



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

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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.

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

Objectives:

- 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

Strategies:

- 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

- Section 1: Team Project
- Section 2: Data Analysis
and Presentations
- Section 3: Field Safety
- Section 4: Infiltration
- Section 5: Supporting
Information

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	<p>Identify a research question Collect data / conduct investigation</p> <ul style="list-style-type: none"> ➤ ➤ ➤ ➤ ➤
December– March	<p>Project Presentation</p> <ul style="list-style-type: none"> ➤ 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	2
Viewing and Downloading Streams Project Data.....	3
Presenting Your Data: VT EPSCoR Student Research Symposium	4
Posters.....	5
How to Create a Poster Using PowerPoint.....	5
Oral Presentations.....	7
Oral Presentation Structure (<i>suggested</i>):	7
Resources.....	8

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/redirect/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 then 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:

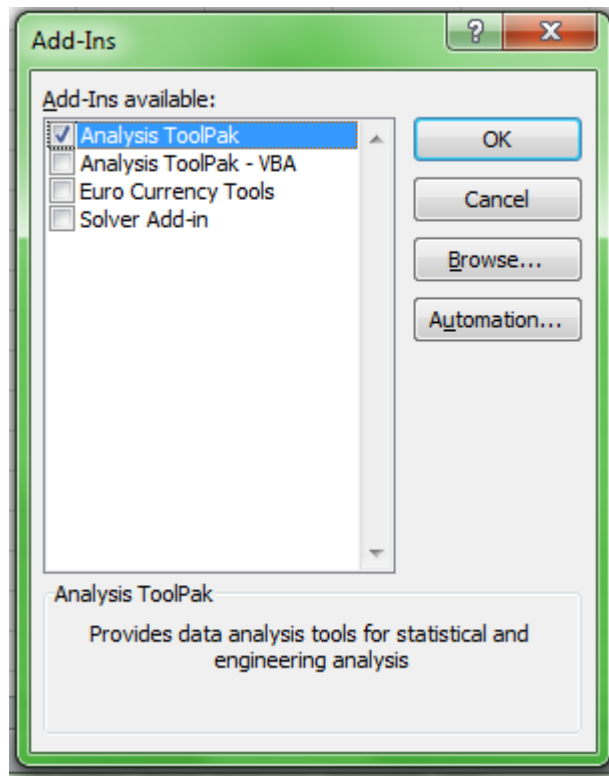
<http://www.uvm.edu/~epscor/new02/?q=node/1237>

- 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.
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:

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

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						
Source of Variance	SS	df	MS	F	P-value	F crit
Between Groups	14.77778	2	7.388889	7.150538	0.006593	3.68232
Within Groups	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

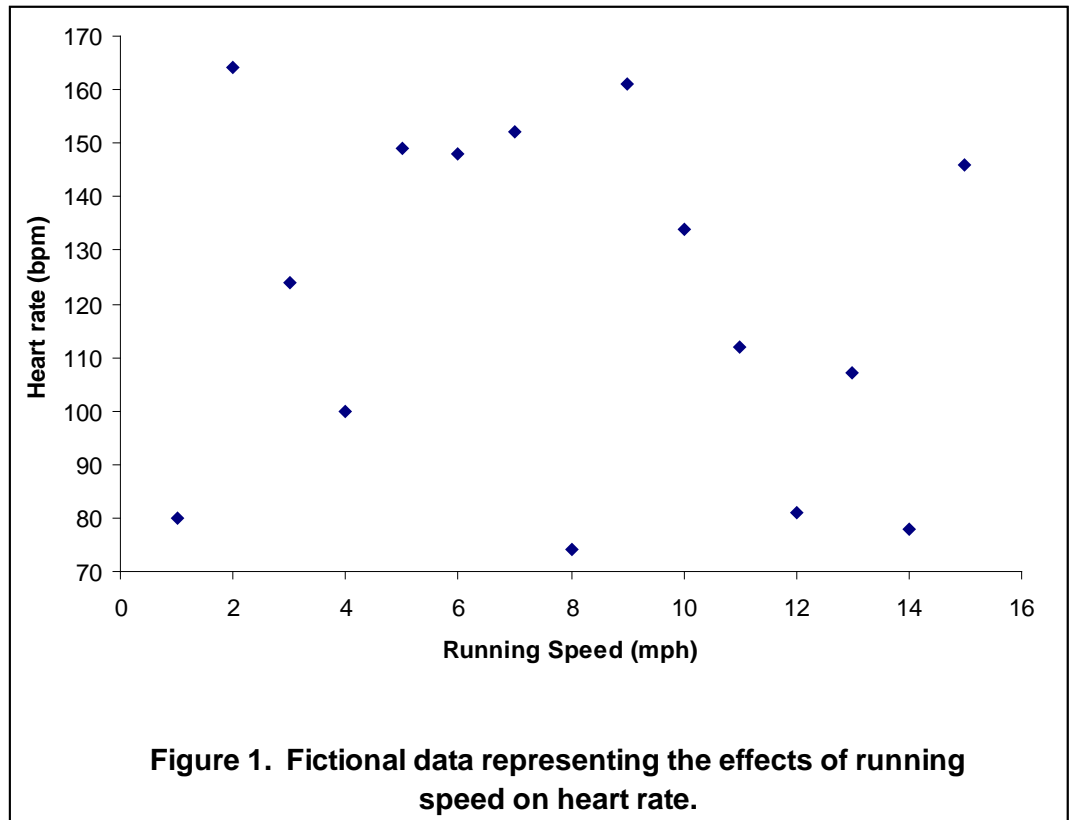
Does blood pressure increase with age? Does shrub cover decrease with increasing canopy cover? Is there a relationship between phosphorus concentration and algal cell density in ponds? All of these questions can be addressed using regression.

Nature of the data

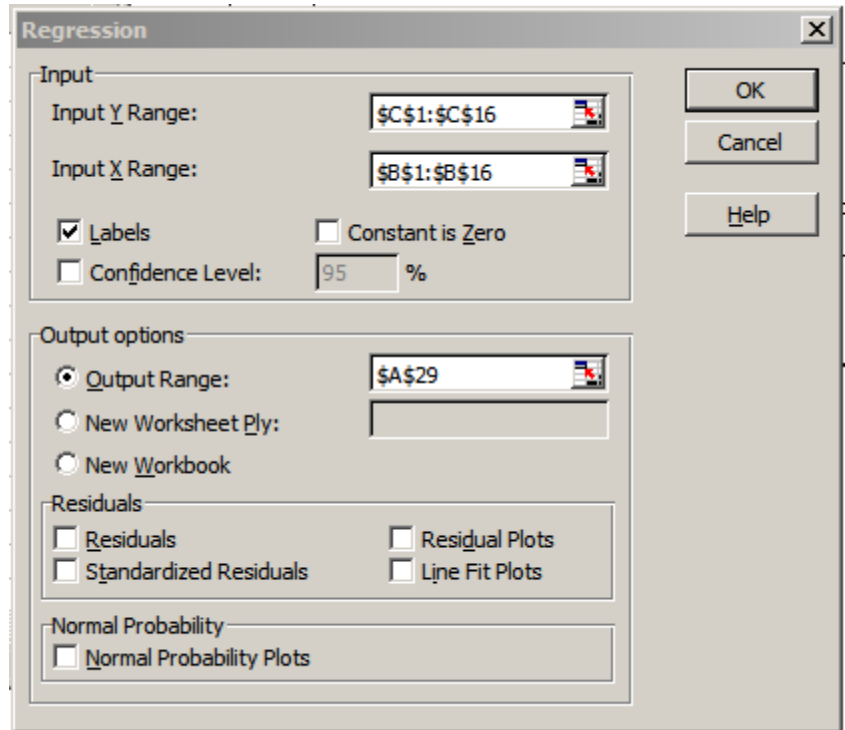
All of the datasets described above are *continuous*; that is to say, they vary over some range without breaks. They are not *categorical* (like male and female), that are not *discrete* (like number of people in a single car; you would not typically think about 3.5 people in a car). As the range of 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) axis. 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.



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								
<i>Regression Statistics</i>								
Multiple R	0.169583375							
R Square	0.028758521							
Adjusted R	-0.045952362							
Standard Error	33.23140781							
Observations	15							
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	425.0892857	425.0893	0.384931	0.545699			
Residual	13	14356.24405	1104.326					
Total	14	14781.33333						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	130.5238095	18.05655676	7.22861	6.66E-06	91.51499	169.5326	91.51499	169.5326
Running Speed	-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 Error	27.01902							
Observations	29							
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	357850.2	357850.2	490.1875	7.62E-19			
Residual	27	19710.73	730.0272					
Total	28	377561						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
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

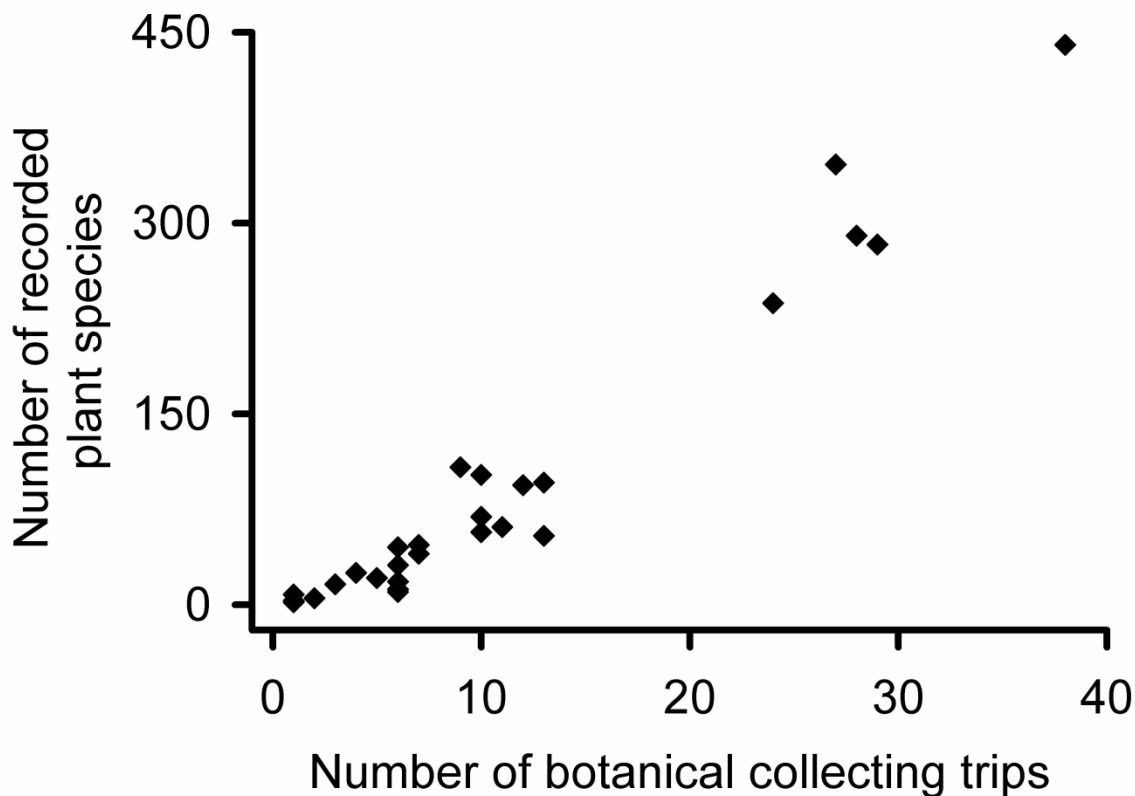


Figure 1. Illustrating the point that more sampling leads to more species observed. Connor & Simberloff (1978) analyzed data from collecting trips to the Galapagos Islands and found that number of collecting trips better explained number of species recorded than did island area, elevation, or isolation.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

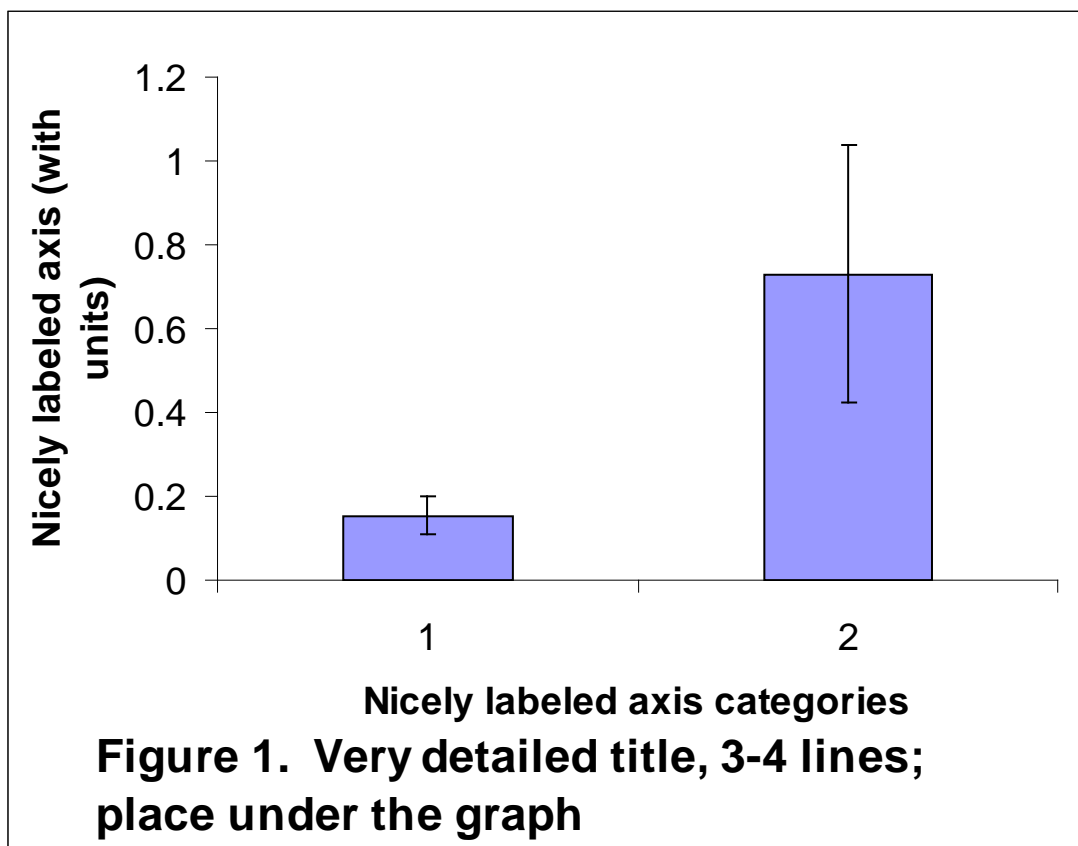
The figure legend is always placed underneath and contains roughly a paragraph of information describing the figure content in sufficient detail that the figure stands alone. The

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.



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: $(\text{standard deviation})/(\text{square root of the number of samples})$. 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.

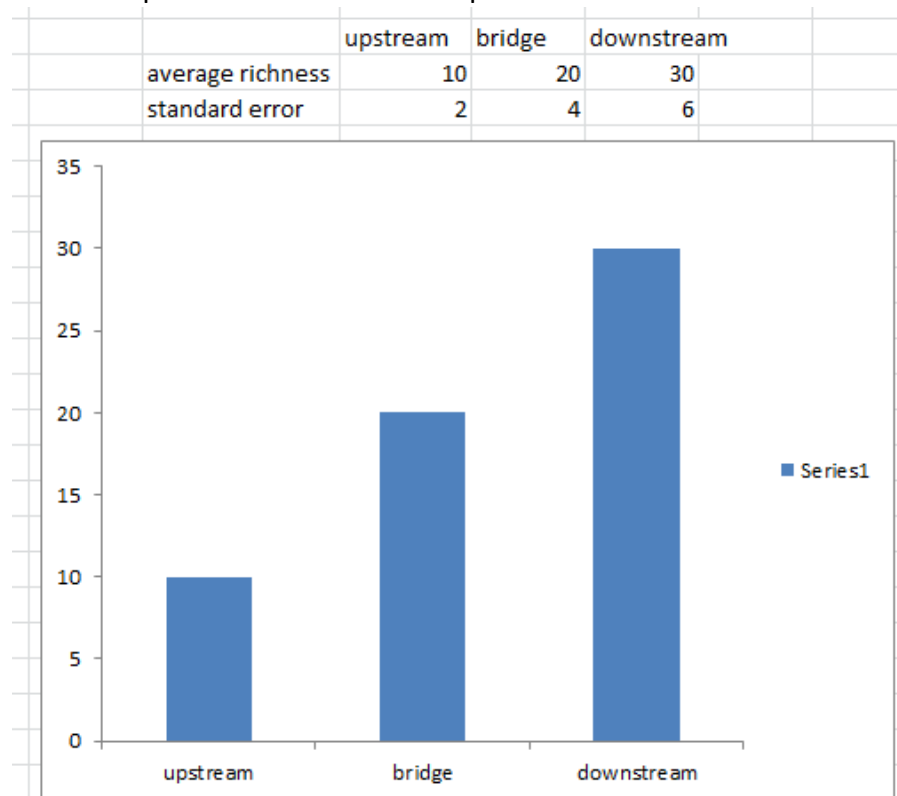
Standard error adjusts the value of standard deviation based upon the sample size using Formula 2

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

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.



Note:

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

The screenshot shows an Excel spreadsheet with a bar chart. The spreadsheet has columns labeled 'F', 'G', and 'H', and rows labeled 'pstream', 'bridge', and 'downstream'. The data values are: 'pstream' (10, 20, 30), 'bridge' (2, 4, 6). The bar chart shows two bars: 'bridge' and 'downstream'. The 'Format Error Bars' dialog box is open, showing options for 'Vertical Error Bars' such as 'Line Color', 'Line Style', 'Shadow', and 'Glow and Soft Edges'. The 'Display' section is set to 'Both' for 'Direction' and 'Cap' for 'End Style'. The 'Error Amount' section is set to 'Custom' with a 'Specify Value' button. The 'Custom Error Bars' dialog box is also open, showing 'Positive Error Value' and 'Negative Error Value' both set to '= {1}'.

F	G	H
pstream	bridge	downstream
10	20	30
2	4	6

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 beautiful error bars will now grace your bar graph!

Field Safety

Contents

First Aid Kit.....	2
Didmyo Fact Sheet.....	3
Disinfecting Waders	4
Field Precautions	5
Poison Parsnip	5
Poison Ivy.....	6
Ticks & Lyme Disease	7
Cyanobacteria	10

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

Didymo Fact Sheet



Didymosphenia geminata, 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 redden 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

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

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

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.



Leaf size varies greatly.



Ticks & Lyme Disease

T I C K S & L Y M E D I S E A S E

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



Adult Dog Tick Actual Size



Enlarged View Female Deer Tick



Enlarged View, Male and Female Dog Ticks

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.

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:

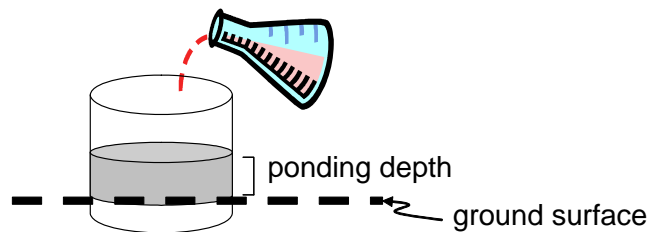
Infiltration is the movement of water into a soil profile. The rate at which infiltration occurs is controlled both by the inherent properties of the soil and by the ways in which humans have modified the landscape. Infiltration rates, in turn, control runoff rates and soil erosion, which are important 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°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?

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 volume¹ 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 cm³.

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)

Aquatic insects of Puerto Rico: a list of families

Insectos acuáticos de Puerto Rico: lista de familias

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RESUMEN

Los estudios con insectos acuáticos en Puerto Rico se iniciaron a principios del siglo pasado. La mayoría de los taxa han sido bien documentados; sin embargo, carecemos de información sobre otros taxa y no existe un documento único que contiene toda la información dispersa. Estos son los principales obstáculos que enfrenta el estudio de insectos acuáticos en la isla. En este trabajo realizamos una recopilación de datos recolectados en artículos publicados, tesis de grado, cursos universitarios, estudios de impacto ambiental y una revisión del material depositado en Museo de Zoología de la Universidad de Puerto Rico. El objetivo fue compilar la primera lista de familias de insectos acuáticos de Puerto Rico. En total se registraron 61 familias de siete órdenes de insectos. Los órdenes mejor estudiados han sido Ephemeroptera, Trichoptera y Odonata. El orden más diverso es Diptera, seguido de Coleoptera y Hemiptera. En términos generales, Puerto Rico es una isla diversa comparada con otras islas de las Antillas Mayores, no obstante su tamaño. Este estudio es un primer intento por integrar el conocimiento de los insectos acuáticos en una lista y de esta manera contribuir a mejorar el conocimiento de los insectos acuáticos. Adicionalmente, esperamos que la información ayude a los responsables en la toma de decisiones relacionadas a la conservación, y también incentive los estudios ecológicos y biogeográficos en los ecosistemas acuáticos de Puerto Rico.

Palabras clave: Insectos acuáticos, Antillas Mayores, islas, Puerto Rico, riqueza taxonómica.

ABSTRACT

Studies on aquatic insects in Puerto Rico began early last century. Most taxa have been well documented; however, we lack information on some taxa and there is no single document containing all the scattered information. These are major obstacles for the study of insects on the island. Here we reviewed data collected in published articles, graduate theses, university courses, environmental impact studies and reviewed material deposited in the Museum of Zoology at the University of Puerto Rico. The objective was to compile the first list of aquatic insect families of Puerto Rico. Overall, 61 families belonging to seven insect orders were found. The best known orders were Ephemeroptera, Trichoptera and Odonata. The most diverse orders were Diptera, followed by Coleoptera and Hemiptera. Despite its small size, Puerto Rico is a diverse island compared to the remaining Greater Antilles. This study is the first attempt to develop a list with all information available and contribute to advance our knowledge of aquatic insects. In addition, we hope to aid decision makers and encourage ecological and biogeographical studies on aquatic ecosystems in Puerto Rico.

Key words: Aquatic insects, Greater Antilles, island, Puerto Rico, taxonomic richness.

INTRODUCTION

Aquatic insects are conspicuous components of freshwater ecosystems. Insects play important functions within stream ecosystems and are also indicators of their ecological status, due to their differential responses to changes in the environment (Rosenberg & Resh 1993). Detailed taxonomic studies of local fauna are an imperative initial step toward using aquatic insects in ecological and monitoring studies. In Puerto Rico there is a lack of extensive island-wide taxonomic studies. Most published surveys have been directed at specific taxonomic groups, such as Ephemeroptera, Odonata and Trichoptera. Furthermore, while there is a reference collection at the Zoology Museum at the University of Puerto Rico, Rio Piedras Campus, most specimens were collected in the early to mid-twentieth century and are in need of revision. The collection also needs to be updated and expanded to provide adequate support to future taxonomic and distributional studies.

Puerto Rico, a United States commonwealth since 1898, has a different economic history than other locations in Latin

America and in the 1940s the economy of Puerto Rico started to shift from agricultural to industrial (Grau *et al.*, 2003). Along with this shift came rural to urban migrations, which resulted in an increase in natural forest succession on most of the island. Although the 2010 census shows that Puerto Rico is now less populated than in 2000, population density is high and the island is more densely populated than Japan (Hattam 2006). Puerto Rico's urban growth is characterized by urban sprawl around urban centers, a process influencing over 40% of the island (Martinuzzi *et al.*, 2007).

Most urban areas in Puerto Rico are connected to sewage systems and eventually to waste water treatment plants. However, illegal and accidental discharges occur and sewage overflows are common occurrences (particularly after heavy rains). In the context of Latin America, the organic pollution present in most urban river systems on the island is relatively mild (Ramírez *et al.* 2009). The high amount of urbanization and forested areas, along with key waste water legislation, makes Puerto Rico a rare case within the tropics.

These characteristics also represent a unique opportunity to understand macroinvertebrate responses to urbanization. Lessons from Puerto Rico could serve as a model of potential changes in tropical stream ecosystems once organic pollution is reduced.

Given the lack of comprehensive taxonomic studies in Puerto Rico, we present a list of aquatic insect families from Puerto Rico. The goal is to provide a basis of information to encourage the study of aquatic insects, the development of identification guides, and the use of insects in biomonitoring and ecological studies. In addition, we compare and contrast family richness with what has been reported for other islands in the Caribbean.

State of knowledge. One of the pioneers in entomological research in Puerto Rico was George Norton Wolcott, who made intensive collecting expeditions in Puerto Rico and other Caribbean islands between 1910 and 1956. He collected thousands of insect specimens, including aquatic insects that are still deposited in the Museum of Zoology at UPR, and wrote "Insects of Puerto Rico" (Wolcott 1948), which is still the primary reference for most of the current insect groups of the island (Lawrence 2000).

In Puerto Rico, some orders of insects have been extensively studied, including Ephemeroptera, Odonata and Trichoptera. In contrast, other groups have received less attention, such as Hemiptera, Coleoptera and Diptera. Intensive collecting occurred in the first half of last century. Ephemeroptera are relatively well studied due to their reduced taxonomic diversity in Puerto Rico. Traver (1938) reported 20 species in six genera and three families. Peters (1971) revised the family Leptophlebiidae and Lugo-Ortiz & McCafferty (1994) described a new species, *Farrodes taino*. Odonata has also been well studied; initial studies reported 55 species (Klots 1932, García-Díaz 1938), with only minor changes to date (Paulson 2011). Most studies within Hemiptera are focused on water striders (Barber 1939, Drake & Maldonado 1954) with 23 species in five families. Maldonado-Capriles & Navarro (1967) added seven species in five families of non-water strider Hemiptera. For Trichoptera, Flint (1964) presented a comprehensive study with 35 species, 22 genera and ten families. He further expanded this list in 1992 (Flint 1992, Harris & Flint 1992). Lepidoptera and Coleoptera have been poorly studied, aside from studies that presented general lists from a specific site (e.g. Wolcott 1948) and a hydrophilid species described in bromeliads (Hansen & Richardson 1998). Wolcott (1948) published a list of Diptera which was revised and expanded by Maldonado-Capriles & Navarro (1967). Wagner & Masteller (1996) and Wagner *et al.* (2010) described new species of Psychodidae and Hernandez & Courtner (2010) new Blephariceridae.

MATERIALS AND METHODS

Study site

Puerto Rico (18°15'N, 66°30'W) is an oceanic island in the Caribbean Sea, the smallest and most densely populated island of the Greater Antilles. It has a maritime climate with

average temperatures ranging from 25 and 31°C. Average rainfall ranges from 1000mm in seasonally dry areas, where streams are often intermittent, to ~4000mm in humid areas where rainfall is frequent and streams perennial (Calvesbert 1970). Cold fronts and tropical depressions are a major source of weather changes (García-Martinó *et al.* 1996). Even though it is small in size (8900 km²), it possess a wide range of geomorphological areas with an interior mountain range of volcanic origin with elevations reaching 1338m, alluvial plains near the coasts, and a karst region that covers most of the north of the island (López-Marrero & Villanueva-Colón 2006). Its life zones are dominated by humid subtropical forests, very humid subtropical forests, and dry forest (DRNA 2004). The island has 64 major watersheds, ten of which are intermittent. Also, it has one natural lagoon and around 22 artificial reservoirs which were constructed mainly as potable water sources (DRNA 2004). A great number of fish species have been introduced in these reservoirs for recreational purposes (Neal *et al.* 2009).

Data survey

The data were obtained from our laboratory research collections (<http://www.ramirezlab.net/research/prlist>), which are the result of numerous academic projects, master and doctoral theses, field courses, and research experience for undergraduates (REU). We also had access to material related to environmental impact studies and other independent research from outside our laboratory. We also consulted the entomology collection at the Museum of Zoology of the University of Puerto Rico, Río Piedras and conducted literature reviews.

To develop a regional context for our findings and understand the state of knowledge of the aquatic fauna of Puerto Rico, we made a comparative analysis of the number of families reported for the Greater Antilles. Publications on the aquatic insects of Cuba, Hispaniola and Jamaica were reviewed to obtain the most complete list of families possible.

RESULTS

A total of 61 families in seven orders of aquatic insects have been reported for Puerto Rico. The most diverse group in the list, at family level, is the order Diptera, followed by Coleoptera and Hemiptera. The list of families divided by order is presented in Table 1.

Our review of the aquatic insect fauna of the Greater Antilles shows that some groups, such as Diptera, Coleoptera and Trichoptera, are dominant in family diversity and are also widely distributed across the Greater Antilles. In contrast, groups like Ephemeroptera and Odonata seem to be more diverse only in the northern most islands, with Puerto Rico housing the lowest number. For example, Cuba and Hispaniola houses at least two more families of Ephemeroptera and three of Odonata, than the remaining island.

It is also difficult to assess how complete is our summary for the Greater Antilles. However, using this information the islands have fairly similar richness of aquatic insect families (Table 2) despite differences in area. The only exception is Jamaica with 32 families. Although this could be the result

of island characteristics, it is more likely the result of limited research or obscure publications rather than a real lack of diversity.

DISCUSSION

Information on aquatic insects of the Caribbean is distributed in many publications and while several past projects compiled information, the literature remains scattered. The list presented here represents a significant advance in the study of aquatic insects of Puerto Rico. This is the first time such a list is compiled using all available information, including collections, manuscripts and technical reports. Our findings suggest that despite its small size, Puerto Rico has a high diversity of aquatic insect families compared to the other islands of the Greater Antilles (Table 2). However, we recommend caution when using these data, as the lists completed from other islands might be still incomplete, perhaps with the exception of Cuba (Muñoz-Riveaux *et al.* 2006, Naranjo *et al.* 2010). In relation to continental areas, Puerto Rico shows the reduced diversity expected from islands and dominance by groups that are able to disperse over long distances.

As in the other Caribbean islands, taxonomic studies in Puerto Rico are the result of the work of a limited group of specialists whose expertise have biased information toward particular groups of taxa. For example, available information on Ephemeroptera, Odonata and Trichoptera is much more abundant than information on other groups. Although there is a clear lack of information on certain groups, we do not expect to find many more families in addition to those reported here for the Caribbean. However, studies at lower taxonomic levels (i.e., genus, species) will certainly result in new reports and even new species to science. The lack of a taxonomic list for the entire Caribbean is a major limitation to the study of aquatic insects in the region.

Island studies have played an important role advancing our knowledge of factors controlling biodiversity patterns on the planet. In depth studies of island faunas were key for the development of the theory of island biogeography by MacArthur and Wilson (1963, 1967). This theory was later extrapolated to forest islands within human-dominated landscapes (Haila 2002) and now plays an important role aiding policy-makers, water quality managers, and conservation practitioners. Many studies have shown clear relations between island area and biodiversity (Bass 2003). In addition, islands have played key roles in understanding biogeographic patterns and linkages between North and South America (Morrone 2006). In the case of Puerto Rico, strong anthropogenic pressures on stream ecosystems (e.g., urban expansion and construction of dams) exacerbate the need to understand patterns in stream biodiversity and the role that organisms play in their ecosystems. In addition, Puerto Rico provides a window into the future for tropical developing countries as they strive to control and manage residual waters and protect their water resources. Stream ecosystems in Puerto Rico are representative of those present in other tropical islands and in some tropical coastal areas.

In conclusion, Puerto Rico has a high diversity of aquatic

insects with some well-known groups (Ephemeroptera, Odonata and Trichoptera). Nevertheless, other groups require further research to understand their status or to complete inventories (Coleoptera, Hemiptera and Diptera). While taxonomic studies on the island started a long time ago, most information is scattered and not readily accessible. To our knowledge, this is the first list of aquatic insect families for Puerto Rico. It is our hope that this list will provide a basis for further studies on the ecology, biomonitoring and conservation of aquatic insects in Puerto Rico.

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Table 1. List of aquatic insect families reported for Puerto Rico

Order	Family	Order	Family
Ephemeroptera	Baetidae	Lepidoptera	Crambidae
	Caenidae	Coleoptera	Dytiscidae
	Leptophlebiidae		Elmidae
Odonata	Aeshnidae		Gyrinidae
	Coenagrionidae		Haliplidae
	Lestidae		Hydraenidae
	Libellulidae		Hydrophilidae
	Protoneuridae		Lampyridae
Hemiptera	Belostomatidae		Noteridae
	Corixidae		Ptiliidae
	Gerridae		Scarabidae
	Hebridae		Scirtidae
	Hydrometridae		Staphylinidae
	Mesoveliidae	Diptera	Blephariceridae
	Naucoridae		Ceratopogonidae
	Nepidae		Chaoboridae
	Notonectidae		Chironomidae
	Pleidae		Corethrellidae
	Saldidae		Culicidae
	Veliidae		Dixidae
	Trichoptera	Calamoceratidae	
Glossosomatidae			Empididae
Helicopsychidae			Muscidae
Hydrobiosidae			Psychodidae
Hydropsychidae			Sciomyzidae
Hydroptilidae			Simuliidae
Leptoceridae			Stratiomyidae
Philopotamidae			Syrphidae
Polycentropodidae			Tabanidae
Xiphocentronidae			Thaumelidae
			Tipulidae

Table 2. Family richness in the Greater Antilles.

Order	Cuba*	Hispaniola**	Jamaica***	Puerto Rico
Ephemeroptera	5	3	3	3
Odonata	7	8	7	5
Hemiptera	13	10	2	12
Trichoptera	12	12	11	10
Lepidoptera	1	1	1	1
Coleoptera	10	14	3	12
Diptera	12	15	5	18
Total	60	63	32	61

Source: Muñoz-Riveaux *et al.* (2006)*, Perez-Gelabert (2008)**, Hyslop & Hunte-Brown (2012)***

Macroinvertebrates

Contents

Macroinvertebrates General Info	2
Macroinvertebrate Equipment Field Checklist	3
Macroinvertebrate Communities in Wadeable Streams.....	4
Field Method:.....	5
Macroinvertebrate Sampling.....	5
Modified Pebble Count of Riffle Habitat	6
Laboratory Method:	7
Identifying, Preserving, & Counting Macroinvertebrates	7
Macroinvertebrate Habitat Data Sheet.....	9
Macroinvertebrate Data Sheet.....	10

Macroinvertebrates General Info

There are several components to assessing macroinvertebrate communities in streams:

- Discharge or flow (recorded on Water Quality Assessment Data Sheet from Water Quality Section)
- Substrate (recorded on Macroinvertebrate Habitat Data Sheet)
- Macroinvertebrate Identification (recorded on Macroinvertebrate Data Sheet)

Take all the components listed above each time you sample for macroinvertebrates. You will sample for macroinvertebrates once at each of your two stream sites.

Use the “Macroinvertebrate Habitat Data Sheet” and the “Macroinvertebrate Data Sheet.” Also, complete the “Water Quality Assessment Data Sheet” each time you visit and sample the stream.

The data sheet and field labels that you need to take macroinvertebrate samples are at the end of this section of your manual. You should enter the data that you collect and record in the field on your “Water Quality Assessment Data Sheet” and “Macroinvertebrate Habitat Data Sheet” online as soon as possible after your field visit. You may enter the “Macroinvertebrate Data Sheet” online whenever you are ready to do so.

If you wish, you may choose to sample for macroinvertebrates a second time, such as a week after a major storm event has occurred. This will provide you with two sampling dates for each stream. Your first sampling date acts as a “baseline” sample and your second sampling date could be used to assess the impact of the storm event on the macroinvertebrate community.

Macroinvertebrate Equipment Field Checklist

General Equipment

- Waders
- Spray bottles with disinfectant solution and water
- Gloves
- Pencils and permanent marker
- Datasheets (one for each site)
- Clipboard
- Insect repellent/sunscreen
- Sunglasses
- Camera
- First Aid kit
- Cell phone
- Meter stick
- Water temperature/pH meter

Bug collection

- Kick net
- Kitty litter tray
- #30 sieve
- 4 Whirlpaks for each site + extras
- 2 large mason jars per site
- Ethanol
- Field forceps
- Plastic spoon

Macroinvertebrate Communities in Wadeable Streams

All macroinvertebrate samples are collected during the late-Summer, early-fall index period, from September to mid-October unless otherwise discussed. A field crew selects a representative riffle section in the stream reach to be sampled. Physical characteristics recorded at each selected site include: stream width, depth, water velocity, water temperature, weather conditions, substrate composition, substrate embeddedness, canopy cover, stream bank condition, and immediate upstream land use. All data are entered onto a field sheet with appropriate site and sampling event identifiers, along with additional comments that may be applicable to the site evaluation. This sampling protocol is based on methods used by the Vermont Department of Environmental Conservation.

Complete a “Macroinvertebrate Habitat Data Sheet” for each macroinvertebrate sample you collect.

Field Method:

Macroinvertebrate Sampling

Macroinvertebrate samples are collected using an 18 inch wide x 9 inch high rectangular frame net with a 500 micron mesh size.

- 1) One person operates the net while the other person operates the stopwatch.
- 2) Place the net in the riffle, being sure the base of the net is firmly set against the stream bottom and there is water flowing into the net.
- 3) Using your hands, disturb an area immediately upstream of the net (square area, 18" x 18"), ensuring that all pieces of substrate are moved and rubbed clean of attached organisms and flow into the net opening. After scrubbing the larger substrates, disturb any underlying gravel to an approximate depth of 10 cm. This typically takes about 30 seconds but it is more important to complete the procedure than to exactly time 30 seconds.
- 4) Turn the contents of the net inside out into the kitty litter tray with lots of rinse water taken from the stream.
- 5) Rinse and scrub large gravel of remaining organisms and remove it from the net along with leaves and sticks. Any material adhered to gravel, leaves, and sticks is likely to contain macroinvertebrates, so be thorough.
- 6) Transfer the contents of the kitty litter tray into a #30 (=600 μ m) sieve to remove small particles and water from the sample.
- 7) Using forceps and a plastic spoon, transfer contents of sieve into a Whirl pak[®] and fill approximately half the Whirl pak[®] with 100% ethanol, being sure to cover the entire sample but also leave enough room to close the bag. Be sure the Whirl pak[®] contains a paper label with the following information: Stream name @ road name, town/state/country, site code, replicate number, month-day-year, Collector name/School name. The label should be inside the bag in the ethanol – for that reason, do not use pen or ink-jet printouts. If a sample occupies more than one bag then label each part of the sample with the same sample number and write *1 of 4; 2 of 4...* etc. **Do not rely on sharpie markings on the outside of the bag. Leaking ethanol removes all traces and the sample becomes useless.**
- 8) Turn the net inside out and rinse thoroughly to remove debris. Use the net inside out for the next sample. The act of sampling will further rinse the outside of the net (and it will become the inside for the following sample).
- 9) Moving up-stream, repeat steps 1-8 at 3 additional locations within the riffle *representing a range of velocities and substrate types* characteristic of that riffle, being careful to avoid areas that have been previously disturbed. The total active sampling time should roughly equal 2 minutes for the sampling site (approximately 30 seconds at each location). Do not mix the four replicates – they should be maintained as separate samples through all field and lab procedures.
- 10) You will end up with 4 separate replicates from each site. Store 4 Whirl-paks in quart-size mason jar (or as many as are needed) until ready to process. This “composite” sampling methodology effectively collects samples representative of the entire macroinvertebrate community of that riffle.

Field Method:

Modified Pebble Count of Riffle Habitat

This method is used to describe the substrate particle size classes within the “riffle” habitat of high gradient stream types that is targeted by the VTDEC for macroinvertebrate community assessments. The method is based on the more rigorous technique developed by Wolman (1954) to describe coarse river bed materials, and modifications of this technique developed by the Forest Service developed to describe the channel bed materials within stream reaches Bevenger and King (1995) and Harrelson, et al (1994).

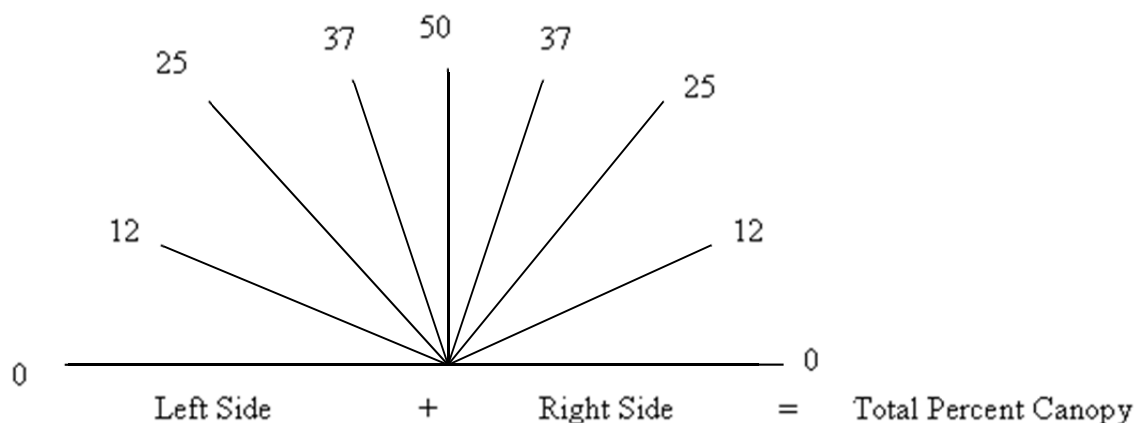
Riffle Pebble count Procedure:

1. A minimum of 100 particles are to be recorded on a tally sheet.
2. Diagonal transects across the stream are paced off until a minimum 100 count is reached. Transects begin at the lower end of the wetted portion of the stream bed within the macroinvertebrate sampling section or riffle. A pebble is selected as described below every two paces in larger streams > 20m across, or every pace in smaller streams <20m across.
3. Averting (closing) one's eyes, a pebble is selected by touching the bottom with one's index finger. The randomly selected pebble is then placed in a particle size category. Size categories were initially based on the Wentworth's size classes, which were then lumped into larger biologically based size classes used by the VTDEC to describe substrate composition. The VTDEC size categories are: Sand <2mm (.08"), Gravel 2-16mm(.08-2.5"), Course Gravel 16-64mm (.63-2.5"), Cobble 64-256mm (2.5-10.1"), Boulder >256mm (>10.1").
4. Size categories are determined by using a gravelometer, essentially a metal plate with squares of the above size classes cut out, or by estimation. The size category is called out to a recorder, who keeps track of the tally until the minimum of 100 particles is reached. If this occurs in the middle of a transect, the transect is completed.

Percent Canopy Measurement Guidance

Stand in center of stream/river, extend both of your arms straight out creating a 180-degree angle. Observing the overhead canopy cover, start to lift your arms up from the straight out position slowly towards your head. Stop when each arm is in alignment with the overhead canopy. Then estimate the angle of your left and right arm using the figure below for guidance. Combine the percent canopy values from the left and right side to obtain the total percent canopy.

Percent Canopy Calculator



Laboratory Method:

Identifying, Preserving, & Counting Macroinvertebrates

- 1) Pour contents of one individual sample (usually one Whirl pak ®) into a bucket. Add water and gently pour organic matter into a #30 sieve to remove all excess ethanol. Continue to add water and swirl sample until organic matter has been removed and sand remains in bucket. This will be processed later.
- 2) Spread organic matter evenly over a tray that is divided into 12-squares. Add a small amount of water to the tray to allow the sample to be evenly spread, but not so much as to cause the macroinvertebrates to float freely around the tray.
- 3) Randomly choose a number between 1 and 12, which will correspond to a square on your tray (use 12-sided dice or this excel formula: =int(rand()*12)+1). Use dominoes to separate this square and the next 3 consecutive squares from the rest of the sample. This will represent one quarter of your sample. Alternatively, generate a series of random numbers and work through the list until you've reached 4 squares or 75 insects. Pick all organisms from the selected sections with the aid of a 2x magnifier while keeping a tally. Completely pick each of the 4 squares (i.e., do not leave any insects remaining). For bugs which are not intact, only tally the heads not other body parts which are found.
- 4) After the 4 squares have been completely picked either take a break and check the area again later for bugs which have been missed, or have someone else check your sample. If after this time the minimum number of 75 organisms from the sample has not been reached, pick additional grids on the tray to reach that number. **Record the total number of grids (squares) that were picked** so that sample density or relative abundance can be calculated.
- 5) Sort animals into major groups, and preserve in 75% ETOH with 1% glycerin.
- 6) Using the keys provided, identify each individual to genus/species (depends on reference collection) except for the Chironomidae and Oligochaeta which will not be identified beyond the family and subclass level, respectively.
- 7) Store identified insects in a plastic vial with label indicating information on the site name, replicate sample number, date, identification (**in pencil or laser printed**).
- 8) Keep a record of all identification data on your Macroinvertebrate Data sheet and enter the data online.

Macroinvertebrate Field Labels

*Please use labels provided by the Streams Staff

*Labels should be complete **IN PENCIL** and placed **INSIDE** the Whirl pak ®. Labels filled out with markers will be erased by the ethanol!

Site Code
Replicate Number
Collectors
School Name
Sample Date
Major Drainage
Stream Name
Town
Nearest Street



Macroinvertebrate Habitat Data Sheet

2014-2015

Stream Name:	Site Code:
Latitude/Longitude:	Date/Time:
Site Description:	Investigators:

Sample Collection	Time spent collecting each replicate sample (should be 30 seconds): 1) 2) 3) 4) Comments:
Field Measurements	Air Temp: __°C Water temp: __°C pH: ____ Velocity (m/s) (at mid-point): ____ Bank full width (m): ____ Wetted width (m): ____ <u>Depths where samples collected(m):</u> 1) 2) 3) 4) <u>Canopy cover:</u> 100 90 80 70 60 50 40 30 20 10 0 %

PEBBLE COUNT

Particle	Millimeters	Transect 1 (100 pebbles)	Total #	Item %
Clay/Silt/Sand	< 0.004-2.0			
Gravel	2.0-16			
Coarse gravel	16-64			
Cobble	64-256			
Boulder	> 256			
Bedrock				
		Totals:		

Comments:

Short-term changes in-stream macroinvertebrate communities following a severe fire in the Lake Tahoe basin, California

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Abstract Large and severe wildfires can dramatically alter terrestrial and aquatic ecosystems. We documented changes in benthic macroinvertebrate communities and physical habitat at two sites along Angora Creek, CA, USA for 2 years following a severe fire. Although post-fire years had low precipitation, canopy cover and bank stability declined dramatically following the wildfire (canopy cover: 88% pre-fire, 22% post-fire; stable bank: 93% pre-fire, 11% post-fire). Substrate also changed substantially, with fine sediment 8× more abundant post-fire and cobble 7× less abundant post-fire. We found no consistent changes in taxonomic richness or diversity following the fire, but post-fire densities and percentage of sensitive taxa were significantly reduced. We observed large reductions in relative abundances of

shredder and scraper taxa, while collector-gatherer abundances increased. Community composition shifted away from pre-fire configurations, and continued to diverge in the second year following the fire. Scores from a regionally derived index of biotic integrity (IBI) were variable but overall much lower in post-fire samples and did not show recovery after 2 years. Overall, our study demonstrated substantial post-fire effects to aquatic ecosystems even in the absence of large flooding or scouring events, and showed that these effects can be transmitted downstream into unburned reaches.

Keywords Benthic · Subalpine streams · Wildfire ecology · Macroinvertebrates · Bioassessment

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Introduction

Natural wildfire regimes play a critical role in terrestrial ecosystem health by maintaining diversity and promoting natural ecosystem function (Covington et al., 1994). The role of wildfire effects on aquatic ecosystems has received increasing attention in the last two decades as researchers seek to better understand how natural disturbances structure aquatic communities (Gresswell, 1999; Minshall, 2003). Changes in aquatic ecosystems following fire disturbance are often linked to indirect fire effects associated with a suite of variables including fire severity, extent of watershed burned, topography, geology, climate,

timing of precipitation, hydrologic response, vegetation, stream size, and land-use history (Turner et al., 1998; Minshall, 2003; Vieira et al., 2004). These diverse factors, in conjunction with the unpredictability of wildfires and a frequent lack of pre-fire data, make it difficult to predict and evaluate the effects of wildfire on aquatic systems.

Benthic macroinvertebrates are commonly used as bioindicators in the evaluation of ecosystem processes and ecological change because their life histories allow them to integrate environmental conditions over time and thus reflect discrete, continuous, and cumulative changes within their environment (Rosenburg & Resh, 1993; McGeoch, 1998). When combined with information on physical and chemical parameters, a comprehensive bioassessment can provide valuable insight into the structure and function of an aquatic ecosystem.

In the past few decades, the use of benthic macroinvertebrate communities as bioindicators in evaluating the effects of disturbances has become increasingly popular (e.g., Rinne, 1996; Earl & Blinn, 2003). Previous studies have investigated the response of benthic macroinvertebrate communities to wildfire disturbances of differing intensities and extent of watershed area burned, but overall results have been inconclusive (e.g., Minshall et al., 1995; Roby & Azuma, 1995; Minshall et al., 2001b; Vieira et al., 2004).

This study investigated the short-term effects (1 and 2 years post-fire) of a catastrophic wildfire (Angora Fire) on the physical habitat and benthic macroinvertebrate communities of a small, sub-alpine stream in the Sierra Nevada, California, USA. This study is distinguished from previous studies due to the variety of montane landscapes affected within the watershed and the severe, localized nature of the fire. In addition, the existence of pre-fire data makes this a unique case study in the context of post-fire monitoring in subalpine and urbanized montane landscapes. Following the fire, an intensive post-fire, multi-agency monitoring program was established to track discharge and water quality (i.e., nutrient and sediments) within the affected watershed (Oliver et al., 2011). Our study was designed to enhance the resolution of the post-fire water quality monitoring program by incorporating bioassessment as a tool to investigate impacts on the aquatic ecosystem. Given the severe nature of the fire and the surrounding watershed characteristics

including topography, soil and vegetation types, and varying levels of urbanization, we anticipated that (1) changes in physical habitat and food resources would favor post-fire colonization by opportunistic taxa with high dispersal and omnivorous feeding habits, (2) the largest effects would be apparent in the first year following fire, and (3) the succession trajectory of the community would largely depend on watershed responses such as the magnitude of runoff, erosion, and vegetation succession. Information from this study may be used to guide management for subalpine Sierra Nevada aquatic ecosystems that may experience greater wildfire impacts due to global climate change (Westerling et al., 2006).

Methods

Study area

The Angora Fire occurred from June 24 to July 2, 2007 on the southwest shore of Lake Tahoe, California and was the largest wildfire recorded within recent history (c. 100 years) in the Lake Tahoe basin (Fig. 1). The Angora Fire occurred under high winds and extremely dry fuel conditions and, as a result, was high in both severity and intensity (Murphy et al., 2007; Safford et al., 2009). Remote-sensing assessment of fire severity indicated that approximately 53% of the Angora Fire burned at high severity (>75% canopy mortality), 21% at moderate/mixed severity (25–75% mortality), and 26% at low severity (<25% canopy mortality) (Miller et al., 2009). The fire burned a total of 1,255 ha, the majority (~67%) located within the subalpine Angora Creek watershed.

Angora Creek is a perennial first-order stream originating from the Angora Lakes basin (2270 m). The stream enters the burn area ~100 m from the outlet of lower Angora Lake and flows down a steep area of coniferous forest for approximately 3.2 km before crossing into a lower-gradient meadow. The stream then enters an urban area (58 ha) for 1 km prior to exiting the burned area. Post-fire potential threats identified within the urban area included impacts of increased runoff from impervious surfaces and sedimentation (USFS, 2007). Below the burned area, the stream flows through a large meadow for an additional 1.2 km before joining the Upper Truckee River, which flows into Lake Tahoe.

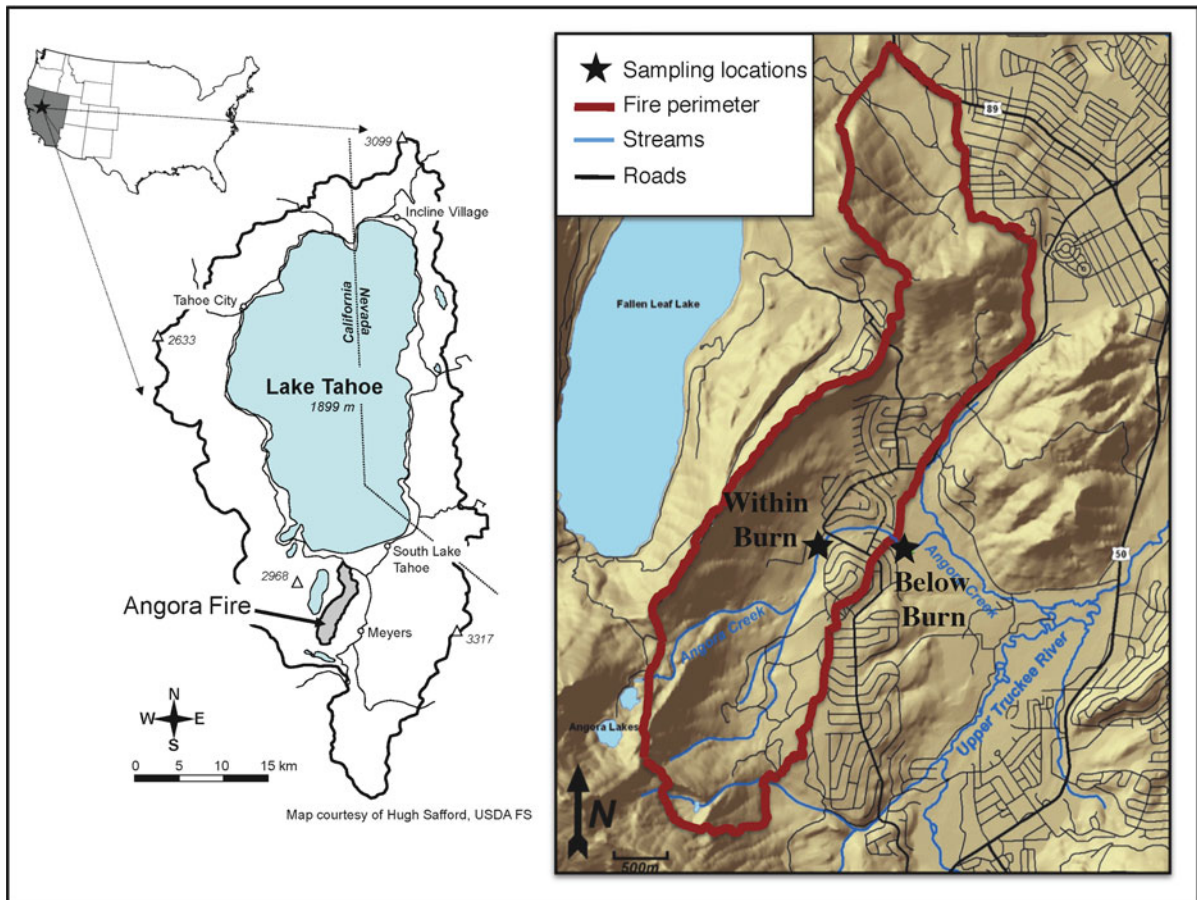


Fig. 1 Location of Angora Fire and sampling locations within the Angora Creek watershed

Mean annual temperature at the elevation of Lake Tahoe (1,898 m) is 6°C with a mean July temperature of 15°C and mean January temperature of −2°C. Precipitation varies as a function of elevation, with the majority of precipitation falling as snow between November and March. Pre-fire vegetation within the Angora Fire boundary was a mature mixed conifer forest, with riparian corridor vegetation such as alder (*Alnus incana*), aspen (*Populus tremuloides*), willow (*Salix* spp), sedges, and other forbs. Soils on steeper slopes are derived from granitic glacial till and have gravelly, loamy sand textures, while soils in lower elevation meadows are poorly drained, with gravelly loamy coarse sands grading to silt loams.

Two sites on Angora Creek were selected for benthic macroinvertebrate and physical habitat surveys (Fig. 1). These locations were chosen to capture stream conditions within and below the fire (Table 1), and to correspond with sites chosen as hydrologic and

water quality monitoring stations (Oliver et al., 2011). Our uppermost site (designated “Within Burn”) was located within the burned area, and represented conditions draining the undeveloped, severely burned upper watershed. In addition, there were pre-fire macroinvertebrate and habitat data from the Within Burn site, collected in 2002, which we used as a reference point for the effects of fire on in-stream and riparian habitat and community composition. The lower site (designated “Below Burn”) was located just below the fire boundary (~100 m) to capture conditions in Angora Creek incorporating the entire burn area. The Below Burn site received drainage from both the burned upper watershed and the burned urban area, however, the area immediately surrounding the Below Burn site was unburned and composed largely of mixed conifer, with similar riparian species as described above. No pre-fire data were available for the Below Burn site.

Table 1 Sub-watershed characteristics for the two sampling sites

Site name	Landscape features	Area (ha)	% Total watershed	% Area burned	% Area burned high severity
Within Burn	Forested, high-gradient slopes, undeveloped	459	31	78	35
Below Burn	Urban and forest, variable gradient, extensive development	120	8	56	12

The Within Burn subwatershed represents the area of the watershed below Angora Lakes and the Below Burn subwatershed represents the area between the Within Burn and Below Burn sites. The remaining portion of the Angora Creek watershed (53%) remained largely unburned

The environmental setting of Angora Creek makes this stream especially vulnerable to wildfire impacts. Much of the watershed has a south or southeast facing aspect, and experiences earlier snowmelt, accompanied by dryer forest litter and soils. Slopes of the upper drainage area are quite steep (average slope 45–60%), but the lower portion of the drainage is comprised of low gradient meadows (average slope 0–5%) where sediment may accumulate. We compare physical and biological conditions before and after the fire at two sites on Angora Creek (slope $\sim 2.3\%$). Reaches above the wildfire on Angora Creek were inappropriate for comparison or use as a control because they were not perennial, so we used an index of biological integrity (IBI), which defines the range of biological metrics for habitats with minimal exposure to human disturbance. The IBI used in our study was derived from regional reference streams of the eastern Sierra Nevada, including Angora Creek and other nearby streams in the Tahoe Basin, to set expectations and evaluate the biological potential of Angora Creek (Herbst & Silldorff, 2009).

Field and laboratory procedures

Sampling occurred in June, July, and August for two summers following the fire (2008 and 2009). At each site, benthic macroinvertebrates (BMI) were collected from riffle habitat within a 100 m reach by disturbing a $30 \times 30 \text{ cm}^2$ area of substrate in front of a 250 μm *D*-ring net. Rocks and other substrates were overturned and gently brushed to dislodge individuals and allow them to be carried by the current into the net. A total of eight individual replicates were collected and composited for each 100 m reach. Invertebrate samples were picked by hand and stored in 90% ethanol. In the laboratory a Folsom plankton splitter (Wildlife Supply Company, Buffalo, NY) was used to obtain subsamples with a minimum count of 500 individuals for

identification. The remaining fraction of the unprocessed sample was sorted by hand for large and rare organisms. Invertebrates were identified with a dissecting microscope at $10\times$ magnification to the lowest feasible taxonomic level (usually genus).

Physical habitat assessments were conducted in August of each year. Throughout the 2-year study, sites were outfitted with automated samplers (ISCO 6710; Teledyne Isco Inc., Lincoln, NE, USA) and instrumented to record stage, velocity, temperature, conductivity, and turbidity (Campbell CR10X; Campbell Scientific, Logan, UT, USA). During each sampling event we measured pH and dissolved oxygen with a handheld meter (YSI 556 meter; YSI, Yellow Springs, OH, USA). A transect was established at each sample location, and major categories of in-stream substrate type (categories: fines ($<0.06 \text{ mm}$), sand ($0.06\text{--}2 \text{ mm}$), gravel ($2\text{--}63 \text{ mm}$), or cobble ($63\text{--}250 \text{ mm}$)) and substrate cover (categories: algae, aquatic vegetation, aquatic moss, wood, detritus, leaves, roots, or bare) were identified at five evenly distributed points across the channel and recorded in terms of percent abundance for each transect. Percent abundances for each transect were then averaged for the entire sample reach by site and year. Riparian vegetation type (categories: herb, bush, deciduous tree, evergreen tree), percent cover (using a densitometer), and bank stability (categories: stable, vulnerable, eroding) were identified and recorded at each of five transects spaced at 20 m increments throughout the 100 m sampling reach, and then averaged to determine mean values by site and year.

Most studies on wildfire and stream interactions lack pre-fire data. Fortunately, Angora Creek was sampled prior to the fire in August 2002 at the Within Burn site as part of a project aimed at developing a regional index of biotic integrity (Herbst & Silldorff, 2009). In addition, climate and hydrologic conditions were similar in 2002 to the two post-fire years

investigated here, allowing for greater confidence in the comparability between datasets despite the 6 year gap between pre- and post-fire samples. Pre-fire sampling included collection of five samples of three individual replicates from riffle habitats, as well as physical habitat surveys as described above. All pre-fire invertebrate samples were subsampled to 250 individuals each, enumerated, and identified using the same methods described above.

Community composition

Taxa were assigned a functional feeding group category (predator, shredder, grazer, filterer, and collector) and tolerance value (TV), which represents the relative sensitivity to perturbation and/or stressors based on previous data from Barbour et al. (1999). Metrics of community composition were determined for each sample, including benthic macroinvertebrate (BMI) density, taxa richness, EPT (orders Ephemeroptera, Trichoptera, and Plecoptera) richness, percentage of sensitive taxa, and percentage of specific functional feeding groups. BMI communities were evaluated for diversity (within sites) and similarity (between sites). Species diversity was evaluated using the Shannon index (H'). All univariate comparisons of differences between means at each site between post-fire years were conducted using paired t tests or nonparametric Kruskal–Wallis ANOVA on ranks. BMI communities tend to show high intra- and inter-annual temporal variability (Resh & Rosenberg, 1989), and because all pre-fire data used in this study were collected in August, direct community comparisons to pre-fire data are made using only the August post-fire samples in 2008 and 2009. The pre-fire sampling technique also used a lower minimum count of 250 individuals for each replicate (versus 500 for post-fire samples), so we chose to make all comparisons using the average value determined from all 5 pre-fire replicates.

Nonmetric multidimensional scaling (NMS) of Sørensen dissimilarity matrices was used to examine the composition (species occurrence and abundance) of the BMI community before and after fire, and to assess how composition was related to physical habitat parameters. To evaluate differences between a priori sample groups, a multi-response permutation procedure (MRPP) was used to test the hypotheses of (1) no difference between pre-fire (Aug 2002: $n = 5$) and post-fire samples (Jun–Aug 2008, 2009: $n = 6$) at the

Within Burn site and (2) no difference between the Within Burn samples (Jun–Aug 2008, 2009: $n = 6$) and Below Burn samples (Jun–Aug 2008, 2009: $n = 6$). MRPP quantifies within-group agreement and distinctness (see Mielke et al., 1981). Indicator species analysis (ISA) was used to determine which BMI taxa were associated with each of the three sample groups: (1) pre-fire Within Burn ($n = 5$), (2) post-fire Within Burn ($n = 6$), and (3) post-fire Below Burn ($n = 6$). The statistical significance of each indicator value (IV) was tested using a Monte Carlo randomization with 5,000 runs. All multivariate nonparametric statistical analyses were conducted using the software program PC-ORD Version 5.10 (McCune & Mefford, 2006).

Eastern sierra-index of biological integrity

The Eastern sierra-index of biological integrity (ES-IBI) is a multimetric index developed to aid in long-term monitoring strategies for the Lahontan region of the Sierra Nevada (Herbst & Silldorff, 2009). The ES-IBI integrates aquatic invertebrate bioassessment data compiled from streams within the ES (including the Tahoe basin and Angora Creek) to define reference-standard conditions and determine responses to stressors. The ten metrics included in the ES-IBI are: (1) a modified Hilsenhoff index, the richness values of (2) all taxa, (3) Ephemeroptera, (4) Plecoptera, (5) Trichoptera, (6) Acari, and the relative abundances of (7) Chironomidae, (8) tolerant taxa, (9) shredders, and (10) the dominant three taxa. To evaluate community responses and overall stream habitat suitability following the Angora Fire, pre- and post-fire community data were evaluated using the ES-IBI. The use of a regional reference condition reduces error associated with comparing impaired conditions to only a few local reference streams. The ES-IBI values determined from test sites can be compared with the range of reference values to designate stream condition in terms of regulatory standards (Herbst & Silldorff, 2009).

Results

Environmental variables

Relative to the 26-year precipitation mean of 117 cm, both pre- and post-fire years were drier than average

(102 cm in 2002; 79 cm in 2008; 103 cm in 2009). Precipitation data indicate that hydrologic conditions were especially similar between pre-fire and the second year following fire (data acquired from SNOwpack TELemetry stations; USDA-NRCS). Post-fire hydrology and water quality response for each site is not covered extensively here, but see Oliver et al. (2011) for additional information. Stream water discharge was consistently higher at the Below Burn site (average was 60 and 37% higher than discharge at Within Burn in 2008 and 2009, respectively), and was greater overall in the second year following fire. Physical habitat

varied between sites due to effects from the fire (i.e., canopy loss, vegetation type) as well as site-specific differences in hydrology, water quality (Table 2), and stream geomorphology (Table 3). Comparisons between sites reveal that the Within Burn site exhibited higher water temperatures ($t = 3.53$, $P < 0.01$), and lower EC ($t = -6.66$, $P < 0.001$) and pH ($t = -3.43$, $P < 0.05$) than the Below Burn site. Stream flow velocity was higher at the Below Burn site ($t = -3.32$, $P < 0.05$), especially in 2009.

Comparisons between pre- and post-fire years show dramatic differences in physical habitat characteristics

Table 2 Summary of mean water velocity and water quality measurements on Angora Creek recorded during sampling events

	Pre-fire, 2002	2008		2009	
	Within Burn	Within Burn	Below Burn	Within Burn	Below Burn
Velocity (m/s)	1.7	0.5 (± 0.4)	0.5 (± 0.3)	0.3 (± 0.1)	0.4 (± 0.1)
Temperature ($^{\circ}\text{C}$)	9.0	16.8 (± 4.0)	15.0 (± 2.8)	17.1 (± 3.2)	14.2 (± 3.5)
Conductivity ($\mu\text{S}/\text{cm}$)	51.8	28.9 (± 5.4)	51.4 (± 13.6)	32.5 (± 16.5)	66.0 (± 29.9)
pH	7.2	6.7 (± 0.3)	7.2 (± 0.2)	6.7 (± 0.2)	7.0 (± 0.2)
Dissolved oxygen (mg/L)	8.9	8.4 (± 0.5)	8.3 (± 0.2)	6.8 (± 0.1)	7.1 (± 0.3)

Values are mean \pm standard deviation. Pre-fire samples were taken only during the month of August

Table 3 Physical habitat data from pre- and post-fire physical habitat surveys

	Pre-fire, 2002	2008		2009	
	Within Burn	Within Burn	Below Burn	Within Burn	Below Burn
% Riparian cover	87.9	21.7 (± 2.6)	21.3 (± 7.1)	21.3 (± 3.2)	20.0 (± 5.0)
% Banks undercut and/or eroding	26.7	89.9 (± 4.4)	15.0 (± 4.3)	88.3 (± 3.6)	23.0 (± 4.72)
% Banks stable	93.3	10.1 (± 4.2)	85.0 (± 4.4)	11.2 (± 2.4)	77.0 (± 8.08)
<i>Substrate</i>					
% Fines (<0.06 mm)	4.0	32.8 (± 5.5)	5.8 (± 2.5)	30.8 (± 6.2)	ND
% Sand (0.06–2 mm)	25.3	32.2 (± 2.5)	43.9 (± 6.0)	ND	34.3 (± 9.3)
% Gravel (2–63 mm)	25.3	28.7 (± 1.5)	50.3 (± 8.5)	69.2 (± 6.2)	65.1 (± 9.4)
% Cobble (63–250 mm)	45.3	6.5 (± 1.5)	ND	ND	ND
<i>Substrate cover</i>					
% Algae	8.0	43.3 (± 8.0)	17.9 (± 7.5)	18.8 (± 6.3)	12.8 (± 8.2)
% Aquatic vegetation	ND	25.0 (± 6.0)	31.5 (± 6.6)	69.2 (± 12.5)	37.8 (± 10.6)
% Wood	17.3	18.6 (± 11.5)	3.3 (± 5.8)	ND	ND
% Aquatic moss	13.3	ND	12.5 (± 2.5)	6.3 (± 6.2)	ND
% Leaves	2.7	ND	ND	ND	ND
% Bare/other	4.0	13.2 (± 2.6)	39.2 (± 1.4)	12.3 (± 12.3)	41.0 (± 15.5)

For uniform comparison across years, all physical habitat data were collected during the month of August. Values are mean \pm standard deviation

ND not detected

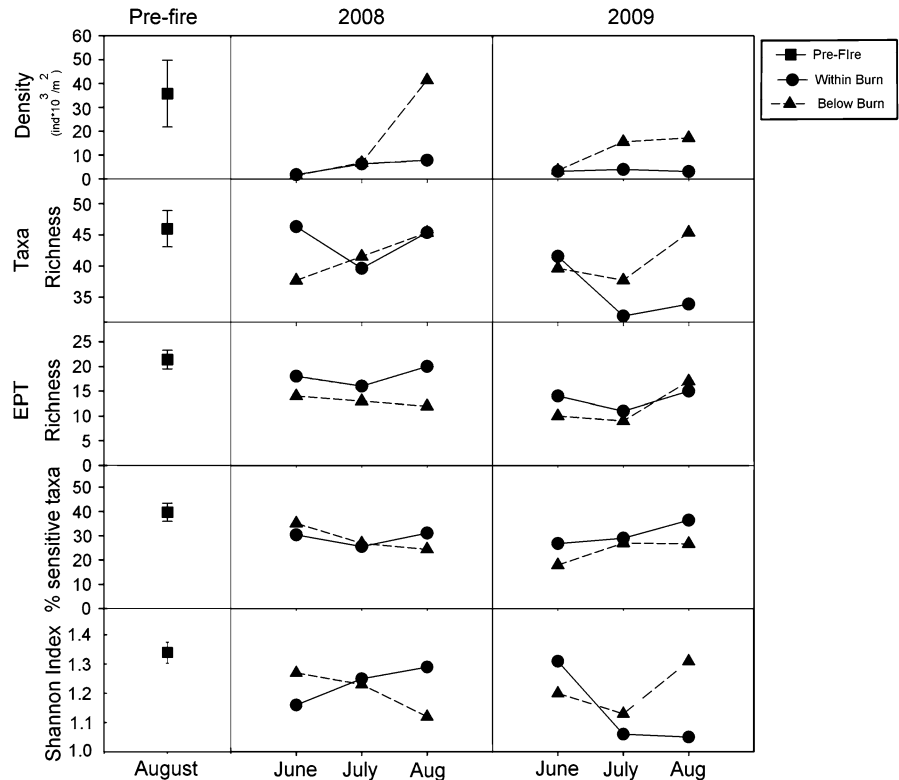
(Table 3). Riparian cover decreased at the Within Burn site from 88% to a mean of 21%, with the majority of post-fire cover consisting of burned, large woody debris within the stream channel. The geomorphology of the stream also changed following fire. In the first year post-fire (2008) the Within Burn site had largely unstable, eroding, and undercut banks, which were predominately unvegetated and lacked canopy cover. The small amount of vegetation present post-fire at the Within Burn site consisted of immature willows, grasses, and forbs. In contrast to the Within Burn site, the Below Burn stream banks were significantly more stable ($t = -21.89, P < 0.001$), with fewer undercut or eroding banks ($t = 23.79, P < 0.001$) and the canopy was composed of large conifers, mature willows, grasses, and forbs. Cobble was the most abundant substrate type at the Within Burn site in 2002, followed by gravel and sand. Following the fire, cobble was nearly absent from the Within Burn site while fine sediments greatly increased. The Below Burn site also lacked cobble substrate in 2008 and 2009, but did not have the fine sediment cover observed post-fire at the Within Burn site ($t = 10.46, P < 0.001$). Instead, gravel and sand

were the dominate substrate types, with significantly more sand at the Below Burn site than the Within Burn site ($t = -4.03, P < 0.01$). In addition, the percentage of algal and aquatic vegetation cover increased dramatically following the fire at the Within Burn site, although only the algae increase was significant ($t = 2.82, P < 0.05$).

Community comparisons

Following the fire, the average density of individuals declined at both sites, although density increased at the Below Burn site during the first post-fire August (2008) (Fig. 2). In the first year following fire, taxa richness and EPT richness at the Within Burn site were similar to pre-fire levels, however, both declined in the second year. While the difference in EPT richness in the second year post-fire was largely due to a sharp decline in the number of Plecoptera taxa, Ephemeroptera also declined. In comparison to pre-fire levels, the percentage of sensitive taxa decreased from 40 to 30% at the Within Burn site in the first year following fire and remained low for the duration of post-fire sampling.

Fig. 2 Density of individuals, total taxonomic richness, EPT richness, percent abundance of sensitive taxa, and Shannon diversity index for pre-fire (2002, within the future burn site) shown as mean and 95% confidence interval of five intervals, and following the fire (2008 and 2009) at Within Burn and Below Burn sites



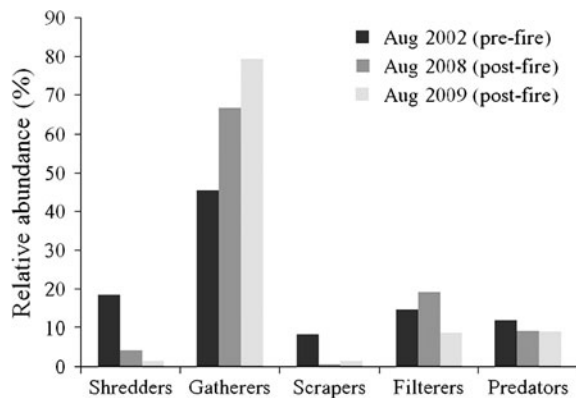


Fig. 3 Mean relative abundances of benthic macroinvertebrate functional feeding groups from Within Burn samples before (August 2002) and after (August 2008 and 2009) the Angola Fire

Comparisons of diversity and community metrics for post-fire samples showed no statistical differences between years or sites. Shannon diversity was similar for both years at each of the two sites when averaged across months, but differed when considering only August samples. Shannon diversity declined from its pre-fire value ($H' = 1.34$) in August 2008 ($H' = 1.29$) and then continued to decline in August 2009 ($H' = 1.05$).

Comparisons of pre-fire versus post-fire August samples at the Within Burn site revealed a large shift in functional feeding group composition (Fig. 3). Pre-fire samples showed a more even distribution of functional feeding groups and much higher relative abundances of shredders and scrapers than either of the post-fire years. In comparison with pre-fire samples, collector-gatherers increased following the fire by 145 and 172% in 2008 and 2009, respectively. Collector-filterers increased from pre-fire abundances by 30% in 2008, but then decreased from pre-fire levels by 58% in 2009. Shredder populations decreased following the fire, particularly in the first year (2008) when percent abundance declined 77% relative to pre-fire samples. Predator abundance was also slightly higher in pre-fire samples, and declined by about 30% in both years post-fire.

When averaged across the 3 months of each post-fire year, collector-gatherers were the dominant functional feeding group at the Within Burn site (relative abundances: 57% in 2008, 72% in 2009). The second most abundant functional feeding group was the

collector-filterer group (26% in 2008, 16% in 2009). In 2008, the remaining functional feeding groups were shredders (8%), predators (8%), and scrapers (1%). However, in the second year following fire (2009), the relative abundance of shredders and scrapers both declined to <1% while the percent abundance of predators increased slightly to 11%.

The Below Burn site was also largely composed of collector-gatherers in both years following fire when averaged across the 3 months (48% in 2008, 55% in 2009). In 2008, the Below Burn site had a greater number and more even distribution of collector-filterers (16%), scrapers (8%), shredders (8%), and predators (17%) than the Within Burn site. In 2009, scrapers and shredders decreased to <1 and 3%, respectively, while filterers increased to 26%. Predator percent abundance decreased slightly in 2009, but overall remained fairly similar across both years.

Community analysis

NMS ordination analysis of all sites and samples resulted in a 2-D solution (stress = 12.6%, instability <0.0001, $P = 0.02$). Upon examination of the resulting ordination, it appeared that two sampling dates (June & July 2008) at the Below Burn site were quite different from the other samples. Outlier analysis confirmed that these Below Burn samples were statistically different from all other samples (standard deviation > 2.0). Based on this information and the results from MRPP, physical habitat analysis, and community metrics we chose to run a separate NMS analysis examining pre-fire versus post-fire communities for all sample dates at the Within Burn site only.

NMS ordination analysis of the pre- and post-fire samples at the Within Burn site resulted in a 2-axis solution (stress = 4.83%, instability <0.0001, $P < 0.01$) with clear separation of samples in community space based on effects of fire (Axis 1) and the month of sampling (Axis 2) (Fig. 4). The ordination explained 93% of the variation in the original community matrix, with axis 1 explaining the majority of the variation in community composition among samples (axis 1 $R^2 = 0.55$, axis 2 $R^2 = 0.38$). Many environmental variables were correlated with the unburned to burned sample gradient described by Axis 1, including percent cobble ($r = -0.93$), percent leaves ($r = -0.91$), water velocity ($r = -0.91$), percent fines ($r = 0.90$), and percent aquatic vegetation ($r = 0.90$).

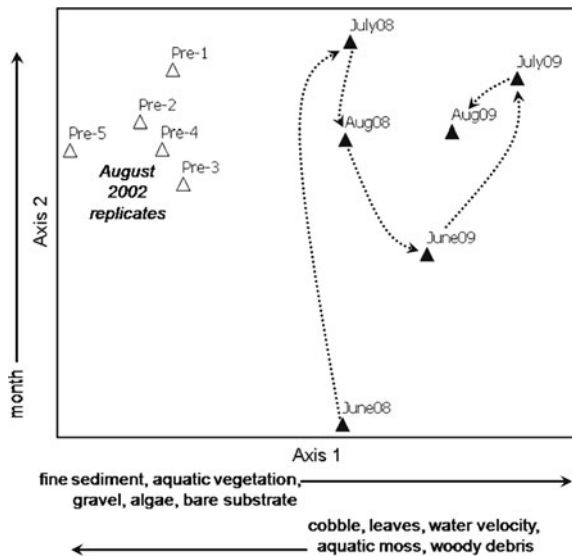


Fig. 4 NMS ordination of pre-fire versus post-fire sample community composition. *Hollow triangles* represent samples collected pre-fire, *solid triangles* indicate samples taken post-fire, and *dotted vectors* connect sequential samples post-fire. All samples shown are from the Within Burn site. *Vectors* and text below the axes indicate the environmental variables that were highly correlated with axes 1 and 2. *Vectors* pointing to increasing values along an axis represent positively correlated environmental variables, while *vectors* pointing to decreasing values along an axis represent negatively correlated environmental variables

MRPP tests revealed that BMI communities in pre- and post-fire samples were distinct from one another ($A = 0.198$; $P < 0.001$). There was no clear distinction between post-fire communities at the Within Burn and Below Burn sites ($A = 0.030$; $P = 0.066$), indicating that the fire had a larger effect on community composition than geographic or fine-scale habitat differences between the Within and Below Burn sites.

Indicator species analysis identified 22 significant ($P < 0.05$) indicators of pre-fire Within Burn samples, six significant indicators of post-fire Within Burn samples, and 1 significant ($P < 0.05$) and five marginally significant ($P < 0.1$) indicators of post-fire Below Burn samples (Table 4). Pre-fire Within Burn indicator taxa were a diverse group of mainly shredders, predators, scrapers, and gatherers, and were sensitive, intolerant taxa (mean Tolerance Value (TV) = 2.8). Post-fire Within Burn indicator taxa were much more tolerant (mean TV = 6.0) and were omnivores, gatherers, filterers, and predators. The only highly significant post-fire Below Burn indicator taxon was the omnivorous caddisfly *Micrasema* ($P < 0.05$),

while the remaining significant taxa ($P < 0.1$) were a small group of omnivores, predators, and gatherers. In general, post-fire Below Burn indicator taxa were fairly tolerant (mean TV = 5.8).

ES-IBI

The ES-IBI scores indicate a loss in biological integrity following the Angora Fire (Fig. 5). The pre-fire mean IBI score was 89.5 (SE \pm 0.8), and falls within the range of values used to designate streams as “unimpaired and acceptable” or “very good” (IBI > 80.4; Herbst & Silldorff, 2009). In the first year post-fire, the mean IBI score at the Within Burn site dropped to 67.5 (SE \pm 6.2), which is designated as “unimpaired and intermediate” or “good” (IBI 63.2–80.4). The IBI score decreased further at the Within Burn site in the second year post-fire, with a mean score of 50.6 (SE \pm 3.8), which qualifies as “impaired and partial supporting” or “poor” condition (IBI 42.2–63.2). The Below Burn site had relatively similar IBI values for both years, 58.3 (SE \pm 2.4) in the first year and 52.8 (SE \pm 12.5) in the second year. Interestingly, while the overall mean for the Below Burn site was low in the second year post-fire, the August sample did show a large increase (reaching IBI = 78), indicating that conditions in Angora Creek at the Below Burn site had improved by August 2009.

Discussion

Large disturbances, such as wildfire, are key drivers of spatial and temporal heterogeneity and can alter ecosystem state and succession trajectories (White & Pickett, 1985). The Angora Fire was a severe wildfire that resulted in altered flow regimes and increased nutrient and sediment concentrations within Angora Creek (Oliver et al., 2011). Our investigation of BMI communities and physical habitat characteristics in Angora Creek indicates that the fire also profoundly affected the stream ecosystem, shifting the structure, and function of the BMI community away from pre-fire conditions. While there were no notable trends in BMI community differences between the Within Burn and Below Burn sites, it is likely that both of these locations experienced effects from the fire, although the particular stressors at each site may have varied.

Table 4 Indicator species analysis results for pre- and post-fire Within Burn samples and post-fire Below Burn samples

Group	Species name	IV	P	FFG
Pre-fire (Within Burn)	Capniidae	100	<0.01	Shredder
	<i>Rhyacophila sibirica</i> grp.	100	<0.01	Predator
	<i>Dugesia tigrina</i>	92	<0.01	Predator
	<i>Pericoma</i>	90	<0.01	Gatherer
	<i>Yoraperla</i>	87	<0.01	Shredder
	<i>Stempellinella</i>	87	<0.01	Gatherer
	<i>Aturus</i>	81	<0.01	Predator
	<i>Malenka</i>	80	<0.01	Shredder
	<i>Cultus</i>	80	<0.01	Predator
	<i>Anagapetus</i>	80	<0.01	Scraper
	<i>Heteroplectron californicum</i>	80	<0.01	Shredder
	<i>Rhyacophila betteni</i>	80	<0.01	Predator
	<i>Feltria</i>	80	<0.01	Predator
	<i>Cinygmula</i>	80	0.01	Scraper
	<i>Zapada</i>	75	<0.01	Shredder
	<i>Stempellina</i>	74	0.01	Gatherer
	<i>Tvetenia bavarica</i>	71	0.01	Gatherer
	<i>Paraleptophlebia</i>	67	<0.01	Gatherer
	<i>Bezzia-Palpomyia</i>	61	<0.01	Predator
	Post-fire (Within Burn)	<i>Cinygma</i>	60	0.02
<i>Dolophilodes</i>		60	0.02	Filterer
<i>Dipheter hageni</i>		58	0.04	Gatherer
<i>Rheocricotopus</i>		85	<0.01	Omnivore
<i>Thienemanniella cf. xena</i>		83	<0.01	Gatherer
<i>Pisidium</i>		80	<0.01	Filterer
<i>Eukiefferiella claripennis</i>		67	0.02	Omnivore
Post-fire (Below Burn)	<i>Isoperla</i>	59	0.04	Predator
	<i>Simulium</i>	56	0.05	Filterer
	<i>Micrasema</i>	75	<0.01	Omnivore
	<i>Parametrioctenus</i>	58	0.07	Gatherer
	<i>Lebertia</i>	53	0.06	Predator
	<i>Narpus concolor</i>	50	0.07	Gatherer
	<i>Eukiefferiella brevicalar</i> grp.	50	0.07	Omnivore
	<i>Larsia</i>	45	0.06	Predator

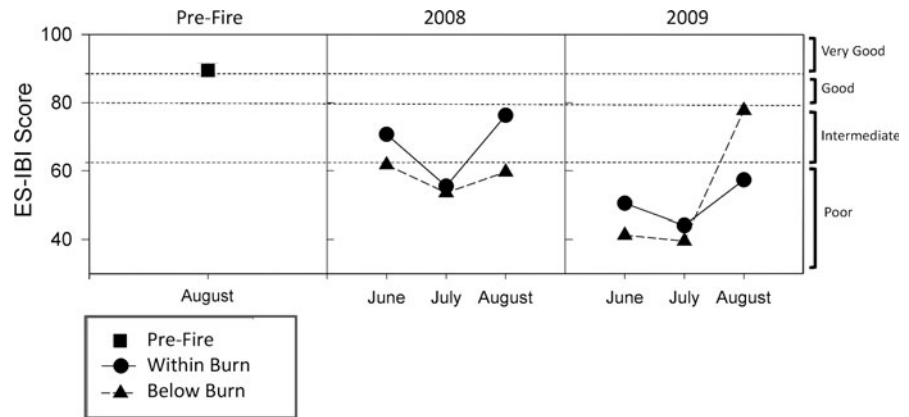
IV indicator value,
P significance of IV, FFG
functional feeding group

For example, as a result of the lower elevation within the watershed and local soil characteristics, substrate at the Below Burn site was sandier, and its position below the burned urbanized area resulted in higher stream flow, colder temperatures, and more impaired post-fire water quality conditions in comparison to the Within Burn site (see Oliver et al., 2011). The differences between the two sites emphasize the need for careful site selection as the Below Burn site likely experienced a combination of effects from different

habitat characteristics, as well as upstream fire and urban effects.

The Angora Fire resulted in large changes to the physical habitat of Angora Creek, which were reflected in shifts in BMI community composition away from pre-fire values. Although the Angora Fire severely burned a large extent of the watershed area, the first year following the fire had low precipitation (79 cm, relative to the 26-year average of 117 cm), whereas the second year following fire had higher

Fig. 5 Eastern ES-IBI scores for Within Burn and Below Burn sites. *Dotted lines* represent thresholds for various levels of stream ecosystem condition



precipitation (103 cm) and stream discharge, and resulted in a higher amount of sediment transport (Oliver et al., 2011). In comparison to pre-fire conditions, temperatures were also higher in Angora Creek as a result of both lower summer stream flow and canopy loss leading to greater solar insolation. These factors increase stress to certain taxonomic groups and can shift abundances within the BMI community. We observed declines in density and percentage of sensitive species immediately following the fire, and declines in Shannon diversity and EPT taxa richness in the second year following the fire, which were likely a result of the higher discharge and sediment loads in that year. These findings are corroborated by numerous other studies that have documented short-term decreases in BMI density, taxa richness, and diversity following severe wildfire and hydrological disturbance (e.g., Roby & Azuma, 1995; Earl & Blinn, 2003; Hall & Lombardozzi, 2008). However, our study demonstrates that significant changes in BMI communities can be observed even without large post-fire flooding and also that these effects can be transmitted downstream to unburned reaches.

Notable short-term changes in the relative abundances of functional feeding groups following the fire further indicated shifts in the availability of resources and habitat. Community composition became increasingly dominated by opportunistic taxa with strong larval dispersal capable of exploiting a variety of feeding strategies over a wide range of aquatic conditions. The most abundant of these taxa were gatherers, opportunistic omnivores that feed using a variety of methods. More specialized feeders, such as

shredders and scrapers, decreased in abundance. These observations are consistent with previous studies where fire effects were shown to alter functional feeding group abundances and favor community dominance by trophic generalists (Mihuc & Minshall, 1995; Minshall et al., 2001a; Vieira et al., 2004). These results also support general predictions about functional feeding groups, which suggest that shredders will respond to the loss of riparian canopy.

In contrast to previous observations where increased light availability and nutrient flux following canopy loss tended to favor periphyton growth, and thus increase scraper abundances (Minshall et al., 2001c), we observed a severe decline in scraper abundance in Angora Creek for both years following the fire. The increase in fine sediment deposition following the fire may have inhibited periphyton growth necessary to support higher scraper abundances. The abundance of filterer groups also declined in the second year following fire. While filterers are also considered generalist feeders, these groups tend to have more specific food source requirements, and require adequate flows for transporting food sources (Hawkins & Sedell, 1981). In addition, detritus particle size may also play a role in supporting the abundance of certain filterer taxa (Drake, 1984). Increased stream flow has the capacity to transport larger particle sizes, therefore detritus dynamics in the second year following fire may have been less favorable for filterer groups than conditions during the lower-flow year immediately following fire. Alternatively, higher snowpack and a larger volume of snowmelt flushing in the second year may have depleted the standing stock of suitable detritus early in

the season (Stubblefield et al., 2007) resulting in a deficit of food resources for filterers later in the summer.

Changes in BMI community composition result from the interaction of species, species traits, environmental variables, and hydrologic conditions (e.g., Townsend, 1989; Poff, 1997). Ordination and MRPP tests of Angora Creek community samples illustrated that post-fire communities were very distinct from pre-fire communities at the Within Burn site, despite significant seasonal variability in post-fire samples. In addition, the trajectory of BMI communities following the fire continued to diverge from pre-fire configurations along NMS axis 1 until August 2009, the second year after the fire. Habitat factors that were strongly correlated with this shift in community structure (e.g., reduced cobble and woody debris cover, increased fine substrate and algae cover) imply that Angora Creek was still experiencing indirect effects from the fire after 2 years. The continued divergence of the BMI community from pre-fire conditions and deteriorating in-stream biotic conditions indicate that the resilience of BMI communities to environmental stress in Angora Creek may have declined further in the second year, although that decline may have begun to reverse during our last sampling period (August 2009). Longer-term studies have observed that in small streams with well-managed and intact watersheds, divergence from pre-fire conditions may persist from 1 to 10 years, and high within-year variability may continue for an unknown (>15 years) length of time (Roby & Azuma, 1995; Mihuc et al., 1996; Minshall et al., 2001b, c). We report significant community changes for at least 2 years following the Angora fire, but further sampling is needed to determine if recovery indeed began in August 2009.

Numerous individual species contributed to the strong community distinction between pre- and post-fire samples at the Within Burn site. Perhaps unsurprisingly, many of the 22 pre-fire indicator taxa are sensitive EPT species including a number of shredders such as the stoneflies *Yoraperla*, *Malenka*, *Zapada*, and Capniidae, and the caddisfly *Heteroplectron californicum*. Thus, shredder stoneflies appear to be especially sensitive to wildfire-driven stream disturbance. Nemourid stoneflies, such as *Malenka* and *Zapada*, were eliminated from a New Mexico stream following a severe wildfire and post-fire floods, and remained rare for at least several more years despite

the abatement of severe floods (Vieira et al., 2004). At Angora Creek, only six taxa were indicative of post-fire Within Burn samples, including three midge taxa (Chironomidae) and the blackfly *Simulium*; none of these taxa were shredders or scrapers, but rather were omnivores, gatherers, filterers, and predators. Both midges and blackflies have been previously identified as opportunistic taxa that can reach quite high densities immediately following riparian wildfires (both taxa: Vieira et al., 2004; midges: Mihuc et al., 1996; Minshall et al., 2001c) and these increased densities may last for several years (Malison & Baxter, 2010). However, unlike previous studies where increased predator populations were associated with increased productivity and density of primary consumers such as Chironomidae and *Simulium* (Malison & Baxter, 2010), we observed only a slight increase in predator populations in the second year following fire. The only sensitive post-fire indicator taxon at Angora Creek was the stonefly *Isoperla*. Vieira et al. (2004) noted that although *Isoperla* abundance was severely reduced immediately following fire, they were prominent community members soon after post-fire floods abated. Since Angora Creek did not experience significant flooding immediately following the fire, perhaps *Isoperla* was able to establish much quicker in the post-fire Within Burn reach.

The decline in the ES-IBI of Angora Creek over the 2 years following the Angora Fire indicated that, in comparison to pre-fire conditions, Angora Creek exhibited degraded conditions and reduced biological integrity. While we acknowledge that local reference sites can sometimes provide useful information for comparisons, they can also be problematic due to particular differences between sites that limit extrapolation and the ability to calculate variance estimates (Reynoldson et al., 1995). In this analysis, changes at Angora Creek were compared both to the state of the stream before fire, and to regional reference streams that represent a variety of habitat types, encompassing the range of variations expected for least-impaired reference conditions in the region. While certain individual metrics of community composition indicate deviation from pre-fire conditions, and in some cases high variability between months and years, overall the average values of individual metrics were not statistically different from 2008 to 2009. The large decrease from the pre-fire ES-IBI scores and seasonal changes in 2008–2009 indicates that the multi-metric index

may be more informative about recovery than single metrics.

Changes in environmental conditions and resource availability within a stream following wildfire can be highly variable due to inherent differences between individual streams and watersheds (Vieira et al., 2004; Pettit & Naiman, 2007; Jackson et al., 2009). In general, larger effects tend to be observed in small, first-order streams, similar to Angora Creek (Minshall et al., 2001b, c; Hall & Lombardozzi, 2008). This study provides information on the short-term effects of a severe fire on high-elevation aquatic benthic macroinvertebrates in the context of low precipitation years. While we acknowledge the short-term nature of our study, it does represent an important snapshot of post-fire conditions and initial recovery, or lack thereof, in the first 2 years following the severe Angora fire. We demonstrate that post-fire BMI communities and physical habitat can shift dramatically from pre-fire conditions despite the lack of post-fire flooding disturbance, which is often determined to be the primary driver of post-fire biotic community responses. Since wildfire often occurs suddenly and without warning, researchers should design studies that can be rapidly implemented to track community responses to these unpredictable events (e.g., Lindenmayer et al., 2010) within and below burned areas and should utilize multi-metrics like indices of biological integrity when available. To effectively reintroduce wildfire as a natural process to Sierra Nevada ecosystems, it is necessary to consider the potential short- and long-term effects of fire on high-elevation headwater streams and the impact of these events on the overall resilience and recovery of aquatic ecosystems.

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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 whirlpaks.

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 macroinvertebrates, 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 stream's 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 provided 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 against 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 (PO₄). 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 %

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 material 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.

Whirlpicks - 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