RACC
Research on Adaptation to Climate Change

REFERENCE MANUAL FOR HIGH SCHOOL TEAMS

2014-2015

INDEPENDENT

Vermont EPSCoR
CWDD
Center for Workforce Development & Diversity
AT SAINT MICHAEL'S COLLEGE

VT EPSCoR Research on Adaptation to Climate Change (RACC) in the Lake Champlain Basin High School Program 2014-15

Contact Information:

VT EPSCoR Center for Workforce Development and Diversity
Saint Michael's College
One Winooski Park, Box 137
Colchester, VT 05439

Email: *cwdd@smcvt.edu*
Website: www.uvm.edu/~cwdd
www.smcvt.edu/academics/epscor

Office: 251 Founder's Annex, Saint Michael's College
Lab: 126 Cheray Science Hall, Saint Michael's College **Lab Phone**: 802-654-1916

Lindsay Wieland, CWDD Director
Phone: 802-654-3272
Email: *lwieland@smcvt.edu*

Katie Chang, Research Technician
Phone: 802-654-3271
Email: *kchang@smcvt.edu*

Kerrie Garvey, CWDD Project Manager
Phone: 802-654-3270
Email: *kgarvey2@smcvt.edu*

Introduction:

Established in 2011, the VT EPSCoR CWDD is one of two centers funded by the National Science Foundation and created through the Research on Adaptation to Climate Change in the Lake Champlain Basin (RACC) award. RACC is focused on understanding the effects of changing climate on the Lake Champlain Basin and to develop adaptive management strategies for the Basin.

RACC builds transdisciplinary teams of social and natural scientists to study the Lake Champlain Basin as a coupled human and natural system affected by climate change. We combine collections of data on physical processes, governance, and land use with complex systems modeling. Models will enable scenario testing to help Basin managers and policy makers investigate how adaptive management can be designed and implemented to respond to climate change.

CWDD increases the Vermont Science-Technology-Engineering-Math (STEM) workforce in size and diversity through multiple approaches:

- Inspire diverse high school students and undergraduates to enter STEM careers by involving them directly in RACC research. Support the professional development of high school and middle school teachers through involving them in RACC research.

- Match high school teams, undergraduates and middle school teachers with RACC social and natural scientists, who will act as research mentors.
- Target support for girls and underrepresented minorities, veterans, economically disadvantaged high school students, and students with disabilities.
- Involve students from Puerto Rico, New York, Maryland, Texas and other locations outside Vermont to bring a diverse pool of participants into the STEM pipeline.
- Cap off the year with at the VT EPSCoR Student Research Symposium where CWDD participants share research results and network with other STEM professionals.
- Support Native American and First Generation Vermont college students through scholarships to study STEM majors in Vermont.
- Enable the Governor's Institutes of Vermont (GIV) to reach out to every high school in Vermont with scholarships so that girls and economically disadvantaged students can attend the STEM summer institutes and Winter Weekends.
- Work with the Vermont Technology Council to connect undergraduates and small technology businesses that provide students with paid internships.

Research on Adaptation to Climate Change in the Lake Champlain Basin (RACC):

The RACC center is organized around an overarching theme with three research hypothesis driven questions, involving a diversity of scientists and engineers from academia and the private sector that are integrated with public and private stakeholders, undergraduates, middle school teachers, and high school students and teachers. They will study climate change-driven impacts on hydrological processes and nutrient transport in the lake basin (Questions 1 and 2), and develop ecosystem assessment scenarios and models to inform the work of policymakers (Question 3 and Integrated Assessment Model (IAModel)).

Overarching Question**:** How will the interaction of climate change and land use alter hydrological processes and nutrient transport from the landscape, internal processing and eutrophic state within the lake and what are the implications for adaptive management strategies?

Question 1: What is the relative importance of endogenous in-lake processes (e.g. internal loading, ice cover, hydrodynamics) versus exogenous to-lake processes (e.g. land use change, snow/rain timing, storm frequency and intensity, land management) to lake eutrophication and algal blooms?

Question 2: Which alternative stable states can emerge in the watershed and lake resulting from non-linear dynamics of climate drivers, lake basin processes, social behavior, and policy decisions?

Question 3: In the face of uncertainties about alternate climate change, land use and lake response scenarios, how can adaptive management interventions (e.g. regulation, incentives, treaties) be designed, valued and implemented in the multi-jurisdictional Lake Champlain Basin?

For more information visit: www.uvm.edu/~epscor

2014-2015 High School Program:

The CWDD supports high school teams interested in engaging in RACC research as either Independent Project teams or Streams Project teams. This year will be the sixth year of the VT EPSCoR Streams Project. Each year, the project changes to align with the needs of the overall research program. Independent Project teams work on non-stream related research projects.

<u>Goal:</u> Increase the number and diversity of high school students interested in STEM careers.

<u>Objectives:</u>

- Students and teachers experience active research;
- Students and teachers develop scientific field and lab knowledge and skills;
- Students make connections with college science faculty, programs, and campuses

<u>Strategies:</u>

- Train students and teachers in watershed ecology, climate change, systems thinking, and field and lab skills during residential training week.
- Task HS teams with collecting high quality data for the VT EPSCoR research project Research on Adaptation to Climate Change (RACC).
- Convene a Symposium for presentations of RACC research progress, an opportunity for students to experience presenting scientific research, and a venue for students to see where their efforts fit into the overall research program.

RACC High School Program 2014-2015

Manual Contents

About this manual:

- Become familiar with it at the outset of your participation.
- Use the "Team Project" section of the manual to keep track of your research
- Use this in conjunction with the RACC website (www.uvm.edu/epscor/highschool) which hosts a wealth of additional resources:
    - data analysis tutorials
    - mapping and site information
    - links to useful websites
    - presentation and symposium information

Email cwdd@smcvt.edu if you need assistance. Your message will be directed to the appropriate staff member.

High School Team Calendar – Independent Projects 2014-15

June 23-27	**Training Week**
July – winter	Identify a research question Collect data / conduct investigation ➢ ➢ ➢ ➢ ➢
December–March	**Project Presentation** ➢ Export data from websites, if needed: www.uvm.edu/epscor/redir/streamsprojectdata and/or other data sites, if applicable ➢ Analyze data ➢ Create a poster or PowerPoint presentation describing your research
February	Submit application for 2015-165 program, if applicable
April, date tbd	Present your research at the 2015 VT EPSCoR Student Research Symposium!

Data Analysis and Presentations

Contents

Data Analysis Overview

You should begin thinking about your preparing your poster or presentation for the VT EPSCoR Student Research Symposium in April as soon as possible. The basis of your poster or presentation will be an analysis of the data you have gathered during the past year and/or historical data (from the Streams Project online database, or other sources).

The Streams Project has created a **data analysis tutorial** to help guide you through the process of exploring and asking more in-depth analysis questions about your dataset. This should be your primary guide for beginning your data analysis, but the VT EPSCoR CWDD staff members are always available to help you along the way. Some modules are Streams Project –specific, while others are useful to anyone interested in analyzing data.

The tutorials can be found on the website here:

http://www.uvm.edu/~epscor/new02/?q=node/1027

The first link on the page that says “Complete Tutorial Series - All Modules” will open a PDF with all of the modules compiled into one document. The subsequent links are for accessing modules individually. The following is a list of the individual modules and what they cover:

- Module 1: What is science?
- Module 2: Understanding Streams Project Data
- Module 3: Refining and Retrieving Data
- Module 4: Data Exploration
- Module 5: Statistical Analysis
- Module 6: Summarizing Results and Drawing Conclusions

In this tutorial, statistical analysis is demonstrated using Microsoft Excel. Within each module, look for the “WATCH VIDEO” icon that looks like this:

These videos help you visualize a number of procedures outlined in the tutorial. **NOTE: To be able to watch the videos, download the QuickTime Player, if it is not already on your computer: http://www.apple.com/quicktime/download/

Viewing and Downloading Streams Project Data

To view or download data in the Streams Project's database, go to the following location website:

www.uvm.edu/epscor/redir/streamsprojectdata

Once you are at the web page:

1. Select the stream sites for which you'd like data. If you'd like data from multiple sites, hold down the "Ctrl" button in between selections. If you'd like data for all the streams sites, select the first stream site, hold down the "Shift" button, and the select the last stream site in the list.

2. Select the report that represents the type of data you are interested in under "Available Reports."

3. Select the date range for which you'd like data.

4. Once you've made these selections click the "Generate Report" button.

5. You can view the data available for these criteria on the webpage that appears. If you click on the heading of a data field in the table, a little box will pop up describing the data contained in that field.

6. To download the data seen here, click the "Export to Excel File" text above the table and save the file on your local computer.

An explanation of the data in the database, and a description of how to download data from this web page can also be found in **Module 3: Refining and Retrieving Data** of the Data Analysis Tutorial. The link to this module can be found here:

http://www.uvm.edu/~epscor/new02/?q=node/1027

Presenting Your Data: VT EPSCoR Student Research Symposium

All participants of the RACC High School program commit to presenting their research findings at the annual Vermont EPSCoR Student Research Symposium. A symposium is a great way for researchers to present and discuss their work and it provides an important channel for the exchange of information between researchers. At the Vermont EPSCoR Student Research Symposium, participants have the option to choose whether they present their research through a poster or an oral presentation. Both are great ways to share your work!

Posters versus Oral Presentations

Although it can be challenging to present a year's worth of work in 10 minutes, oral presentations can be a rewarding experience because you are the only one front of an audience whose attention you know you have. Oral presentations are brief and consequently the presentation must be clearly and succinctly presented.

Posters are a visual presentation of information that is understandable to the viewer without verbal explanation. Poster presenters have the opportunity to share their work with one person at a time, over an extended period of time. This allows the presenter to describe and discuss their research in greater detail than would be possible in an oral presentation to significantly more people, and allows for dialogue with poster viewers.

Posters

A research or academic poster provides a means of communicating your research at a conference or research symposium. Posters printed by Vermont EPSCoR are 3' x 4' (or 36'' x 48"), horizontally or vertically aligned. Upload your final poster file when registering for the symposium by the deadline announced in early March. The CWDD will print and set up your poster at the symposium.

How to Create a Poster Using PowerPoint

For many, this is the first time creating a research poster. Here are some tips for making an informative and attractive research poster:

1. Open PowerPoint
2. Click the 'Design' menu/tab at the top of the screen and select 'Page Setup'
    i. Change the dimensions of the slide from the default setting to: Width=48, Height=36 (for a horizontal poster), or Width=36, Height=48 (for a vertical poster). This is an important **FIRST** step – if you change the dimensions after putting content on the slide, you will have to re-format all text boxes, graphs, tables, photos, etc.
3. Critical poster elements:
    i. Title, Author(s) and affiliation(s)
    ii. Abstract/Summary (*optional*)
    iii. Introduction/Background: a brief but important overview to secure the viewer's attention
    iv. Materials and Methods: a brief description of the processes and procedures used, photos (*optional*) should be >300dpi
    v. Results: outcomes, findings and data displayed through text, tables, graphs, photos, etc.
        - Bulleted lists (rather than paragraphs) may help the reader understand the most important findings
        - Tables, graphs and photos should have captions. Graphs should have a legend, avoid 3-D graphs as they are hard to interpret
    vi. Discussion/Conclusions: summary or discussion of the significance and relevance of the results, identify possible future research
    vii. References
    viii. Acknowledgements
    ix. Please include the following text somewhere on the poster: Funding provided by NSF Grant EPS-1101317
4. Upload final poster file when registering for the symposium

Tips:

A. Use the "Designing Conference Posters" website to get ideas on poster layout and to download poster templates: http://colinpurrington.com/tips/academic/posterdesign
B. Choose a background and text color scheme. No need to go crazy: a white/light poster with black/dark text is often much easier to read than a multi-colored poster. Use cool/muted colors, solid colors, a color gradient, etc.

C. Lettering can make a difference in how easy-to-read your poster is. Here are some suggestions:
    - Title: at least 72 pt., bold preferred
    - Section Headings: at least 48 pt., bold preferred
    - Body Text: at least 24 pt.
    - Avoid using all capital letters
    - Use sans serif (Arial) for titles & headings
    - Use serif (Times New Roman) for body text
    - Use bulleted lists where possible instead of paragraphs
    - Use *italics* instead of underlining
    - White or light colored lettering is hard to read on a dark background when printed. Use black lettering instead on a light colored background

D. Logos: Do not forget to include the logos for the organization(s) that helped make the research possible!
    - Funding source: The National Science Foundation's (NSF) logo can be used by recipients of NSF support for the sole purpose of acknowledging that support: https://www.nsf.gov/policies/logos.jsp. Please include the following text somewhere on the poster: Funding provided by NSF Grant EPS-1101317
    - VT EPSCoR, RACC, CWDD and others if they were important contributors. Logos are available on the "Resources" website: http://www.uvm.edu/~epscor/new02/?q=node/900
    - Your school logo!

Example posters from the 2013 VT EPSCoR Student Research Symposium:

http://www.uvm.edu/~epscor/new02/?q=node/1285

Oral Presentations

A research talk provides a means of communicating your research at a conference or research symposium. Oral presentations at the VT EPSCoR Student Research Symposium are limited to 10 minutes: 8 minutes to present your research, 2 minutes for the audience to ask questions. Presenters often use the general rule of "1 slide per minute"; however the number of slides needed varies based on the complexity of the content of the slides. Upload your final PowerPoint file when registering for the symposium by the deadline announced in early March or bring the file to the symposium on a USB drive. The CWDD will provide the computer, screen, podium, microphone and laser pointer for your use.

Oral Presentation Structure (*suggested*):

- Title, Author(s), Affiliation (1 slide)
- Outline, *optional* (1 slide): overview of the structure of your talk, some speakers prefer to put this at the bottom of their title slide, audiences like predictability
- Introduction/Background
  - Motivation and problem statement (1-2 slides): Why should anyone care? Most researchers overestimate how much the audience knows about the problem they are addressing.
  - Related Work (0-1 slides)
  - Methods (1 slide): Cover quickly in short talks
- Results (4-6 slides): Present key results and key insights. This is the main body of the talk. Its structure varies greatly as a function of the research conducted. Do not superficially cover all results; cover key result well. Do not just present numbers; interpret them to give insights. Do not put up large tables of numbers as your audience will not have time to take in that much information at once.
- Discussion/Conclusions (1 slide): summary or discussion of the significance and relevance of the results, identify possible future research.
- References
- Acknowledgements
- Please include the following text somewhere on your slides: Funding provided by NSF Grant EPS-1101317

Logos: Do not forget to include the logos for the organization(s) that helped make the research possible!

- Funding source: The National Science Foundation's (NSF) logo can be used by recipients of NSF support for the sole purpose of acknowledging that support: https://www.nsf.gov/policies/logos.jsp. Please include the following text somewhere on your slides: Funding provided by NSF Grant EPS-1101317
- VT EPSCoR, RACC, CWDD and others if they were important contributors. Logos are available on the "Resources" website: http://www.uvm.edu/~epscor/new02/?q=node/900
- Your school logo!

Example posters from the 2013 VT EPSCoR Student Research Symposium:

http://www.uvm.edu/~epscor/new02/?q=node/1283

Resources

RACC High School Resources: http://www.uvm.edu/~epscor/new02/?q=node/900

- Includes links to datasets available online, including:

  Data and Data Analysis

  - VT Department of Environmental Conservation Lake Champlain Long Term Monitoring
  - VT Department of Environmental Conservation Volunteer Monitoring
  - USGS Stream Gauge Data
  - Vermont Water Quality Data
  - NOAA Quality Controlled Local Climatological Data
  - VT EPSCoR Data Analysis Tutorials
  - Data Analysis in Excel

- Helpful hints on posters and oral presentations

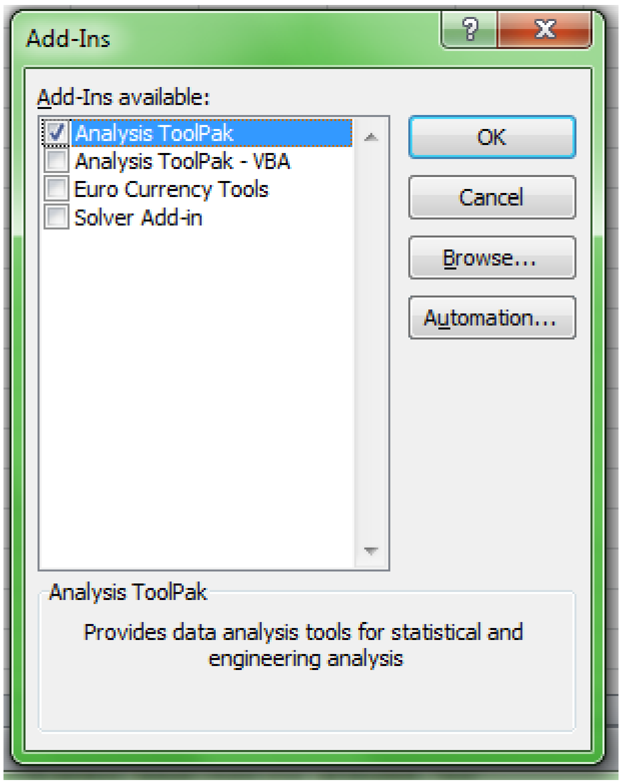
- High resolution logos to include on your poster, etc.

Data Webinar video by Dr. Declan McCabe:
http://www.uvm.edu/~epscor/new02/?q=node/1237

- Walks you through how to find different data sources online, how to groom and present your data using Excel, and how to use PowerPoint to create a presentation

Data analysis

Data analysis in Excel using Windows 7/Office 2010

- Open the "*Data"* tab in Excel
- If "*Data Analysis*" is not visible along the top toolbar then do the following:
  - Right click anywhere on the toolbar and select "*Customize quick access toolbar…*"
  - On the left click on "*Add-Ins*"
  - Near the bottom, use the pull-down menu and select "*Excel Add-Ins*" and click "*Go*" to bring up this menu:
  - 

  - Select the "*Analysis ToolPak*" and click "*OK*".

Using one-way ANOVA in MS Excel

Introduction: When your observations fall into two or more categories of continuous or even discrete variables, you may be interested in asking if the groups differ from each other. Is fish diversity higher in phosphorus-enriched ponds than in low-phosphorus ponds? Does the abundance of forest-floor plants differ between clear-cut, tornado-damaged, and control plots of forest? Questions of this nature are answered using analysis of variance (ANOVA). It is worth mentioning that in the case of 2 categories you can run a *t* test or an ANOVA and the result will be the same.

Analysis:

1. Organize your comparative data in adjacent columns (Table 1). There is no need to average them for analysis, and in fact averages will be calculated automatically during the ANOVA or *t* test.
2. From the "*Data*" tab, select "*data analysis*" (this must be added from the "addin" menu; see previous section).
3. Choose "*ANOVA single factor*"; click OK. Table 1 lists data from three habitats; so the *factor* of interest is habitat.

Number of mammal species		
island	mainland	peninsula
2	5	3
3	4	2
3	6	4
5	5	3
1	4	3
2	4	2

Table 1. Fake data for ANOVA

4. Click the tiny red arrow by "*input range*" and highlight all of the data including the column headings. Click the "Columns" button and check the "Labels in first row" box.
5. Select any of the output options that you like and hit "OK"
6. The output from the fake data should look like this:

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
island	6	16	2.666667	1.866667		
mainland	6	28	4.666667	0.666667		
peninsula	6	17	2.833333	0.566667		
ANOVA						
ce of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	14.77778	2	7.388889	7.150538	0.006593	3.68232
Within Gr	15.5	15	1.033333			
Total	30.27778	17				

7. The conclusion based on the *p-value* would be that number of species differ significantly among the three habitats. Note that the ANOVA does not tell you which groups are different, although in this case it looks like more species are found on the mainland and there is no difference between the island and the peninsula.
8. Finally, if you are making a comparison between just 2 groups, you can use exactly the same procedure. Or you could choose to run a *t*-test and it will give you a result that is mathematically identical to that produced by an ANOVA run on 2 groups. We could go back to the fake data and ask if the island and peninsula differ from each other by running the test without including the mainland data column.

Graphing ANOVA-type data: Use the averages to draw a bar graph. Add standard error bars to the graph. Calculate those using this formula: *=stdev(A1:A6)/Sqrt(6)* (assuming your data are in cells A1 through A6 and you have 6 data points). More detailed instructions are provided in the graphing section of this manual.

Regression in MS Excel

Does blood pressure increase with age? Does shrub cover decrease with increasing canopy cover? Is there a relationship between phosphorus concentration and algal cell density in ponds? All of these questions can be addressed using regression.

Nature of the data

All of the datasets described above are *continuous*; that is to say, they vary over some range without breaks. They are not *categorical* (like male and female), that are not *discrete* (like number of people in a single car; you would not typically think about 3.5 people in a car). As the range of a discrete variable increases (number of plants per hectare for example), the larger number means that what in fact is a discrete variable can be treated as continuous.

Graphing

We typically graph such datasets using a scatter plot (Figure 1) . If we have a basis for considering for example that running speed impacts heart rate, then we would use running speed on the horizontal (*x*) axis, and heart rate on the vertical (*y*). In this case running speed is the *independent variable*. The *dependent*, or *response variable* is heart rate because we expect it to *depend on,* or *respond to* running speed.

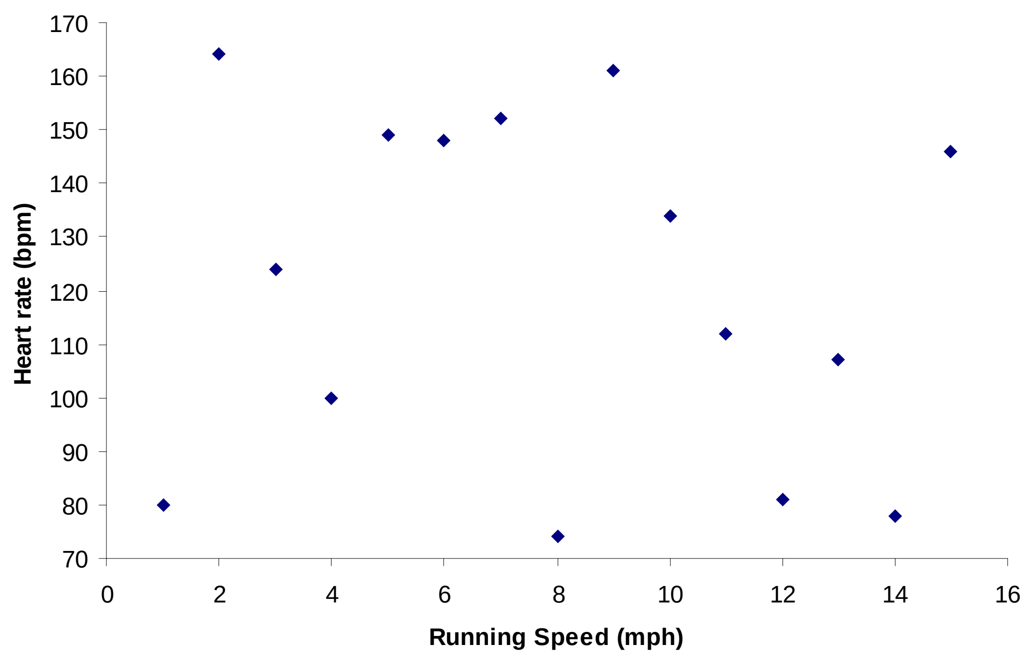
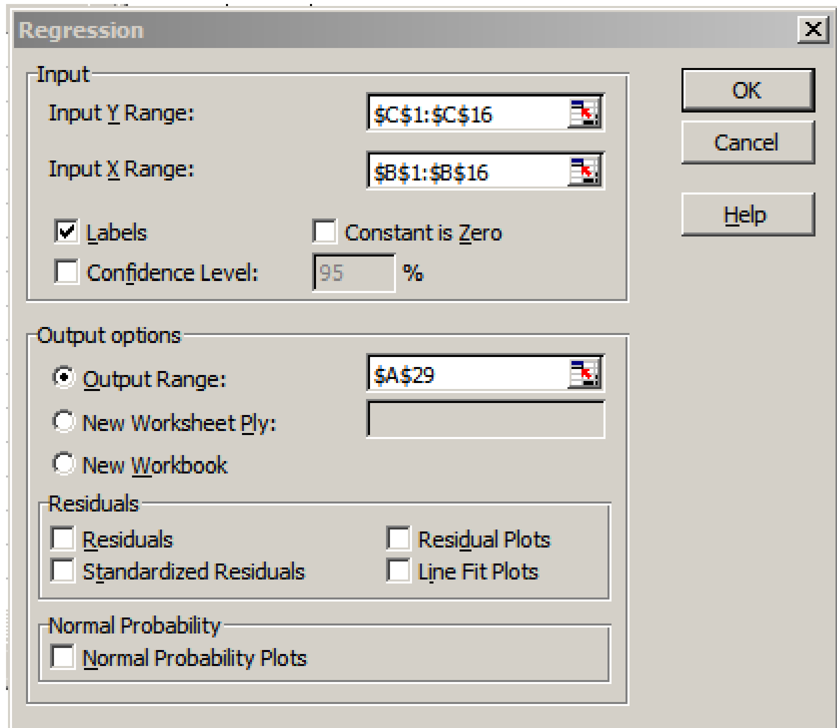


Figure 1. Fictional data representing the effects of running speed on heart rate.

Analysis: We might look at the pattern on the right and perceive a pattern, or not! As is the case with all statistics, the point is to remove subjectivity and have firm criteria for claiming a relationship. The analysis one would use for this sort of question is *regression*. There are many forms of regression for relationships of different shapes, but for our purposes we are considering only *linear regression*. In other words we are asking only if, and how well a straight line can describe the relationship between variables. In excel under the *Data tab,*select_ *data analysis, regression* to bring up this window:



The response variable goes in the Input Y Range and the independent variable goes in the Input X range. You can click on the tiny red arrow in each case and highlight the appropriate portion of the data (including labels). The output range simply is a place for the statistical output to go.

Output: Output from the preceding data set:

SUMMARY OUTPUT									
Regression Statistics									
Multiple R	0.169583375								
R Square	0.028758521								
Adjusted R	-0.045952362								
Standard E	33.23140781								
Observatio	15								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regressioi	1	425.0892857	425.0893	0.384931	0.545699				
Residual	13	14356.24405	1104.326						
Total	14	14781.33333							
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	130.5238095	18.05655676	7.22861	6.66E-06	91.51499	169.5326	91.51499	169.5326	
Running S	-1.232142857	1.985956467	-0.62043	0.545699	-5.52254	3.058255	-5.52254	3.058255	

The number under *Significance F* is the *p* value. In this case the *p* value is greater than 0.05 and we can conclude that there is no relationship between running speed and heart rate.

Regression example 2: Along with other questions, Connon and Simberloff's (1978) paper examined the effect of sampling bias on collection data. They concluded that the number of collecting trips explained more of the variability in number of plant species observed on Galapagos Islands than did Island size or any other island feature measured. The data set:

Species	Collecting
57	10
31	6
3	1
25	4
2	1
18	6
10	6
8	1
2	1
96	13
94	12
40	7
5	2
54	13
346	27
47	7
2	1
102	10
108	9
12	6
69	10
290	28
237	24
440	38
61	11
283	29
45	6
16	3
21	5

And the statistical output:

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.973547
R Square	0.947795
Adjusted R	0.945861
Standard E	27.01902
Observatic	29

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regressior	1	357850.2	357850.2	490.1875	7.62E-19
Residual	27	19710.73	730.0272		
Total	28	377561			

	Coefficients	*andard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-31.902	7.35061	-4.34005	0.000179	-46.9842	-16.8198	-46.9842	-16.8198
Collecting	11.61333	0.524536	22.14018	7.62E-19	10.53707	12.68959	10.53707	12.68959

Output	**Value**	**Standard interpretation**
p value	7.2 E-19	There is a very significant relationship between number of trips and number of species observed
Coefficient (of collecting trips)	11.61	The slope is positive telling us that as number trips increases, so does number of species seen. Negative slopes indicate the opposite trend.
R square	0.947	This measures how tight or strong the relationship is. In this case we can say that collecting trips explain 94.7% of the variability in number of species observed.

Graphing example 2: Connor and Simberloff's (1978) data set is presented graphically in the manual section on graphing. Compare how the data follow a tight linear pattern compared to the fake data on heart rate in this section.

Graphing

Figures in Community Ecology

All graphs, maps, photographs, and sketches are considered "Figures" and appear in a numbered sequence in the order cited in your paper. Any set of numbers and/or letters is considered a table and tables have their own numbered sequence (IE, even after three figures, your first table is still *Table 1*).

A good graph minimizes clutter and unnecessary 'ink'. Use the MS Excel "Scatter Plot" option to make graphs displaying continuous data on the vertical and horizontal axis. The species area data for the upcoming lab report are a good example; area on the *X* axis; number of species on the *Y* axis. **Remove** all of the following items added by Microsoft excel: "Series 1"; background color; frames on right and top; grid lines; 3D effects.

Scatter plots

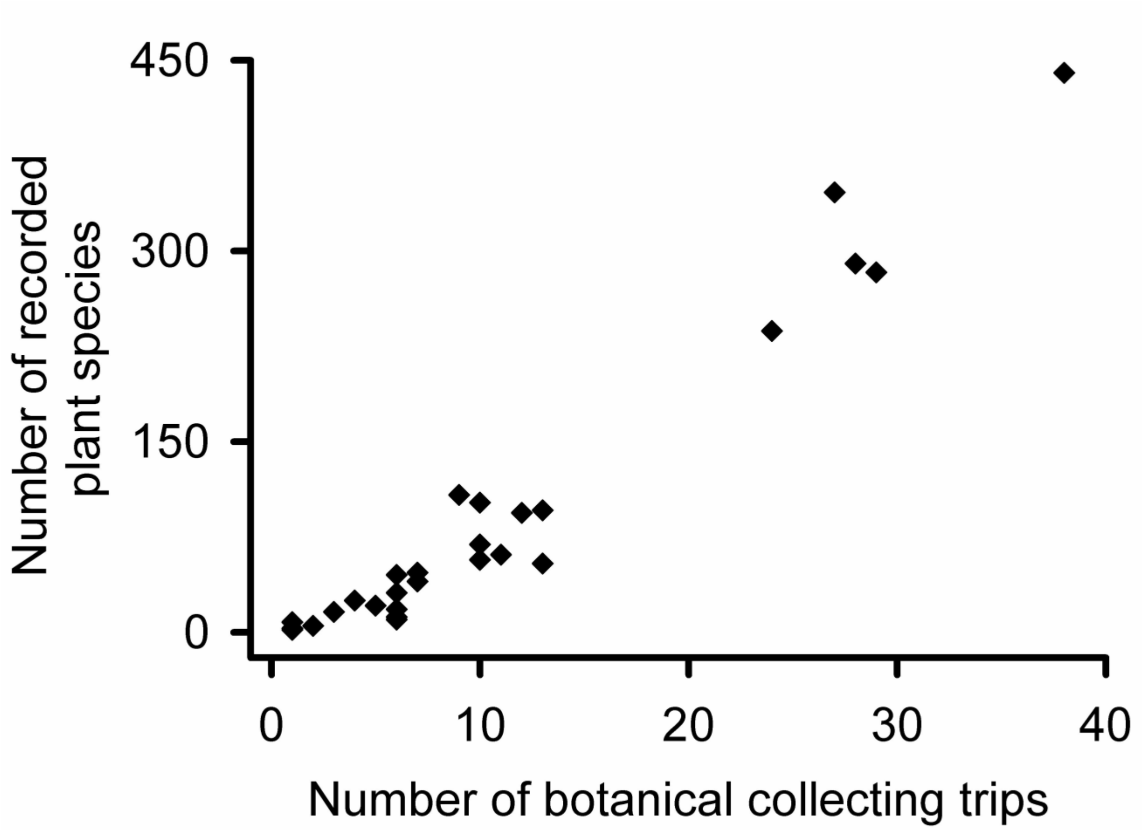


Figure 1. Illustrating the point that more sampling leads to more species observed. Connor & Simberloff (1978) analyzed data from collecting trips to the Galapagos Islands and found that number of collecting trips better explained number of species recorded than did island area, elevation, or isolation. Data extracted from Table 3 in Connor & Simberloff (1978).

The figure legend is always placed underneath and contains roughly a paragraph of information describing the figure content in sufficient detail that the figure stands alone. The *legend* inserted by MS excel is useful *only if two or more data sets are displayed* on one graph using symbols.

This figure contains data that span the nearly entire range presented. If we were presenting data from only the largest five islands we would adjust the horizontal axis to run from 20 to 40, and the vertical axis from 150 to 450. Note that the axis lines have been thickened and fonts enlarged beyond the default. **Important**: Graphs should not start at zero, zero if the data range fall between 75 and 85 (for example).

Bar graphs

We use bar graphs when presenting the averages of *continuous* variables (on the *Y* axis) from one or more *categories* on the horizontal axis.

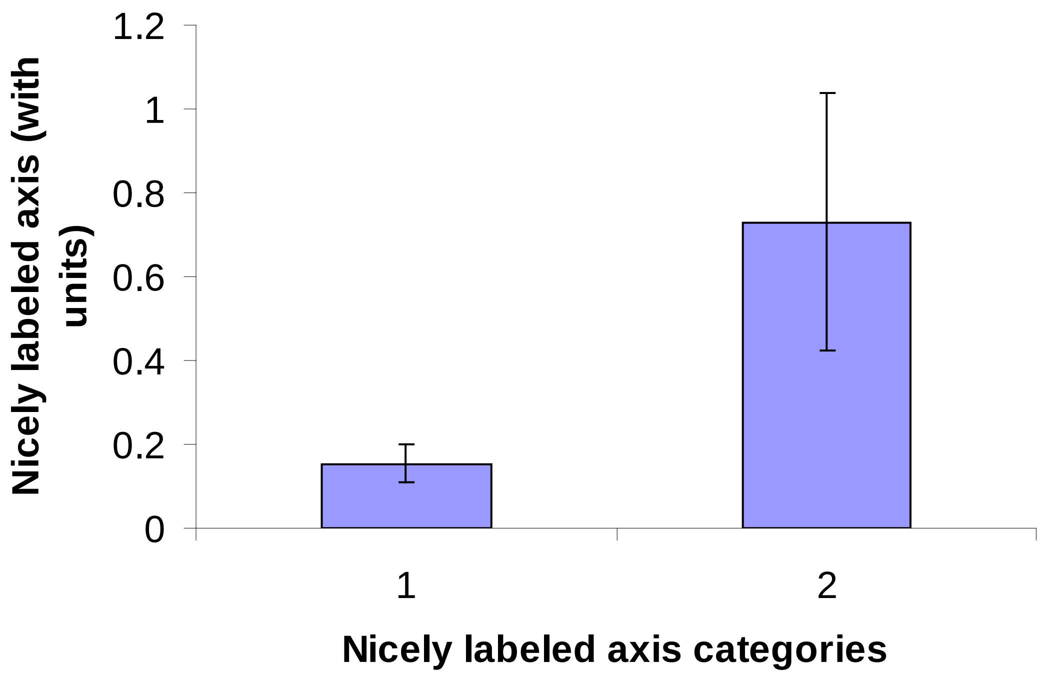


Figure 1. Very detailed title, 3-4 lines; place under the graph

The bar height equals the average of the response variables for treatments 1, and treatments 2. The error bars above and below the average in this case equal standard error; calculate these values as: (standard deviation)/(square root of the number of samples). The scale is appropriate to the data; if the averages were 150 and 200, I might start the axis at 100 rather than zero. **Important:** You should replace the numbers on the horizontal axis with names of sites or treatments (see example under adding error bars handout).

Adding error bars to bar graphs in excel

Introduction: Bar graphs are among the most common ways to present the averages of a set of treatments or conditions in community ecology and many other fields. Every average is based on raw data measured from a sample of several individuals. If I care about grass density in my lawn I might count the number of stems from several small quadrats and then calculate the average number of stems. The numbers of stems in each of my individual quadrats will be greater than or less than the average. In other words *there is variability in the raw data*. We might expect more variability in the heights of people than in the heights of Volkswagens. *Some data sets are more variable than others*. We use error bars above and below the average to depict that variability

How to measure variability: There are several metrics used to express variability. Standard deviation expresses the *variability in your sample* and is calculated in MS Excel using this Formula 1.

= stdev(A1:A6)…………………………………………….Formula 1

The formula calculates the standard deviation from the raw data you entered in the cells *A1* through *A6* in the spreadsheet. You can refer to any set of cells in the spreadsheet by changing the letters and numbers in parentheses in Formula 1. The disadvantage of standard deviation is that it increases in magnitude as your sample size decreases. Samples can be expensive or time consuming to collect and so we often need to work with small sample sizes. What we really need is a measure of variability in the entire population, and not just in our sample.

Standard error adjusts the value of standard deviation based upon the sample size using Formula 2

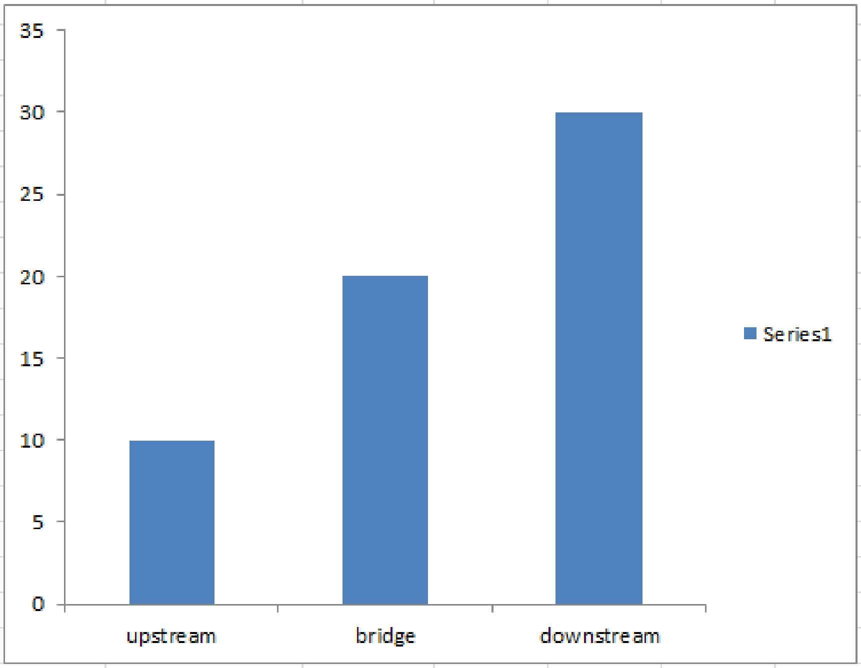
= stdev(A1:A6)/sqrt(n)…………………………….Formula 1

Where *n* = the number of replicates in your sample; don't enter the letter *n*, enter the number of samples you took or refer to a cell in the spreadsheet that contains that information. *Sqrt* calculates the square root of whatever value you use to replace *n* in Formula 2. **Standard error will be the preferred measure of variability used throughout this course**.

How to add the error bars to your bar graph:

Lay your data out as illustrated below. In this case the fake data represent the average number of insect species found several samples taken from each of three locations in a stream.

	upstream	bridge	downstream
average richness	10	20	30
standard error	2	4	6

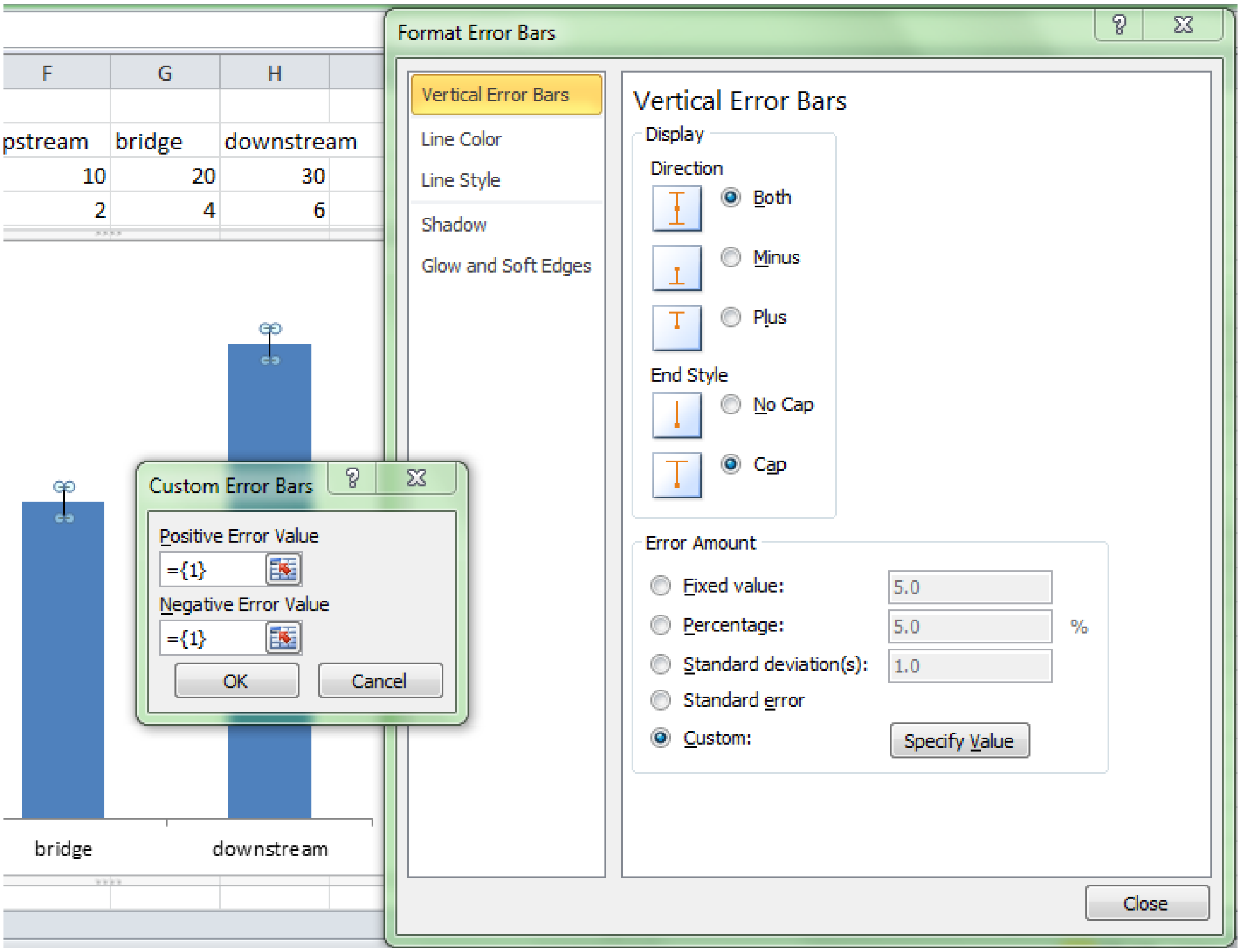


Note:

- Standard error values are underneath the graphed averages.
- The graph has been moved in the spreadsheet so as not hide the numerical values.

1. Click anywhere on the chart - this will reveal the "*Chart Tools*" at the top of the window. Click "*Layout*"
2. Right click on any bar in the graph – 2 small windows will pop up – work in the smaller upper one. Click the little drop down arrow and select the data set to which you'd like to add error bars (*Series 1* unless you have renamed the data set).
3. Now, go up to "*Chart Tools*" at the top and select "*Error Bars*"/ "*More error Bar Options*" (because all of the other options offered are, to be perfectly honest, fake).

4. Click "*Custom*" and "*Specify Value*".



5. Next click the tiny red arrow in the box under "*Positive Error Bar*"; highlight the values for the standard errors that are lined up under the averages. Hit "*Enter*"!
6. Now, you would think that having selected "both", that both the upper and lower error bars would be displayed; you would be wrong! Repeat the process for "*Negative Error Bars*".
7. Click "*Close*".
8. Truly beauteous error bars will now grace your bar graph!

Field Safety

Contents

First Aid Kit

When working in the field, it is important to be prepared for emergencies. Although you will not be traveling far from your car when you visit your field sites for the VT Streams Project, accidents may still happen. Therefore, a well-stocked first aid kit is an important thing to have. Carry a first aid kit with you to your site or keep one in the car. You may purchase a pre-made kit at the store, or you may make your own using the recommended list of items below as a reference. Whichever you chose, it is important to include any personal items such as medications and emergency phone numbers. Check the kit regularly and replace any used or out-of-date items.

- Adhesive bandages (assorted sizes)
- Antibiotic ointment
- Antiseptic wipes
- Instant cold compress
- Hydrocortisone ointment
- Scissors
- Sterile gauze pads (assorted sizes)
- Butterfly bandages
- Tweezers
- Prescription medications (asthma inhalers, Epipen)
- Emergency phone numbers
- Charged cell phone

<u>Didmyo Fact Sheet</u>

Didymosphenia geminate, commonly known as “Rock Snot” or “Didymo,” is an aggressive freshwater alga that has undergone a recent large expansion in range. It has the potential to form nuisance blooms during which it can form mats several inches thick by attaching itself to streambeds by stalks that form a thick brown mat on rocks, plants, and other aquatic surfaces. The thick growth reduces the quantity and quality of aquatic habitat.

Didymo was detected in rivers of Vermont, New York, and New Hampshire during the summers of 2006 and 2007. Because the factors that cause Didymo to undergo rapid growth are unknown and there is no known method of eradication, it is important to prevent the spread of these algae to uninhabited streams. Therefore, ***we disinfect all waders and equipment when traveling between streams***. In order to prevent the spread of didymo to other regions waders should not be transported and used in different regions or countries.

Follow the link for a detailed description of Didymo by the Vermont Department of Environment Conservation Water Quality Division:

http://www.anr.state.vt.us/dec//waterq/lakes/htm/ans/lp_didymo.htm#how_can_I_disinfect

Disinfecting Waders

We have supplied your team with concentrated Quaternary Ammonium Disinfectant (Quat solution) to kill and prevent the spread of nuisance biological agents such as Didymo. This procedure is adapted from the Vermont Agency of Natural Resources method for equipment disinfection.

****ATTENTION: Quat is a highly basic solution. Protective gloves MUST be worn when handling the concentrated solution. Once diluted with water, it is safe to handle****

To prepare a 2.5% solution:

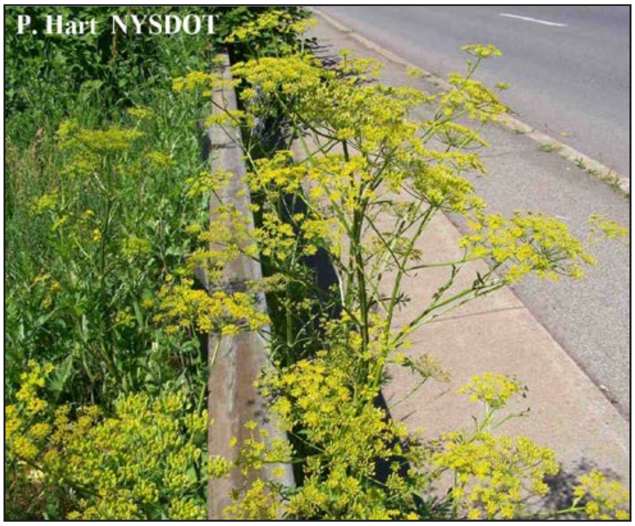
- Add 25mL of concentrated Quat to a spray bottle. Dilute to 1L. (For 500mL of solution, add 12.5mL of concentrated Quat and dilute with water to 500mL.) **Quat solutions should be replaced every 2 – 3 days to remain effective, so prepare only as much as is necessary for a site visit.**

- Fill the second spray bottle with water.

- When exiting the stream following sampling, spray waders and other equipment thoroughly with the 2.5% Quat solution. Let sit for ~2 minutes. Spray with the water to rinse.

Field Precautions

Poison Parsnip



- **Location**: Predominately found on the sides of highways and fields throughout Vermont.

- **Appearance**: The plants typically grow 3-6 feet tall and resemble Queen Anne's Lace, but the flowers are yellow instead of white.

- **Danger**:
  - The plant contains a high concentration of furocoumarin chemicals
  - The plant's juices may be transferred to your skin if you brush against the flower tops or broken leaves or stems
  - When the juices on the skin are exposed to ultraviolet light on both sunny and cloudy days the furocoumarin chemicals bind with nuclear DNA and cell membranes.
  - **This process destroys cells and skin tissue, causing severe burns in which the skin to reddens and blisters**

- **Protecting Yourself:**
  - Avoid exposure to the plant by choosing stream sites or access areas free from poison parsnip
  - If unavoidable, wear long sleeve shirts, pants (or your waders!), and gloves to prevent direct contact with your skin
  - Rinse and wash all clothing items and skin surfaces immediately following possible exposure. Keep exposed skin out of sunlight.

Poison Ivy

Poison ivy in spring.

Image © Jonathan Sachs 2002

Avoid poison ivy

Preventing contact with poison ivy

- Do not touch or handle any part of the plant
- Remove and wash shoes or clothing that has contacted poison ivy. Wash your hands immediately with soap and water

Preventative treatment Modified From http://poisoncontrol.uchc.edu

- If you have touched poison ivy, avoid spreading the oils to other body parts and wash the affected skin with soap and water within 15 minutes
- Use a nail brush to clean under finger nails
- Swab with rubbing alcohol after washing

Poison ivy in summer.

www.kentuckycrosswords.com

Myths Vs Facts: Fact #1: this fact list is modified from www.zanfel.com

Myth: Scratching poison ivy blisters will spread the rash.
Fact: Fluids from blisters will not spread the rash. Before blisters form, the rash can only be spread by unbound urushiol. Scratching of blisters can cause bacterial infection.

Myth: Poison ivy rash is "contagious."
Fact: The rash is a reaction to urushiol. The rash cannot pass from person to person after the urushiol binds to skin.

Myth: After the first time, I can't get poison ivy again.
Fact: Not everyone reacts to poison ivy upon first or subsequent exposures, people generally become more sensitized with each contact and may react more severely to subsequent exposures.

Myth: Once allergic, always allergic to poison ivy.
Fact: A person's sensitivity changes over time, even from season to season. People who were sensitive to poison ivy as children may not be allergic as adults.

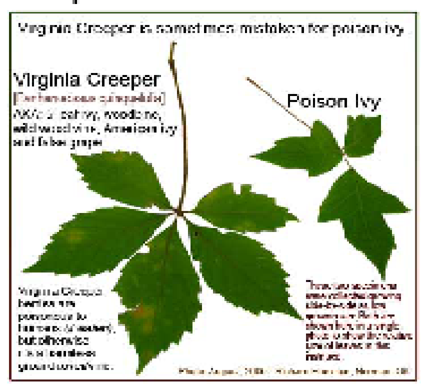
Myth: Dead poison ivy plants are no longer toxic.
Fact: Urushiol remains active for up to five years. Never handle dead plants that look like poison ivy without proper protection.

Myth: Burning is the best way to dispose of poison ivy.
Fact: The toxic oils from poison ivy spread in the smoke and can cause full-body rash and more serious health problems if inhaled.

Zanfel Laboratories provides poison ivy treatment brochures for free to BSA troops. Call 1800 401 4002

If a rash develops From http://poisoncontrol.uchc.edu

- Apply calamine lotion, cool compresses, or over the counter corticosteroid creams to lessen itching. Oatmeal baths can also help. Avoid scratching and cover open blisters to avoid infection. If face or genitals are involved, see a doctor for evaluation. If symptoms are persistent after these treatments see a doctor.



Ticks & Lyme Disease

What Is Lyme Disease?

Lyme disease is a bacterial infection caused by the bite of an infected deer tick. Untreated, the disease can cause a number of health problems. Patients treated with antibiotics in the early stage of the infection usually recover rapidly and completely.

Where Is Lyme Disease Found?

In the United States, infected ticks can be found in the north-east, including New York State; in the upper Midwest; and along the northwest coast.

What Are the Symptoms of Lyme Disease?

The early symptoms of Lyme disease may be mild and easily missed. If you find a tick attached to your skin, remove the tick with tweezers and watch for the symptoms of Lyme disease. In 60-80% of cases the first symptom is a rash, known as *erythema migrans,* that:

- Occurs at or near the site of the tick bite.
- Is a "bulls-eye" circular patch or solid red patch that grows larger.
- Appears between three days and one month after the tick bite.
- Has a diameter of two to six inches.
- Lasts for about three to five weeks.
- May or may not be warm to the touch.
- Is usually not painful or itchy.
- Sometimes multiple rashes appear.

How Can I Safely Remove a Tick?

If you DO find a tick attached to your skin, do not panic. Not all ticks are infected, and your risk of Lyme disease is greatly reduced if the tick is removed within the first 36 hours.

To remove a tick:

- Use a pair of pointed tweezers to grasp the tick by the head or mouth parts right where they enter the skin. DO NOT grasp the tick by the body.
- Pull firmly and steadily outward. DO NOT jerk or twist the tick.
- Place the tick in a small container of rubbing alcohol to kill it.
- Clean the bite wound with rubbing alcohol or hydrogen peroxide.
- Monitor the site of the bite for the next 30 days, for the appearance of a rash. If you develop a rash or flu-like symptoms, contact your health care provider immediately.

What Else Can Be Done?

- Keep lawns mowed and edges trimmed.
- Clear brush, leaf litter and tall grass around the house, and at the edges of gardens and stone walls.
- Stack woodpiles neatly away from the house and preferably off the ground.
- Clear all leaf litter (including the remains of perennials) out of the garden in the fall.
- Keep the ground under bird feeders clean so as not to attract small animals.
- Locate children's swing sets and other play equipment in sunny, dry areas of the yard, away from the woods.

*For more information on Lyme disease, contact your local health department or refer to the NYS Department of Health web site at **www.health.state.ny.us***

- Do NOT apply repellents directly to children. Apply to your own hands and then put it on the child.
- When applying repellents, avoid the child's face and hands.
- Do not apply repellents on skin damaged by sunburn, cuts, bruises or other conditions, such as psoriasis.
- Avoid prolonged and excessive use of DEET.
- Do NOT apply repellents in enclosed areas.
- Do NOT apply directly on your face.
- Do NOT apply near eyes, nose or mouth.
- Wash treated skin and clothing after returning indoors.
- If you believe you or a child is having an adverse reaction to a repellent containing DEET, wash the treated area immediately and contact your local health care provider or local poison control center.

Also consider these important facts:

- If you tuck pants into socks and shirts into pants, be aware that ticks will climb upward to hidden areas of the head and neck, so spot-check clothes frequently.
- Clothes can be sprayed with DEET or treated with permethrin. Follow label instructions carefully.
- Upon returning home, clothes can be put in a high temperature dryer for 20 minutes to kill any unseen ticks. A shower and shampoo may help to dislodge crawling ticks, but this is not always effective.
- Any contact with vegetation, even playing in the yard, can result in exposure to ticks. Frequent tick checks should be followed by a whole-body examination and tick removal each night. This is the single most effective method for prevention of Lyme disease.

Ticks will attach themselves anywhere including the thighs, groin, trunk, armpits and behind the ears. If you are infected, the rash may be found in one of these areas.

Around the time the rash appears, other symptoms, such as joint pain, chills, fever and fatigue can occur, but they may seem too mild to require medical attention. As Lyme disease progresses, severe fatigue, a stiff aching neck, and tingling or numbness in the arms and legs, or facial paralysis can occur.

The most severe symptoms of Lyme disease may not appear until weeks, months or years after the tick bite. These can include severe headaches, painful arthritis, swelling of the joints, and heart and central nervous system problems.

How Is Lyme Disease Diagnosed?

If you think you have Lyme disease, you should see your health care provider immediately. Early diagnosis of Lyme disease should be made on the basis of symptoms and history of possible exposure to ticks. Blood tests may give false negative results if performed in the first month after the tick bite.

How Is Lyme Disease Treated?

Early treatment of Lyme disease involves antibiotics and almost always results in a full cure. However, the chances of a complete cure decrease if treatment is delayed.

In a small number of cases, Lyme disease can become a chronic condition. However, some patients have reported slow improvement and even an end to symptoms, months or even years after treatment.

How Can I Protect Against Ticks and Prevent Lyme Disease?

Deer ticks live in shady, moist areas at ground level. They will cling to tall grass, brush and shrubs, usually no more than 18-24 inches off the ground. They also live in lawns and gardens, especially at the edges of woods and around old stone walls.

Deer ticks cannot jump or fly, and do not drop onto passing people or animals. They get on humans and animals only by direct contact. Once a tick gets on the skin, it generally climbs upward until it reaches a protected area.

In tick-infested areas, your best protection is to avoid contact with soil, leaf litter and vegetation. However, if you garden, hike, camp, hunt, work, or otherwise spend time in the outdoors, you can still protect yourself:

- **Wear light-colored clothing** with a tight weave to spot ticks easily.
- **Wear enclosed shoes, long pants and a long-sleeved shirt.** Tuck pant legs into socks or boots and shirt into pants.
- **Check clothes and any exposed skin frequently** for ticks while outdoors.
- **Consider using insect repellent.**
- **Stay on cleared, well-traveled trails. Avoid contacting vegetation.**
- **Avoid sitting directly on the ground or on stone walls.**
- **Keep long hair tied back,** especially when gardening.
- **Do a final, full-body tick check at the end of the day** (also check children and pets), and remove ticks promptly.

What Do Ticks Look Like?

Two common types of ticks are dog ticks and deer ticks. Deer ticks can carry Lyme disease. Dog ticks can carry Rocky Mountain spotted fever but have not been known to carry Lyme disease.

Deer Ticks Actual Size

Enlarged View Female Deer Tick

Female deer ticks have four pairs of legs and are red and black in color, while the male is all black. Young deer ticks - nymphs, are brown, the size of poppy seeds and very difficult to spot. An adult deer tick is only about the size of a sesame seed – still very small.

Adult Dog Tick Actual Size

Enlarged View, Male and Female Dog Ticks

Dog ticks are the most common type of tick, and, while feeding, can be as large as a small pea. They have four pairs of legs, are reddish-brown and are easier to spot. Dog ticks turn gray while feeding. Ticks can be found throughout the year, but they are most active during the spring, early summer and fall, when it is warm and moist.

What About Insect Repellent?

Two active ingredients found in repellents are DEET (the label may say N, N-diethyl-m-toluamide) and permethrin. Permethrin is only used on clothes. DEET repellents or products come in many different concentrations, with percentages as low as five percent or as high as 100 percent. In general, the higher the concentration the higher the protection, but the risk of negative health effects goes up too. Use the lowest concentration that you think will provide the protection you need. The New York State Health Department recommends taking these precautions when using repellents that contain these active ingredients:

- Store out of the reach of children and read all instructions on the label before applying.
- Do NOT allow children to apply repellents themselves.

Cyanobacteria

What is cyanobacteria?

Cyanobacteria, also known as blue-green algae, are naturally occurring bacteria that are present in Lake Champlain and other water bodies around the world. Like plants, they use photosynthesis to convert sunlight into energy. Usually cyanobacteria cannot be seen by the naked eye. However, under certain conditions, the algae grow prolifically and are visible as blooms. The blooms appear as a cloudy pea green accumulation in the water. Generally, these blooms of cyanobacteria occur when there is a balance of certain factors including: an abundance of available nutrients, warm surface water temperatures, and calm winds.

Why should be concerned?

Unfortunately, certain types of blue-green algae produce toxins or poisons. When the algae die and break down, these toxins are released into the water. Exposure to these toxins have health impacts on humans and animals. Human health effects from cyanobacteria blooms vary depending on the type and duration of exposure (including inhalation of water droplets). In the summers of 1999 and 2000, the deaths of several dogs were linked to the cyanobacteria in Lake Champlain.

Photo source: Lake Champlain Basin Program

Identification and Avoidance: *When in Doubt, Stay Out*

In general, blooms have the appearance of:

- Cloudy water as thick as pea soup or green paint on the water
- While generally green or blue-green in color, they can be brown or even purple
- A thick mat or foam may form as it accumulates onto shore

Blooms usually occur in August or September and can appear and disappear rapidly. There is no accurate way to identify the algae without a microscope. If you are suspicious, simply stay out of and away from the water.

References and Resources:

Check Current Conditions Online:

http://healthvermont.gov/enviro/bg_algae/weekly_status.aspx

Vermont Department of Health's Blue-Green Algae Guidance Document:

http://healthvermont.gov/enviro/bg_algae/documents/BGA_guide.pdf

Websites:

http://healthvermont.gov/enviro/bg_algae/bgalgae.aspx
http://www.lcbp.org/water-environment/human-health/cyanobacteria/

http://www.lakechamplaincommittee.org/lcc-at-work/algae-in-lake/

Photo Galleries:

http://www.lcbp.org/2012/12/photo-gallery-2008-cyanobacteria-blooms/
http://healthvermont.gov/enviro/bg_algae/photos.aspx#bg

Report a Blue-green Algae Bloom:
If you have questions or want to report a suspected bloom:
Call 1-800-439-8550 or 802-863-7220, or
email AHS.VDHBlueGreenAlgae@state.vt.us

If you believe that someone has become ill because of exposure to blue-green algae, seek medical attention and contact the Health Department at 1-800-439-8550.

Measuring Infiltration Rates

This exercise is included in the manual for RACC teachers to use with their classes, if interested. It is not a required data collection task for your participation in the RACC Streams Project and these data will not be uploaded to the Streams Project database.

Introduction:
Infiltration is the movement of water into a soil profile. The rate at which infiltration occurs is controlled both by the inherent properties of the soil and by the ways in which humans have modified the landscape. Infiltration rates, in turn, control runoff rates and soil erosion, which are important because these processes influence the behavior of hillslopes. This exercise is designed to introduce you to a simple method for measuring infiltration rates. You will use a ring infiltrometer to measure infiltration at plots that represent differences in disturbance of the soil surface. You may also measure the soil bulk density and gravimetric moisture content at the measurement sites and compare these to measured infiltration rates.

Methods:
Select two sites for measurement of soil properties and infiltration rates representing (1) a forested site showing no signs of noticeable compaction or human traffic, and (2) a site located on a designated hiking trail or one showing noticeable signs of compaction. You will extract soil cores from a location immediately adjacent to your infiltration test.

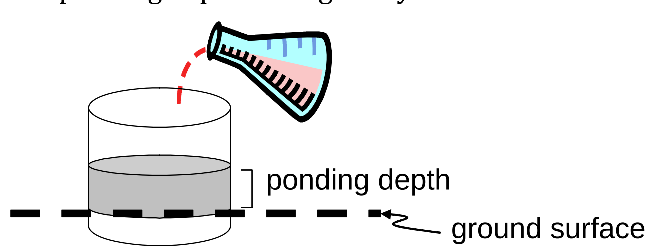
A. Infiltration test

1. Select a level site for your test. Remove loose debris (leaves, sticks) from an area the size of your infiltrometer (but do not pull up rooted plants; this will affect the pores in the soil).

2. Insert the ring infiltrometer several centimeters into the soil. Record this penetration depth. The ring should be inserted deeply enough and sealed adequately to the soil to preclude any leakage from the ring.

3. Fill out the top of the data sheet to record your group members and experimental set up.

4. To conduct the infiltration test, establish a standing pond of water within the ring that you maintain to within about 10% of this depth throughout the test. Once you have established this ponding depth, add water to maintain a constant ponding depth throughout your experiment. This should require frequent additions of water at the start of your experiment and less frequent additions as your test proceeds. Continue to make measurements of water additions for at least one hour, recording additions at least every 10 minutes, but more frequently if needed to maintain a constant ponding depth.



B. Soil extraction for bulk physical properties

1. Immediately adjacent to each of your infiltration tests, extract a bulk sample of the mineral soil using the soil auger. Retain only the center ring of your extracted sample. Be sure to record the dimensions (diameter, length) of the device used to extract your sample.

2. Place the sample into a plastic bag, labeled with your name(s) and indicate whether it is from the “forest” or “trail” site.

3. In the lab, weigh an empty aluminum pan to determine the tare weight, then place your sample in the pan and weigh again. Place the soil sample in the oven for overnight drying at 103^{o}C. When drying is complete, weigh the sample again to determine dry weight.

C. Data reduction, analysis and interpretation

1. Use the data reduction instructions following each data sheet to make calculations from your raw field data.

2. Enter your infiltration data for both sites into a spreadsheet with columns to record time, elapsed time, volume of water added, and depth of water infiltrated at each time step. Your entries should include at least one hour of observations.

3. Plot the data in your spreadsheet as an x,y scatterplot with elapsed time on the x axis and infiltration rate on the y axis (see for example figure 5.4 in your textbook).

4. Estimate a steady state infiltration capacity from your data plot for both sites by taking an average of measurements over a time interval during which infiltration rate shows little or no change.

5. Consider/discuss:
   - How do the steady state infiltration rates differ between the two sites you measured?
   - What factors influence the rate at which infiltration occurs; how do your measurements of bulk density relate to any of these factors?
   - What are the limitations associated with inferring infiltration rates across the landscape based on the measurements you have made?

Infiltration Test Data Sheet

Group member names: ____

Experiment date: ________________ Location: ______________________________

Experimental Set-up

Diameter of infiltrometer (d): ___________

Site type: forest | trail

Infiltrometer length (cm) _________ Depth inserted into soil (cm) _________

Ponding depth (cm) __________________________

DATA:

time (hr:min:sec)	volume start (ml)	volume end (ml)	volume added ( )		time (hr:min:sec)	volume start (ml)	volume end (ml)	volume added ( )
0:00:00	--	--	--					
	1000							
			.					.

Infiltration Test Data Sheet

Group member names: ____

Experiment date: ________________ Location: ______________________________

Experimental Set-up

Diameter of infiltrometer (d): ___________

Site type: forest | trail

Infiltrometer length (cm) _________ Depth inserted into soil (cm) __________

Ponding depth (cm) ___________________________

DATA:

time (hr:min:sec)	volume start (ml)	volume end (ml)	volume added ( )		time (hr:min:sec)	volume start (ml)	volume end (ml)	volume added ( )
0:00:00	--	--	--					
	1000							
			.					.

Data reduction:

To compute infiltration rates from your experiment, you will need to convert the volume of water to a water depth, then divide by the elapsed time. Follow the steps below to reduce your data and compute infiltration rates for each experiment. In each step, write the formula you use, then clearly show your calculations with units:

1. Calculate the surface area (A) of the infiltrometer from the diameter of the ring. (4 pts)

2. For one time step on one your data sheet, compute depth of water infiltrated (D) as the volume[1] of water (V) divided by the surface area (a) of the infiltrometer. Use an arrow on your data sheet to indicate the time step for which you are making this calculation. (4 pts)

3. For the time step used in #2 above, convert the elapsed time (t) in minutes and seconds to time in hours (this should be a fraction of an hour). (3 pts)

4. Compute infiltration rate (I) by dividing water depth (D) by elapsed time (t). Express your answer in cm/hr (4 pts)

[1] Note: Water volume for the experiment is measured in milliliters. 1 ml = 1 cm^3.

Bulk Density Data Sheet

Plot 1 (circle one): forest | trail

Auger ring diameter (cm) ________________ Auger ring length (cm) ___________________

Sample tare weight (g): ___________

Sample field weight (g): ___________

Sample dry weight (g): ____________

Notes on site conditions:

Plot 2 (circle one): forest | trail

Auger ring diameter (cm) ________________ Auger ring length (cm) ___________________

Sample tare weight (g): ___________

Sample field weight (g): ___________

Sample dry weight (g): ____________

Notes on site conditions:

Data reduction:

To compute bulk density and gravimetric moisture content, you will need to calculate the volume of soil extracted, then weigh it to get mass of the soil and mass of water lost with drying. Follow the steps below to reduce your data. For each step, write the formula you use and clearly show your calculations with units:

Forest site:

1. Calculate ring volume. (3 pts)

2. Calculate the bulk density of the soil sample. (3 pts)

3. Calculate the gravimetric moisture content of the soil sample. (3 pts)

Trail site:

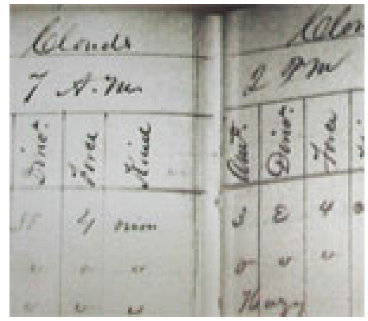
1. Calculate ring volume. (2 pts)

2. Calculate the bulk density of the soil sample. (2 pts)

3. Calculate the gravimetric moisture content of the soil sample. (2 pts)

History

Why is the Museum involved with weather?



The Fairbanks Museum & Planetarium has been a weather observation site continuously since March 1894. Even before Franklin Fairbanks founded the Museum, he kept meticulous weather records at his family home in St. Johnsbury, Vermont during the 1850's and 1860's. Shortly after the Museum doors opened in 1891, Museum staff kept recording daily weather statistics for the newly formed Weather Bureau.

Data still kept at the Museum such as maximum and minimum temperatures, precipitation, relative humidity, wind direction and speed, barometric pressure and general character of the day represent the longest continuous record of weather at the same location in Vermont.

In 1948, Fred Mold became the director of the Fairbanks Museum. Mold shared a passion for weather phenomena and natural history with the Museum's founder, Franklin Fairbanks. He took advantage of an important technology, newly available to the northern Vermont region – radio. WTWN was the first local broadcasting station, and Mold initiated three-minute weather reports three times a day. Together with his Museum staff, Mold brought the Museum's weather observation and reporting system to a more efficient, professional level. Part of the popularity of these early broadcasts came from Mold's folksy style, peppering his forecasts with local stories, bird calls, and nature lore. This tradition of bringing history and folklore into weather broadcasts continues today, with the addition of agricultural, recreational, and astronomical information, and remains one of its most distinctive features.

Meteorologists Mark Breen and Steve Maleski became familiar voices in December 1981 with the debut of "Eye on the Sky" weather forecasts, which launched the partnership between the Fairbanks Museum & Planetarium and Vermont Public Radio (VPR).

Climatic Change (2013) 116:457–477
DOI 10.1007/s10584-012-0517-2

Climate change at the ecosystem scale: a 50-year record in New Hampshire

Steven P. Hamburg · Matthew A. Vadeboncoeur · Andrew D. Richardson · Amey S. Bailey

Received: 21 November 2010 / Accepted: 4 June 2012 / Published online: 18 July 2012

Abstract Observing the full range of climate change impacts at the local scale is difficult. Predicted rates of change are often small relative to interannual variability, and few locations have sufficiently comprehensive long-term records of environmental variables to enable researchers to observe the fine-scale patterns that may be important to understanding the influence of climate change on biological systems at the taxon, community, and ecosystem levels. We examined a 50-year meteorological and hydrological record from the Hubbard Brook Experimental Forest (HBEF) in New Hampshire, an intensively monitored Long-Term Ecological Research site. Of the examined climate metrics, trends in temperature were the most significant (ranging from 0.7 to 1.3 °C increase over 40–50 year records at 4

S. P. Hamburg · M. A. Vadeboncoeur
Center for Environmental Studies, Brown University, 135 Angell Street, Providence, RI 02912, USA

A. D. Richardson
Earth Systems Research Center, University of New Hampshire,
8 College Road, Durham, NH 03824, USA

A. S. Bailey
USDA Forest Service, Hubbard Brook Experimental Forest,
234 Mirror Lake Road, Woodstock, NH 03262, USA

Present Address:
S. P. Hamburg
Environmental Defense Fund, 257 Park Avenue South, New York, NY 10010, USA

Present Address:
M. A. Vadeboncoeur (✉)
Earth Systems Research Center, University of New Hampshire,
8 College Road, Durham, NH 03824, USA
e-mail: vadeboncoeur@alumni.brown.edu

Present Address:
A. D. Richardson
Department of Organismic and Evolutionary Biology, Harvard University, HUH, 22 Divinity Avenue,
Cambridge, MA 02138, USA

temperature stations), while analysis of precipitation and hydrologic data yielded mixed results. Regional records show generally similar trends over the same time period, though longer-term (70–102 year) trends are less dramatic. Taken together, the results from HBEF and the regional records indicate that the climate has warmed detectably over 50 years, with important consequences for hydrological processes. Understanding effects on ecosystems will require a diversity of metrics and concurrent ecological observations at a range of sites, as well as a recognition that ecosystems have existed in a directionally changing climate for decades, and are not necessarily in equilibrium with the current climate.

1 Introduction

To better understand the effects of past and future climate change on ecosystems, we must first examine trends in changing climatic variables and their effects on physical and biological processes critical to ecosystem functioning. Climate models cannot resolve climate-ecosystem interactions at all biologically or ecologically relevant scales, given the complexity of real-world landscapes and their dependence on spatially variable histories of disturbance. Some predictions made at the regional scale may not represent trajectories at specific well-studied locations, (conversely, no single location is likely to adequately represent the region). Therefore, existing empirical data are of critical importance, as they allow us to examine interactions among diverse climate variables in real-world ecosystems and thus better understand the effects of climate change on specific taxa, communities, and ecosystem processes, including inputs and outputs of water, nutrients, and carbon.

New England has experienced significant climatic change over the 20th Century, and given its long history of climate observations provides a good study system for understanding the relationship between local and regional trends. For example, mean annual temperature in New England and New York increased about 1.1 °C over the 20th Century (Trombulak and Wolfson 2004). In New Hampshire, warming appears to have been greater in the southern part of the state than in the north (Keim et al. 2003; Trombulak and Wolfson 2004), and total annual precipitation has increased by approximately 10 mm per decade over the 20th Century in the northeast (Hayhoe et al. 2007). Winters have warmed more than summers, consistent with the globally observed pattern (Lugina et al. 2004), and the fraction of precipitation falling as snow has decreased (Huntington et al. 2004). Biologically relevant seasonal transitions are also changing, from earlier snowmelt (Hodgkins and Dudley 2006) to a longer frost-free season (Easterling 2002). Leaf-out is occurring earlier throughout the northern hemisphere (Schwartz et al. 2006), as is flowering across many taxa in the northeast (Primack et al. 2004; Houle 2007), and growing season is lengthening significantly (Kunkel et al. 2004; Wolfe et al. 2005; Richardson et al. 2006). Similarly, long-term records show trends toward earlier ice-out dates on lakes and rivers across the northeast (Hodgkins et al. 2002; Huntington et al. 2003), and reduced duration of snowcover (Burakowski et al. 2008).

Over the 21st Century, models predict a dramatic warming trend in the northeastern United States, with modest increases in total precipitation. Christensen et al. (2007) averaged 21 models to predict approximately 3.5–4 °C of warming and a 5–10 % increase in precipitation in New England over the 21st century, with greater changes in the winter than in the summer. Easterling et al. (2000) and Schär et al. (2004) report evidence of increases in the frequency of extreme climate events globally and climate modeling indicates a likely increase in the frequency and intensity of extreme events at the extremes of previously established frequency distributions (including drought) in the northeastern U.S. (Wehner 2004; Tebaldi et al. 2006; Hayhoe et al. 2007).

1.1 Question and hypotheses

Here, we test whether the 50-year climate record at Hubbard Brook Experimental Forest matches modeled changes for the 21st century - a warmer, wetter, more variable climate. We also hypothesize that trends in directly measured climate data (air temperature, precipitation) will be reflected by trends in ecologically relevant derived variables (e.g. degree day metrics) and measurements of variables that are driven by both temperature and precipitation (e.g. evapotranspiration, soil frost). If the existing 50-year record of climatic change qualitatively matches expected future change, there may be important lessons to be learned from the changes observed in the existing long-term ecosystem process datasets of the Hubbard Brook Ecosystem Study. These expected trends include:

- Increased mean annual temperature
- Increased mean seasonal temperatures (summer and winter)
- Increased maximum and minimum annual temperatures
- Increased annual total growing degree-days
- Increased winter thawing degree-days
- Increased length of the frost-free growing season
- Increased total annual precipitation
- Increased length of periods without measurable precipitation
- Increased frequency of days with intense precipitation
- Increased frequency of extreme high and low streamflow
- Increased total annual evapotranspiration
- Earlier spring thaw streamflow conditions
- Decreased duration of snowpack
- Decreased maximum snow pack water content
- Increased soil frost (as a consequence of reduced snowpack)

While a variety of studies, including those cited above, have examined many of these variables in distributed regional and national data sets, we take a different approach, examining a comprehensive hydrometerologic data set from a single study site, which may provide insight into interactions among processes that averaged data from regional networks would obscure. We ask whether the hypothesized and regionally-observed changes are detectable in the 50-year hydrological and meteorological records from one intensively monitored forest ecosystem, and compare the trends observed at the local scale to other local stations with similar data sets to determine whether trends are representative regionally. While problems with long-term changes in some climate data networks have been resolved (e.g. the Historic Climatology Network maintained by NOAA; see Keim et al. 2003), comparison to highly complete records from a small number of stable sites in the region with a documented lack of changes in land-cover, instrumentation, and methodology may provide additional confidence in observed trends. The long-term maintenance of high-quality hydrological and meteorological records across a single, large and intensively studied ecological research site provides a unique opportunity to investigate the influence of concurrent changes in multiple dimensions of climate on ecosystem processes.

1.2 Site description

The Hubbard Brook Experimental Forest (HBEF) was established in 1955 for the study of forest hydrology. The 3,160 ha forest (43°56′N, 71°45′W) is located in the White Mountain region of New Hampshire (Fig. 1a). Native peoples never lived in the valley, so selective cutting circa 1900 represents the only major historic disturbance. Today the forest is dominated by American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britt.), transitioning to balsam fir (*Abies balsamea* L.) and red spruce (*Picea rubens* Sarg.) at the ridge tops. Eastern hemlock (*Tsuga canadensis* L.) is important at the lowest elevations (Schwarz et al. 2001). Existing research on forest processes (Likens and Bormann 1995) and high-quality long-term climate records (Bailey et al. 2003) make HBEF an ideal place to study the effects of a continuously changing climate on ecosystem structure and function in the northern hardwood forest. Recent work, for example, has focused on snowpack and soil frost (Groffman et al. 2001; Campbell et al. 2010), the response of canopy structure and composition to a severe ice storm (Rhoads et al. 2002; Weeks et al. 2009), climatic drivers of variation in tree phenology (Richardson et al. 2006) and winter injury in red spruce (Hawley et al. 2006).

2 Data and methods

Meteorological data are collected continuously at the HBEF using standard methods and simple mechanical instruments with proven reliability in harsh environmental conditions. All instruments are visited weekly ensuring that the instruments are well maintained and that problems, when they do occur, are short-lived. The data-collection network currently includes 24 precipitation collectors (those used in this study are mapped in Fig. 1a). Hygrothermographs housed in standard shelters are co-located with seven of the precipitation collectors (Fig. 1b; Bailey et al. 2003). A realtime network with electronic probes and radio transmission has recently been established, to eventually replace historic measurement techniques. The network is currently in a period of calibration and observation with co-located instruments for data quality assurance. Data used here are from original instruments that have undergone consistent and routine calibration and data processing procedures, and span from the start of each record in the 1950's or 1960's through 2005. The headquarters site (G22) has a more dynamic recent land-use history (building expansion, road paving, and parking lot expansion) than the other studied locations, which may affect the integrity of the record. There are nine gauged watersheds; continuous stream-height measurements are made in a stilling well attached to a V-notch weir at the bottom of each watershed; each weir has been calibrated to measured flow rates (Bailey et al. 2003). As a general rule, we selected the longest available records that were not affected by experimental manipulation (e.g. forest cutting) for trend analysis.

2.1 Temperature

We analyzed temperature records from the four longest-running meteorological stations at HBEF (Table 1, Fig. 1a). For each station, we calculated the annual mean temperature, based on daily means (reported as the mean of the daily minimum and daily maximum temperatures). Annual means were calculated on a calendar-year basis. Seasonal means were calculated on a calendar-month basis (DJF, MAM, JJA, SON), so that the mean winter

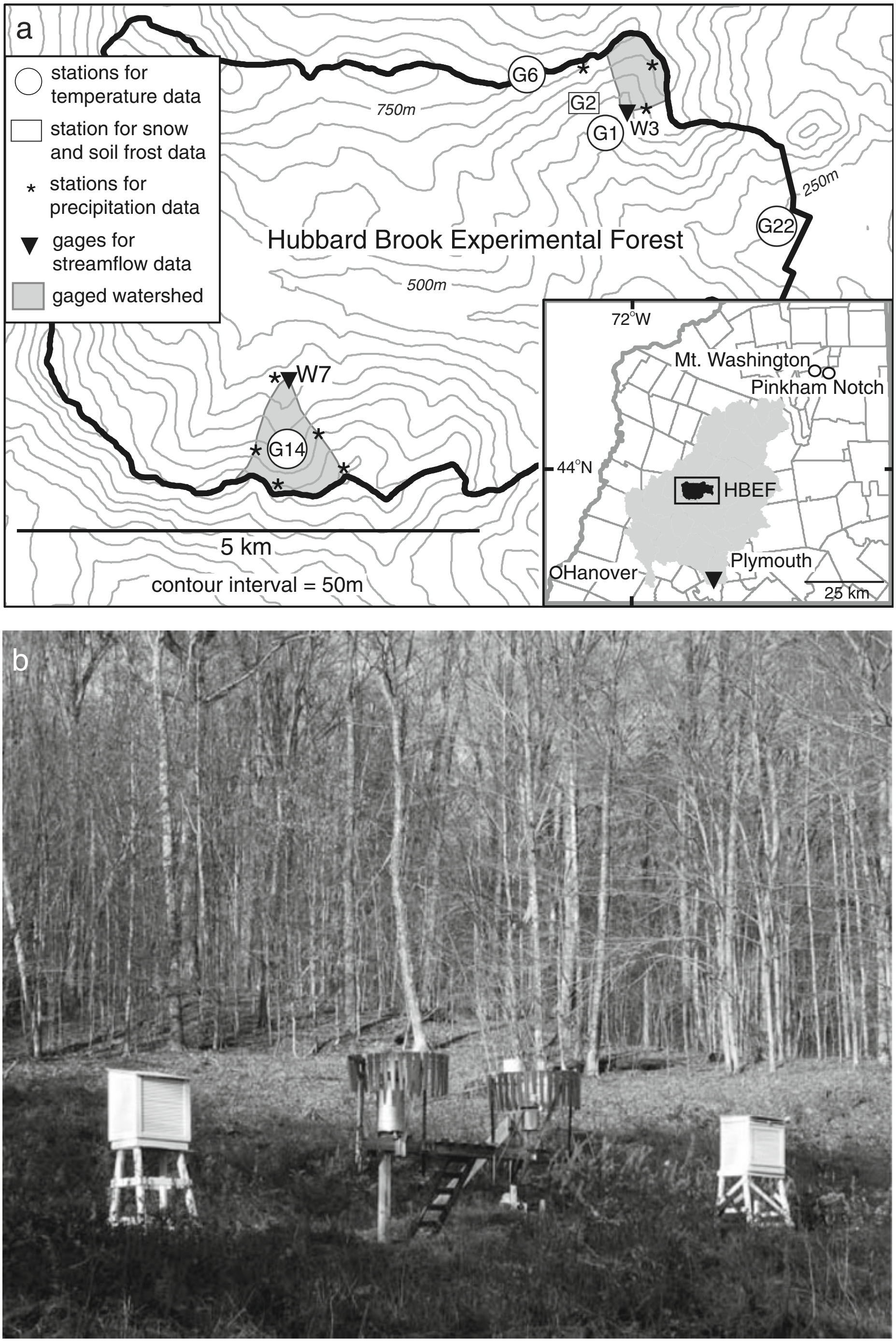


Fig. 1 **a** Location of hydrometerologic stations used in this study. **b** Gage 1 at HBEF. Temperature and precipitation data have been collected continuously at this location since 1955

Table 1 Characteristics of the meteorological stations at HBEF and the surrounding region

Data from HBEF

TEMPERATURE

Station	Elev. (m)	Aspect	Record	Completeness
G1	490	SSE	1956-2005	>99.99%
G6	750	SSE	1961-2005	99.96%
G14	730	N	1965-2005	99.83%
G22	250	--	1957-2005	>99.99%

SNOW DEPTH AND SOIL FROST

Station	Elev. (m)	Aspect	Record
G2	560	SSE	winters 1955-6 thru 2005-6; six winters' soil frost data missing

PRECIPITATION AND STREAMFLOW

Station	Elev. (m)	Aspect	Watershed	Record
W3	530-730	SW	42 ha	1958-2005
W7	620-900	N	77 ha	1965-2005

Data from other regional stations

TEMPERATURE

Station	Source	Elev. (m)	Record	Completeness
Hanover	NCDC	180	1893-2005	98.73%
Pinkham Notch	NCDC	610	1930-2005	98.81%
Mt. Washington	NCDC	1910	1948-2005	99.68%

RIVER FLOW

Station	Source	Elev. (m)	Watershed	Record
Plymouth	USGS	140-1600	1610 km^2	1904-2004

value of each year includes December of the previous year. Annual minimum and maximum temperatures were also determined.

We also derived secondary temperature-based climate metrics, including the annual total number of growing degree days (GDD; the annual sum of the difference between each day's mean temperature and a base temperature of 4 °C; Richardson et al. 2006) in each calendar year, thawing degree-days (TDD; from a base temperature of 0 °C) for the periods December–March and January–February, as well as the dates of the first and last frost each year.

2.2 Hydrological cycle

We examined precipitation data from W3, a southwest-facing watershed used as the hydrologic reference at HBEF, and W7, which has the longest record among the north-facing watersheds (Table 1). Precipitation for each watershed is calculated as a Thiessen-polygon weighted mean of precipitation collected at rain gauges within and near each watershed (Fig. 1a;

Bailey et al. 2003). We summed precipitation on a calendar year basis. Though we did not have a specific directional-change hypothesis to test (Hayhoe et al. 2007), we also tabulated summer precipitation (June through August), the period when evapotranspirative flux is greatest, and major ecosystem processes (e.g., photosynthesis, soil respiration) are most likely to be water-limited. We also analyzed the shorter precipitation record at G22, which receives less precipitation than the experimental watersheds due to its lower elevation and topographic position.

The daily precipitation record allowed us to analyze the timing of precipitation in addition to the annual total. For each calendar year, we tabulated the number of days with ≥50 mm in total precipitation, and determined the length of the longest period in each year with no recorded daily rainfall greater than 1 mm.

Total annual streamflow data from W3 were analyzed on a calendar year basis between 1959 and 2005, and from W7 between 1966 and 2005. For each calendar year, we calculated the number of days with ≥50 mm in total streamflow (the convention at HBEF is to express streamflow volume divided by the area of the contributing watershed, so that it can be directly compared to precipitation data in mm), and length of the longest period during which daily streamflow did not exceed 0.1 mm day^{-1}.

We analyzed the timing of spring melt-influenced streamflow conditions following the center-of-volume date methodology used by Hodgkins et al. (2003). For each year, we calculated the total January–May streamflow, and identified the date at which half the total volume had passed the weir.

Having both precipitation (water input) and streamflow (water output) for the same watershed allows us to estimate evapotranspiration, an output which can otherwise be measured only using eddy covariance methods (which are unsuitable for the steep topography at HBEF). This method assumes that ecosystem water storage (soil water and snowpack) is the same at the beginning and end of each measured period. High interannual variation in snowpack water content and persistence is the reason a June 1 water year is traditionally used at HBEF. Over many years any errors in storage must approximately cancel, making this method appropriate for examining long-term trends. We calculated evapotranspiration at W3 and W7 for water years beginning June 1.

2.3 Snowpack and soil frost

Snow course transects are located near several rain gauges in the watersheds, with the longest continuous record at G2 (Fig. 1a; Table 1). Snow is sampled for depth and water content with a Mount Rose snow tube each week during the winter. Snow surveys begin as soon as there is 6” (~15 cm) of snow that is expected to remain all winter, and continue as long as there are patches of snow to measure. Each week, 10 measurements of the snow pack are made every 2 m along a transect, and are averaged. An entry of 0 indicates no snow at any of the 10 sampling points on the transect; when snow is patchy, zero values are included in the average. We analyzed the maximum observed snow water content recorded each winter, as well as the period of snow cover. Data on the presence or absence of soil frost are also taken each time snow is measured; we analyzed the maximum soil frost occurrence observed each winter.

2.4 Regional and global data

To determine how consistent HBEF data were with records taken elsewhere in the region, and to provide a longer-term context for interpreting trends, we examined long-term temperature records from other weather stations in the White Mountain region (Fig. 1a; Table 1). We included temperature data from three sites: Mt. Washington (47 km NE of

HBEF), the highest peak in the northeastern United States; Pinkham Notch (50 km NE of HBEF), a mid-elevation location; and Hanover (50 km SW of HBEF), which has an exceptionally long and complete temperature record. We calculated annual and seasonal mean temperatures for each station using the same methods we applied to the HBEF data. However, as these datasets were less complete than those from HBEF (Table 1), we excluded any year with >10 days missing data. In years with ≤10 days missing, missing maximum and minimum daily temperatures were linearly interpolated before calculating daily mean temperatures.

Additionally, we examined temperature records in the context of two broader data sets. As an indicator of regionally integrated trends, we extracted annual and seasonal mean data from 1901 to 2002 for the grid cell centered on 43.75°N, 72.75°W from a global dataset (Mitchell and Jones 2005). These values were calculated using a weighted mean of all stations located within 1,200 km of the pixel. We also examined the global annual and seasonal mean temperature record for the 30–60°N latitude band (Lugina et al. 2004). To facilitate comparison, all temperature data were normalized to represent deviations from the 1991–1996 mean, the longest recent period for which all records were complete.

The analysis of spring streamflow center-of-volume date was performed on 101 years of gage data (1904–2004) from the Pemigewasset River at Plymouth (USGS-01076500, 43°46′N 71°41′W), which drains a 1,610 km^2 watershed, including the HBEF (Table 1).

2.5 Statistics

We used a non-parametric Mann-Kendall test to detect trends (Helsel and Hirsch 1992). This test does not require normally distributed data, but does assume (as does ordinary least-squares regression) there is no significant autocorrelation in the time series. We confirmed this with a Durbin-Watson test, which indicated that model residuals were not significantly autocorrelated for any time series (though any long-term persistence is not accounted for, resulting in potentially smaller-than-justified p-values; Cohn and Lins 2005). The rate of change in each variable was determined with the *Sen slope*, a non-parametric estimate of the rate of change in a variable over time. It is attractive for this kind of analysis because it requires fewer assumptions than, for example, least-squares regression, and is relatively insensitive to outliers. The *Sen slope* is the median slope among all pairs of points in the dataset (Gilbert 1987). A custom SAS program (Winkler 2004) was used for the Mann-Kendall and *Sen slope* analyses. All analyses were done both for the entire length of the record, and also for the period 1966–2005, which allows direct comparison among all HBEF records, some of which began as late as 1966. Trends for both periods are expressed per decade. Where trends were small in magnitude and there were a large number of data ties among years (e.g. for metrics that were counts of days with given conditions), confidence intervals were often not meaningful and are not reported. Due to a large number of years with no observed soil frost, the soil frost record was analyzed using linear least-squares regression, despite its acknowledged limitations. Trends with $p<0.10$ were considered significant, though trends with $p<0.05$ were tallied separately.

Temperature at G1 and streamflow for W3 were analyzed using a frequency distribution approach. These are the longest-term records of their respective types that are not subject to experimental manipulation (forest cutting or fertilization). Temperature data were classed into 5 °C bins and the daily streamflow (in mm/day) was classed into 20 bins on a logarithmic scale. We compared the frequency distribution of the 20-year period at the beginning of the record (1958–1977) to that of the 20-year period at the end of the record (1986–2005). Differences between the two time periods are expressed as percent change in frequency in each class.

3 Results

3.1 Temperature

The four HBEF temperature records examined are highly correlated in mean annual temperature (Fig. 2a). The offset among these sites is largely a factor of elevation; the lapse rate calculated using G1 and G6 is −5.2 °C/1,000 m and shows no detectable trend over time. Three of the four stations showed significant increases in mean annual temperature over the entire available record; trends ranged from 0.13 to 0.32 °C/decade (Fig. 2a; Table 2). When only the 1966–2005 record was examined, three of four were still significant, and the mean trend was 0.21±0.08 °C/decade (95 % CI). Over both time periods, G14 had the strongest trend, while G1 and G6 had the weakest. Over the last 40 years of the record, trends observed at HBEF are similar to those seen elsewhere in the region and globally (Fig. 2). Pearson's correlation coefficients (r) between G1 and regional records range from 0.83 (Pinkham Notch) to 0.88 (Mt. Washington), while correlation with the global record (r=0.52) is poorer. Observed changes in mean annual temperature at HBEF (0.13–0.32 per decade in the 40–50 years leading up to 2005) are decidedly greater than the longer-term regional data we examined (Table 2), and are also greater than the ~0.04–0.1 °C/decade trends observed in NH from 1931 to 2000 (Keim et al. 2003) and the ~0.12 °C/decade trend observed over the full 20th century (Trombulak and Wolfson 2004) using statewide networks of stations.

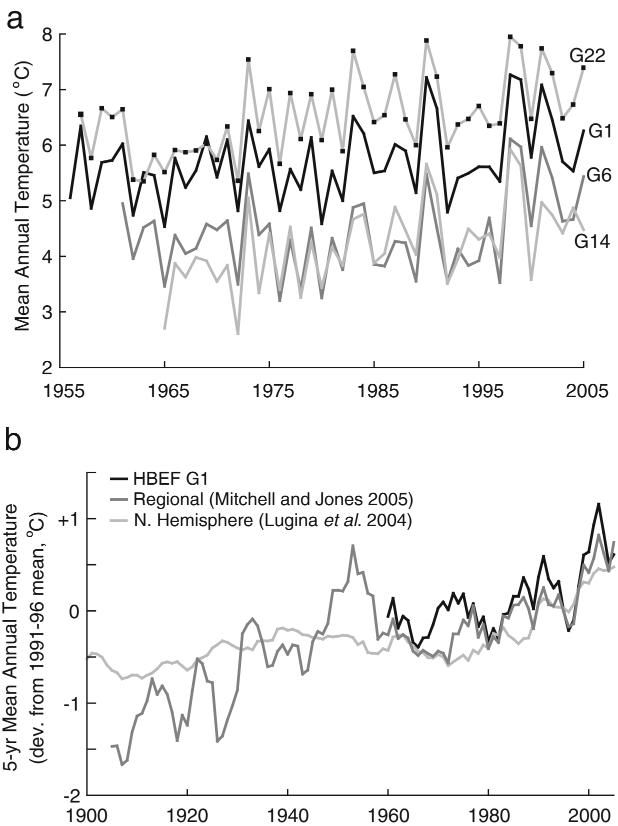


Fig. 2 **a** Mean annual temperature at the four longest-operating stations at HBEF. Differences in temperature among stations are attributable to elevation and aspect (Table 1). All four show significant warming trends. **b** Mean annual temperature at G1 station shows a pattern similar to integrated regional data (Mitchell and Jones 2005) and global data (Lugina et al. 2004)

Examined individually, records of mean seasonal temperatures often look very different from mean annual temperatures (Table 2). At HBEF, mean winter temperatures (G1 stdev for 1996–2005=1.80 °C) are more variable than are summer temperatures (G1 stdev for 1996–2005=0.74 °C). Trends for mean winter and mean summer temperatures are each significant at three of the four stations examined (Table 2), and rates of winter warming over the past 40 years (0.31–0.45 °C/decade) are non-significantly greater than rates of summer warming (0.02–0.33 °C/decade) at all sites except G22 at the headquarters building. This difference is consistent in pattern with the findings of Burakowski et al. (2008) who documented a similar rate of winter warming (0.43 °C/decade) in the northeast over a similar time period (1965–

Table 2 Climatic metrics examined at HBEF and regionally, with predicted direction of change (H) identified prior to the analysis. Trends are reported for the full length of each record, and also for only the most recent 40 years of data. Trends and 90 % confidence interval limits are reported per decade; "M" indicates that missing data precluded the calculation of a confidence interval. "T" indicates a lack of valid confidence intervals in data sets with a large number of ties and near-zero trends. Slopes in bold differ significantly from 0 ($p<0.10$; asterisks indicate $p<0.05$). Shaded cells indicate trends in the hypothesized direction

	H	years	units	full record Trend (units/decade)	full record 90% CI	1966-2005 Trend (units/decade)	1966-2005 90% CI
MEAN ANNUAL TEMPERATURE							
G1	+	50	ºC	**0.13***	0.03 – 0.26	0.13	-0.01 – 0.32
G6	+	45	ºC	0.13	-0.02 – 0.27	**0.19***	0.01 – 0.37
G14	+	41	ºC	**0.32***	0.17 – 0.48	**0.28**	0.14 – 0.46
G22	+	49	ºC	**0.24***	0.16 – 0.34	**0.26**	0.15 – 0.41
Hanover	+	102	ºC	**0.12***	0.09 – 0.15	**0.29***	M
Mt. Washington	+	56	ºC	0.06	-0.03 – 0.16	**0.26***	M
Pinkham Notch	+	69	ºC	-0.04	-0.11 – 0.02	**0.25***	M
Regional (Mitchell and Jones 2005)	+	102	ºC	**0.14***	0.10 – 0.18	**0.23***	M
Global 30-60ºN (Lugina et al. 2004)	+	117	ºC	**0.07***	0.05 – 0.08	**0.29***	M
MEAN SUMMER TEMPERATURE							
G1	+	50	ºC	0.12	-0.02 – 0.27	0.02	-0.24 – 0.23
G6	+	45	ºC	**0.23***	0.08 – 0.40	0.21	-0.01 – 0.40
G14	+	41	ºC	**0.25***	0.07 – 0.43	**0.20**	0.02 – 0.39
G22	+	49	ºC	**0.37***	0.25 – 0.50	**0.33***	0.17 – 0.49
MEAN WINTER TEMPERATURE							
G1	+	50	ºC	**0.38***	0.11 – 0.69	**0.45**	0.04 – 0.87
G6	+	44	ºC	0.27	-0.01 – 0.56	0.26	-0.08 – 0.62
G14	+	40	ºC	**0.45***	0.09 – 0.81	**0.45***	0.09 – 0.81
G22	+	48	ºC	**0.36***	0.15 – 0.61	**0.31***	0.07 – 0.62
ANNUAL MAXIMUM TEMPERATURE							
G1	+	50	ºC	0	T	0	T
G6	+	45	ºC	0	T	0	T
G14	+	41	ºC	0	T	0	T
G22	+	49	ºC	**0.53***	0.00 – 0.90	**0.71***	0.00 – 1.25
ANNUAL MINIMUM TEMPERATURE							
G1	+	50	ºC	0	T	0	T
G6	+	45	ºC	0	T	0	T
G14	+	41	ºC	**1.25***	0.00 – 1.91	**1.00***	0.00 – 1.74
G22	+	49	ºC	0.27	0.00 – 0.86	0	T
GROWING DEGREE DAYS							
G1	+	50	ºC*days/yr	20.5	-5.6 – 4.8	12.7	-18.6 – 43.3
G6	+	45	ºC*days/yr	**28.1**	4.6 – 52.4	**30.9***	6.4 – 65.2
G14	+	41	ºC*days/yr	**42.4***	17.9 – 73.0	**35.4***	13.8 – 64.8
G22	+	49	ºC*days/yr	**54.2***	30.5 – 78.0	**51.3***	25.3 – 84.3
THAWING DEGREE DAYS (G1)							
January and February	+	50	ºC*days/yr	**2.9***	5.3 – 16.4	1.96	-0.77 – 5.00
December - March	+	49	ºC*days/yr	**10.5***	4.6 – 52.4	**8.82***	1.37 – 16.78

Table 2 (continued)

	H	years	units	full record Trend (units/decade)	full record 90% CI limits	1966-2005 Trend (units/decade)	1966-2005 90% CI limits
FROST-FREE SEASON (G1)							
Last spring frost	-	50	date	-1.58	-3.33 – 0.00	0.62	-1.94 – 3.21
First fall frost	+	50	date	**1.92***	0.32 – 3.33	0	T
Frost-free season	+	50	days/yr	**3.75***	0.81 – 6.57	0	T
TOTAL ANNUAL PRECIPITATION							
W3	+	48	mm/yr	34.2	-3.0 – 69.4	7.0	-34.0 – 64.9
W7	+	40	mm/yr	--	--	16.5	-35.4 – 67.8
SUMMER PRECIPITATION							
W3		48	mm/yr	**17.1***	2.0 – 30.0	2.8	-15.7 – 25.0
W7		40	mm/yr	--	--	10.0	-12.1 – 33.5
LONGEST DRY PERIOD							
W3	+	48	days	0	T	0	T
W7	+	40	days	--	--	0	T
INTENSE PRECIPITATION							
Days of precipitation > 50mm W3	+	48	days/yr	0	T	0	T
Days of precipitation > 50mm W7	+	40	days/yr	--	--	**0.33**	0.00 – 0.79
LOW STREAMFLOW							
Days with streamflow <0.1mm at W3	+	48	days/yr	**-8.74***	-14.78 – -4.26	-2.50	-8.86 – 4.69
Days with streamflow <0.1mm at W7	+	40	days/yr	--	--	-1.18	-8.39 – 4.58
HIGH STREAMFLOW							
Days with streamflow >50 mm at W3	+	48	days/yr	0	T	0	T
Days with streamflow >50 mm at W7	+	40	days/yr	--	--	0	T
EVAPOTRANSPIRATION							
W3	+	47	mm/yr	**-10.9**	-19.6 – -3.5	-4.7	-14.2 – 4.0
W7	+	40	mm/yr	--	--	3.1	-3.6 – 10.0
TIMING OF SPRING RUNOFF							
W3	-	48	date	**-2.07***	-3.33 – -0.35	-1.89	-3.27 – 0.61
W7	-	40	date	--	--	**-3.06***	-5.23 – -1.04
Pemigewasset R. at Plymouth	-	101	date	-0.29	-0.83 – -0.24	**-1.92**	M
SNOWPACK DURATION (G2)							
First measurable snowpack	+	51	date	1.67	-1.08 – 4.48	3.28	-0.48 – 7.82
Last measurable snowpack	-	51	date	**-2.50***	-4.27 – -0.83	**-5.00***	-7.33 – -2.11
Snowpack duration	-	51	days/yr	**-4.00**	-7.39 – 0.00	**-8.60***	-12.18 – -4.36
MAXIMUM SNOWPACK							
G2	-	51	mm water	**-10.5**	-21.9 – 0.0	**-16.7**	-31.0 – -0.9
MAXIMUM SOIL FROST [a]							
G2	+	45	% area	**8.8***	2.1–15.6	3.1	-8.1–14.3

[a] Soil frost statistics are from least-squares linear regression; the non-parametric method was inappropriate due to a large number of ties resulting from years with no soil frost observed

2005). Hayhoe et al. (2007) also observed greater warming in winter than summer in New England from 1970 to 2000, though the increases were smaller in magnitude.

Of the four temperature records at HBEF, only G22 showed a significant increase in maximum annual temperature (0.52 °C/decade between 1957 and 2005, $p<0.01$). This could be the result of increasing the extent of paving in the immediate surrounding area. Minimum annual temperature only increased significantly at G14 (1.24 °C/decade between 1965 and

2005, $p=0.03$). Overall temperature extremes are a stochastic metric, and it is not surprising that few statistically significant trends were observed.

Annual growing degree days (GDD) increased significantly in three of four HBEF temperature records examined. The mean slope was 32.6 GDD/decade between 1966 and 2005. Thawing degree days (TDD) have increased significantly at G1 both in January–February and December–March (Fig. 3). When the 1956–2005 record is examined, the slope is +2.9 TDD/decade for January and February alone, and 10.5 TDD/decade for December–March. The length of the frost-free growing season has increased significantly at G1, by 3.75 days/decade between 1956 and 2005 ($p=0.03$). This result is driven both by a later date of the first autumn frost (1.9 days/decade, $p=0.04$) as well as a non-significantly earlier date for the last spring frost (1.6 days/decade, $p=0.15$).

3.2 Precipitation and hydrology

No significant trend was observed for total annual precipitation at either W3 or W7, though the nonsignificant trends were both positive (note that a prolonged drought occurred in the early 1960s, but was over by the start of the W7 record in 1966). Summer precipitation showed a significant trend (17.1 mm/year/decade) in W3 between 1958 and 2005, but the trend was not significant between 1966 and 2005, or at W7. There were no significant changes in the length of each year's longest precipitation-free period, and the frequency of days with >50 mm of precipitation increased significantly at W7 but not at W3.

The frequency of days with low streamflow (<0.1 mm daily) at W3 decreased significantly between 1958 and 2005 (−8.7 days/year/decade, $p<0.01$). A very small but significant increase in the frequency of days with intense precipitation (>50 mm daily) occurred at W7. Evapotranspiration decreased significantly at W3 (−10.9 mm/year/decade, $p=0.01$) but not at W7.

Spring streamflow center-of-volume date has become significantly earlier at W3 (2.1 days earlier per decade over 1958–2005) and at W7 (3.1 days earlier per decade over 1966–2005), though the trend was not significant in the 1966–2005 record from W3 (Table 1; Fig. 4). The mean spring center-of-volume date from these two first-order watersheds correlates remarkably well with those from the Pemigewasset River at Plymouth ($r=0.94$), despite the fact that the watersheds differ in area by a factor of more than three orders of magnitude and in elevation range by a factor of >5 (Table 1). Spring center-of-volume date on the

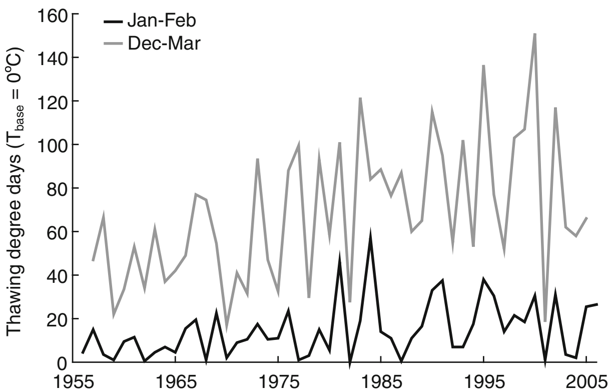


Fig. 3 Thawing degree days at station G1, have doubled for both the mid-winter months (January and February) as well as the entire winter (December to March)

Pemigewasset has not changed significantly over the entire 101-year records, but its trend since 1966 is similar to those at HBEF, (1.9 days/decade earlier).

3.3 Snowpack and soil frost

The observed trend in date of first measurable snowpack each season, 1.7 days later/decade was not significant, while the date of last measurable snowpack in spring has become significantly earlier at a rate of 2.5 days/decade, for a significant net reduction by 4.2 days/decade in the snowpack duration ($p=0.06$). Regionally, Burakowski et al. (2008) found a similar reduction in snowpack duration (3.6 days/decade), as well as significantly reduced total snowfall, which we did not examine. Maximum snowpack water content at G2, the only long-term record of its kind at HBEF, decreased significantly between winters 1956 and 2006, with a slope of −10.5 mm/decade (about −5 %/decade; $p=0.08$).

Soil frost coverage is expected to be negatively correlated with snowpack depth and water content, but is highly variable both spatially and interannually. No soil frost was observed at G2 between 1965 and 1969, though the sampling intensity during these years is not well documented (we did not include these years in the trend analysis). While widespread frost was not observed at HBEF before 1970, it is not uncommon now (Likens and Bormann 1995; Campbell et al. 2010).

3.4 Frequency analyses–temperature and runoff

Frequency distribution of daily mean temperature at G1 (Fig. 5a) and daily total streamflow at W3 (Fig. 5b) shifted observably over the record. In particular, days with a mean temperature of −25±2.5 °C were 39 % less frequent from 1986 to 2005 compared to 1958–1977, while days of 25±2.5 °C were 5 % more frequent. The temperature with the greatest increase was 5±2.5 °C, which was 10 % more frequent. This temperature occurs most commonly in early spring and mid-autumn, times when organisms are transitioning physiologically and are thus particularly sensitive to swings above and below freezing. The pattern of streamflow at W3 also changed, with low rates becoming less common and high rates becoming more common although it is important to note that this pattern is likely to have been influenced by a severe drought that affected the northeast in 1963–5.

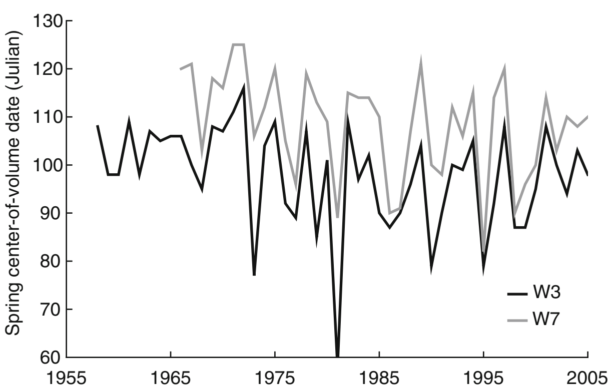


Fig. 4 Date of spring center-of-volume stream flow at W3 (south-facing) and W7 (north-facing). This date is a good indicator of the timing of spring thaw conditions, and occurs 10–12 days earlier now than at the start of the record

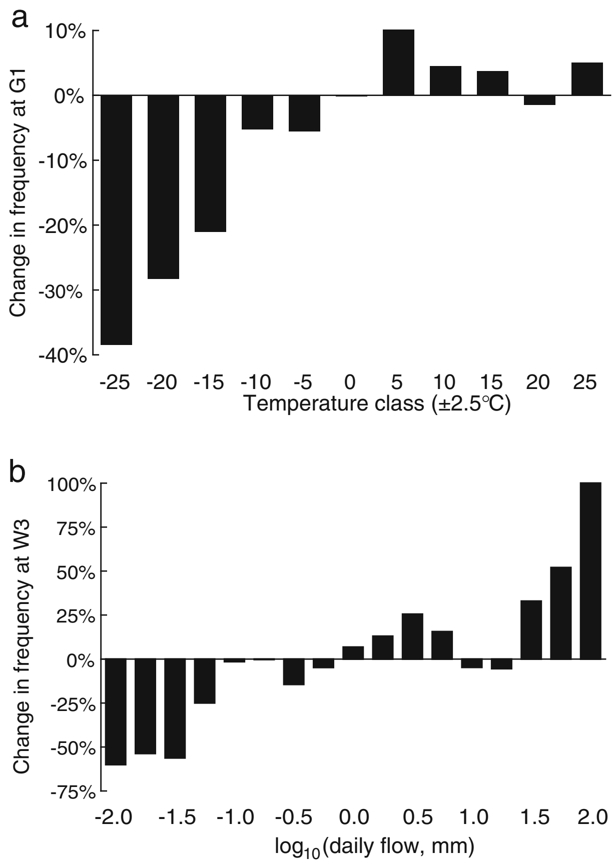


Fig. 5 Frequency analysis of (**a**) daily mean temperature at G1 and (**b**) daily streamflow at W3. The frequency of days in each bin between 1986 and 2005 is expressed as a percentage change from its frequency between 1958 and 1977. Under the null hypothesis of no climate change, we would expect small, non-systematic deviations from the 0 % change line. Extreme cold days have become far less frequent, while extreme hot days have become slightly more frequent. Days of extreme low flow have become less frequent, while extreme high flows have become more frequent

3.5 Pattern of change

Out of 18 metrics examined over the past 40–50 years, 13 have changed significantly ($p<0.10$) in the hypothesized direction in at least one location at HBEF (of which 11 had $p<0.05$), while two (evapotranspiration and frequency of low streamflow) have changed significantly in the opposite direction (Table 2). These metrics are not statistically independent (we did not include our one observationally non-independent metric, evapotranspiration, in the count), but demonstrate that a wide variety of climate metrics yield similar qualitative results. Observed trends depend somewhat on the length of record analyzed: measured temperature and temperature-derived trends have larger slopes and greater significance when examined for the period 1966–2005 than for longer time periods. While this result matches the general observation that global temperatures began rising rapidly in the 1970's (Folland et al. 2001), it is also true that the 1966 start date we selected to compare the maximum length of record across all sites examined (Table 1), anchors the beginning of our time series in an anomalously cold period for the region (Fig 2b). On the other hand, the late-1950's were considerably warmer than either the preceding 50 years or the following 30 years globally and at other regional stations (Fig 2b), and only around 1980 does the start of a clear rising trend become obvious in the longer-term data, which provide important context for interpreting the trends observed in the 40–50 year records examined at HBEF.

4 Discussion

4.1 Climate shifts

Changes in frequency distributions of temperature and streamflow (Fig. 5) show that the width of the probability density functions for these two variables have remained approximately constant over the past 50 years at HBEF, while the means of those distributions have shifted. Put simply, the climate as a whole is becoming warmer, and streamflow is increasing, but the (admittedly variable) extremes do not appear to be changing faster than the means. This finding, while similar to those reported by Frich et al. (2002), who examined 10 climatic parameters at the global scale over the past 50 years, contrasts somewhat with the more mixed findings of larger-scale analyses of the frequency of extreme events in some climate metrics (Schär et al. 2004; Tiebaldi et al. 2006; Alexander et al. 2006), though differences among the metrics examined make such comparisons difficult.

4.2 Changes in the timing of seasonal transitions

Greater warming in winter and spring than summer has been widely observed in the northern hemisphere (Liu et al. 2007) and can lead to large changes in the timing of ecologically relevant seasonal transitions. For example, streamflow conditions indicative of spring snowmelt advanced 8–12 days over the ~50-year record, similar to the 1–2 week advance observed regionally by Hodgkins et al. (2003). On the other hand, the 18-day advance in ice-out on Mirror Lake (adjacent to HBEF) since the late 1960's (Likens 2009) appears quite dramatic in comparison to the longer record presented by Hodgkins et al. (2002). Along with earlier snowpack melting at G2 (12 days earlier since 1955), these results point to a significantly earlier transition to spring thaw conditions characterized by the availability of liquid water and soil temperatures permitting root activity. The end of the snowpack likely represents a major "tipping point" in the seasonal transition, when surface soil temperature is released from control by the thermal insulation and high albedo of existing snowpack, as well as latent heat loss of the melting snowpack. Following this transition, soil temperatures generally warm rapidly, but are also subject to more dramatic fluctuation, with potential consequences for physical and physiological disturbance to shallow roots and ground-level vegetation.

Similar changes appear to be occurring in the fall as well. Easterling (2002) found that since 1948 the first frost has occurred about 2–3 days later, while the date of last frost has occurred about 5 days earlier throughout the northeast. The HBEF data from G1 for the period 1956–2005 indicate a much larger shift, with first frost occurring 10 days later ($p=0.05$).

Changes in seasonal timing can affect the growing season utilized by plants. Global data suggest that the onset of the northern hemisphere spring advanced approximately 1 week from the 1970s to 1990s (Keeling et al. 1996), and similar trends are found in studies of budburst and flowering at multiple scales (8 days earlier over 100 years in Boston, Primack et al. 2004; 5 to 6 days earlier over 35 years across the US, Schwartz and Reiter 2000). Tree phenology data are collected at HBEF and correlate well with spring temperatures (Richardson et al. 2006). While the 16-year record is insufficient for time-series analysis, they allowed the calibration of a model that estimated a slow trend towards earlier spring (0.2 days advance per decade) for the period 1957–2004 (Richardson et al. 2006).

4.3 Changes in precipitation and streamflow

While there are some broad trends in the hydrologic record over the last 50 years at HBEF, few are statistically significant (Table 2). This is probably due both to interannual and decadal-scale variation which are large relative to the magnitude of any long-term trend. For example, annual precipitation at W3 ranges from 979 to 1,793 mm, and the observed increase (~34 mm annual total per decade) was non-significant, but at least generally consistent with the range of trends observed by Lins and Slack (1999), who showed significant increases in streamflow across most of the continental US on streams with multi-decadal records. Streamflow is highly correlated with precipitation, (r=0.96 at W3 on a water-year basis).

At HBEF, trends in evapotranspiration were mixed, with a significant decrease at W3 over the full record, and a non-significant increase at W7 since 1966; trends at W3 and W7 did not differ significantly during this period. This result is also unexpected, as warmer and longer growing seasons would be expected to increase, rather than decrease, total annual ET (Huntington et al. 2009). However, a complicating factor is that the forest canopy at HBEF has increased in structural complexity (i.e. spatial variation in maximum height) since the 1950's, due to the aging of the forest, as well as a number of disturbance events (e.g. the 1998 ice storm). Alternatively, the observed decrease in ET may be related to trends in unexamined climatic factors, such as cloudiness, relative humidity, and windiness, for which the records at HBEF are not complete enough to justify trend analysis. Changes in stomatal density and regulation related to forest age and structure, atmospheric CO_2 concentrations, nutrient availability, and acid deposition in northern hardwood species are other potential explanations for changes in ET, and are the focus of much current research at HBEF and throughout the region.

Lins and Slack (2005) and McCabe and Wolock (2002) observed increases in the lower end of the flow-volume distribution at both the national and regional scales, which they interpret as due to increased precipitation in the warm (low-flow) months, while high flows have generally not changed significantly. At W3, we observed an unexpected decrease in the frequency of days with low streamflow (<0.1 mm), precisely the transient conditions in which evapotranspiration might be expected to be water-limited rather than energy-limited, *sensu* Budyko (1974). We did not observe a significant change in the maximum duration of precipitation-free periods which might be expected to contribute such temporary water limitation. These trends (presumed increases in soil water availability as reflected by reduced low-streamflow events, along with decreases in apparent annual evapotranspiration) appear to run counter to each other, unless the factor driving the change in the system is a decrease in evapotranspirative demand. Another un-investigated pathway that may help explain the change in evapotranspiration in light of observed winter warming is snowpack sublimation. It is important to note, however, that none of these trends are significant in the 40-year record (1966–2005), only in the 50-year record, which includes the unusually dry period of the early 1960's.

4.4 Vegetation community implications

Species distributions worldwide have been observed to respond to 20th century climate change (Parmesan and Yohe 2003). Iverson and Prasad (2002) show the potential for dramatic climate-driven shifts in forest species composition in New England by the year 2100, though range expansions are unlikely to keep up with the expected rate of climate change, and species shifts may be delayed, abrupt, and asynchronous across the landscape (Mohan et al. 2009). The 1 °C of warming in the 50-year temperature record at HBEF is equivalent to a drop in elevation of 150–200 m, roughly the elevation range covered by the south-facing experimental watersheds, across which forest composition ranges from northern hardwoods at lower elevations to boreal spruce-fir at higher elevations. Presettlement forest records (Vadeboncoeur et al. 2012) suggest that the hardwood/boreal ecotone has moved ~60 m upslope in ~200 years, due in part to the decline of red spruce, which has been attributed to climate change (Hamburg and Cogbill 1988; Beckage et al. 2008). Further upslope encroachment of hardwoods seems likely; on low ranges such as those at Hubbard Brook, spruce-fir forests may be extirpated completely as has been previously suggested (Iverson and Prasad 2002). Lund and Livingston (1999) suggest that spruce damage is brought on by cold temperatures following midwinter thaws that result in the foliage dehardening, rendering it susceptible to frost damage. Hawley et al. (2006) found significant damage in 2003 on W6 at HBEF, in a year when the temperature reached −26 °C at G6 only 8 days after a significant thaw. Spruce cold tolerance is also decreased in areas of high N-deposition and low soil Ca (Hawley et al. 2006). The combined effect of increased winter thawing (Fig. 3), and a decrease in the frequency of extreme cold temperatures (Fig. 5a) on red spruce in the future remains unclear, and may depend on future trends in acid deposition.

Other tree species may also be affected by changing patterns of winter temperatures, particularly with regard to specific thresholds and extremes. Changes in snowpack depth and duration, and associated changes in soil frost, seem particularly likely to affect young size classes of trees and evergreen forest herbs. Borque et al. (2005) suggest that yellow birch suffers winter damage when the minimum temperature falls below −4 °C after experiencing 50 growing degree days in the spring. At G1, at an elevation where yellow birch is abundant at HBEF, 1981 was the year with the greatest potential for yellow birch damage according to these criteria. In fact 1981 saw a major regional dieback of birches and sugar maple (Auclair 2005). However, systemic dieback of yellow birch has not been reported at HBEF, and no trend in the frequency of such events since 1956 is evident in the data from G1. To the extent that spring phenology is determined by accumulated degree days rather than by photoperiod, an earlier and more variable spring might lead to more frequent spring-freeze defoliation events (e.g. Gu et al. 2008); indeed a hard frost in May 2010 following budburst occurred at Hubbard Brook and elsewhere in the northeast, with important effects on carbon balance in several canopy species (Hufkens et al. 2011). Whether such events become more frequent is dependent on the rate at which frost-sensitive phenological stages advance relative to the advance in the latest occurrence of damaging cold each spring (Scheifinger et al. 2003); similar interactions may occur with soil freeze-thaw events and root activity. Continued increases in atmospheric CO_2 concentration may also mitigate stresses caused by extreme or unusually-timed extreme temperatures (Wayne et al. 1998).

Insects as well as trees may respond to changes in winter climate. The hemlock wooly adelgid, an introduced insect, has decimated hemlock forests in southern New England, but has not yet spread to northern New England. Temperatures of −25 °C are >98 % lethal to hemlock wooly adelgids (Skinner et al. 2003), yet at G22, at the elevation where hemlock is most important at HBEF, wintertime temperature minima have dropped below −25 °C in only four of the last 10 years, compared with eight of the first 10 years of the record. If such winter warming continues, the adelgid can be expected to expand its range northward toward HBEF in years with warm winters (Evans and Gregoire 2007).

4.5 Biogeochemical implications

The effect of a changing climate on ecosystem-level C cycling is likely to be mixed. Campbell et al. (2009) modeled increased primary production due to a longer growing season. However, if severe storms become more frequent (Easterling et al. 2000), or if winter dieback increases or new pathogens invade, there could be a net loss of standing live biomass and a resulting increase in litterfall, which would be rapidly respired particularly under a warmer, wetter climate (Rustad et al. 2001; White and Nemani 2003). Reduced snowpack may or may not increase soil frost in light of warmer winter temperatures (Campbell et al. 2010), perhaps affecting fine root turnover (Groffman et al. 2001). Soil frost and temperature-driven increases in N mineralization and nitrification may increase nitrate leaching (Groffman et al. 2001; Campbell et al. 2009), transferring N from terrestrial to aquatic ecosystems, though the long-term trajectory of anthropogenic N loading on these ecosystems remains uncertain and will interact with the effects of a changing climate on ecosystem processes.

Hollinger et al. (2004) showed that warm spring and autumn temperatures correlated with increased production, while hot summers correlated with decreased production, so the end result of disproportionate winter and transition-season warming might be an increase in ecosystem C storage. Warm springs that lead to early budburst may lead to both immediate and time-lagged effects on ecosystem C exchange, and increases in production may be greater for deciduous species (Richardson et al. 2009). Huntington (2005) proposed that the Ca status of forested sites in Maine may decline with increased production over a longer growing season, increased base cation leaching from greater rainfall, as well as shifts from spruce and fir to more Ca-demanding hardwoods. Indeed, over the longer term, the indirect effects of climate changes on biogeochemical cycles via species shifts (e.g. spruce and hemlock giving way to deciduous species) will be important to consider.

4.6 Conclusions

Ecologically meaningful changes in the climate at HBEF have occurred over the past 50 years, and predicted changes are likely to further alter the forest's community ecology and biogeochemistry. A complete understanding of these changes requires long-term studies at the ecosystem scale where the multiple interacting climatic variables are monitored alongside ecological observations and other changes (e.g. CO_2 and O_3 concentrations, atmospheric inputs of acidity and nutrients). Inherent in a great deal of ecological research is the assumption that the system is in equilibrium. However, we show here that significant changes in multiple climatic variables have occurred over the 50-year history of ecological research at HBEF. The non-equilibrium status of the current forest ecosystem with respect to climate and other perturbations is an important consideration when examining responses to disturbance, or parameterizing models describing future ecosystem function.

Acknowledgments The data presented were collected and processed by dozens of USFS employees, whose careful attention to detail was critical to maintaining the quality of this record. We are grateful to all those involved, especially Wayne Martin, Tony Federer and Jim Hornbeck. We thank Mark Green for helpful discussion regarding hydrologic trends. HBEF is now an NSF-funded Long-Term Ecological Research site, operated by the USFS Northern Research Station. This work was funded by NSF grant 0423259 to SPH, and is a contribution to the Hubbard Brook Ecosystem Study.

References

Alexander LV, Zhang X, Peterson TC et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:1–22. doi:10.1029/2005JD006290.

Auclair AND (2005) Patterns and general characteristics of severe forest dieback from 1950 to 1995 in the northeastern United States. Can J For Res 35:1342–1355. doi:10.1139/x05-066

Bailey AS, Hornbeck JW, Campbell JL, Eagar C (2003) Hydrometerological database for Hubbard Brook Experimental Forest: 1955–2000. USDA Forest Service, NE Research Station General Technical Report NE-305. http://www.treesearch.fs.fed.us/pubs/5406

Beckage B, Osborne B, Gavin DG, Pucko C, Siccama T, Perkins T (2008) A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont. Proc Nat Acad Sci 105:4197–4202. doi:10.1073/pnas.0708921105

Borque CP, Cox RM, Allen DJ, Arp PA, Meng FR (2005) Spatial extent of winter thaw events in eastern North America: historical weather records in relation to yellow birch decline. Global Change Biol 11:1477–1492. doi:10.1111/j.1365-2486.2005.00956.x

Budyko MI (1974) Climate and life. Academic Press

Burakowski EA, Wake CP, Braswell B, Brown DP (2008) Trends in wintertime climate in the northeastern United States: 1965–2005. J Geophys Res 113:D20114. doi:10.1029/2008JD009870

Campbell JL, Rustad LE, Boyer EW et al (2009) Consequences of climate change for biogeochemical cycling in forests of northeastern North America. Can J For Res 39:264–284. doi:10.1139/X08-104

Campbell JL, Ollinger SV, Flerchinger GN, Wicklein H, Hayhoe K, Bailey AS (2010) Past and projected future changes in snowpack and soil frost at the Hubbard Brook Experimental Forest, New Hampshire, USA. Hydrol Proc 24:2465–2480. doi:10.1002/hyp.7666

Christensen JH, Hewitson B, Busuioc A et al (2007) Regional Climate Projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: the physical science basis. Cambridge University Press, New York

Cohn TA, Lins HF (2005) Nature's style: naturally trendy. Geophys Res Lett 32:L23402. doi:10.1029/2005GL024476

Easterling DR (2002) Recent changes in frost days and the frost-free season in the United States. Bull Am Meteorol Soc 83:1327–1332

Easterling DR, Evans JL, Groisman PY, Karl TR, Kunkel KE, Ambenje P (2000) Observed variability and trends in extreme climate events: a brief review. Bull Am Meteorol Soc 81:417–425

Evans AM, Gregoire TG (2007) A geographically variable model of hemlock woolly adelgid spread. Biol Invas 9:369–382. doi:10.1007/s10533-008-9256-x

Folland CK, Rayner NA, Brown SJ et al (2001) Global temperature change and its uncertainties since 1861. Geophys Res Let 28:2621–2624. doi:10.1029/2001GL012877

Frich P, Alexander LV, Della-Marta P, Gleason P, Haylock M, Klein AMG, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19:193–212. doi:10.3354/cr019193

Gilbert RO (1987) Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York

Groffman PM, Driscoll CT, Fahey TJ, Hardy JP, Fitzhugh RD, Tierney GL (2001) Colder soils in a warmer world: a snow manipulation study in a northern hardwood forest ecosystem. Biogeochemistry 56:135–150. doi:10.1139/x84-173

Gu L, Hanson PJ, MacPost W, Kaiser DP, Yang B, Nemani R, Pallardy SG, Meyers T (2008) The 2007 eastern US spring freeze: increased cold damage in a warming world? Bioscience 58:253–262. doi:10.1641/B580311

Hamburg SP, Cogbill CV (1988) Historical decline of red spruce populations and climatic warming. Nature 331:428–431. doi:10.1038/331428a0

Hawley GJ, Schaberg PG, Eagar C, Borer CH (2006) Calcium addition at the Hubbard Brook Experimental Forest reduced winter injury to red spruce in a high-injury year. Can J For Res 36:2544–2549. doi:10.1139/X06-221

Hayhoe K, Wake CP, Huntington TG et al (2007) Past and future changes in climate and hydrological indicators in the US Northeast. Clim Dyn 28:381–407. doi:10.1007/s00382-006-0187-8

Helsel DR, Hirsch RM (1992) Statistical methods in water resources. Studies in Environmental Science 49. Elsevier Science, Amsterdam

Hodgkins GA, Dudley RW (2006) Changes in late-winter snowpack depth, water equivalent, and density in Maine, 1926–2004. Hydrol Proc 20:741–751. doi:10.1002/hyp.6111

Hodgkins GA, James IC, Huntington TG (2002) Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000. Int J Climatol 22:1819–1827. doi:10.1002/joc.857

Hodgkins GA, Dudley RW, Huntington TG (2003) Changes in the timing of high river flows in New England over the 20th Century. J Hydrol 278:244–252

Hollinger DY, Aber J, Dail B et al (2004) Spatial and temporal variability in forest-atmosphere CO2 exchange. Glob Chang Biol 10:1689–1706. doi:10.1111/j.1365-2486.2004.00847.x
Houle G (2007) Spring-flowering herbaceous plant species of the deciduous forests of eastern Canada and 20th century climate warming. Can J For Res 37:505–512. doi:10.1139/X06-239
Hufkens K, Sonnentag O, Keenan TF et al (2011) Community impacts of mid-May frost event during an anomalously warm spring. Am Geophys U. http://static.coreapps.net/agu2011/html/B21J-08.html
Huntington TG (2005). Assessment of calcium status in Maine forests: review and future projection. Can J Forest Res 35:1109–1121. doi:10.1139/x05-034
Huntington TG, Hodgkins GA, Dudley RW (2003) Historical trend in river ice thickness and coherence in hydroclimatlogical trends in Maine. Clim Change 61:217–236. doi:10.1023/A:1026360615401
Huntington TG, Hodgkins GA, Keim BD, Dudley RW (2004) Changes in precipitation occurring as snow in New England (1949–2000). J Clim 17:2626–2636
Huntington TG, Richardson AD, McGuire KJ, Hayhoe K (2009) Climate and hydrological changes in the northeastern United States: recent trends and implications for forested and aquatic ecosystems. Can J For Res 39:199–212. doi:10.1139/X08-116
Iverson LR, Prasad AM (2002) Potential redistribution of tree species habitat under five climate change scenarios in the eastern US. For Ecol Manage 155:205–222. doi:10.1016/S0378-1127(01)00559-X
Keeling CD, Chin JFS, Whorf TP (1996) Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. Nature 382:146–149. doi:10.1038/382146a0
Keim BD, Wilson AM, Wake CP, Huntington TG (2003) Are there spurious temperature trends in the United States Climate Division database? Geophys Res Lett 30:1404. doi:10.1029/2002GL016295
Kunkel KE, Easterling DR, Hubbard K, Redmond K (2004) Temporal variations in frost-free season in the United States: 1895–2000. Geophys Res Lett 31:L03201. doi:10.1029/2003GL018624
Likens GE (2009) A limnological introduction to Mirror Lake. In: Winter TC, Likens GE (eds) Mirror Lake: interactions among air, land, and water. University of California Press, Berkeley
Likens GE, Bormann FH (1995) Biogeochemistry of a forested ecosystem. Springer, New York, p 195
Lins HF, Slack JR (1999) Streamflow trends in the United States. Geophys Res Lett 26:227–230
Lins HF, Slack JR (2005) Seasonal and regional characteristics of US streamflow trends in the United States from 1940 to 1999. Phys Geogr 26:489–501. doi:10.2747/0272-3646.26.6.489
Liu J, Curry JA, Dai Y, Horton R (2007) Causes of the northern high-latitude land surface winter climate change. Geophys Res Lett 34:L14702
Lugina KM, Groisman PY, Vinnikov KY, Koknaeva VV, Speranskaya NA (2004) Monthly surface air temperature time series area-averaged over the 30-degree latitudinal belts of the globe, 1881–2004. Oak Ridge National Laboratory, Oak Ridge
Lund AE, Livingston WH (1999) Freezing cycles enhance winter injury in *Picea rubens*. Tree Phys 19:65–69. doi:10.1093/treephys/19.1.65
McCabe GJ, Wolock DM (2002) A step increase in streamflow in the conterminous United States. Geophys Res Lett 29(24):2185. doi:10.1029/2002GL015999
Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25:693–712. doi:10.1002/joc.1181
Mohan JE, Cox RM, Iverson LR (2009) Composition and carbon dynamics of forests in northeastern North America in a future, warmer world. Can J For Res 39:213–230. doi:10.1139/X08-185
Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42. doi:10.1038/nature01286
Primack D, Imbres C, Primack RB, Miller-Rushing AJ, Del Tredici P (2004) Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. Am J Bot 91:1260–1264
Rhoads AG, Hamburg S, Fahey TJ et al (2002) Effects of an intense ice storm on the structure of a northern hardwood forest. Can J For Res 32:1763–1775. doi:10.1139/X02-089
Richardson AD, Bailey AS, Denny EG, Martin CW, O'Keefe J (2006) Phenology of a northern hardwood forest canopy. Global Change Biol 12:1174–1188. doi:10.1111/j.1365-2486.2006.01164.x
Richardson AD, Hollinger DY, Dail DB et al (2009) Influence of spring phenology on seasonal and annual carbon balance in two contrasting New England forests. Tree Phys 29:321–331. doi:10.1093/treephys/tpn040
Rustad LE, Campbell JL, Marion GM et al (2001) A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia 126:543–562. doi:10.1007/s004420000544
Schär C, Vidale PL, Lüthi D, Frei C, Häberli C, Liniger MA, Appenzeller C (2004) The role of increasing temperature variability in European summer heatwaves. Nature 427:332–336. doi:10.1038/nature02300
Scheifinger H, Menzel A, Koch E, Peter C (2003) Trends of spring time frost events and phenological dates in central Europe. Theor Appl Climatol 74:41–51. doi:10.1007/s00704-002-0704-6

Schwartz MD, Reiter BE (2000) Changes in North American Spring. Int J Climatol 20:929–932
Schwartz MD, Ahas R, Aasa A (2006) Onset of spring starting earlier across the Northern Hemisphere. Global Change Biol 12:43–351. doi:10.1111/j.1365-2486.2005.01097.x
Schwarz PA, Fahey TJ, Martin CW, Siccama TG, Bailey A (2001) Structure and composition of three northern hardwood-conifer forests with differing disturbance histories. For Ecol Manage 144:201–212. doi:10.1016/S0378-1127(00)00371-6
Skinner M, Parker BL, Gouli S, Ashikaga T (2003) Regional responses of hemlock woolly adelgid to low temperatures. Environ Entomol 32:523–528
Tebaldi C, Hayhoe K, Arblaster JM, Meehl GA (2006) Going to the Extremes: an intercomparison of model-simulated historical and future changes in extreme events. Clim Change 79:185–211
Trombulak SC, Wolfson R (2004) Twentieth-century climate change in New England and New York, USA. Geophys Res Lett 31:L19202. doi:10.1029/2004GL020574
Vadeboncoeur MA, Hamburg SP, Cogbill CV, Sigamura WY (2012) A comparison of presettlement and modern forest composition along an elevation gradient in central New Hampshire. Can J For Res 41:190–202. doi:10.1139/x11-169
Wayne PM, Reekie EG, Bazzaz FA (1998) Elevated CO_2 ameliorates birch response to high temperature and frost stress: implications for modeling climate-induced geographic range shifts. Oecologia 114:335–342. doi:10.1007/s004420050455
Weeks BC, Hamburg SP, Vadeboncoeur MA (2009) Ice storm effects on the canopy structure of a northern hardwood forest after 8 years. Can J For Res 39:1475–1483. doi:10.1007/s004420050455
Wehner MF (2004) Predicted twenty-first-century changes in seasonal extreme precipitation events in the parallel climate model. J Clim 17:4281–4290
White MA, Nemani RR (2003) Canopy duration has little influence on annual carbon storage in the deciduous broad leaf forest. Global Change Biol 9:967–972. doi:10.1046/j.1365-2486.2003.00585.x
Winkler S (2004) A user-written SAS program for estimating temporal trends and their magnitude. Technical Publication SJ2004-4. St. Johns River Water Management District, Palatka, FL. Available at: http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ2004-4.pdf (Accessed March 19, 2005)
Wolfe DW, Schwartz MD, Lakso AN et al (2005) Climate change and shifts in spring phenology of three horticultural woody perennials in northeastern USA. Int J Biometeorol 49:303–309

Glossary

#

#30 sieve - A strainer that the contents of the kick net is emptied into to remove unwanted debris. The sample material remaining is placed in whirlpacks.

A

Attached Algae - Algae that has grown attached to a solid object or organism.

B

Bank Full Width - Width of a stream bank at full flood stage.

Bank Stability - The ability of a stream bank to counteract erosion or gravitational forces.

Baseline Sample - A sample of the quality of water when the body of water is at a normal or resting state. This can be used later on as a comparison to samples that are taken during or after storms.

Benthic Macroinvertebrates - Organisms that do not have spines, and are generally small, but visible without a microscope. They are abundant near bodies of water and surrounding ecosystems, and usually live in water at some stage of their lives.

Berm - A level space, shelf, or raised barrier separating two areas. These are constructed to control runoff and direct flow.

Bioassessment - (or Biological Assessment) A method of assessing aquatic conditions by surveying biological organisms, such as macroinvertebretes, fish, or plants.

Biological Sampling - Conducting a survey of biological organisms used for beneficial research.

C

Canopy Cover - The amount of sky covered by trees and vegetation over a stream bank.

Channel - In the context of this research, refers to the physical confinement of a stream that the water flows through, consisting of the stream bed and banks.

Channelized - Is the straightening and modification of a river corridor as a way to control the water. However, it is difficult to maintain a straight river, as the water tends to erode along the banks to return to a natural winding river.

Channel Sinuosity - A streams natural ability to bend and wind, an important characteristic of rivers to divert high flows and carry/deposit sediment.

Chemical Constituents - The amount of oil, alcohols, aldehydes, esters, ketones, lactones, phenols and terpenes in a water sample.

Cross sectional area - The area of a slice of river, perpendicular to flow; used to help determine stream velocity.

D

Deposition - The accumulation of material out of the water and onto the stream bed.

Didymo (Rock Snot) - A type of freshwater algae that is a nuisance when it blooms, creating thick, brown mats on the streambed. It is found in certain areas of Vermont, therefore waders and nets are decontaminated after use to avoid spreading it.

Discharge (flow) - The rate that a volume of water (and its associated suspended solids, dissolved chemicals, and biological materials) flows over a specific time. Usually provide in cubic feet per second.

Dissolved Oxygen - A relative measure of the amount of oxygen that is dissolved or carried in the stream water.

Dredging - The scooping and removal of sediment etc. from the bottom of a stream.

E

Ecological Integrity - The abundance and diversity of organisms at all levels, and the ecological patterns, processes, and structural attributes responsible for that biological diversity and for ecosystem resilience.

Eddies - The swirling of stream water , usually downstream and past a barrier.

Embeddedness - How much of an object is submerged into the substrate under the water.

Epifaunal - Animals that live on the surface of substrate, such as rocks, pilings, vegetation, or the streambed itself.

Ethanol - A form of alcohol that is used to clean lab materials, as well as to preserve insect specimens.

F

Floating Algae - Algae that is not attached to anything, typically refers to mats of algae that have accumulated and are growing together on the water's surface.

Free Floating Algae- Algae that is not attached to anything, such as duckweed.

H

Habitat Assessment Data Sheet - A field sheet used to determine habitat parameters of a stream site.

Habitat Equality - The balance of things within a given habitat.

Headwaters - A tributary stream of a river close to or forming part of its source.

I

iButton - A sensor that measures and records temperature. It works by transferring data in and out of the sensor when it is connected by a USB device.

iButton Capsule - A capsule that protects the iButton from environmental conditions such as temperature, moisture, pressure, and solvents, and allows the iButton to be securely mounted in a stream environment.

Infiltration - The movement of water into and through soil.

In Situ Measurements - Standard parameters that can be taken on the stream site with a water quality instrument.

J

K

Kick net - A net that is placed, with the opening facing upstream, into the riverbed with the motive of capturing benthic macroinvertebrates. While holding the net stable again the stream bottom, the researcher kicks and stirs up the sediment in front of the net, capturing any organisms living in and around the area.

L

Large Woody Debris - Large pieces of wood found in streams, that acts as important habitat for aquatic organisms.

M

Macroinvertebrates - see *Benthic Macroinvertebrates*

Macroinvertebrate Data Sheet - A sheet which records the conditions of the stream. This includes pebble count, canopy cover, temperature, water velocity, pH, and width data. It is used to record Macroinvertebrate collecting locations.

Macroinvertebrate Habitat Data Sheet - A field sheet that focuses on macroinvertebrates. It includes the pebble count.

N

Nitrogen - An odorless and colorless element that makes up about 78% of the earth's atmosphere and is necessary for life to exist. Too much dissolved nitrogen in a water source can lead to eutrophication.

NOAA - Stands for the National Oceanic and Atmospheric Administration, a Department of Commerce agency that maps out oceans, predicts climate changes, provides weather and natural disaster reports, and helps conserve oceanic resources.

O

One-Wire Viewer - iButton temperature sensor software for your computer. A Java demonstration application for iButton that features from your PC.

Orthophosphate - A lone phosphate molecule, a phosphorus atom connected to four oxygen atoms. Orthophosphate is directly taken up by algae .

Outfalls - The place where a river, drain, or sewer empties into the sea, a river, or a lake.

P

Pebble Count - The tallying of 100 or more random sediment samples, measured by walking up and downstream in a zig-zag pattern and selecting random points to measure along the way.

Phosphorus - A solid, nonmetal element (P) that is necessary for life and typically exists in nature as a phosphate molecule (PO_4). Inorganic and organic phosphorus can be dissolved or suspended in water and too much phosphorus in a water source can lead to eutrophication.

Physical Characterization - The physical things that describe the stream.

Physical Constituents - The physical makeup of a stream.

Pools - Deep parts of streams that typically occur after riffles.

Poison ivy - A toxic, flowering plant with three leaves that is common locally. It is known for irritating skin that comes in contact with it.

Poison parsnip - A common, local, flowering plant with yellow flowers. Can be an irritant if the inner sap is exposed and comes in contact with skin.

Q

Quaternary Ammonium Disinfectant - A combination of water and quaternary ammonium (QUAT) that is used to sanitize waders after using them; ensuring that nothing harmful is transmitted when they are transported.

R

RACC - Stands for Research on Adaptation to Climate Change that aims to answer the following overarching question: How will the interaction of climate change and land use alter hydrological processes and nutrient transport from the landscape, internal processing and eutrophic state within the lake and what are the implications for adaptive management strategies?

Replicate Number - The numbering of multiple samples for the purpose of organization.

Riffles - A rocky or shallow part of a stream or river with rough water that is typically high in dissolved oxygen.

Riparian Zone - The area between land and river or stream.

Riprap - Loose stone used to form a foundation for a breakwater or other structure.

Rooted Emergent - Refers to a plant that is rooted in sediment below a body of water, such as cattails.

Rooted Floating - Refers to an aquatic plant that is rooted below a body of water that floats to the top, such as lilies.

Rooted Submergent - Sediment rooted under a body of water that does not stick out, such as water milfoil.

S

Sample ID Number - Located at the top of the Macroinvertebrate Data Sheet, this ID Number consists of yy/mm/dd and the Replicate number.

Sensor Field Data Sheet - To be completed at each field site; records temperature and sage sensor data.

Snag - In aquatic systems, this refers to trees and branches that have fallen into the stream.

Stage Sensor (HOBO Water Level Logger) - A battery powered device that is used by RACC which measures stage or water level of fresh water streams.

Stream Gradient - The slope of a stream. How to know if your stream site is high or low gradient:

1. Determine the stream type using this chart below.
    a. Is your stream site confined by valley walls?
    b. What is the general valley slope of your site?
        i. Valley width is important because it is an indicator of how confined the stream is and whether it will have access to a floodplain at different flood levels. To determine valley width differences look for relative changes in the distance between toes of opposing valley walls. The toe of a valley wall can be identified as the bottom of the more steeply sloped portion of the valley.
        ii. If your site is unconfined by valley walls and <2% slope (think fairly flat, not down a steep hill, the water has access to a floodplain when it rains, etc) you'd classify it as a type C stream.
        iii. If your site has a steeper slope and valley walls that confine the stream (does it have room to meander or change course?), you'd classify it as a type A stream.

Table 2.2 Phase 1 – Reference Stream Typing Chart

Reference Stream Type	Confinement (Valley Type)	Valley Slope
A	Narrowly confined (NC)	Very Steep > 6.5 %
A	Confined (NC)	Very Steep 4.0 - 6.5 %
B	Confined or Semi-confined (NC, SC)	Steep 3.0 - 4.0 %
B	Confined or Semi-confined or Narrow (NC, SC, NW)	Mod.- Steep 2.0 – 3.0 %
C or E	Unconfined (NW, BD, VB)	Mod.- Gentle < 2.0 %
D	Unconfined (NW, BD, VB)	Mod.- Gentle < 4.0 %

Phase 1 Stream Geomorphic Assessment VT Agency of Natural Resources

2. Once you know what your stream type is, you can use the table below to determine if your site is high or low gradient.
    a. If your site is a type C stream, think about the substrate. Is the stream mostly gravel, cobble, or boulders? If so, you're in a high gradient stream.
    b. If your site is a type C stream but has mostly sand or fine gravel substrate, your site is a low gradient stream.

When to use high gradient RHA field form	**When to use low gradient RHA field form**
- reference stream type is A or B	- reference stream type is E
- reference stream type is C characterized by riffle/pool bed features and a dominant substrate size of gravel or larger	- reference stream type is C with ripple/dune or riffle/pool bed features and dominant substrate size is fine gravel, sand or smaller

For example, our training week field sites are classified below:

Potash Brook:

Stream Type: C
Substrate: Gravel and larger (cobbles)
Classification: High Gradient

Allen Brook:

Stream Type: C
Substrate: Sand and silt
Classification: Low Gradient

Munroe Brook:
Stream Type: B
Classification: High Gradient

Indian Brook (by Essex High School):
Stream Type: C
Substrate: Sand and silt
Classification: Low Gradient

Indian Brook (by Mill Pond):
Stream Type: C
Substrate: Gravel and larger (cobbles)
Classification: High Gradient

Stream Reach - A section of stream having relatively uniform physical attributes, such as confinement, valley slope, sinuosity, dominant bed material, sediment regime, tributary influence, and bed form. Reach determinations do not take into account human disturbances, but rather are based on variables related to valley setting, stream morphology, and their inherent fluvial processes.

Stream Site Code - A code given to any stream being tested so it can be easily identified in a lab.

Stream Site General Assessment Data Sheet - A field sheet that is filled out annually for a stream site. It provides general information about the location, surrounding area, and watershed features (such as a nearby dam or bridge).

Stream Stage - The height (typically in ft) of water from an established point, typically from stream bottom to surface. Often maintained by the USGS and can be measured in a variety of ways.

Substrate - Represents the variety of matieral that is present in the stream, ranging from clay and gravel, to boulder and bedrock, and includes woody debris. Refer to the following table for sizes:

Clay/Silt/Sand	< 0.004-2.0	Fine, granular pieces of sediment measuring under 2.0 cm
Gravel	2.0-16	Small rocks measuring 16 cm or less
Course gravel	16-64	Larger (softball size or bigger) rocks that are smaller than 64 cm
Cobble	64-256	Chunks of rock that are not large enough to be boulders but are still noticeably sizeable.
Boulder	>256	Large Rock measuring above 256 cm, tall (relative to surrounding sediment) and above the bedrock.
Bedrock	---	Solid rock, providing a base layer over which there are other sediments.

T

Thalweg - A line connecting the lowest or deepest points of successive cross-sections along the course of a valley or river. This where the largest volume of water flows within the stream.

Ticks - Small, parasitic (blood sucking) organisms found locally. May transmit diseases including Lyme disease. Following time in the field, researchers should check for ticks on clothing and exposed skin.

Total Suspended Solids (TSS) - The total amount of suspended solids in a sample of water; listed as a pollutant in the US Clean Water Act and is therefore measured as a water quality indication. Includes mostly sediment and algae.

Total phosphorus (test) - A test that measures all phosphorus forms, such as orthophosphate, condensed phosphate, and organic phosphate, in a given sample of water.

Tributaries - A river or stream flowing into a larger river or lake.

Turbidity - The cloudiness of water caused by small particles.

U

USB adaptor - An adapter that allows information to be directed between the iButton and a computer via a USB port.

USEPA - Stands for the United States Environment Protection Agency, a US federal agency that protects human health and the environment through enforcing regulations and laws passed by Congress.

USGS - Stands for the US Geological Survey, a US federal agency that studies the landscape of the United States and its natural resources and hazards.

V

Valley Slope - While you don't need to calculate the actual valley slope, it is good to know how the calculation is done.

Example – Calculating Valley Slope

1140 ft	**upstream elevation**
- 1000 ft.	**downstream elevation**
140 ft	**change in elevation**

$$\frac{\text{difference in elevation (ft.)}}{\text{length of valley (ft.)}} = \frac{140}{4{,}000} = 0.035 \times 100 = 3.5\ \%\ \text{valley slope}$$

Velocity - In this context, the speed at which the water is flowing downstream.

W

Water Quality Assessment - An evaluation of the conditions of a body of water. Specifically, biologically and chemically assessing and analyzing components such as flow, pH, TSS and nutrients of the body of water.

Water Quality Monitoring - Sampling and analysis of water constituents and conditions such as pollutants, natural components, dissolved chemicals, bacteria, etc. to know the base condition and target changes that may occur.

Water Quality Parameters - The general measurements of water that are healthy.

Watershed - An area or ridge of land that separates waters flowing to different rivers, basins, or seas.

Wetted Width - The width of the water in a stream bank.

Whirlpacks - Small bags that captured specimen are placed in after being captured in the kick net. Following this step, add ethanol for preservation.

X

Y

Z