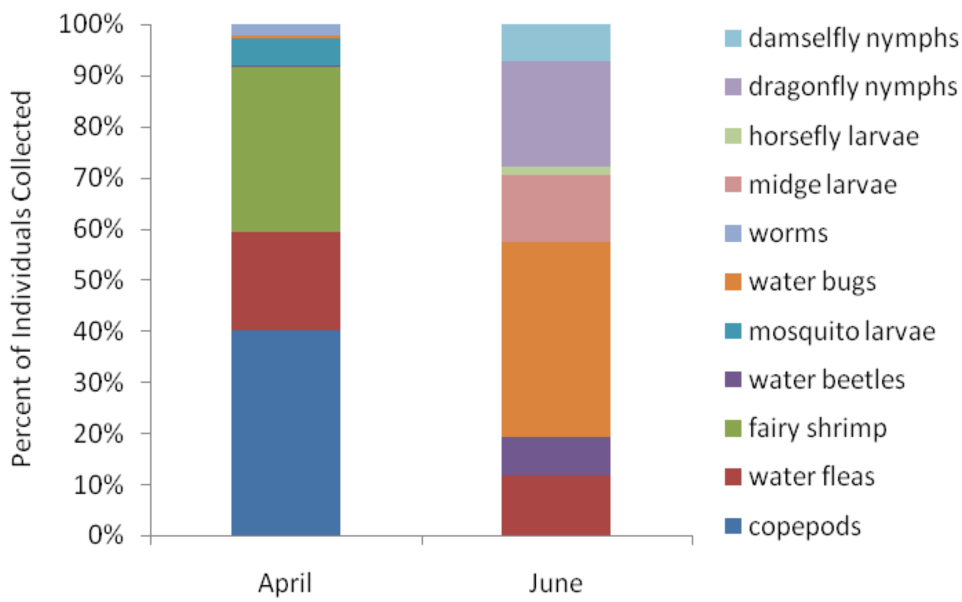


Figure 9. Stacked bar graphs showing percent composition of the macroinvertebrate community in vernal pool #1 in April and June, 1996. April: N = 376. June: N = 68. Source: Colburn, unpublished data.

Figure 10 presents another bar graph of the same data, using the raw numbers as in Figure 8. In this graph, the different kinds of invertebrates are ranged along the X axis, and the numbers of individuals collected in the two sample months are stacked in a single column. The data could also be presented with the data for the two months side-by-side, in separate bars for each invertebrate group.

This graph illustrates the decrease in the overall numbers of individuals from April to June, the disappearance of the early spring crustaceans, and the shift to a community dominated by aquatic insects. It provides a more dynamic sense of the changes that occurred over time in the pool over the study period. Unlike Figure 8, this graph makes it easy to follow the changes in relative abundance of all of the invertebrate taxa over the study period.

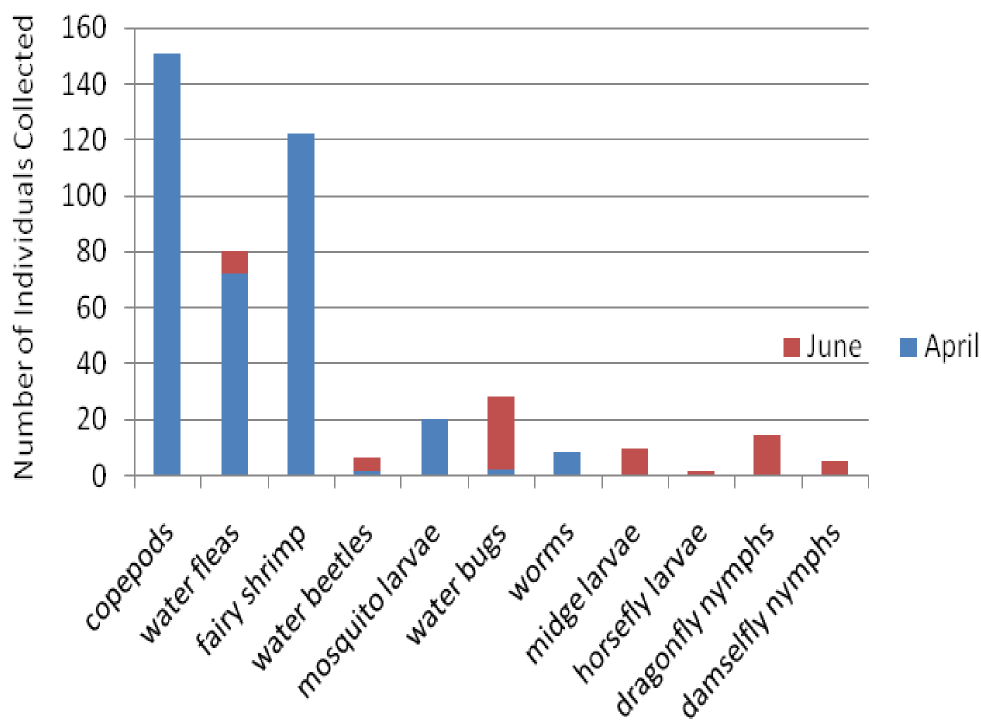


Figure 10. Stacked bar graphs showing the taxonomic composition of the aquatic macroinvertebrate community in vernal pool #1 in April and June, 1996. April: N = 376, June: N = 68. Source: Colburn, unpublished data.

These examples show how you can sometimes extract different kinds of information from a data set, simply by varying the way you graph the data and by changing the units you use for the results. As you and your students work with data collected in schoolyard science projects, you should feel free to experiment with different options for graphing the results, so that you get a feeling for the kinds of information that may be revealed as you present the data in various ways.

4. Preparing Data For Graphing

Chapter Overview:

This chapter covers
- Steps involved in getting data ready to be graphed
- Selecting data for analysis
- Sorting and manipulating data
- Converting leaf-fall data to a percent
- Extracting tree-species data
- Extracting data on first and last dates of leaf fall

Once scientists have collected data in the field or laboratory and entered them into a spreadsheet or data base, the next step involves looking at the data. First, researchers organize and check their data to identify errors or problems associated with sampling methodology, field conditions during sampling, record keeping, or data entry. Then, often, they graph the data to obtain a quick overview of the results.

In this chapter, the focus is on the steps involved in getting data ready for graphing. We start with general information that applies to preparing data in general. The focus then moves to more detailed examples illustrating each of the steps involved. We describe sorting the data and converting the raw field data into a form that is suitable for graphing. We also give an example to show how additional data can sometimes be extracted from a data set.

Steps Involved in Organizing and Graphing Data

Usually, before a graph can be created from research data, the original data (as in Tables 1-3 in Chapter 3) need to be converted into a form that is readily recognized by the computer graphing program. This tends to be the case for graphing generally, no matter what graphing software is being used. It is also true even if the graph is being prepared by hand or by a computer program. Much of the time involved in making graphs from research data is taken up with getting the data into an appropriate format for the computer.

Getting data organized into a format that the computer can turn into a graph usually involves several steps. These may include:

- selecting the data of interest from a data set,
- copying the data into spreadsheets or other formats that allow them to be worked with easily,
- manipulating the data to make the results clearer (for example, sometimes it is preferable to present results as percentages than as raw numbers),

- organizing the data into categories that lend themselves to graphing,
- lining up columns of data in an order that the computer can work with – this step is often specific to different graphing programs, and usually the instructions will specify the way data need to be organized,
- choosing the type of graph you want to make,
- formatting the graph, and
- making final adjustments.

The examples in the rest of this chapter address the steps involved in preparing data for graphing. We use examples of leaf-fall data collected by Judy Miller's classes at Athol-Royalston Middle School in Athol, MA, a portion of which is presented in the tables on pages 14 and 17. The full data set provides data for eleven trees and includes four years of results.

Sorting and Evaluating Data

Data in spreadsheets and data bases are arranged in a variety of ways. Usually, scientists need to rearrange the data before they can carry out analyses of the results. This is the case for statistical analyses, graphing data, and other approaches to data assessment.

In the phenology data sets, data are presented chronologically for each sampling date in each year, with all trees listed by date (see Table 2, on page 17). However, if we want to prepare a graph of the data to illustrate the progress of leaf fall in individual trees, we need to do some manipulations and rearrangements of the file, so that the computer will make the appropriate graph.

Such data preparation is required for most graphics programs, and also is generally necessary for statistical analysis of the data.

Sorting Data

It is easy to sort data in most computerized spreadsheets. You select the set of data you want to work with, tell the computer what variables to sort by, and in what order, and instruct the computer to sort the data. If your data set is small, you can also sort it by hand, but this is a much more cumbersome process.

We recommend that you keep the original data set intact when sorting, and that you copy the file onto a second worksheet or table. You can perform different kinds of manipulations on the copy without a risk of losing any of the original data.

To begin with, we are going to rearrange the phenology data so that all the results from each tree (or each branch or other measured entity, depending on the specific data you are looking at) will be together. Each tree's data will be organized by date. Thus, the computer is instructed to sort the data first by Tree ID and then by Date. The same basic procedures are followed when sorting spring bud-burst data, fall color-change data, and other kinds of data sets.

The first 32 rows of the sorted data from the ARM phenology study, representing all four years of data for tree #1, a yellow birch, are presented in Table 5. The first two years of data for tree #5, a chestnut, are shown in Table 6.

Table 5. The first 32 rows of the sorted ARM Schoolyard Phenology Data, showing results for Tree #1, 2004-2007.

School	Teacher	Date	Julian	TreeID	Species	Ltotal	Lfallen	Tcolor
ARM	Miller	9/22/2004	266	1	YB	10	0	NA
ARM	Miller	9/29/2004	273	1	YB	10	0	NA
ARM	Miller	10/6/2004	280	1	YB	10	0	NA
ARM	Miller	10/13/2004	287	1	YB	10	0	NA
ARM	Miller	10/19/2004	293	1	YB	10	0	NA
ARM	Miller	10/27/2004	301	1	YB	10	0	NA
ARM	Miller	11/4/2004	309	1	YB	5	5	NA
ARM	Miller	9/28/2005	271	1	YB	24	3	2
ARM	Miller	10/5/2005	278	1	YB	24	3	2
ARM	Miller	10/12/2005	285	1	YB	24	8	3
ARM	Miller	10/19/2005	292	1	YB	24	10	4
ARM	Miller	10/26/2005	299	1	YB	24	13	4
ARM	Miller	11/2/2005	306	1	YB	24	20	4
ARM	Miller	11/10/2005	314	1	YB	24	24	4
ARM	Miller	9/20/2006	263	1	YB	24	2	2
ARM	Miller	9/27/2006	270	1	YB	18	6	2
ARM	Miller	10/4/2006	277	1	YB	24	11	2
ARM	Miller	10/11/2006	284	1	YB	24	16	2
ARM	Miller	10/18/2006	291	1	YB	24	17	4
ARM	Miller	10/25/2006	298	1	YB	24	18	4
ARM	Miller	11/1/2006	305	1	YB	24	23	4
ARM	Miller	11/8/2006	312	1	YB	12	12	NA
ARM	Miller	9/12/2007	255	1	YB	24	4	NA
ARM	Miller	9/19/2007	262	1	YB	24	4	NA
ARM	Miller	9/26/2007	269	1	YB	24	9	NA
ARM	Miller	10/3/2007	276	1	YB	24	13	NA
ARM	Miller	10/10/2007	283	1	YB	24	20	NA
ARM	Miller	10/17/2007	290	1	YB	24	21	NA
ARM	Miller	10/24/2007	297	1	YB	24	23	NA
ARM	Miller	10/31/2007	304	1	YB	6	6	NA
ARM	Miller	11/7/2007	312	1	YB	NA	NA	NA
ARM	Miller	11/14/2007	319	1	YB	NA	NA	NA

Table 6. Leaf-fall data for Tree #5 in ARM Schoolyard Phenology Study, 2004 and 2005.

School	Teacher	Date	Julian	TreeID	Species	Ltotal	Lfallen	Tcolor
ARM	Miller	9/22/2004	266	5	CH	10	0	NA
ARM	Miller	9/29/2004	273	5	CH	10	0	NA
ARM	Miller	10/6/2004	280	5	CH	10	0	NA
ARM	Miller	10/13/2004	287	5	CH	10	0	NA
ARM	Miller	10/19/2004	293	5	CH	10	1	NA
ARM	Miller	10/26/2004	300	5	CH	10	8	NA
ARM	Miller	10/27/2004	301	5	CH	5	4	NA
ARM	Miller	11/5/2004	310	5	CH	10	10	NA
ARM	Miller	9/28/2005	271	5	CH	24	0	1
ARM	Miller	10/5/2005	278	5	CH	24	0	1
ARM	Miller	10/12/2005	285	5	CH	24	0	2
ARM	Miller	10/19/2005	292	5	CH	24	4	3
ARM	Miller	10/26/2005	299	5	CH	24	12	4
ARM	Miller	11/2/2005	306	5	CH	24	19	4
ARM	Miller	11/10/2005	314	5	CH	24	19	4
ARM	Miller	11/16/2005	320	5	CH	24	24	4

NOTE: Depending on the data set you are working with, you may find it easier to sort the data set more than once. For example, first you might want to use Date as the primary sort variable, and look at the results to see if there are issues with repeat samples in the same week, missing results, or other potential problems associated with sampling dates. Then sort the data set again using TreeID as the primary sort variable. Every data set is different, so sort based on the kinds of information in the data and the kinds of information you need to check.

Removing Rows and Columns with Missing Data

Once the data have been sorted, we need to examine the data set to identify features of the data that may need to be addressed before we can graph the results, and to get a sense of ways that the data might be graphed. In particular, we will look for missing data, indicating rows or columns that need to be removed, and inconsistencies in the data.

Data are missing in several rows of the data set; these rows need to be removed. In Table 5, we see that no data on leaf-fall or leaf color are available for Tree YB #1 on the November, 2007 sampling dates (missing data are entered as NA). Each row that has missing data in one or more cells should be removed from the data set.

Also, in this data set, leaf-color data are available only for 2005 and 2006. We will not be looking further at leaf-color data in this manual, so we will remove the Tcolor column.

NOTE: If you prefer, you can remove unwanted columns and rows before sorting the data set. When you carry out these actions is totally up to you and may vary, depending on the characteristics of each data set you are working with. The idea is, simply, to make life easier by eliminating information that is not needed, and removing excess clutter from your working area.

Evaluating Data for Needed Adjustments

Once missing or unwanted data have been removed from the working data set, the remaining data need to be examined to see if there are any adjustments, standardizations, or transformations that may be necessary, appropriate, or useful in analyzing the results. A researcher is likely to look at the data to see if any potential problems are evident, and to determine if any manipulations are needed. This might involve:

(1) checking all of the columns and rows to be sure there aren't any strange results that need to be examined more carefully, or that might require some adjustments in the data. Sorting often lets you identify errors in data entry, or to find missing data that need to be removed before the data set is analyzed, and
(2) for the leaf-fall results, looking at data for individual trees, and also data for each year.

Depending on the results of the examination, the data may need to be adjusted. It is beyond the scope of this manual to go through all of the kinds of standardizations, manipulations, and transformations that may be appropriate for different kinds of data. Instead, we look at some changes that are appropriate for the sample data set and use them as illustrations of the way you might want to think about your data.

Some of the kinds of adjustments that might be needed could include consolidating samples collected on different days in the same week, addressing inconsistencies in numbers of leaves sampled from one week to the next, accounting for missing data, and dealing with data that do not make sense (for example, a result that says that some previously fallen leaves on a branch are back on a later sampling date! – see Figure 17 on page 52).

In the sample ARM data set, observe the following potential problems.

Adjusting for uneven sampling effort. The leaf-fall data are not comparable across sampling dates (examples are evident in Tables 5 and 6).

For some trees studied in 2004, there are 5 samples for some dates and 10 samples for others. For all trees, more leaves were studied in years after 2004 than in the first year.

Because the numbers are not comparable across dates within years, or between years, using the raw numbers for comparisons of the data through graphing will be a problem.

The best way to deal with this problem is to convert the data for Lfallen to percentages before they can be graphed, to account for the fact that different numbers of leaves were examined on different dates. The easiest way to do this is to use your spreadsheet program to calculate a percent from the raw leaf-fall numbers. The basic formula for the calculation is:

$$\text{Lfallen} / \text{Ltotal} \times 100 = \text{percent of all leaves that have fallen.}$$

Adjusting for inconsistencies in sampling. As we look at the sample data, we see that not all trees were sampled on the same dates, and not all branches on each tree were sampled at the same time. We may need to adjust how data are presented to reflect these inconsistencies.

In the ARM data set, most samples were collected on one day in each week, but in a few cases a particular tree was sampled on two successive days. For instance, CH5 was sampled on 10/26 and 10/27 in 2004 (Table 6). Not only were the dates different, but also different numbers of leaves were sampled on those dates (and, in fact, different branches were sampled by different classes). In some weeks, certain trees were sampled on one date and others on a second date.

For some kinds of computer-generated graphs, all of the study variables need to be sampled at the same time, or the graphing program will not plot the data correctly. Other kinds of graphs can plot every data point on its specific sampling date. Another option is to plot all the data for different trees or branches together by week, rather than day of sampling. This might be a good solution if you want to compare among trees, but the trees were sampled on different days of the week.

If you want to graph the ARM data set, you will need to consider whether you want to graph a single record or both data points for any tree that was sampled more than once in a given week. A very good way to handle this problem is to have separate graphs for the data collected by the different research teams – even if they are sampling the same tree. The graphs can be plotted next to each other on the same axes, or they can be plotted as two completely separate graphs. (In the case of chestnut tree #5, the same proportion of leaves had fallen on the two back-to-back sampling dates, so the interpretation of the data is not as problematic as it would have been if the results of the two dates' sampling were not the same!).

NOTE: Designing a research project so that sampling will be consistent over time is a great challenge. Whenever you are collecting data over time, if the individuals monitored or the numbers of samples taken were not the same on the different dates, there may be problems with interpreting the data. Unforeseen problems in study design that result in inconsistent sampling need to be addressed early on, so that the data will be suitable for analysis and interpretation. In schoolyard science projects, though, practical and logistical issues sometimes result in sampling issues such as those noted here – these just need to be recognized and dealt with when working with the data. Sometimes, you can make use of the differences to obtain some interesting information that will be valuable for teaching about science. For example, if different classes are looking at leaves on different branches on the same tree, they can graph the data for each branch to see how much variability there is between branches.

Extracting Additional Information From the Data

A final exercise that can be productive, once initial data evaluation is complete, is to look at the data to see if there is more information that can be extracted.

The data on leaf fall recorded in this data set represent only some of the information available from the ARM schoolyard phenology study. As noted in the discussion of data in Chapter 3, additional information may be found in the Metadata that describe the data set, as well as in the individual sets of data collected by student research teams. But, even without those sources, additional information can also be obtained by careful examination of the data presented here.

We have seen that this data set presents results from eleven trees representing six different species. It might be interesting to graph how the sampling is distributed across species. Table 7 summarizes the species that were sampled in the ARM Schoolyard Phenology project, and the number of individuals of each species. Three examples of graphs of these data are shown in Figure 11, on page 47.

Table 7. Breakdown of sampled trees by species, ARM Schoolyard Phenology Study, 2004-2007.

Tree Species	Number of Trees
Beech	2
Chestnut	2
Hawthorn	1
Red maple	4
Witch Hazel	1
Yellow Birch	1

Looking at these results, you might want to consider whether the distribution of samples parallels the relative abundance of the different tree species in the schoolyard or neighborhood. Or, if more trees were to be added to the study, you might want to consider adding a second individual of species currently represented by only one tree, so that students could look at variation within the different species. Many other possible questions probably come to mind as you look at this information.

There are also different ways to look at leaf fall. The chronological data set shows the gradual progress of trees losing their leaves over the sampling period. It might also be useful to extract from the data set the dates when the first leaves were observed to fall from each tree (or branch), and/or the dates when all leaves had fallen. Table 8 shows these data for tree #1; similar data can readily be extracted for the other 10 trees in the sampled population. Two examples of graphs created from these data are shown in Figure 13 and Figure 14, on page 49.

Table 8. Data Table for first and last leaf-fall dates for tree YB1, 2004-2007. Dates presented as Julian Day.

Year	First leaf fall	100% Fallen
2004	309	309
2005	271	314
2006	263	312
2007	255	304

Overall, depending on the data being collected in a particular research study, a variety of other reorganizations of information may be possible. The additional information can often provide new insights into the results of your study.

Chapter 5. Graphs of Schoolyard Data

Chapter Overview:

This chapter presents sample graphs of Schoolyard Ecology Data:

Phenology
- Tree species in a sample population
- Leaf fall in a tree over time
- Dates of first and last leaf fall in a tree
- Leaf fall in multiple trees

HWA
- Egg production on three hemlock trees

Water in the Landscape
- Water depth in a stream
- Water level and diameter in vernal pools

This chapter gives examples of graphs that we created using data submitted by teachers participating in Harvard Forest's schoolyard ecology program. The data used in all of the graphs can be downloaded from the Harvard Forest websites for the different research protocols and data (http://harvardforest.fas.harvard.edu/museum/schoolyard.html), as can additional data sets from other participating classrooms.

Most of the graphing examples shown here illustrate data from fall phenology studies. A few examples are also presented at the end of the chapter from schoolyard studies of hemlock woolly adelgid and water in the landscape. You can create similar graphs from your own data, regardless of the study system, if the data are appropriate for illustration in the chosen graph format. Note, too, that other graphing options for schoolyard ecology data are available – the examples shown here only illustrate some potential options.

You should feel free to experiment with graphing your classroom data in many different ways. Look at how different graphing approaches yield different insights into the research questions. And, think about what graphing formats are most effective in showing your results to others.

Phenology

A variety of options for graphing fall phenology data are shown. All use the schoolyard data set from Athol-Royalston Middle School, the ARM data set discussed in Chapter 4. Instructions for downloading this data set are included in the accompanying hands-on exercises. The hands-on exercises also provide specific instructions for creating several of these graphs. Similar graphs can be made for many of the data collected for spring phenology and for other schoolyard ecology protocols.

Tree Species in a Sample Population

The first three examples show how the trees being sampled in the ARM schoolyard study of leaf-fall phenology vary by species. The tree-species data extracted from the larger data set and shown in Table 7 (p. 43) are displayed in a pie graph, a stacked bar graph, and a bar graph of the individual species data (Figure 11).

The pie graph in Figure 11a and the stacked bar graph in Figure 11b both show the proportions of the tree species as part of the whole study population. If your classes are studying 20 trees between them, and if the trees are divided among more than one species, you can make a stacked bar graph or a pie graph that shows how the total population of study trees is divided up, in terms of species composition.

Usually, a pie graph would be preferred over a stacked bar graph for this kind of presentation. The stacked bar graph would be more appropriate for a graph comparing how sampled tree species varied from one year to the next, if the class was looking at different population of trees each year, or for a comparison of the species of trees sampled by students in different schools – where, probably, the species sampled and their proportions would differ.
The bar graph in Figure 30c presents the same set of data on tree species, but it shows the number of trees for each species separately.

Presenting the data in this format emphasizes that red maple is the most heavily sampled tree in the study. It also makes it very evident that there is only one individual of yellow birch, witch hazel, and hawthorn in the sample. A graph such as this might be useful if a teacher was thinking about adding more trees to a study, because it suggests that having more individuals of poorly represented species might provide information on within-species variability. Or, it might suggest which species could lose an individual, if it is found necessary to scale down the study for any reason. On the other hand, it might be desirable to combine the information in this graph with separate information on the relative abundance of the different species in the neighborhood of the schoolyard. If the study is trying to obtain an overview of phenology that reflects the local forest, and if red maples represent 90 percent of the local trees, then this species is under-represented in the sample, even though it is the most heavily sampled species.

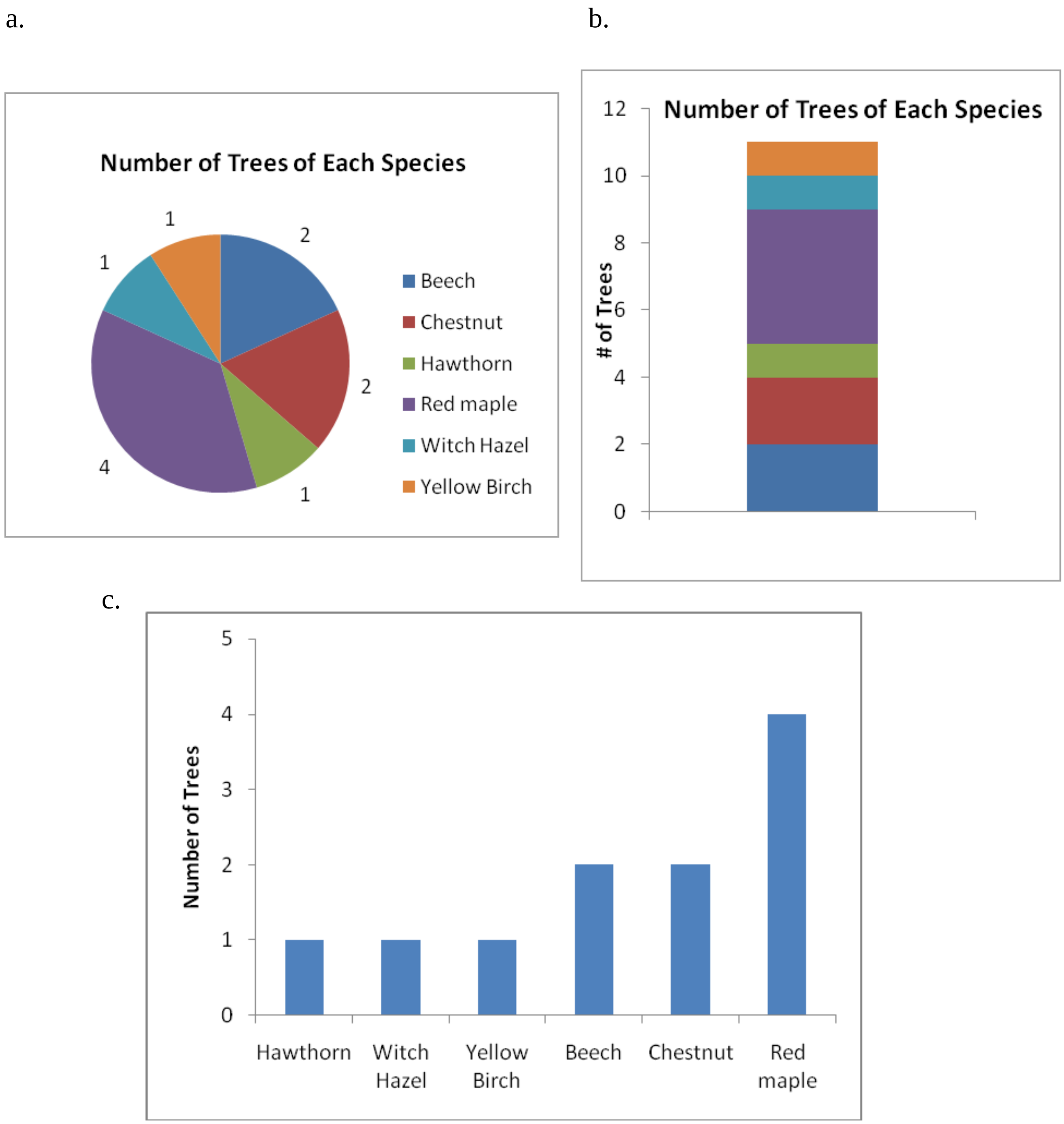


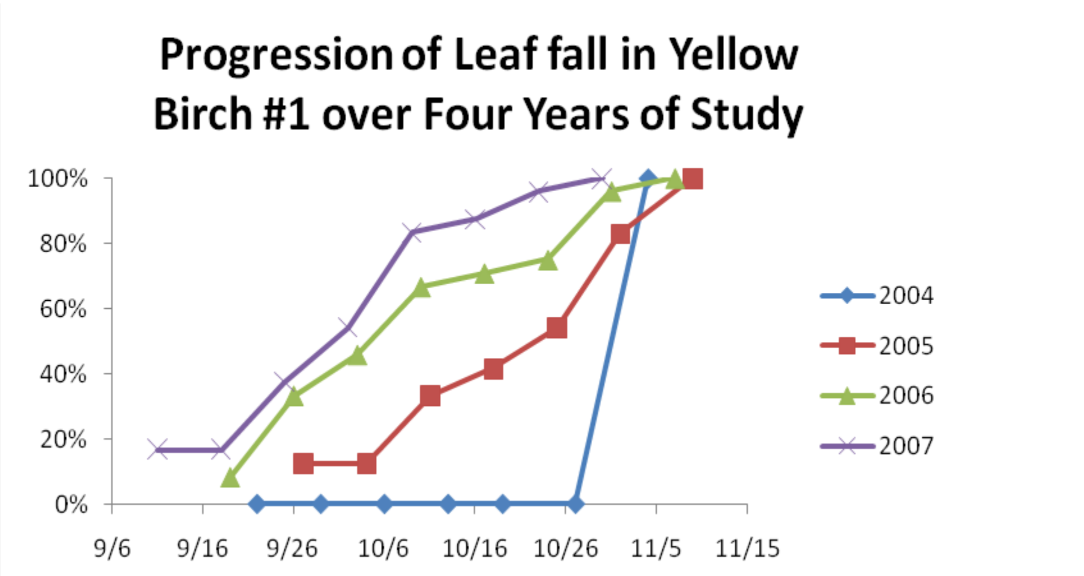
Figure 11. Three ways to graph the species of trees sampled in a schoolyard phenology study, Athol-Royalston Middle School. a. Pie graph. b. Stacked bar graph. (Species codes as in a.) c. Bar graph.

Leaf Fall in One Tree Over Time

Figure 12 shows four years of leaf-fall data for a single tree, a yellow birch (tree #1 in the samples; see data in Table 5, p. 39). From this graph, we can see that in 2004, all of the leaves fell in one week, between the sampling in the last week of October and the first week in November. In subsequent years, leaves fell from the tree over the course of more than a month.

If we go to the ARM data set and look at the data for tree YB1 in 2004, we see that only half of the leaves that were observed during most of the study were sampled on November 4, and that all of them had fallen on that date. Note that we do not have information on whether all of the leaves that had been being studied had fallen by November 4! Therefore, it is difficult to draw any conclusions about what might have been happening on that date. It might be a good idea to include a note on the graph indicating that some data were missing for November 4, 2004.

Figure 12. Leaf fall over four years in one tree studied by the ARM Schoolyard Phenology Project.



Dates of First and Last Leaf-fall

Figures 13 and 14 show two ways of comparing the first and last dates when leaves were observed to fall from Yellow Birch #1 during the four years of the study, using the data presented in Table 8 (p. 43). Note that in Figure 13, Julian Day has been converted to Date.

In both graphs, it is easy to see how the dates when the students observed the first fallen leaves became earlier each year over the four years for which data are available. The similar but less consistent trend in the date of last leaf fall is also visible. Note how the date of first leaf fall occurred earlier in each year of the study. Is there a similar trend in the date of last leaf-fall?

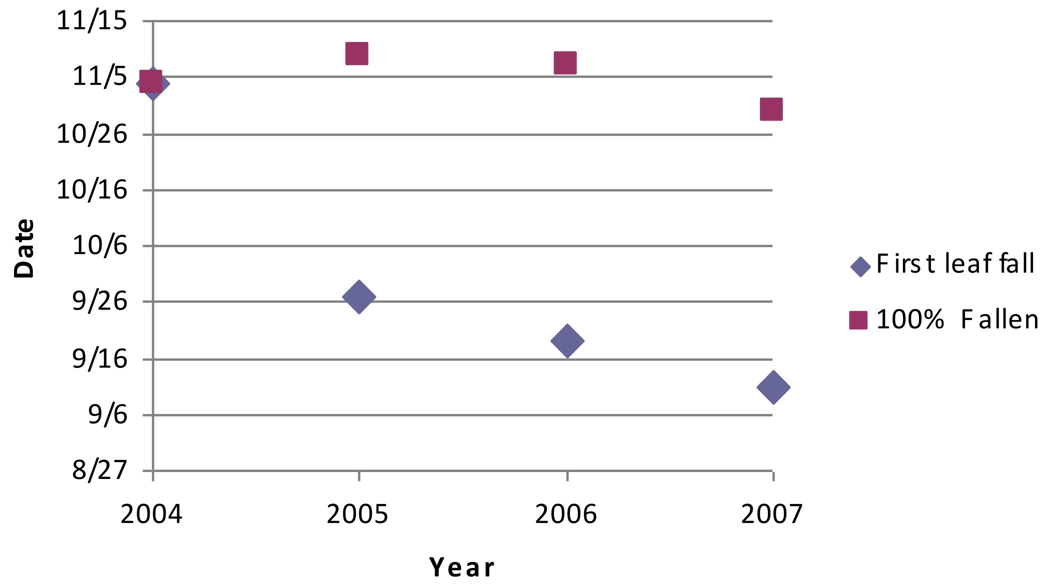


Figure 13. First and Last Dates of Leaf Fall in Yellow Birch #1, 2004-2007.

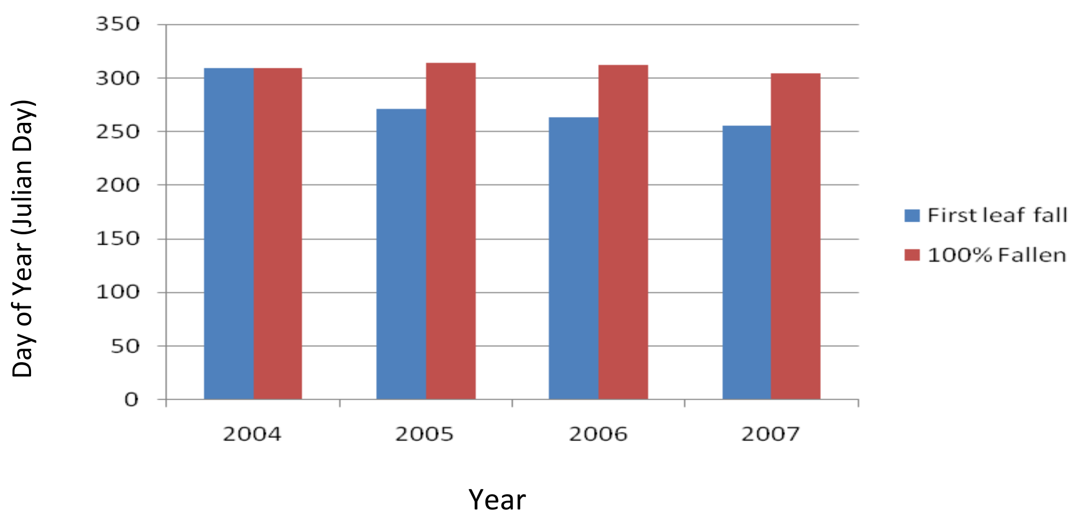


Figure 14. First and last dates of leaf fall in Yellow Birch #1, 2004-2007.

This result might seem a bit surprising in the context of a study about climate change and potential effects of global warming on the growing season. It could provide an opportunity for examination of local weather data for the study years, classroom discussions of short-term and long-term trends, and consideration of the importance of looking at more than one source of information. For example, do all eleven trees in the study show this same pattern of earlier leaf-drop? What if more leaves had been studied on each tree?

Leaves Remaining Over Time

Figure 15 presents leaf-fall data in a slightly different way. Instead of following leaves that fall, it tracks the leaves that remain on a hawthorn, HA11, during the sampling period in 2005. The data are the inverse of the data used in Figures 2, 3, and 5; that is, they represent 100% of sampled leaves minus % Fallen.

How does the information presented, and the interpretation of the information, change if the data are presented in this way, rather than in terms of percent of leaves fallen?

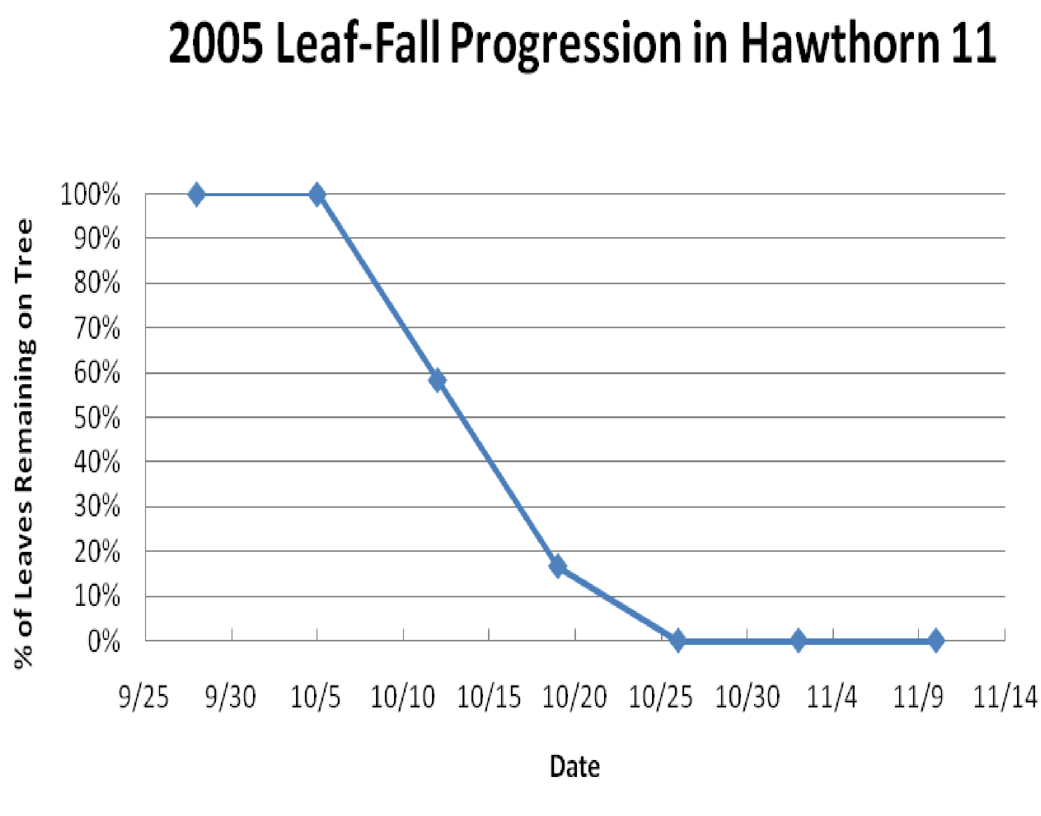


Figure 15. Time course of leaf fall in a hawthorn, HA11, in 2005. Data from Athol-Royalston Middle School Schoolyard Science Program.

Leaf-Fall in Multiple Trees

Figure 16 graphs leaf-fall results from seven trees sampled by students at the Athol-Royalston Middle School in 2004, as well as the progression of leaf fall in the same trees, plus four others, in 2005.

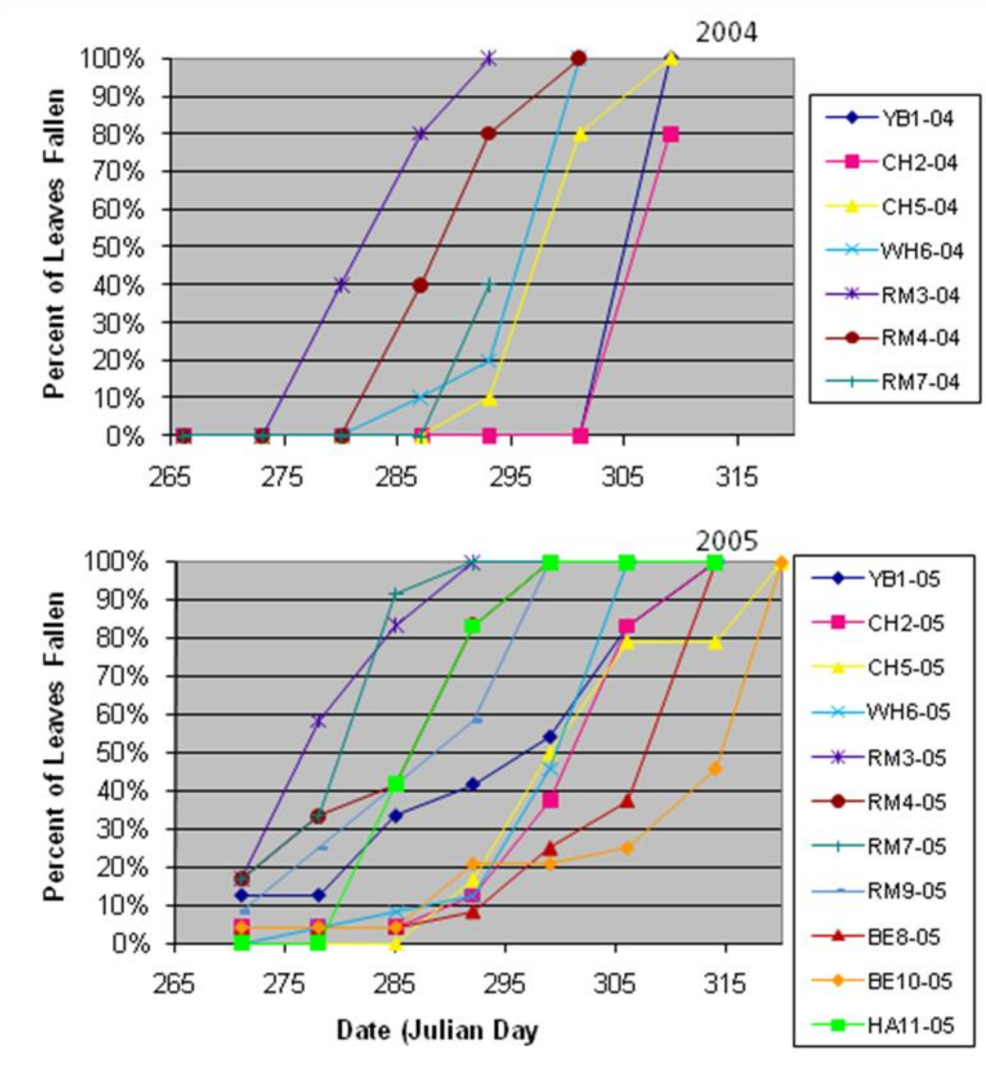


Figure 16. Progression of autumn leaf fall in trees studied by students at Athol-Royalston Middle School, Athol, MA. Seven trees were surveyed in fall, 2004, and the same trees plus four more were examined in 2005. Tree species codes: YB = yellow birch, RM = red maple, WH = witch hazel, CH = chestnut, BE = beech, HA = hawthorn

From this graph, it is easy to follow how leaf fall took place over time for each of the study trees, and also to compare individual trees across years. A student research team can prepare a graph like this, showing a single line, for the tree or branch that they study, and the class can put the results together to make a graph that illustrates all of the trees, combined. When trees have been sampled for more than one year, the graphs can be put next to each other and compared. Other graphing approaches allow comparisons between trees and years.

Figure 17 is similar to Figure 16, but instead of graphing the results for a single tree, it compares three trees of the same species, red maple, over three years.

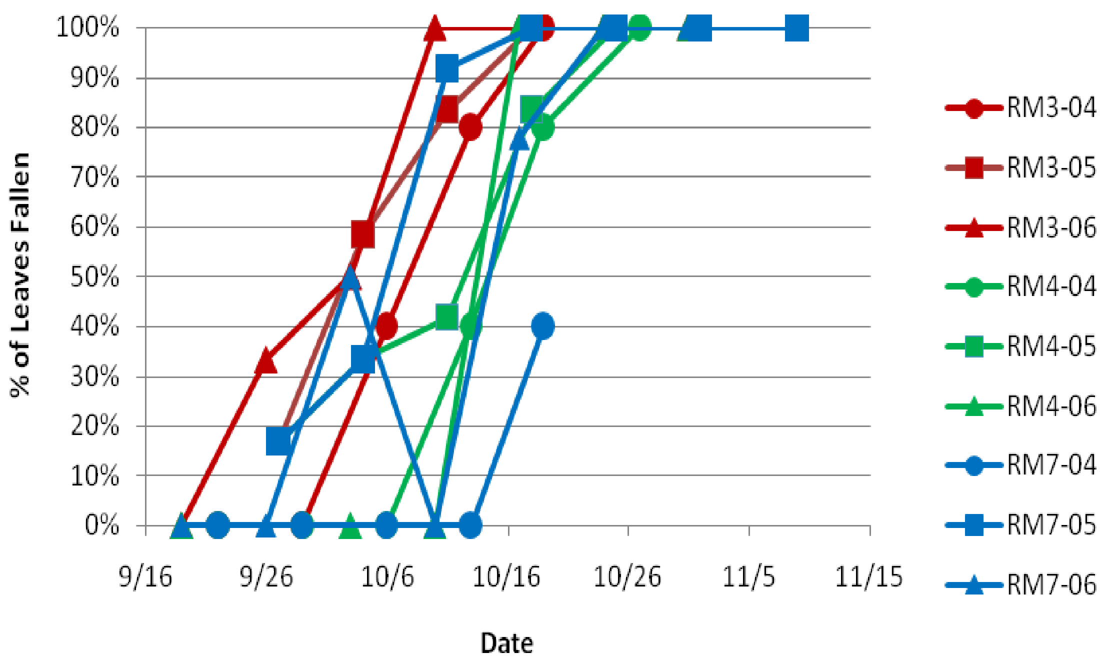


Figure 17. Progression of leaf fall in three red maples, 2004-2006. Tree codes include tree identification number (e.g., RM3) and year sampled (e.g., -05). Data from Athol-Royalston Middle School Schoolyard Science Program.

Several kinds of information are evident from the graph.

First, during the study, RM3 and RM4 show the same trend of earlier leaf-fall in successive years as was seen in YB1, above (Figures 12-14).

Second, RM3 consistently lost its leaves earlier than RM4.

Third, in 2005, when the first sampling did not occur until late in the last week in September, all three trees had already lost some of their leaves.

Fourth, RM7 showed the most inter-annual variability in the timing of leaf fall.

Fifth, the data for RM7 in 2006 seem to indicate that the tree lost half of its leaves by the end of September but miraculously regained them in early October. This result reflects the fact that only half as many leaves were sampled in the early October sampling period as in the preceding and successive weeks. In late September, twelve leaves were sampled; of these, six had fallen and six were still on the tree. The next week only six leaves were sampled and they were all still on the tree. The following week, all twelve leaves were again sampled, and almost 80% of them had fallen.

In a case like this, it would be better to leave out the data for the early October sampling date. Or, you could graph the data from only the six leaves that were sampled through the entire study period.

NOTE: Graphs comparable to those presented thus far can be created using spring bud-burst data, instead of autumn leaf-fall data. Instead of number of leaves that have fallen, the data would be number of buds that have burst, plotted against sampling date.

Similar graphs can be made from any data that measure changes in a variable over time.

Hemlock Woolly Adelgid

Classrooms studying the spread and effects of the invasive insect, the hemlock woolly adelgid, evaluate the crown health of one or more hemlock trees, look at two or more branches on the tree(s) to determine if hemlock woolly adelgid is present, count egg masses to get an estimate of adelgid abundance, and measure each year's new growth on the study branches.

Graphs of HWA data could include the number of egg masses counted per year on each study branch; egg mass densities averaged for the whole tree; changes in egg mass densities over time; and branch growth relative to egg density.

Egg density in Three Study Trees

Figure 18 shows the density of eggs of the hemlock woolly adelgid on three different hemlock trees sampled by students at the Wildwood Elementary School, Amherst, MA, in 2004. We see that there is considerable variation between the trees. As additional data are collected over time, the changes can be tracked in bar graphs or scatter plots comparable to those for leaf-fall data in the phenology studies.

Figure 18. Egg production by the hemlock woolly adelgid on three hemlock trees sampled by students at Wildwood Elementary School, Amherst, MA, in 2004.

Water in the Landscape

Research protocols for water in the landscape focus on documenting how water levels change through time. In stream studies, students collect data on water depth at several locations in a study stream, along with temperature data. Additional information is collected at the discretion of the teacher involved. In vernal pools, students monitor depth changes in the deepest part of a pool, record changes in pool diameter, and track temperatures. Some classes also look at aquatic life. The depth data can be related to additional information on weather (e.g., precipitation, long-term temperature changes), to animals and other life observed at the study site, and to pool diameter (or stream width, if measured).

Water Depth in a Stream

Figure 19 illustrates two ways of graphing data on water depth in a study stream. The data are from Pelham Elementary School. Both graphs show that depth increased between the two fall sampling dates, and decreased between the two spring sampling dates.

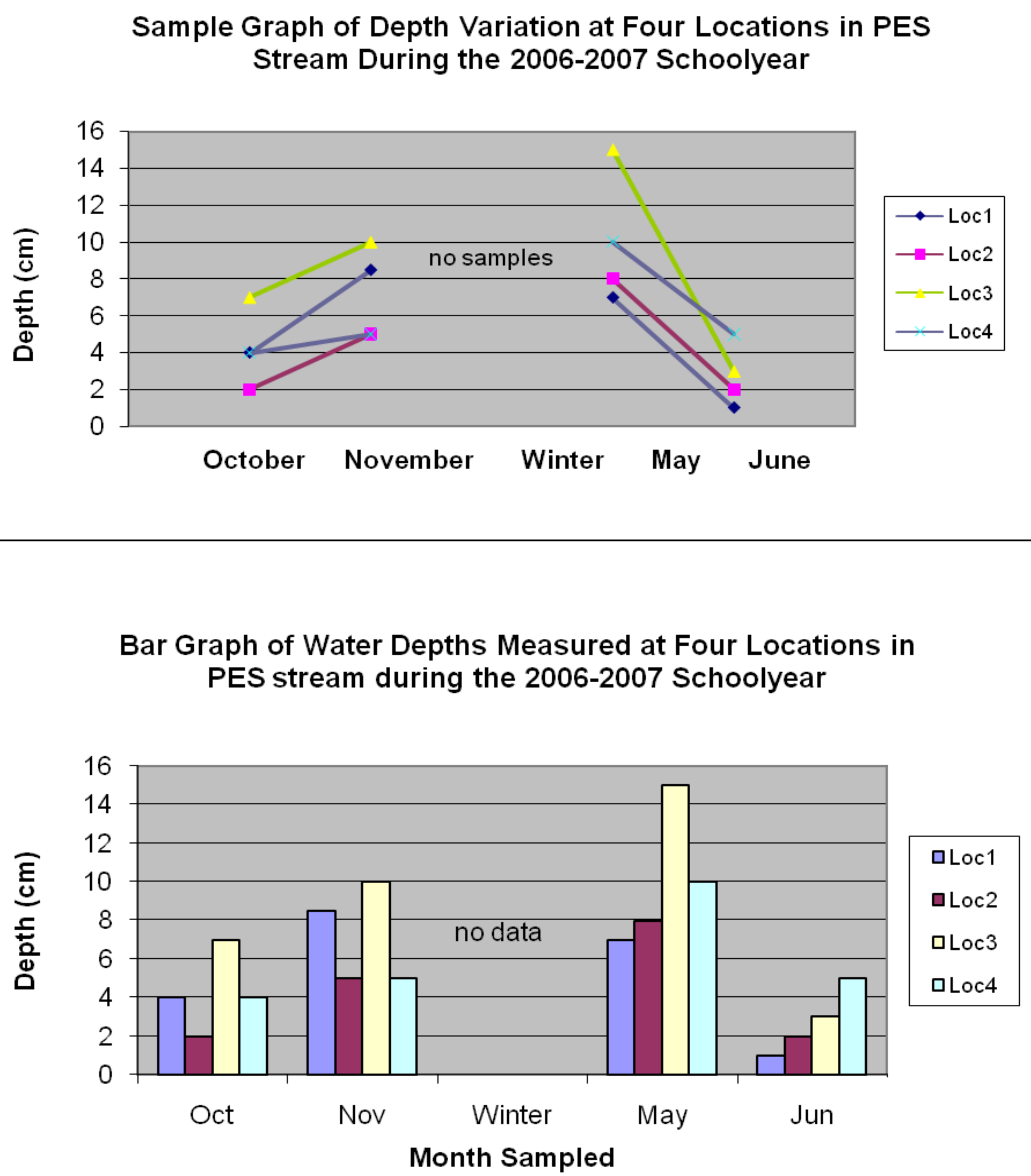


Figure 19. Two ways to illustrate depth variation at four locations sampled by students at Pelham Elementary School, 2006-2007.

Note that the lines connecting the points in the upper graph of Figure 19 do not indicate that the water levels increased consistently along the line, but only that the overall pattern between the two sampling dates showed an increase. There were probably many changes in water depth between the sampling dates, as illustrated in the detailed stream discharge graphs from Bigelow Brook presented on pp. 32 and 33.

Also, note that the relative depth relationships between the four sampling sites changed during the course of the study. For example, Location 3 was deepest on the first three sampling dates, but in June, Location 4 was deeper. There may be a need to check the way the samples are being collected to be sure that the location has not varied. Or, additional measurements of the stream bottom and how water is distributed at high- and low-flow conditions may be appropriate.

Water Level and Diameter in Vernal Pools

An understanding of pool depth profiles may contribute to a better understanding of depth-habitat relationships and the patterns of animal distributions in vernal pools. Figure 20 presents schoolyard data on water levels from two vernal pools, one in Petersham and one in Ashburnham, MA.

By looking at the water-level data graphed in Figure 20, we can see that both pools appear to fill in fall and to reach their maximum depth in winter/spring (based on the small number of seasons studied thus far). The timing of sampling is important for showing this pattern. The water levels in the Ashburnham pool (JRB) were sampled by two classes. Data for this pool are available only for fall in the 2005-2006 season; both classes found a dry pool early in fall and class one, sampling a second time later in the fall, found that the pool had flooded. In the 2006-2007 season, class one (yellow diamonds) started sampling later in the year than class two (green triangles) and missed the early fall period when the pool was dry. Without the fall data, one might conclude that the pool is permanently flooded. The combined data show the typical vernal-pool pattern of dry conditions in early fall, filling in late fall, and water levels starting to draw down slightly in late spring.

Similarly, in fall, 2005, the Petersham pool (PCS) (purple dots) was not sampled until November, when it was already flooded. The following year (red dots), this pool was sampled starting in late August, and it was dry through the end of September; it again contained water in early November. The timing of flooding is important for the life cycles of many pool animals and plants, and having an understanding of when a pool fills and dries can contribute to better knowledge of the biology of pool inhabitants. When a pool dries is also important in determining whether different kinds of animals and plants have enough time to finish their development in a given year.

Figure 20 also shows that the pools have different maximum water depths. The greatest depth measured in the Petersham pool is 140 cm, as compared with a maximum measured depth of just over 90 cm for the Ashburnham pool.

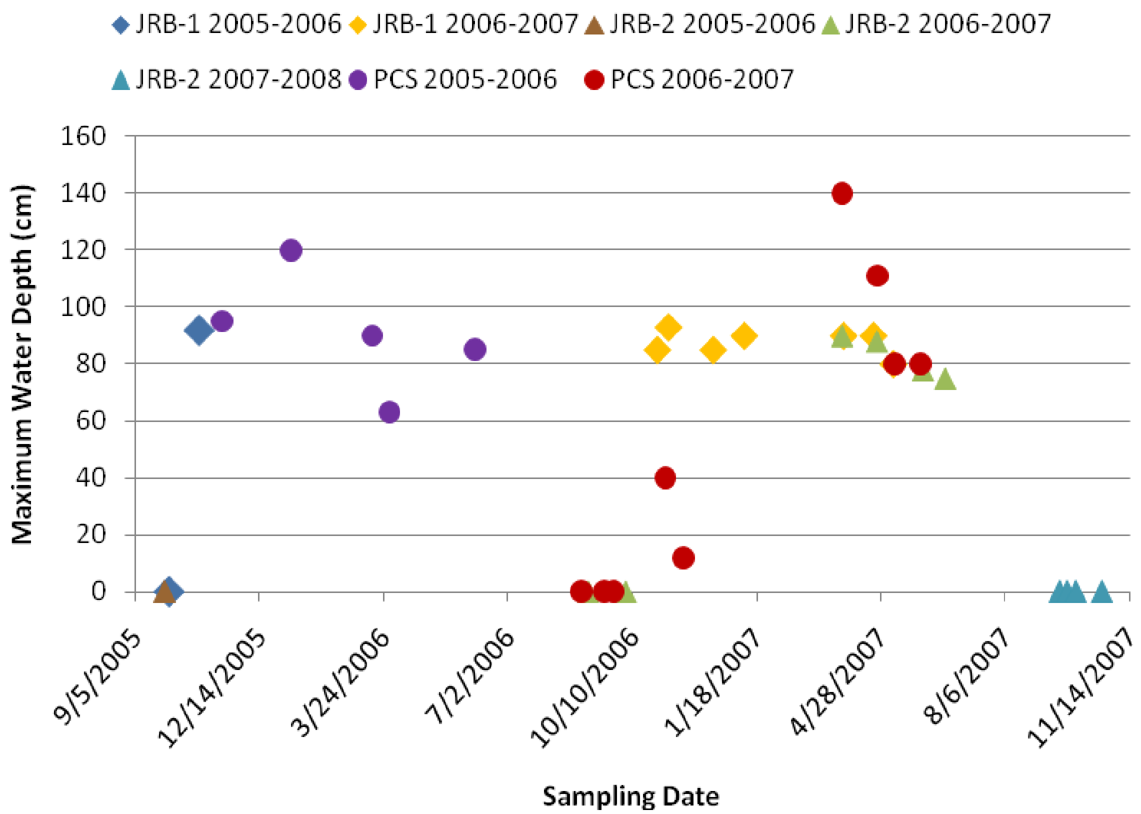


Figure 20. Water levels in two vernal pools studied by classrooms in different towns, between fall, 2005 and fall, 2007. Data from JR Briggs Elementary School (JRB), Ashburnham, MA, and Petersham Central School (PCS), Petersham, MA. PCS 2005-2006 data were collected at c. two-month intervals. Pools were not sampled in mid-summer, and few-or no mid-winter samples were collected by either school due to pool freezing.

The pools differ not only in their absolute depths but also in the amount that the water depth fluctuates. The measured water depths changed more from one sampling date to the next in the Petersham pool than in the pool studied by the students in Ashburnham. Measured depths in the Ashburnham pool remained quite constant from late October in 2006 to early May of 2007. During the same time period, water depths in the Petersham pool varied by more than one meter.

Comparing data from multiple years can show year-to-year changes in conditions that may affect animals that live in the pool. At maximum flooding, the Petersham pool was 20 cm deeper in 2006-2007 than it was the previous year. The timing of maximum observed water depth in the Petersham pool also varied between the years; in 2005-2006, the pool was at its deepest in January, and the following year the maximum depth was observed in March. It may be instructive to look at data on snowfall, rainfall, and temperatures, to see if there are patterns in the local weather that are related to variations in pool water depths over time. If the students are looking at aquatic life in the pool, they may see changes in the amount of available habitat or in the distributions of different species as water levels change.

Data on pool diameters in relation to maximum water depths are also of interest. A graph of the data on the diameter of the same vernal pools in relation to the measured water depths (Figure 21) shows that the depth-diameter relationships of the two pools are very different.

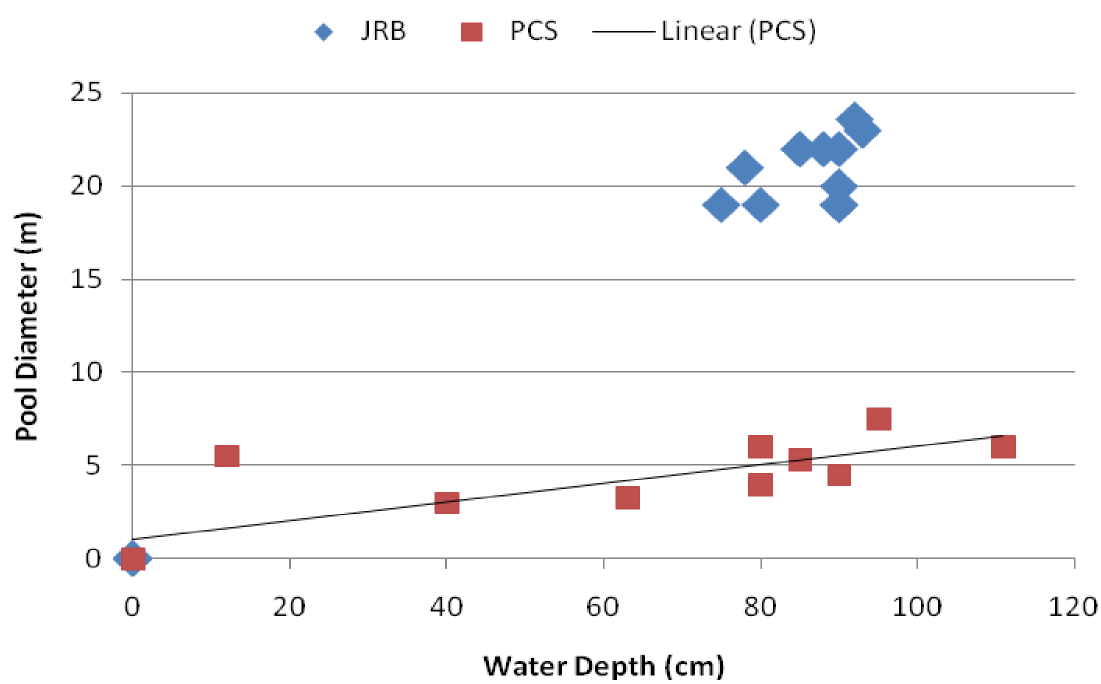


Figure 21. Pool diameter relative to water depth in two vernal pools in different towns. Data as in Figure 20.

The Petersham pool has a diameter only about a third as great as the Ashburnham pool when full, despite being half a meter deeper, and its diameter increases regularly as the depth increases. A trend line fit to the data suggests that the pool slopes gradually and that as depth increases, more aquatic habitat becomes available. The sampled points are close to the fitted line, suggesting a strong relationship. (Classes at appropriate grade levels could test this kind of relationship statistically.) The one measurement of a 5.5 m diameter at 12 cm depth suggests possible sampling error, or an interesting irregularity in the pool profile; mapping the pool bottom when the pool is dry could address this possibility.

In contrast, the data suggest that the Ashburnham pool drops rapidly in depth near the shore. During the sampling period, this pool either contained fairly deep water that covered most of the basin, or it was dry. The sampling has not covered dates when intermediate water levels were present. The measured diameters vary by 5 m for a given water depth, suggesting that the methods for measuring water depth or diameter may need to be adjusted.

Graphing Data From Your Own Schoolyard Studies

The examples presented here should give you some ideas of ways to look at data you and your students collect in the course of schoolyard ecology research. We hope you will go ahead and explore your data and different ways of presenting your results through graphs, and that the experience will contribute to your understanding of the data, and of possible answers to the research questions you and your students are asking.