BIOL340: Ecology Lab Manual

Daniel J. Hocking

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Contents

Course Information

Instructor

Dr. Daniel Hocking, Compton 309, djhocking@frostburg.edu, 301-687-4343

Meeting Times and Locations

Lecture: Tuesday/Thursday 8:00-8:50 am; Compton 327

Laboratory:

- Section 1: Tuesday 2:00-5:50 pm; Compton 321
- Section 2: Wednesday 8:00-11:50 am; Compton 321

Office Hours: Compton 309; Monday 10:00-11:00 am, Tuesday & Thursday 9:00-10:30 am, Wednesday 3:00-4:00 pm, or by appointment

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Description

Environmental relationships of plants and animals. Field laboratory experience. Measuring environmental variables in terrestrial and aquatic ecosystems. Two hrs. lecture, one 4-hr. lab. Every semester.

Prerequisites

BIOL 150, 160 or 161; CHEM 202 (or CHEM 201 and permission of the instructor); MATH 109/209.

Learning Outcomes

The primary objective of the lab section is to provide you with experience collecting real, relevant ecological data. Specifically you will:

1. become familiar with ecological data collection for various taxa and in a variety of ecosystems.
2. be able to analyze data and interpret results.
3. practice and improve writtn and oral communication skills.

Grades:

Task	Pct	Grade
Lecture Exams	45%	A $>= 90\%$
Homework, quizzes, & In-class work	10%	B $= 80 - 89\%$
Final Exam, comprehensive	20%	C $= 70 - 79\%$
Lab Reports	25%	D $= 60 - 69\%$
		F $< 60\%$

Total points, percentages, and assignments may change to accommodate teaching and learning parameters. Grades are still based on percentage of total points. Grades from individual assignments will be posted on blackboard; **however, the grade calculated by blackboard could be incorrect because of differences in weighting of assignments**. It is your responsibility to calculate your current grade based on the grading scheme described above.

Extra Credit

Extra credit may total up to 10% on your lowest exam grade (except the final).

- Species of the week (1 pt per approved submission - see below)
- Diving vans for field trips (1 pt for training/registration + 1 pt per trip driving)

Species of the Week

Over the course of the semester (no more than one submision per week), each student may upload to blackboard a description of the ecology and life history of a species observed in the wild. This can be any wild plant or animal but must be positively identified to species (non-native species and planted trees count but not planted flowers). The description and location of the sighting should be included. No animals should be disturbed or handled for this assignment. Additional instructions on uploading will be provided in lab. Once a species has been reported, another member of class may not receive credit for it. The description of the ecology and life history must be a minimum of 1 page, single-spaced with 12 pt font and 1 inch margins. Students will receive 1 pt for each approved submission up to a total maximum of 10.

Expectation of Student Work

Student work is defined as assignments, homework, and other academic activities to be completed outside of instructional time, including reading, studying, writing, research etc. Students should expect to spend a minimum of two hours per week completing this work for each credit hour enrolled (thus 6 hours of work outside of class for a 3-credit course), although the time spent outside of class may increase based on the topic and level of the course.

Late Policy: Assignments turned in after the due date will lose 10% per day for a maximum of 3 days, after which they will not be accepted and will receive a zero. Assignments turned in at any point after the time due (even 1 minute late) will lose a minimum of 10%. This excludes quizzes, in-class assignments, in-lab activities, exams, and presentations, which can not be turned in late or made up without prior arrangement with the instructor for extremely extenuating circumstances.

General Laboratory Information

Labs are an opportunity to gain hands-on experience with ecological techniques and gain a greater appreciation of the scientific process. Lab assignments will help guide you through the development of ecological

questions, formation of hypotheses, and design of ecological studies. Studies will be conducted in the field or via computer simulation. Students will learn and be expected to use appropriate statistical techniques along with data visualizations (e.g. figures/plots/graphs) to summarize the data and test the hypotheses. Some labs will require full reports (intro, methods, results, dicussion, literature cited) but most will just require answering a series of questions to help guide inference and understanding of the results.

Please note that many of our labs will be conducted at local field sites. These labs will be conducted outside so you are expected to use common sense in deciding what to wear and what to bring. You will get dirty and you will get wet during these labs. Be prepared to spend 4 hours in areas without restrooms, if you have questions about outdoor restroom etiquette please consult leave-no-trace (lnt) principles: http://www.lnt.org/training/educationaltraining.php, http://lnt.org/training/OnlineCourse/ or ask the instructor if you have specific questions. You must notify the instructor during the first week of class if you are allergic to bees or have never been stung by a bee. Refer to the safety 1 section for additional information.

Course Topics and Schedule

The laboratory schedule is flexible based on previous lab timing and weather. We will often go out in the field during inclement weather as long as it does not result in undue risk of injury. Thus, come to all labs prepared to go out in the field and get wet and dirty. More about the lab schedule will be provided during your lab section. Below is a tentative laboratory schedule.

Week	Activity	Assignment Due
1	No Lab	
2	Set up population and competition experiments	
3	Questions, Hypotheses from 3 scientific papers	
4	Sampling	Qs & Hypotheses
5	Excel, graphics, and statistics	Sampling lab
6	Cemetery demographics	Excel & Stats
7	Food Webs	Cemetery lab
8	*SPRING BREAK* - no classes	
9	Ant distributions	
10	Forest stand dynamics	Forest stand reading
11	No Lab - Count Beetles	Forest lab
12	Sampling invertebrates	
13	Invertebrate diversity; Radishes	
14	Turtle Mark-Recapture	Diversity lab
15	Beetle populations	Raddish comp lab

Important dates and information

- February 2: Last day to add/drop courses
- February 16: Last day to file pass/fail option
- April 6: last day to withdraw with a "W"
- May 15: Last day of classes
- **Friday May 18: Final Exam, 2:30 - 5:00 pm, Compton 327**
- Email and Blackboard: access to your email and Blackboard is required for this class. Check your email daily.

Attendance

If you miss class, you miss whatever quizzes, exams, or activities that were administered and you will receive a zero. Attendance is critical to success. Makeup exams are extremely rare, and will likely be a different format from the original exam. However, you will be allowed to make up missed exams if you have a documented, excused absence. Additionally, if the absence was planned, you must notify me before the absence.

Attendance is required for all laboratory sessions. You will receive a zero for any work associated with that lab. Additionally, any assignments due in lab that day will be late. *If you show up late to lab and miss the van, it will be considered an absence. The van will not wait for anyone.* For indoor labs, arriving more than 15 minutes late will count as an absence, but you will be able to participate for half credit in any activities associated with the lab.

Documented excused absences are generally limited to the following examples: university sanctioned events (field trips, or events where the student is an athlete/performer), funerals (requires an obituary or other proof), or illness/medical emergencies (requires a doctor's note or other proof). For all of these, documentation must be provided. If a student is participating in extracurricular activities or has an excused absence, I must be notified within one week to arrange makeup assignments.

If you have an unexcused absence, you do not need to contact me. Common examples of unexcused absences are "family emergencies", "car trouble", and "my ride is leaving early this week." While you may deem these as legitimate excuses, accepting them as excusable absences and allowing students to make up work will only encourage widespread abuse. Makeups of any kind are not allowed for unexcused absences.

Class Policies

There will be no cell phones on the desk or in lab. There will be no use of laptops unless prior consent is obtained for special circumstances. You may not eat food or use tobacco products including electronic cigarettes in class or labs. Disruptive behavior (using phones, talking, etc.): I will kick you out if I think you are being disruptive.

"The University will not tolerate disorderly or disruptive conduct which substantially threatens, harms, or interferes with university personnel or orderly university processes and functions. A faculty member may require a student to leave the classroom when his/her behavior disrupts the learning environment of the class. A student found responsible for disruptive behavior in the classroom may be administratively withdrawn from the course."

Beacon Early Warning System: all students should have a network of people who will support them in their educational journey. For that reason, the University uses a system known as Beacon, whereby your instructors and coaches, if applicable, can post notices about your academic behavior. For instance, if you are absent repeatedly from a class or are not completing assignments, your instructor may post a notice on Beacon. That information may be shared with your other instructors and/or your athletic coach. I will be monitoring notices posted on Beacon so that you and I may address any issues before they become obstacles to your academic success.

Confidentiality and Mandatory Reporting

Frostburg State University and its faculty are committed to maintaining a safe learning environment and supporting survivors of violence. To meet this commitment and comply with federal and state law, FSU requires all faculty and staff (other than the confidential employees in CAPS and Brady Health) to report any instances of gender-based harassment, sexual misconduct, relationship violence, or stalking against students. This means if you share your or another FSU student's experience with gender-based harassment, sexual misconduct, relationship violence, or, stalking, I have a duty to report the information to the University's Title

IX Coordinator. The only exception to my reporting obligation is when such incidents are communicated during class discussion, as part of an assignment for a class, or as part of a University-approved research project.

Faculty and staff are also obligated to report allegations of child abuse and neglect to University Police and to Child Protective Services. This obligation extends to disclosures of past abuse even if the victim is now an adult and the abuser is deceased. My duty to report suspected child abuse and neglect extends to disclosures that are made as part of classroom discussions and in writing assignments.

If you or someone you know has experienced an incident of harassment or violence, please go to www.frostburg.edu/titleix to find information on reporting options and the resources and services available for support.

Academic Honesty

Definition of Academic Dishonesty from your student handbook: "Academic dishonesty is defined to include any form of cheating and/or plagiarism. Cheating includes, but is not limited to, such acts as stealing or altering testing instruments; falsifying the identity of persons for any academic purpose; offering, giving or receiving unauthorized assistance on an examination, quiz or other written or oral material in a course; or falsifying information on any type of academic record. Plagiarism is the presentation of written or oral material in a manner which conceals the true source of documentary material; or the presentation of materials which uses hypotheses, conclusions, evidence, data or the like, in a way that the student appears to have done work which he/she did not, in fact, do. In cases involving academic dishonesty, a failing grade or a grade of zero (0) for either an assignment and/or a course may be administered. Students who are expelled or suspended for reasons of academic dishonesty are not admissible to other institutions within the University System of Maryland. Suspension or expulsion for academic dishonesty is noted on a student's academic transcript."

Any violation of academic honesty will result in a zero for that graded work, and a repeat violation will result in failure of the course. Cheating will be reported and further disciplinary action may be pursued by the University Judicial Board This includes plagiarism. I will check long answers, essays, and lab reports with plagiarism-checking software. When in doubt, just cite the source. There's nothing wrong with building on somone else's ideas, in fact it's the way progress in made in science. Just give that person credit.

Persons with Disabilities

Frostburg State University is committed to providing equal educational opportunities for students with documented disabilities. Students who require disability serves or reasonable accommodations must identify themselves as having a disability and provide current diagnostic documentation to Disability Support Services. All information is confidential. Please call 4483 or visit 150 Pullen Hall for more information.

Chapter 1

Biology Field Safety Regulations

Basic Safety Rules

General Field Safety

1. Safety is paramount. A student who willfully endangers the safety and welfare of him/herself or another will be required to leave the field and return home at the student's own expense.
2. Footwear: Closed-toe shoes and boots with a good sole are essential in avoiding accidents and falls. Be prepared to walk off of trails and encounter slippery conditions. Watch before you step.
3. Clothing: Students are required to be prepared for outside conditions, including raingear, warm coats and clothing, hats, and gloves.
4. Additional equipment: Insect repellant and hand sanitizer are beneficial additions to any field bag.
5. Field participants will take part in activities of the field trip group or one of the field trip subgroups at all times. You are not allowed to leave the group at any point.
6. Fieldtrip leaders will make the final decision on whether any proposed activity is appropriate or not, and participants will abide by that decision.
7. When students return from a fieldtrip, each person will be responsible for helping to clean the equipment and return it to its proper spot in the storeroom.
8. All accidents must be reported to the instructor or supervisor.

Field Hazards

1. Bees and other stinging creatures may be encountered during field experiences. If you are allergic to bees, it is your responsibility to notify the instructor of the course during the first week of the course. If you have never been stung by a bee before, you must also notify the instructor of the course during the first week of the course. If you require the use of an epi-pen you must bring your own prescription pen and self-administer the medicine in case of a bee sting.
2. Poisonous plants: eastern poison ivy and poison sumac are both native and naturally occurring in the area and may cause adverse reactions. Please be aware that you may encounter poisonous plants.
3. Do not consume any part of any plant or fungi material during laboratory activities. Doing so, even if you are aware of the species, is not safe.

4. Animals: venomous snakes and other hazardous animals are present in the field. Please be aware of your surroundings, stay together as a group, and do not handle animals of any kind.

Alcohol and Drugs

1. All fieldtrips and field labs are tobacco-free, no dipping, chewing or smoking in vans or in the field.
2. All fieldtrips and field labs are "dry" and drug-free. This means that students who go on fieldtrips agree not to consume alcoholic beverages of any kind or to use illegal substances for the duration of the fieldtrip, including during the evenings. A student or students violating this rule will be required to leave the field trip and return home at the student's own expense.
3. Drinks containing any percentage of alcohol are considered alcoholic beverages.

Vehicle Use

1. All students who operate vans for fieldtrip activities must be recognized by the college as qualified drivers. Qualification to operate vans for college-sanctioned events does not, however, give any individual the right to drive a van. The field trip leader will use his/her discretion in deciding which qualified students will drive the vans.
2. The field trip leader will hold all van keys during off hours, and students will not normally be permitted to drive the vans if not accompanied by the field trip leader.
3. When more than 1 van is used on a fieldtrip vans are required to stay together while traveling to and from destinations.

4. Students will not be permitted to sleep in the vans during the night, nor will students be allowed to prepare food or eat meals in the vans.

In Case of Illness or Health Emergency

1. If a student is injured, becomes ill, faints or has a seizure, carefully move them to the ground or keep them on the ground until emergency help arrives. The instructor must stay with the student while someone else calls 911 and Campus Police (301-687-4222) for emergency assistance or gets help to do so from a faculty member, lab manager or administrative assistant.

2. Keep the student prone and calm until help arrives. Do not give them anything to eat or drink.
3. Do not administer first aid unless trained to do so or get the help of someone who is trained in First Aid.

4. Report the incident to the Chair of the Department and complete an incident report.

Students' Responsibility Statement

I, the undersigned, have received a copy of the Field Safety Procedures. These safety procedures were explained to my satisfaction. I have been notified by the instructor on proper field attire and the hazards of field exercises I agree to follow these field safety regulations as require by this course. I understand that failure to follow these regulations can result in my dismissal from the field and will have a negative impact on my grade for this course.

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Signature _____

Print Name _____

Date _____

Course and Section _____

Safety Instructor _____
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In case of an accident, name, address and telephone numbers of who should be notified. (Optional)

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Chapter 2

Introduction: From Observation to Experimentation

Research is to see what everybody else has seen, and to think what nobody else has thought. - Arthur Schopenhauer

An important part of any science, and ecology in particular, is the creative process of turning observations into hypotheses.

2.1 Active Group Observation

If weather is acceptable, go outside and make observations as a group and discuss the process of turning these into ecological questions and testable hypotheses. If poor weather conditions, use photographs to demonstrate observations and the process.

2.2 Hypotheses

Discuss strong vs weak hypotheses with examples.

2.3 Observations

Walk then sit quietly for 10-15 minutes. Write down ecological observations. If the weather isn't suitable, have students think about patterns of species abundances or distributions they've previously noticed and develop questions from those.

Share some observations.

Turn at least 1 observation into a (strong) hypothesis.

2.4   Observation: Starting the Process of Ecological Study

1._____

2._____

3._____

4._____

5._____

6._____

7._____

8._____

9._____

10._____

11._____

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24._____

25._____

26._____

27._____

28._____

29._____

30._____

2.4.1   Hypothesis

Hypothesis 1.

Null:

Alternative:

Hypothesis 2.

Null:

Alternative:

Hypothesis 3.

Null:

Alternative:

2.4.2   Research Design

2.5   Homework

Read three scientific papers from the journal *Ecology* and write down the questions/objectives and hypotheses tested in each paper. Include citations for the papers in the format used in the journal *Ecology*. This will be due in class next week and should be typed and printed out. Regardless of "printer issues" it will be considered late if not submitted at the start of class.

Chapter 3

Data Organization in Spreadsheets

Authors:**Christie Bahlai**, **Aleksandra Pawlik**

Good data organization is the foundation of your research project. Most researchers have data or do data entry in spreadsheets. Spreadsheet programs are very useful graphical interfaces for designing data tables and handling very basic data quality control functions.

3.0.1 Spreadsheet outline

In this lesson, we're going to talk about:

- Good data entry practices - formatting data tables in spreadsheets
- How to avoid common formatting mistakes
- Dates as data - beware!
- Basic quality control and data manipulation in spreadsheets
- Exporting data from spreadsheets

Overall good data practices

Spreadsheets are good for data entry. Therefore we have a lot of data in spreadsheets. Much of your time as a researcher will be spent in this 'data wrangling' stage. It's not the most fun, but it's necessary. We'll teach you how to think about data organization and some practices for more effective data wrangling.

3.0.2 What this lesson will not teach you

- How to do *statistics* in a spreadsheet
- How to do *plotting* in a spreadsheet
- How to *write code* in spreadsheet programs

If you're looking to do this, a good reference is Head First Excel, published by O'Reilly

3.0.3 Why aren't we teaching data analysis in spreadsheets

- Data analysis in spreadsheets usually requires a lot of manual work. If you want to change a parameter or run an analysis with a new dataset, you usually have to redo everything by hand. (We do know that you can create macros, but see the next point.)

- It is also difficult to track or reproduce statistical or plotting analyses done in spreadsheet programs when you want to go back to your work or someone asks for details of your analysis.

3.0.4   Spreadsheet programs

Many spreadsheet programs are available. Since most participants utilize Excel as their primary spreadsheet program, this lesson will make use of Excel examples.

A free spreadsheet program that can also be used is LibreOffice

Commands may differ a bit between programs, but the general idea is the same. Spreadsheets encompass a lot of the things we need to be able to do as researchers. We can use them for:

- Data entry
- Organizing data
- Subsetting and sorting data
- Statistics
- Plotting

We do a lot of different operations in spreadsheets. What kind of operations do you do in spreadsheets? Which ones do you think spreadsheets are good for?

3.1   Problems with Spreadsheets

Spreadsheets are good for data entry, but in reality we tend to use spreadsheet programs for much more than data entry. We use them to create data tables for publications, to generate summary statistics, and make figures.

Generating tables for publications in a spreadsheet is not optimal - often, when formatting a data table for publication, we're reporting key summary statistics in a way that is not really meant to be read as data, and often involves special formatting (merging cells, creating borders, making it pretty). We advise you to do this sort of operation within your document editing software.

The latter two applications, generating statistics and figures, should be used with caution: because of the graphical, drag and drop nature of spreadsheet programs, it can be very difficult, if not impossible, to replicate your steps (much less retrace anyone else's), particularly if your stats or figures require you to do more complex calculations. Furthermore, in doing calculations in a spreadsheet, it's easy to accidentally apply a slightly different formula to multiple adjacent cells. When using a command-line based statistics program like R or SAS, it's practically impossible to apply a calculation to one observation in your dataset but not another unless you're doing it on purpose.

3.1.1   Using Spreadsheets for Data Entry and Cleaning

However, there are circumstances where you might want to use a spreadsheet program to produce "quick and dirty" calculations or figures, and some of these features can be used in data cleaning, prior to importation into a statistical analysis program. We will show you how to use some features of spreadsheet programs to check your data quality along the way and produce preliminary summary statistics.

In this lesson, we will assume that you are most likely using Excel as your primary spreadsheet program - there are others (gnumeric, Calc from OpenOffice), and their functionality is similar, but Excel seems to be the program most used by biologists and ecologists.

In this lesson we're going to talk about:

1. Formatting data tables in spreadsheets

   2. Formatting problems
   3. Dates as data
   4. Quality control
   5. Exporting data

3.2 Activity

Go through the lessons on the Data Carpentry Spreadsheet website: http://www.datacarpentry.org/ spreadsheet-ecology-lesson/ and reorganize the test data they provide. I will come around and answer questions and then we will regroup to discuss the challenges, issues, and best practices when organizing data in spreadsheets.

Chapter 4

Introduction to Scientific Thinking and Statistics in Ecology

Adapted from:

Taylor, J. 2008. Appendix A: A Primary of Biometry. Ecology Laboratory Manual. University of New Hampshire.

4.1 Introduction to Statistics

To do science is to describe and explain nature through observation. In ecology, most of these observations are quantitative. They are either measurements (e.g. temperature, pH, mass) or counts (e.g. number of individuals in a population). Unfortunately, quantitative phenomena are highly variable, as two observations are rarely identical. We even use "variable" as a synonym for the ecological attirbutes we measure. Therefore, in order to describe nature, we must find ways to describe and expalin the variation we observe. Similarly, we only sample nature so we need to use statistics to test hypotheses if we want our inferences to be relevant to populations rather than just to the specific samples we took.

4.2 Describing Central Tendancy and Variation

The first step in describing observations or samples is to summarize them by reducing many individual observations to one or two statistics that describe the original observations without listing all of them. The simplest **descriptive statistics** is the **mean** (sometimes call the average). The mean is defined as

$$\bar{X} = \frac{\Sigma X_i}{n}$$

where ΣX_i is the sum of all observations and n is the total number of observations.

The mean can reduce many observations into a single number for descriptive or comparative purposes. However, the mean does not describe the amount of **variation** among observations. It is possible for two different groups of observations to have the same mean, but different amounts of variation. Consider Figure 4.1, which shows two normal curves with the same mean(5), but with different variances.

Note that in the sample with less variation (the taller, narrower one), most of the observationsare close to the mean, while in the sample with more variation, there are more observations at greater distances from the mean. This provideds a clue about ways to measure variation: Find a statistics that summarized distances
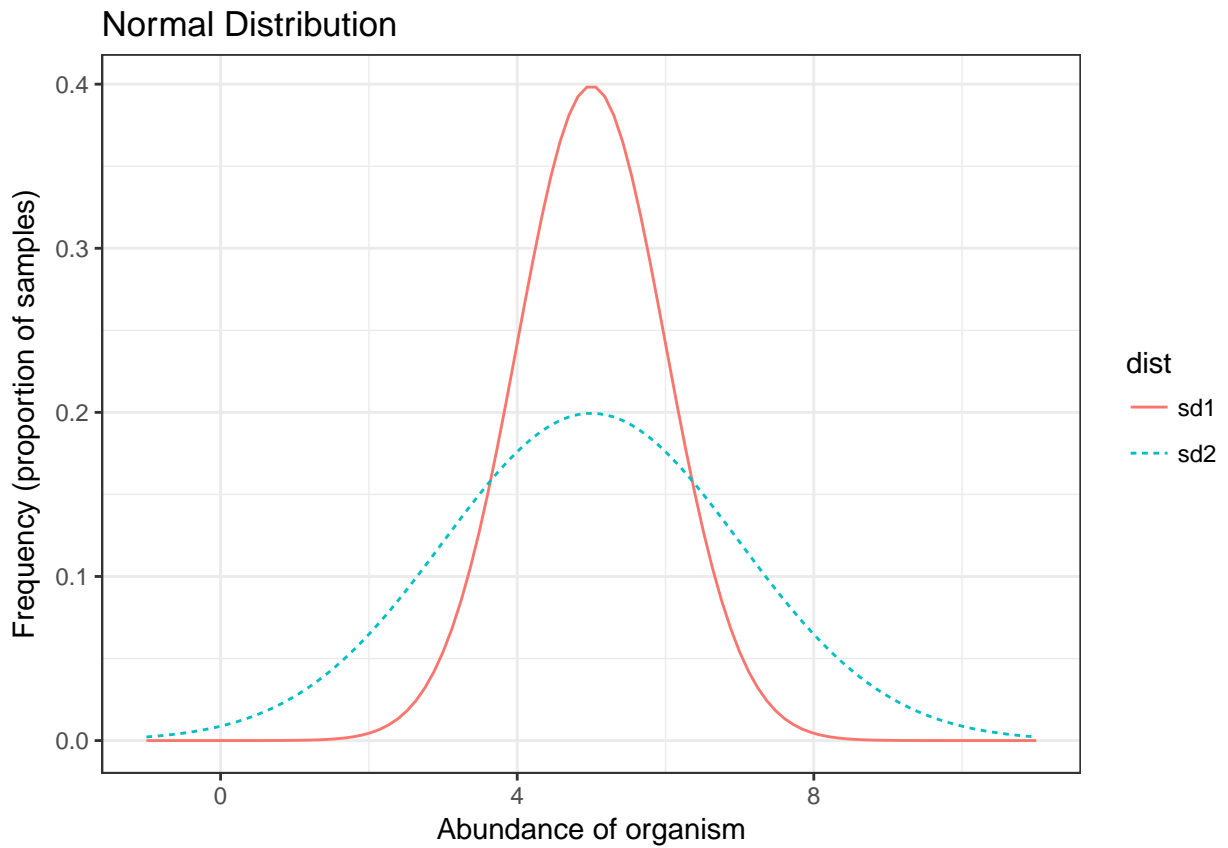
Figure 4.1: Two curves with equal means (5), but unequal variances. The higher, narrower curve has a variance of 1, while the broader, flatter curve has a variance of 2

from the mean to all the observations. Distance from the mean is simply $x_i - \bar{X}$, where x_i represents any one observation and $bar X$ represents the mean of all the observations. Distance from the mean tells us how deviant a single observation is. To summarize all thedistances into an estimate of variability, we calculate the **variance**, which is the average squared distance from the mean. To calculate variance, subtract the mean from each observation:

$$x_i - \bar{X}$$

Square each deviation (This removes negative distances):

$$(x_i - \bar{X})^2$$

Sum the squared deviations:

$$\sum (x_i - \bar{X})^2$$

Find the average of the squared deviations. When taking an average we typically divide by n, the number of observations. In this case, however, we calculate the average by dividing by $n-1$ instead of n. This corrects for a bias caused by sampling only a few of all possible observations. If we observed all members, then it is apprpriate to divide by n.

$$\frac{\sum (x_i - \bar{X})^2}{n - 1}$$

The average of all the squared deviations is also known as the variance, and it is traditionally reresented by σ^2. The variance is a very important descriptor of ecological variation: The greater the variation among the observations, the greater the variance. Knowing the amount of variation in ecological attributes can tell us much about ecological patterns and processes.

Another descriptor of variation is the **standard deviation**, abbreviated as σ or SD, which is the positive square-root of the variance:

$$\sigma = \sqrt{\sigma^2}$$

The standard deviation may be thought of as the average absolute deviation from the mean. It has the same units as the original observations. If our data are normally distributed, such as in Figure 4.1, then about 68% of the observations will fall within 1 standard deviation on either side of the mean (Figure 4.2), and about 95% of the observations will fall within 2 standard deviations of the mean (Figure 4.2).
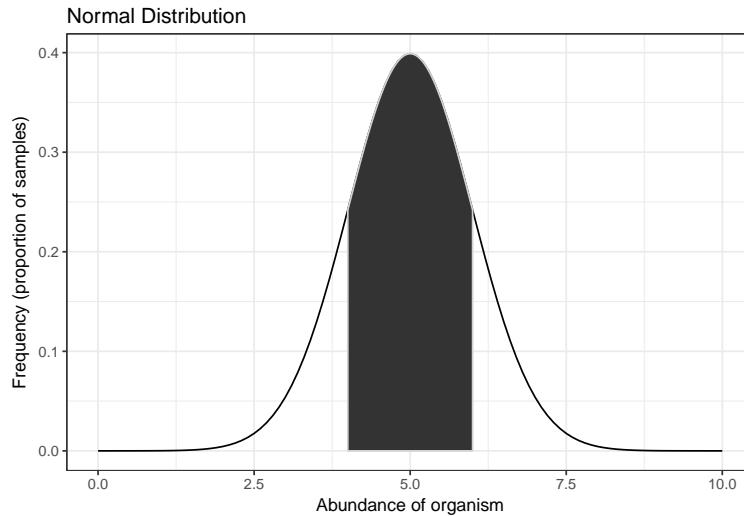
\begin{figure} \caption{Normal curve with colored area indicating occurance of +/-1 standard deviation. Approximately 68% of all observations fall in this area.} \end{figure}
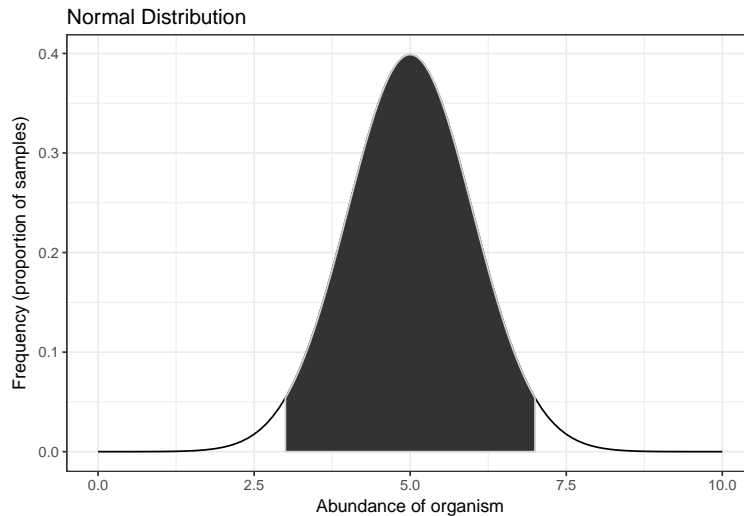
\begin{figure} \caption{Normal curve with colored area indicating occurance of +/-2 standard deviation. Approximately 95% of all observations fall in this area.} \end{figure}

4.3   Explaining Variation: Measuring association with the Coefficient of Determination

To explain things, we try to find other things that are associated with them that change as they change and remain constant when they stay constant. The search for pattern in nature is thus often a search for associations. Although cause and effect can rarely be inferred from such associations, the do have predictive use. If you variables are associated with each other, then knowledge of one tells us something about the other.

A good descriptor of the association between two variables is the **Coefficient of Determination**, R^2. It is the ratio of the variance shared with another variable to the total variance in the two variables.

$$R^2 = \frac{Variance\ in\ Common}{Total\ Variance}$$

Thus, R^2 is the proportion of the variance in one variable explained by, or associated with, another variable. As a proportion, it is a unitless number ranging from 0 to 1. High values, those approaching 1, indicate very close association, because one variable explains a large proprotion of the variance in another variable. Low values, those approaching 0, indicate little or no association. The equation for calculating the Coefficient of Determination is

$$R^2 = \frac{\left(\frac{\sum(x_i - \bar{X})(y_i - \bar{Y})}{n-1}\right)^2}{\sigma_x^2 \sigma_y^2}$$

where X and Y are the data for the two variables and σ_x^2 and σ_y^2 are the variances of the two variables. The part within the parentheses is the **covariance**.

R^2 can also be used to determine which of several hyptheses best explains an association. The hypothesis that generates the largest R^2 between two variables is the best explanation of their association. There are other, better methods ecologists generally use for model comparison, but they are much more complicated and R^2 will be useful for our purposes.

The **Correlation Coefficient**, r, is another measure of association. It varies from 1 (perfect association where the two variables increase or decrease together), to 0 (no association), to -1 (perfect inverse association, where one variable increasesas the other decreases). It is caluclated as the square root of the Coefficient of Determination:

$$r = \sqrt{R^2}$$

Computers easily calculate r and R^2.

4.4 Explaining Variation by Association: Regression

R^2 gives us a measure of the relationship between two variables, tellingus how much variation in one variable is explained by another variable. Sometimes, however, we would like to visualize the relationship. One way to do this is to fit a trend line that shows the change in one variable with change in another. The simplest trend line is a straight line drawn through the data, such that it minimizes the distance from each observation to the line. This is called **linear regression**.

Figure 4.2 shows a linear (straight-line) regression fitted to measurements on some iris flowers. It illustrates the trend of increasing flower petal length with increasing petal with. The equation for a straight line is

$$Y = mX + b$$

and is often written as $Y = b + mX$ since the order of addition doesn't matter and b represents the intercept or overall mean before accounting for the effect of the the independent variable X. In this case, m is the slope of the line (change in Y for one unit change in X), which represents the effect of X on the dependent or response variable Y. The distance between each observed point and the best fitted line are referred to as the **residuals** and in a linear regression it must be assumed that they are normally distributed with a mean of zero (equal amount over and under the line).

It is also possible to fit other lines to data or manipulate equations so they fit the linear regression equation. Figure 4.3 shows the same data with a log-log linear regression.

This assumes an equation following
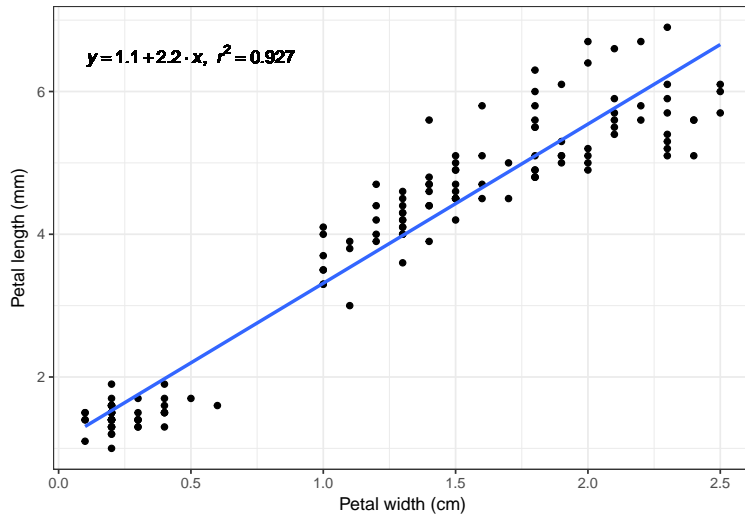
$$Y = bX^m$$

Figure 4.2: Example of a linear regression plot.
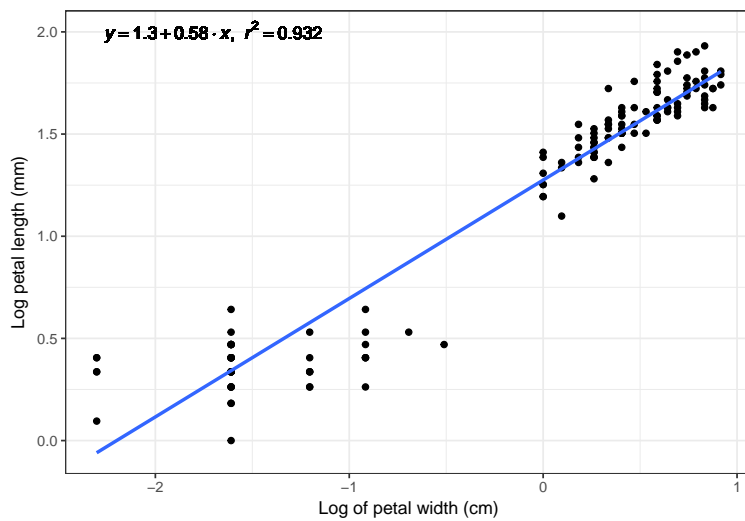
Figure 4.3: Example of a linear regression plot.

and would require a nonlinear regression without transformation of the data. By taking the logarithm of both sides of the equation is is transformed into

$$log(Y) = m * log(X) + log(b)$$

Which of the two lines fits the data better? To answer this kind of question, one is interested in the R^2 value. However, they both assume that the data meet the assumptions for the model which must be checked after the analysis.

4.5 Explaining Variation: Identifying random and nonrandom variation with probabilities

Odd things do happen, even if the probability of their occurrence is extremely small. For example, the probability that two different states would pick the same fout-diit lottery number on the sam day seems remote (it's typically on the order of 1 in one hundred million on any given day), but it has happened. Likewise, it is possible that a seemingly meaningful R^2 or other statistic of association was derived by chance alone rather than from variables that were actually related. To guard against this possibility we can determine the probability that the observed result did occur by chance. If this probability is low, then we can be reasonably (but never absolutely) sure that there is a real association in our observations. A "low" probability is often, but not always, defined as 0.05, or one chance in 20 that the result occurred by chance.

The probability of getting a certain result by chance is called its **statistical significance**. Significance is calculated from the known behavior of random variables, and the particular method depends on the statistic of interest. Computer programs are adept at calculating significance in an apprpriate manner. Significance is often reported as "p =", were p stands for probability. The probability values are often termed "p-values".

Thus, when inferring an association in your data, always look at the p-value as well as the measure of association or effect size of a variable. Only if the p-values is low (e.g., less than 0.05) can one have confidence that one has discovered a real relationship.

4.6 Explaining Variation: Associating differences with group membership

Sometimes one wishes to determine if certain attributes are associate with certain groups or determine whether some characteristic differs among groups. For example, we might hypothesize that wormwood plants growing in the open are taller than those growing in the shade. In this example, we want to determine if "taller" is associated with "open" and if "shorter" is associated with "shade". In order for this to be true, the two populations must be truly different from each other. Suppose we collect data on sun grown plants and shade grown plants and observe the results in Figure 4.4.

We observe a difference btween the two samples, because they do not totally overlap and the means are slightly different (the mean for the shade plants is 5 and the mean for the sun plants is 8). They both have a standard deviation of 2. Can we conclude that our hypothesis ("taller" is associated with "sun" and "shorter" is associated with "shade") is true? The differences between the two groups could be due to chance or sampling erros. We didn't measure every wormwood in the whole world, and we may have accidentally take more taller plants from the "sun" group, when in fact the "sun" may have no affect on wormwood size.

Because out results do suggest a difference in plant height between the two groups, we ask ourselves, *"What is the probability of obtaining our results when in fact the observed difference between groups is jus due to sampling error?".* If the probability of getting our results when there is no true difference is low, then the
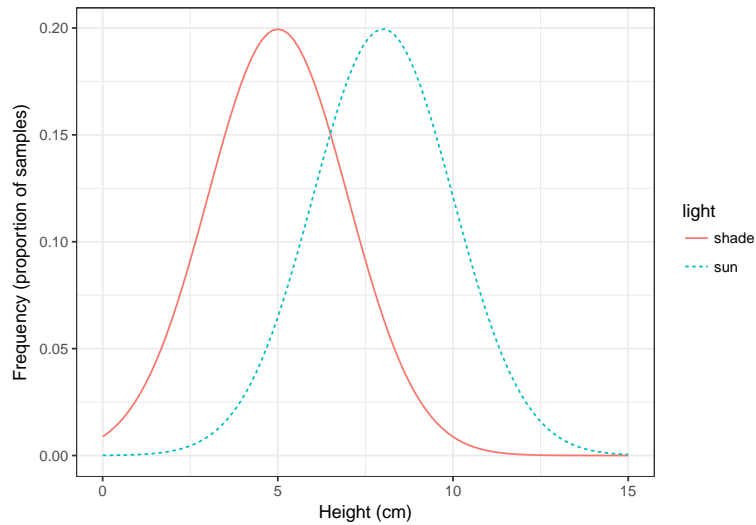
Figure 4.4: Two wormwood populations grown in sun and shade.

difference is probably real. Low probabilities of differences due to chance alone usually indicate meaningful (significant) differences between groups.

There are many ways of determining the probability of obtaining our result when there is no true difference. The two simpliest and most common ways are **t-tests** and the **Analysis of Variance (ANOVA)**. There are many variations of each and choosing the appropriate form requires skill and experience. In pratice it's best to consult with a statistician when designing and analyzing your study. *For this course, you will gain experience determining the appropriate analysis, analyzing data, and drawing inference based on the analysis. We will stick to basic forms of analysis that you can build from in future courses, projects, and jobs.*

An ANOVA is used for testing for a difference among multiple groups. A t-test is essentially a special case of an ANOVA when there are only two groups. Since ANOVA can still be used in cases of two groups, we will focus on ANOVA for this class.

4.7   Activity

Determine what type of test you would use to test each of your hypotheses developed previously? What data would you need to test the hypotheses?

What is one additional question that you had that would require a regression to evaluate (not one used for your hypotheses)?

What are general types of hypotheses that you can test with regression analysis?

What is the hypothesis you would test with an ANOVA?

When do you need to use an ANOVA instead of a t-test to answer the same type of question?

4.8 Introduction to Scientific Programming

Microsoft Excel is capable of doing some basic statistics including t-tests, ANOVA, and regression. However, the user has little control over the analysis, the software is proprietary, and you cannot build on these basics to analyze more complicated data or ask more interesting questions. MS Excel also varies considerably among computer operating systems and versions. Therefore, we are going to be using software designed for statistical analysis in this course, although you may use any appropriate means on your own homework (e.g. hand calculations, MS Excel, Stata, JMP, SAS, SPSS, Minitab, R, etc.). The demonstrations and instruction in this course will be using the **R Statistical Programming Language** and associated integrated development environment (IDE) **RStudio**. Both of these programs are free and open source and available on all major computer operating systems. They also generally look and act the same across operating systems and versions.

R has become the *lingua franca* of statistics and in the field of ecology. Besides the utility in this course and other science courses, having some familiarity with R and programming languages in general can open many graduate school and profession opportunities.

4.9 Assign and Recall an Object

The most basic action in R is to assign a value to an object so you can use the object or recall it later.

```
a <- 5
b <- c(1, 2, 2, 3)

print(a)
```

```
## [1] 5
```

```
b # you generally don't need the "print" command
```

```
## [1] 1 2 2 3
```

```
a * b
```

```
## [1]  5 10 10 15
```

4.10 Calculate the Mean, SD, and Variance

R also has a massive number of built-in functions, especially associated with data manipulation, printing, and statistics. Therefore, it's easy to calculate basic summary statistics such as the mean, median, mode, SD, and Variance.

```
mean(b)
```

```
## [1] 2
```

```
median(b)
```

```
## [1] 2
```

```
sd(b)
```

```
## [1] 0.8164966
```

```
var(b)
```

```
## [1] 0.6666667
```

```r
sd(b)^2
```

```
## [1] 0.6666667
```

```r
sqrt(var(b))
```

```
## [1] 0.8164966
```

4.11   Import Data

When interested in real data, we have to import the data into R. You can code it which as the advantage of being reproducible (like other methods in science).

```r
salamander_data <- read.csv(file = "Data/salamanders.csv", header = TRUE, stringsAsFactors = FALSE)
```

RStudio also has the option under `File -> Import Dataset` to do this through the GUI.

4.12   Calculate Summary Statistics on the Data

One you have imported a dataset and assigned it to an object in R, you are ready to work with it. R has a nice `summary` function for datasets. You can also view the data through the options in RStudio or through R functions.

```r
summary(salamander_data)
```

```
##      Plot              Species              Date               Count
##  Length:72          Length:72          Length:72          Min.   :0.0000
##  Class :character   Class :character   Class :character   1st Qu.:0.0000
##  Mode  :character   Mode  :character   Mode  :character   Median :0.0000
##                                                           Mean   :0.4444
##                                                           3rd Qu.:0.0000
##                                                           Max.   :5.0000
##  Cover_Objects
##  Min.   : 0.00
##  1st Qu.:10.00
##  Median :15.50
##  Mean   :15.22
##  3rd Qu.:17.00
##  Max.   :35.00
```

```r
head(salamander_data)
```

```
##   Plot                          Species    Date Count Cover_Objects
## 1 1--1 Allegheny Mountain Dusky Salamander 10/4/16     0            19
## 2 1--2 Allegheny Mountain Dusky Salamander 10/4/16     1            15
## 3 1--3 Allegheny Mountain Dusky Salamander 10/4/16     0            16
## 4 1--4 Allegheny Mountain Dusky Salamander 10/4/16     0            13
## 5 1--5 Allegheny Mountain Dusky Salamander 10/4/16     0            15
## 6 1--6 Allegheny Mountain Dusky Salamander 10/4/16     0            17
```

```r
str(salamander_data)
```

```
## 'data.frame':    72 obs. of  5 variables:
##  $ Plot         : chr  "1--1" "1--2" "1--3" "1--4" ...
```

```
## $ Species    : chr  "Allegheny Mountain Dusky Salamander" "Allegheny Mountain Dusky Salamander" "Alleghe
## $ Date       : chr  "10/4/16" "10/4/16" "10/4/16" "10/4/16" ...
## $ Count      : int  0 1 0 0 0 0 3 1 1 0 ...
## $ Cover_Objects: int  19 15 16 13 15 17 10 8 16 6 ...
```

4.13   Subset and Recalculate Summary Statistics

You can also subset the data and perform actions on the new object.

```r
pcinereus <- salamander_data[which(salamander_data$Species == "Red-backed Salamander"), ]

summary(pcinereus)
```

```
##      Plot              Species              Date               Count
##  Length:18          Length:18          Length:18          Min.   :0.0000
##  Class :character   Class :character   Class :character   1st Qu.:0.0000
##  Mode  :character   Mode  :character   Mode  :character   Median :0.0000
##                                                           Mean   :0.9444
##                                                           3rd Qu.:2.0000
##                                                           Max.   :5.0000
##  Cover_Objects
##  Min.   : 0.00
##  1st Qu.:10.75
##  Median :15.50
##  Mean   :15.22
##  3rd Qu.:17.00
##  Max.   :35.00
```

```r
mean(pcinereus$Count)
```

```
## [1] 0.9444444
```

```r
sd(pcinereus$Count)
```

```
## [1] 1.349171
```

4.14   Save Script

Once you have finished working on something, it's important to save the script so you can rerun the analysis later, share the code, or reuse code in other places. You do this through RStudio and the file ending is `.R`. You can also output objects as CSV files or as RData files to work with later or work with outside of R.

Chapter 5

Sampling Populations

Adapted from Johnson, P. 2008. Sampling Populations. Ecology Laboratory Manual. University of New Hampshire.

5.1   Introduction

Ecologists expend a considerable amount of effort estimating the characteristics of populations. Two parameters of particular interest are **density** and **dispersion**. The exercise below will demonstrate the basic principals of population sampling. The steps in most sampling programs include:

1. Selecting the sampling **universe**. What are the limits of the area within which you want to estimate these population parameters? The universe may be of any size or shape suitable to your goal.

2. Selecting an appropriate sampling unit, or **quadrat**. In practice this may be a leaf, a plant, a specific volume of soil, etc. Whatever unit is appropriate to your population.

3. Selecting a **sampling scheme**.

5.2   Sampling Schemes

The most appropriate scheme from a statistical point of view is an **unrestricted random sample**, where every quadrat in the sampling universe has an equal opportunity to be selected at each sampling event.

Frequently the sampling universe will include more than one type of habitat represented in varying amounts within the universe. Since individuals may be unequally distributed among these habitats, a completely random scheme might misrepresent the true population density. In this case, to ensure proportionate representation of each habitat, we may use a **stratified random sample**. Each sector (or strata) is sampled at an intensity relative to its proportionate representation, but samples are drawn at random within the sector.

Often it is possible to use **systematic sampling**, selecting quadrats at regular intervals throughout the universe. One advantage is the inclusion of all of the sampling universe in equal proportions. In many cases, this is the easiest scheme to design and implement and can give good results in spite of violating the statistical assumption of random sampling. You must be sure, however, that your selection of sample locations does not bias your results. This requires a good background knowledge of the population's biology.
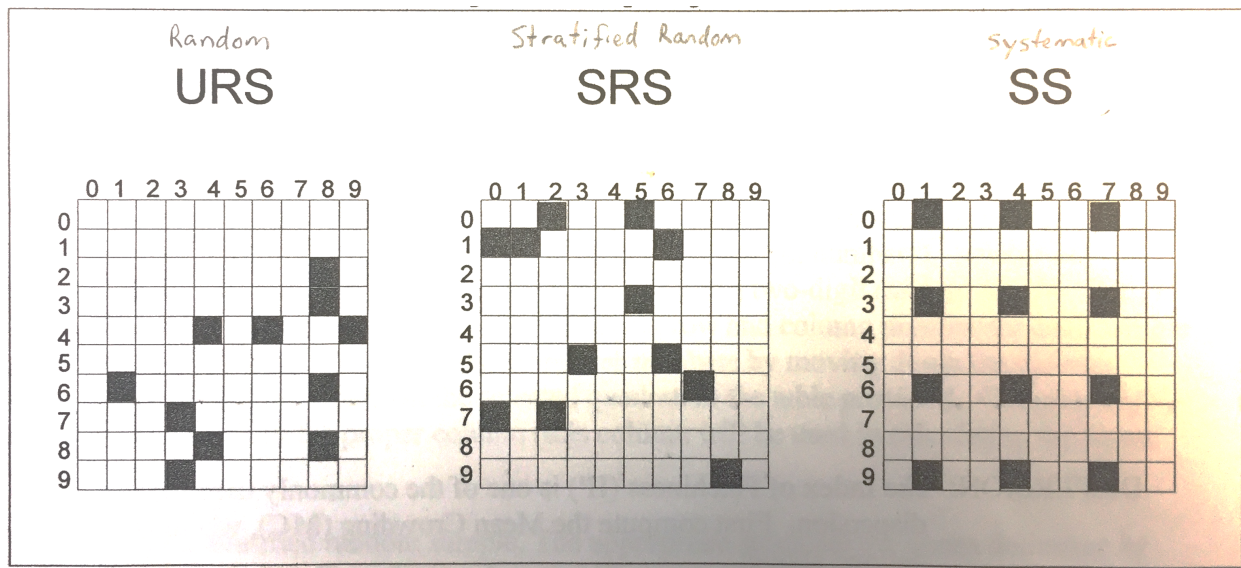
Figure 5.1: Sampling Schemes

5.2.1 Sampling scheme methods

1. Measure approximately 200 grains of white rice (3.8 g)
2. *Gently* shake the grains of rice onto your sampling universe.
3. First try an unrestricted random sample using the supplied random number table. This will be your row and column to sample.
4. Count 12 random quadrats and record your results for each quadrat. Be careful not to disturb the grains of rice during the sampling process.
5. Next, **without disturbing the rice**, apply a stratified random sampling scheme and count three quadrats randomly from each of the four sectors (A, B, C, D). Ignore the random numbers for a sector once you've collected three samples from that sector.
6. Finally, use a systematic sampling scheme for 12 quadrats to estimate the parameters. Record the results on your data sheet and perform the calculations.

Still do not disturb the rice!

Density: Mean number of individuals per quadrat ($1\ cm^2$).

$$x = \frac{\sum N_i}{n}$$

Dispersion: The index of patichness (**IP**) is one of the commonly used indices of dispersion. First compute the **Mean Crowding (MC)**

$$MC = \frac{\sum N_i(N_i - 1)}{\sum N_i}$$

Next compute the IP by dividing MC by the mean density

$$IP = \frac{MC}{x}$$

- IP < 1 is Regular/Uniform
- IP = 1 is Random
- IP > 1 is Aggregate/Clumped

5.3 Sequential Sampling

A variation on this type of sampling is often used in quality control or pest control situations where our interest is in classifying or approximating the population density or in situations when we do not have a good idea how many samples are needed and are constrained in the number of samples we can take.

One basic form of sequential sampling uses the cumulative average density with the number of samples and looks for a leveling off point. This is a type of rarefaction curve. To do this, randomly sample one quadrat and plot the density on the y-axis. Repeat this but for sample two (x-axis), plot the mean density on the y-axis (average density from sample 1 and sample 2). Continue this until the mean density has stabilized. Use the graph paper to record this.

5.3.1 Sequential sampling questions

How many samples are required to reach a decision on the density (and hence population size)? How did you decide?

Does this agree with the estimates from your previous sampling procedures?

Was this more efficient than your previous sampling procedures(i.e. did you get the correct estimate of density/abundance in fewer than 12 samples)?

5.4   The Effects of Distributions

Repeat steps 1-6 from the sampling schemes for

A. Uniformly distributed individuals (place ~2 grains of rice per quadrat) B. Clumped distributions of individuals (put most of the rice into 5 clusters)

5.4.1   Distribution Questions

Does the best sampling scheme depend on the distribution of the individuals in the population?

How do you think matching of the clustering with your stratification would effect the estimates?

5.5   Mark Recapture (Capture Recapture)

For species that are difficult to capture or detect, mark-recapture can provide a much better estimate of population size (abundance) or density. The simplest form of mark-recapture is the Lincoln-Peterson estimator with a single marking (cohort marking) and single recapture effect. The estimator is calculated as

$$N = \frac{nM}{R}$$

where N is the esimate of the total population size, n is the number of the sample size, M is the number of marked individuals released back into the population, and R is the number of marked recaptures in the sample.

5.5.1   Mark-Recapture Simulation Method

1. Measure approximately 100 grains of white rice and 100 grains of colored rice (1.9 g each)
2. Mix your marked rice thoroughly with the rest of your unmarked population
3. Take a sample from the population consisting of *roughly* 0.2 g (5% of population)
4. Record the number of marked and unmarked rice in the sample and calculate the total population size using the Lincoln-Peterson Index.
5. Mix the rice back together and repeat with 0.4 g (10%) and 0.8 g (20%) samples.

5.5.2   Mark-Recapture Questions

Comment on the accuracy of your mark-recapture estimates. Does the size of the sample affect the accuracy of the estimate?

Chapter 6

Life Tables and Population Demographics

Adapted from Johnson, P. 2008. Sampling Populations. Ecology Laboratory Manual. University of New Hampshire.

6.1 Objectives

- Learn how life tables are constructed
- Learn to calculate population parameters from life tables
- Develop understanding of inference and limitations of life tables

6.2 Introduction

By sampling a population (Chapter 5), we can construct age class distributions for a population. This information can be used to generate survivorship curves, construct life tables, which are age-specific summaries of this important life history information.

6.3 Materials

- 100 grains of 5-colored rice (approximated by weighing 1.9 g)
- Sampling universe (1 x 1 cm grid paper)
- Tray to keep rice from going everywhere
- Data sheets
- Calculator (Computer with excel or other software may be used, but not on an exam)

6.4 Methods

Let's pretend that our rice represents a population of an organism with five distinct age classes that are readily available. This could be an insect with an egg, 2 larvae stages, pupa stage, and adult stage. Similarly, it could be a species of frog that lives a maximum of five years. Alternatively, it could be a long-lived animal (think turtle) or tree where we bin the ages into five classes.

We can use the unrestricted random sampling scheme from the distribution lab (Chapter 5, to construct a life table. This is a static approach to life table generation, which assumes our populations are increasing or decreasing at a constant rate or are stable and have reached a stable age distribution. This is probably a safe assumption for our rice population.

1. Sample your population and keep track of the various age classes. You can use the table below, relating color to rice age class.

Age Class	Color
0	White
1	Yellow
2	Green
3	Blue
4	Red

2. Fill in table 6.1 with your sampling results and use this data to compute the proportion of each age class relative to the first age class. To do this, calculate the total number of individuals of age class in the population (mean density * total area), then divide that abundance by the total abundance of Age Class 0 individuals. This will be the survivorship data (l_x) needed for our life table.

$$l_x = \frac{n_x}{n_0}$$

The life table parameters are defined in the table below. The data used to generate a life table is either the number of individuals (n_x) surviving from a chorot of individuals born at the same time (a cohort or horizontal table) or the proportion of individuals (l_x) surviving to each life stage as derived from the age structure of a population (static life table or vertical table). In our case, we will use the proportionate survivorship group data from our sampling.

x	Age class	Calculation
n_x	Number of surviving in cohort	Data or $1000 * l_x$
l_x	Survivorship for x to $x+1$	Data or $\frac{n_x}{n_0}$
d_x	Deaths for x to $x+1$	$
q_x	Mortality rate for x to $x+1$	$\frac{d_x}{n_x}$
L_x	Average number alive during age interval x to $x+1$	$\frac{n_x+n_{x+1}}{2}$
T_x	Total years lived into the future by individuals of age class x	$\sum_x^{X_{max}} L_x$
e_x	Life expectancy for age class x	$\frac{T_x}{n_x}$

Note that we have set the initial n_x value to 1000. This is the traditional cohort, although you can use any value and get the same results. For the expectation of further life, sum the L_x values from the target age class (x) to the bottom of the life table.

$$e_x = \frac{\sum_x^\infty L_x}{n_x}$$

Age Class 0 White		Age Class 1 Yellow		Age Class 2 Green		Age Class 3 Blue		Age Class 4 Red	
x	**count**	**x**	**count**	**x**	**count**	**x**	**count**	**x**	**count**
1		1		1		1		1	
2		2		2		2		2	
3		3		3		3		3	
4		4		4		4		4	
5		5		5		5		5	
6		6		6		6		6	
7		7		7		7		7	
8		8		8		8		8	
9		9		9		9		9	
10		10		10		10		10	
11		11		11		11		11	
12		12		12		12		12	
13		13		13		13		13	
14		14		14		14		14	
15		15		15		15		15	
16		16		16		16		16	
17		17		17		17		17	
18		18		18		18		18	
19		19		19		19		19	
20		20		20		20		20	
Σ		Σ		Σ		Σ		Σ	
Mean Density		Mean Density		Mean Density		Mean Density		Mean Density	
n_x		n_x		n_x		n_x		n_x	

Number Surviving to Age Class (n_x)

Age Class 0 White	Age Class 1 Yellow	Age Class 2 Green	Age Class 3 Blue	Age Class 4 Red
Lab:				

Survivorship (l_x)

Age Class 0 White	Age Class 1 Yellow	Age Class 2 Green	Age Class 3 Blue	Age Class 4 Red
Team:				
Lab:				

Figure 6.1: Demographic sampling data sheet

Fill in life table 6.2 below using the data for our **lab** population data.

In order to use life table information to estimate population growth, we must add an additional column to our life table, the age specific fertility or birth rate (b_x). This is the average number of offspring produced per female of age class x, so it is technically fertility, not fecundity, although you often hear it referred to as the age specific fecundity rate.

Since the calculations that follow use products of x, l_x, and b_x, we have added appropriate columns to the life table. Fill in life table 6.3 using the birth rate information provided.

We can now compute the average generation time, G, for our population. This is sometimes expressed as T so be careful not to get it confused with T_x.

$$G = \frac{\sum_0^\infty x l_x b_x}{R_0}$$

where R_0 is the net reproductive rate calculated as

$$R_0 = \sum_{i=0}^{i=\infty} l_x b_x$$

From this we can estimate the intrinsic growth rate of the population, r as

$$r = \frac{ln R_0}{G}$$

where ln is the base of the natural logrithm, also written as log_e. With this estimate, we can model population growth for a rice grain population with a stable age class distribution using the exponential growth equation

$$N_t = N_0 e^{rt}$$

where N_t is the population abundance at time t and N_0 is the starting population size. Fill in the table and graph (Figure 6.1) provided by computing population values at each of the time points on the x-axis, beginning with a population of 50 females at time zero.

Age (x)	l_x	n_x	d_x	q_x	L_x	e_x
0	1.00	1000				
1						
2						
3						
4						

Figure 6.2: Life Table

Age Class (x)	l_x	b_x	$l_x b_x$	$x l_x b_x$
0	1	0		
1		1		
2		4		
3		2		
4		0		
		$R_0 = \Sigma lxbx$		

Figure 6.3: Life Table Calculations

Days (t)	r	rt	e^{rt}	$N_0 e^{rt}$
10				
20				
30				
40				
50				

Population
Size

0   10   20   30   40   50

Time
(days)
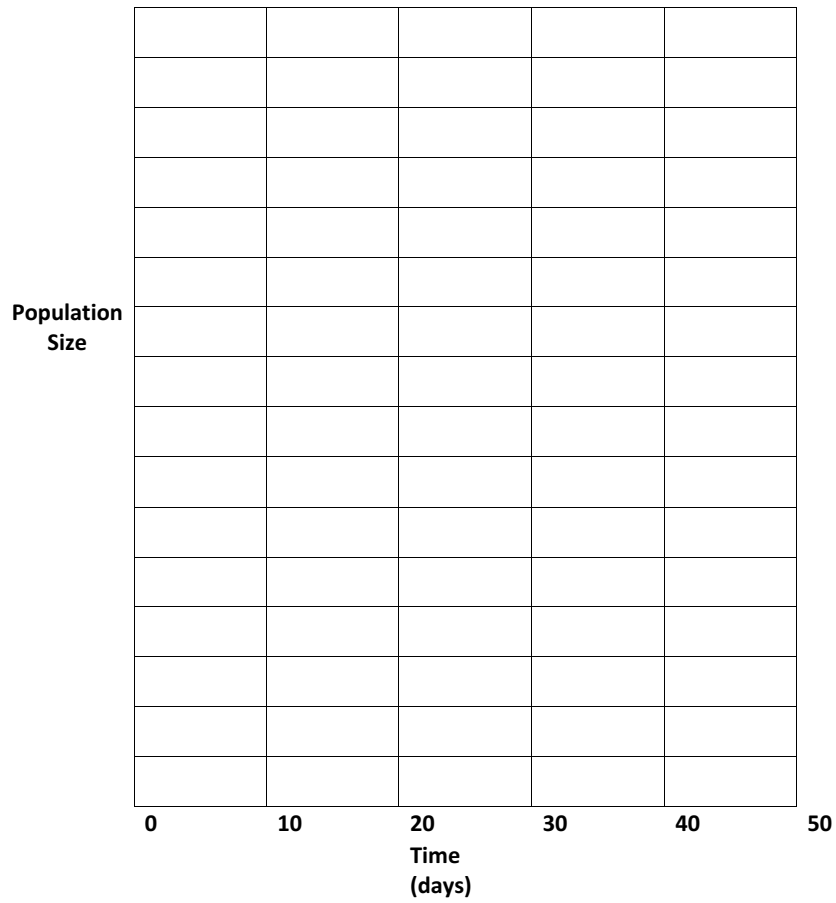
Figure 6.4: Population project from a life table

Chapter 7

Logistic Population Growth

7.1 Lab activities

1. Count flour beetles
2. Conduct logistic growth simulations
3. Answer population growth questions
4. Review for Exam 2
5. Brief lecture on science writing
6. Writing workshop *optional*

7.2 Objectives

- To demonstrate exponential and logistic population growth
- To understand how the growth rate and carrying capacity influences the shapes of these population growth curves
- Develop ability to relate equations and graphs to the concepts of population growth

7.3 Introduction

All organisms tend to show the capability of unlimited exponential growth. Consequently, mathematical models have been developed to try to simulate this phenomenon. It is hoped that by creating models that include enough realism one might be able to explain and even predict the changes that occur in real populations. Realistically, no population grows in an exponential manner forever. Populations are limited by food, space, light, waste build-up, and by populations of other organisms. Once a particular resource becomes limiting, population growth will slow and eventually stop. Populations that are limited by the environment typically exhibit logistic growth.

Mathematical models are created to describe and understand natural phenomena. Based on our knowledge of the reproductive processes of organisms we understand that with unlimited resources a population of organisms will grow exponentially. This happens when there is nothing hindering an individual's ability to access whatever resources it needs. Exponential growth is characterized by a j-shaped numerical response curve (number of organisms vs. time). The number of organisms at any time (N_t) depends on time, intrinsic growth rate (r), and the number of organisms at time zero (N_0) (Figure 7.1). The slope of the exponential growth curve ($\frac{dN}{dt}$) is constantly increasing and is directly proportional to the number of organisms at any time ($\frac{dN}{dt} = rN$). The proportionality constant is the intrinsic growth rate (r). The population size at any

point in time can be calculated following $N_t = N_0 e^{rt}$. Remember that e is a constant equal to the base of natural logarithms (2.71828).
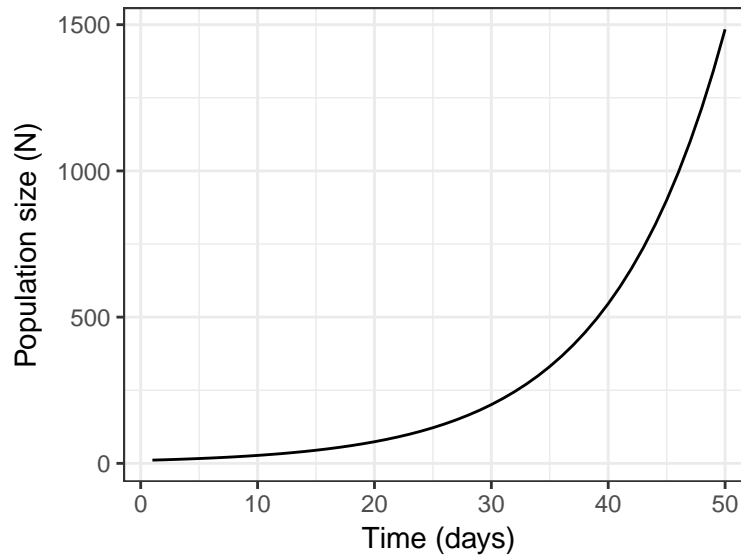
Figure 7.1: Exponential growth

It is important to realize that all populations have the potential to grow exponentially, but few ever do in reality. This is because there are restrictions that limit an organism's ability to survive. Some of these restrictions are brought about by an limited supply of resources (food, light, space) and/or competition for with other populations for these limited resources. As more organisms compete for the same resources, fewer are able to reproduce and population growth slows. When the number of organisms in the population directly influences population growth, growth becomes **density-dependent**. In this situation, the population exhibits logistic growth, and the numerical response curve has an s-shape (Figure 7.2). The maximum number of individuals that can exist in a habitat with limiting resources is referred to as the carrying capacity (K). The slope of the logistic growth curve ($\frac{dN}{dt}$) increases quickly with time but gradually slows to zero (verify this by examining (Figure 7.2)).
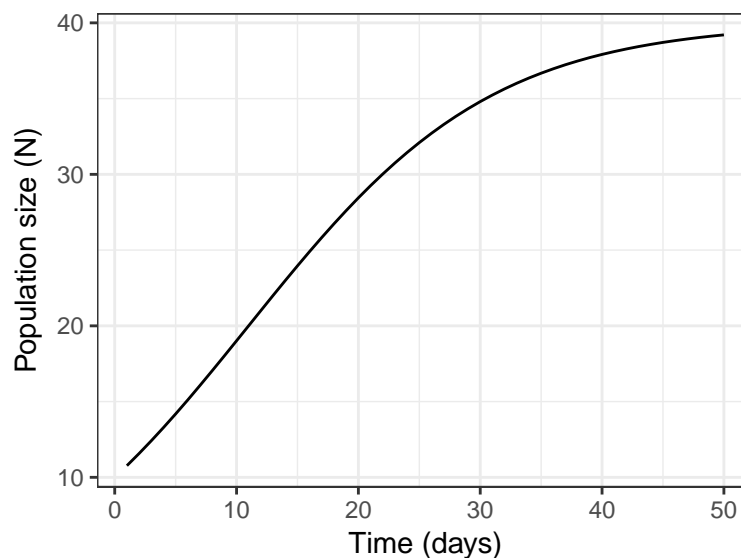
Figure 7.2: Logistic growth where K = 40

The equation for the slope of the logistic curveis similar to the equation for the slope of the exponential curve except that it includes slowing factor that reduces population growth to zero as N approaches K. The rate of population growth follows

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

When a population is very small (2-4 individuals) and far from its carrying capacity, it will grow exponentially. Verify this by examining the value of the slowing factor $(1 - \frac{N}{K})$ for a population whose $K = 200$. What is the value of $(\frac{dN}{dt})$ when $N = 199$?

The population size at a given point in time (N_t) can be calculated using

$$N_t = \frac{K}{1 + \left(\frac{K - N_0}{N_0}\right)e^{-rt}}$$

Sometimes population growth is restricted not by resource limitation but by abiotic factors from outside of the habitat. Storms, fires, earthquakes, and meteor impacts can all limit the growth of a population. These factors typically affect a specific proportion of the population (for example 30%) regardless of the population density. Therefore, they are referred to as **density-independent** factors.

7.3.1   Logistic Growth Assumptions

The logistic growth *model* is certainly more realistic than the exponential growth model but it still requires a variety of assumptions:

1. All individuals in the population have identical ecological properties, that is, they have equal probability of producing young, death, and predation.
2. Changes in the population's birth and death rate occur instantaneously, without lag, with changes in population density.
3. All members of the population are equally affected by crowding. This is true only if the population is dispersed uniformly.
4. There is a constant upper limit to population size (K is constant), implying that the environment is constant and the population never increases over K.
5. The population has a stable age distribution
6. Birth and death rates are not affected by abiotic factors in the environment (density independent events).

Despite these seemly restrictive assumptions, biologists can frequently appoximate populations reasonably well using the logistic growth equation. This is especially true for populations in simple environments. Some populations follow this pattern on average but with stochastic variation around the expected prediction. Additionally, biologists can use this model but allowing r and K to vary over time based on density independent factors. These density-independent factors are generally environmental conditions such as temperature and precipitation. In our next module, we will also see ways that competitors and predators can be added into this type of model to increase realism.

7.4   Materials

- Beans
- Spoons
- Container

7.5   Methods

1. In groups of 8-10, start with 20 beans in your habitat (plastic container).
2. Start with 1 person acting as a bean predator. Gather as many beans as you can in 15 seconds
3. Use the following table to determine your survival and reproduction

Num Beans	Result
< 4	Die
$4 - 6$	Survive
$7 - 10$	Survive + 1 offspring
> 10	Survive + 2 offspring

4. Record the number of births and deaths and the new population size
5. Grow 15 new beans
6. New offspring join the population and repeat

7.6   Questions

1. Plot the data and draw a line through the points.

2. Does the line flatten out? Why or why not? What is the value of K?

3. What were the limiting resources in our scenario?

4. If a bacterial colony starts with 100 individuals and its population size at sampling time 1000 (hrs) was 20,000; what is r? What would the bacterial colonies population size be after 1 day (sampling time 2400)?

5. Calculate the population size at year seven of a lion population with an initial population size of 20 and an instantaneous growth rate of 0.1 (rounded to the nearest whole number).

6. The endangered purple falcon, which is endemic to your state, had a population size of 100 individuals in 2012. The population's instantaneous growth rate over the past decade has been 0.05 assuming a continuously growing population. Delisting of the falcon from the Endangered Species List can occur when the population reaches 1000 individuals. Using the density-independent population growth equation, when should the falcon be delisted?

7. For the population of purple falcon described above, assume there is actually some density dependence and the carrying capacity is only 2000 individuals. What is the expected abundance of the population in 2020, 2050, and 2100?

8. A population of common red-bellied snipe is limited by the number of nesting sites in their habitat. Thus, they grow according to the density- dependent logistic growth equation. Calculate the population growth rate for snipe populations of 25 and 75 given that their instantaneous growth equals 0.1 and their carrying capacity equals 100. Are the growth rates the same or different? Why?

Chapter 8

Community Ecology: Diversity

8.1 Lab activities

1. Collect invertebrates using D-net sweeps of water column and benthic zone (Potential: Leaf litter or pine cone invertebrates with Berlese Funnels)
2. Preserve all invertebrates in 95% ethanol
3. Sort invertebrates into taxonomic units (Order or Family) and record number of each
4. Discuss expectations for lab assignment

8.2 Objectives

- Become familiar with invertebrate groups
- Gain experience with standard invertebrate sampling techniques
- Learn various measures to quantify biological diversity
- Practice organizing and visualizing biological data
- Gain experience with diversity calculations

8.3 Introduction

Lab adapted from Tiffany Troxler's PCB3043L lab manual at Florida International University

8.3.1 Ecological communities

Ecological communities are assemblages of populations of interacting species. People conceptually recognize communities because they are perceptually obvious. Examples of ecological communities include forests, prairies, wetlands, estuaries, lakes, deep ocean hydrothermal vents, and coral reefs. The essential feature of communities is that they are assemblages of species that predictably co-occur.

The structure of ecological communities is measured with a number of different metrics. One method of analyzing ecological communities is the construction of **food webs**, which address the functional relationships among the species of a community. **Species diversity** and **species richness** are also important measures of community structure. Species richness is a measure of the number of species per unit area. Species diversity is a non-dimensional, numerical index generated for a given community, which takes into account both richness and abundance of individual species. Because of the problems associated with mathematical

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measures of species richness that arise in certain situations, many ecologists elect to use measures of species diversity to describe ecological communities.

8.3.2   Sampling effort curves and diversity indices

Ecologists face two main problems when quantifying differences in the abundances of species in communities. First, the total number of species found correlates with the sample size because you are more likely to find a rare species as you increase your sampling frequency. This means that diversity cannot be compared between communities that were sampled at different intensities. Second, the number of individuals representing a species may not be a good indication of the functional importance of that species to the community. To some degree, the functional roles that species play in a community vary in proportion to their overall abundance. There are cases where this is not true, however. An excellent example of a species whose functional role is not proportional to its overall abundance in a community is a keystone predator. A keystone predator species may be represented by only a few individuals, but it plays a critical role in structuring the community in which it lives. The Florida panther in the Everglades is a good example of such a keystone predator. Thus, it is best to have some measure of the functional roles of species in a community in addition to simple measures of the numbers of individuals that represent each species.

One part of the discovery process in assessing communities is identifying when we have exerted a sufficient sampling effort to determine species richness and diversity with some level of confidence. Construction of a **species-area curve** (Figure 8.1) is one approach to determining adequate sampling effort. Species-area curves plot the area examined with repeated samplings (x-axis) versus the total number of species found in those samplings (y-axis). Alternatively, a **sampling effort curve** (Figure @ref(fig:cumulative_species_sampling)) plots the cumulative number of individuals sampled (x-axis) or the number of samples taken (as in this lab) against the total number of species represented by those individuals (y-axis). Both curve types address the same question (i.e., whether species richness is increasing or has leveled off in your sample) but may be appropriate for different situations. For example, data from rapid ecological assessments of species richness with far-reaching conservation consequences frequently do not include accurate measures of area covered but do include numbers of individuals sampled. In such a scenario, a sampling effort curve would be more informative than a species-area curve.

The result for both curve types is a line that increases steeply at first but eventually levels off at an asymptote. The point at which the species-area and sampling effort curves level off is the point where additional sampling is yielding no additional information about the number of species. In other words, the leveling off point or asymptote represents the optimal sample size in terms of area or individuals, depending on the type of curve. The total number of species in a community strongly determines how large the sample should be to reach this optimum, though the number of rare species also plays a critical role.

```
## `geom_smooth()` using method = 'loess'
```

Once you have adequately sampled the species in a community, you can also calculate an index to quantify the species diversity in that community. The two most common indices of species diversity are **Simpson's index (D)** and the **Shannon-Wiener index (H)**. Higher values of D and H represent greater diversity. Both indices are calculated from the proportions (p_i) of individuals in the total sample (N_{total}) that are represented by a given species (i), such that...

$$p_i = \frac{n_i}{N_{total}}$$

...for each species. Simpson's index (D) is calculated as...

$$D = \sum p_i^2$$

but the most useful way to use Simpson's Index is with relation the the reciprocal.
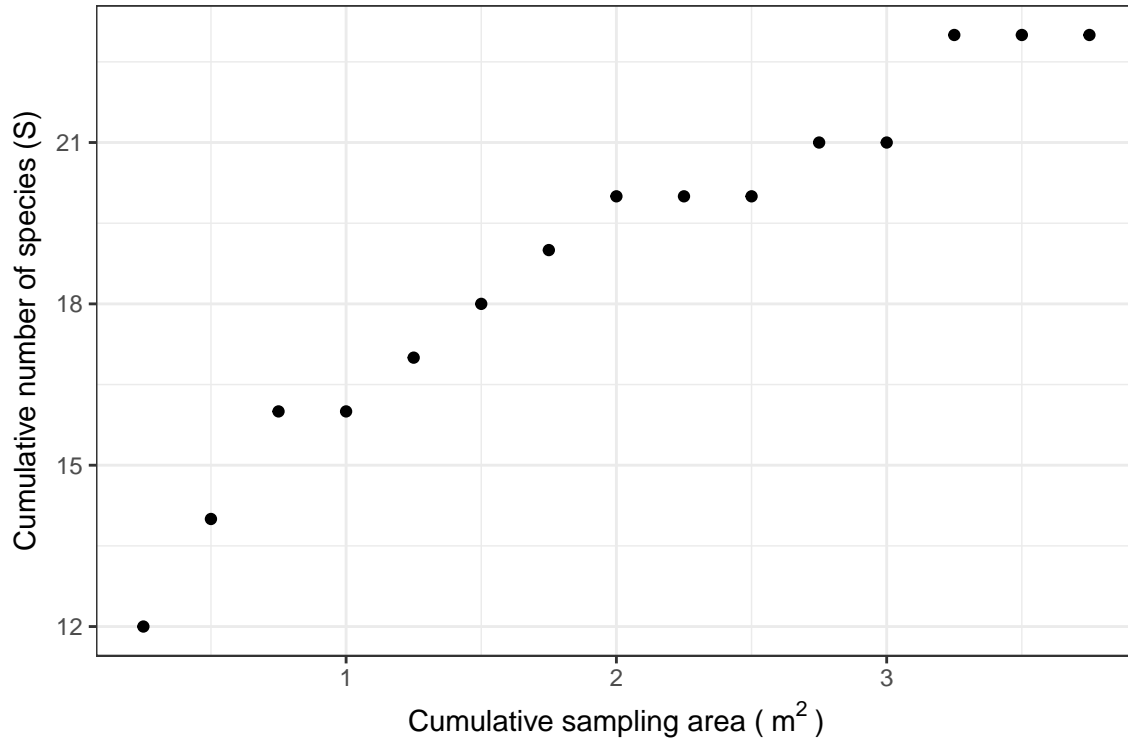
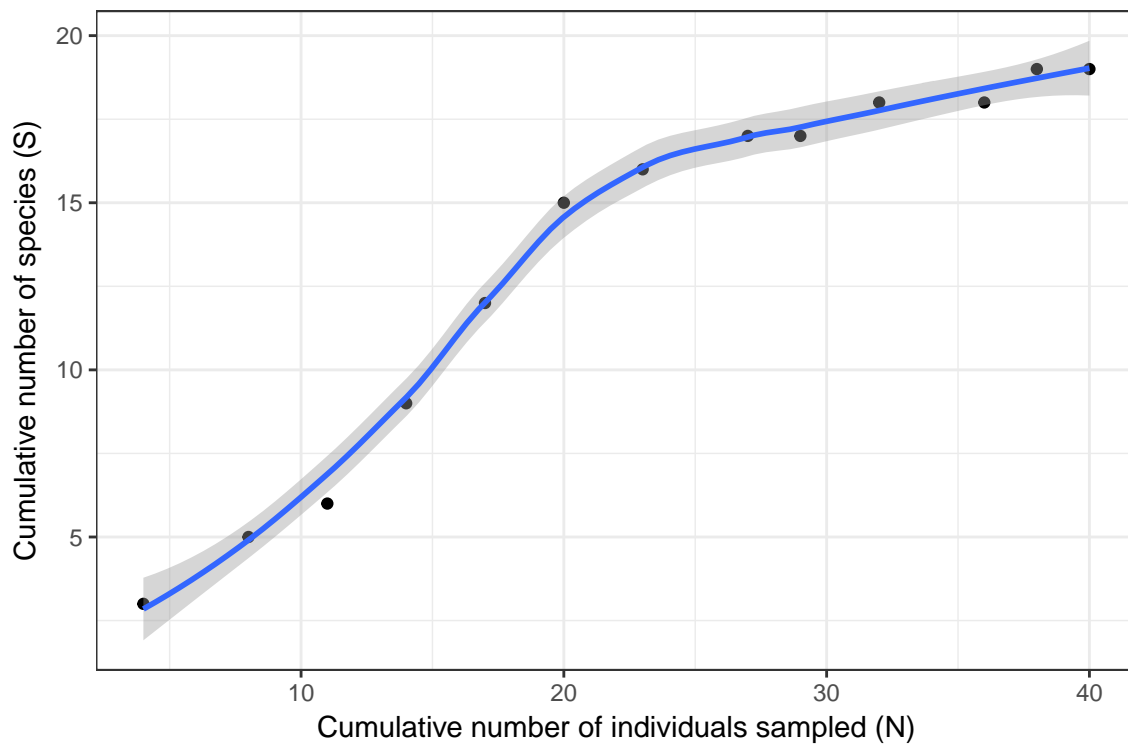Figure 8.1: Herbaceous plant species-area curve

Figure 8.2: Herbaceous plant sampling curve. The line can be drawn by hand or fitted using a smoothing spline or loess fit. However, S is always at least the number of species you caught. Alternatively, you can just connect all the points with a line graph.

$$D' = \frac{1}{\sum p_i^2}$$

This sets the lowest value as 1, representing a coummunity with only one species. The higher the value, the greater the species diversity. The maximal values is equal to the species richenss (S).

The Shannon-Wiener index (H) is calculated as...

$$H = -\sum_{i=1}^{S} p_i \ln(p_i)$$

WHERE:

- H = symbol for the diversity in a sample of S species or kinds
- S = the number of species in the sample
- p_i = relative abundance of ith species or kinds measures, = n_i/N or (# individuals of each species) / (total # individuals in the plot)
- N = total number of individuals of all species or kinds
- n_i = number of individuals of ith species
- ln = log to base e
- $H_{max} = \ln(S)$ = maximum possible diversity given the number of species in the plot

Reminder: S is the species richness (or the number of different species)

Evenness (J) is a component of biological diversity and is a measure of the relative abundances of different species in a community. *Note: your textbook uses E_H for evenness, rather than J, but this is much less common in my experience.* Evenness is calculated as:

$$J = \frac{H}{H_{max}}$$

If all species have the same relative abundance in a community, $J = 1$. For example:

Species	n_i	$p_i = n_i/N$	p_i^2	ln(p_i)	p_i(ln p_i)	
A	16	16/33 = 0.485	0.235	-0.724	0.485 * -0.724 =	-0.351
B	12	12/33 = 0.364	0.132	-1.012	0.364 * -1.01 =	-0.368
C	5	5/33 = 0.152	0.023	-1.887	0.152 * -1.89 =	-0.286
	N = 33	D =	0.391		Sum	-1.005
		D' =	2.558		H	1.005
					H_{max}	1.100
					J	0.915

Figure 8.3: Example calculation of D, D', H and J

8.4   Field Methods

Directions will be given by your laboratory instructor. Generally, a sample of habitat will be taken. The invertebrates will be sorted and later identified to the lowest taxonomic unit possible. The number of each

species in each sample or unit area will be the primary unit of data to start.

Enter these data into a Google Doc for sharing: https://docs.google.com/spreadsheets/d/1dtevbDPMBdJCWaX44GH0TDTL
edit?usp=sharing

8.5 Questions For Homework

Use data from Blackboard and not directly from the google sheet where it was entered. I will clean up and organize the data and post it to blackboard under course documents.

1. Generate a sampling effort curve to determine whether or not your lab samples approach a sufficient sample size to infer aquatic macroinvertebrate diversity. Either make one plot per habitat type (if more than one habitat type listed) or use different symbols for each habitat on a single plot. Be sure to label the axes and symbols. Use data from all dates and years provided.

2. How many species (or taxonomic groups) did we find in total per habitat type (observed S)?

3. How many species (or taxonomic groups) do you estimate there are in each habitat based on your species area or sampling effort curves?

4. Did we do enough sampling to accurately estimate the number of species (Order/Family groups in our case)? How can you tell? If we did not do enough, how many do you think we would have to do?

5. Calculate D, D' H, H_{max}, and J using the combined class data (from Tuesday and Wednesday lab sections) for each habitat type. *Show your work to receive credit. If done in excel, the table should be formatted to be easily readable.*

6. Which habitat has the highest species richness (S)?

7. Which habitat has the highest diversity?

Chapter 9

Ant Spatial Distributions

The Allegheny mound ant (*Formica exsectoides*) occurs throughout the Appalachian Mountains in the eastern United States. They are conspicuous in the large mounds they build for which they get their name. These mounds can be up to 1 m in height. They occur in old fields and other open habitats and maintain these habitats by killing nearby plants with injections of formic acid.

9.1   Materials

- Tape Measures
- Pin Flags
- Permanent Markers
- Meter Sticks or small tape measures
- Datasheets
- Clipboards
- Pencils

9.2   Lab Activities

In this lab we will examine the distribution of Allegheny Mound Ants at Glendenning Park in Frostburg. Most ants, including Allegheny Mound Ants, will bite and sting to defend homes, food, or territories. These ants are not especially dangerous but do be careful to not excessively disturb the mounds. Watch around your feet so as to not get attacked by angry ants.

1. 20 x 20 m grid with 2 m square quadrants. Rows A –K and columns 0-9. In each quadrant, measure the height and diameter of each mount that falls primarily in that quadrant. 2-3 people do all columns within each of ~2 rows.

2. Count the number of trees >2 cm in diameter within the quadrant.

3. Enter the data into a google sheet

9.3   Review

Below is a review from the sampling lab

Density: Mean number of individuals per quadrat ($1\ cm^2$).

$$x = \frac{\sum N_i}{n}$$

Dispersion: The index of patichness (**IP**) is one of the commonly used indices of dispersion. First compute the **Mean Crowding (MC)**

$$MC = \frac{\sum N_i(N_i - 1)}{\sum N_i}$$

Next compute the IP by dividing MC by the mean density

$$IP = \frac{MC}{x}$$

- IP < 1 is Regular/Uniform
- IP = 1 is Random
- IP > 1 is Aggregate/Clumped

9.4   Homework

For next week, answer each of the following questions. Answers should be typed using 12 point font and 1 inch margins. *Some questions may involve looking up information about the species on your own*

1. Make a map of the distribution of ant mounds

2. Calculate the mean density, mean crowding, and index of patchiness of ant mounts. Are they uniformly distributed, randomly distributed, or clumped?

3. Assume a 15 cm diameter mound supports approximately 500 ants, a 45 cm mound has about 2,000 ants, a 1 m mound has approximately 4,500 ants, and a 2 m diameter mound supports approximately 10,000 ants. Make a plot of mound diameter versus ant abundance. Use this information to determine the mean number of ants per meter squared and per hectare.

4. Do another regression to assess the effect of mound size on tree density. Make the plot, report the regression equation, and the variance explained (R^2). hint: this will require a linear regression

5. What is the life cycle of Allegheny Mound Ants?

6. Do these ant colonies have 1 or more ants per mound?

7. Describe the timing and formation of mounds.

8. What do Allegheny Mound Ants eat?

9. What do people say Allegheny Mound Ants taste like?

Chapter 10

Population Growth

Lab adapted from:

Shanholtzer, S. and A.S. Lumsden. 2012. Proceedings of the Association for Biology Laboratory Education. Vol. 33, 195–207, 2012

Johnson, P. 2008. University of New Hampshire Ecology Laboratory Manual: Red Flour Beetle Resource Limited Growth.

10.1 Introduction

When populations of organisms are allowed to grow under constant conditions, the increase in numbers follows a predict- able pattern. A type of graph called a population growth curve is used to describe these patterns by showing the number of organisms on the y-axis (vertical) and the time (or number of generations on the x-axis (horizontal). These curves are usually S-shaped like Figure 10.1 because the numbers of organisms start low, increase ever faster for a while and then eventually reach an upper limit beyond which they do not increase.

The shape of an S-shaped population growth curve is the result of two processes. When the population is small relative to its resources, each individual organism is very successful at producing offspring, and the population grows each generation. If each individual produces three offspring, the population will triple in each generation. When this occurs, population growth is said to be geometric, that is, it increases by a certain factor (by a factor of 3 in this example) in each generation. If population growth continued in this geometric mode, the growth curve would resemble the upper figure boundary in Figure 10.2, and theoretically, would eventually reach infinity.

In real life however, this can never happen. As population size increases, a wide variety of negative influences will begin to act either on the reproducing individuals or their offspring that decreases their reproductive success. Each adult will produce fewer offspring. Finally when individuals produce, on average, only a single offspring, the population increase will stop. There are many factors that have a negative effect on reproductive success, and they may act on either survival or reproduction. Ex- amples of such factors include space, nest sites, food, disease, shelter, predation, accumulation of wastes, or migration. These negative influences on reproduction and survival gradually put the brakes on population growth until it finally ceases and the population size reaches an upper limit (Figure 10.2).

The upper limit of population size is called the carrying capacity (K) for that population. The carrying capacity is a characteristic determined by both the organism and the environment. Carrying capacity may be determined by the same factors that slowed the rate of growth, such as availability of food, shelter, nesting sites, or space, disease, etc. As these environmental conditions change, the carrying capacity of an environment may also change.
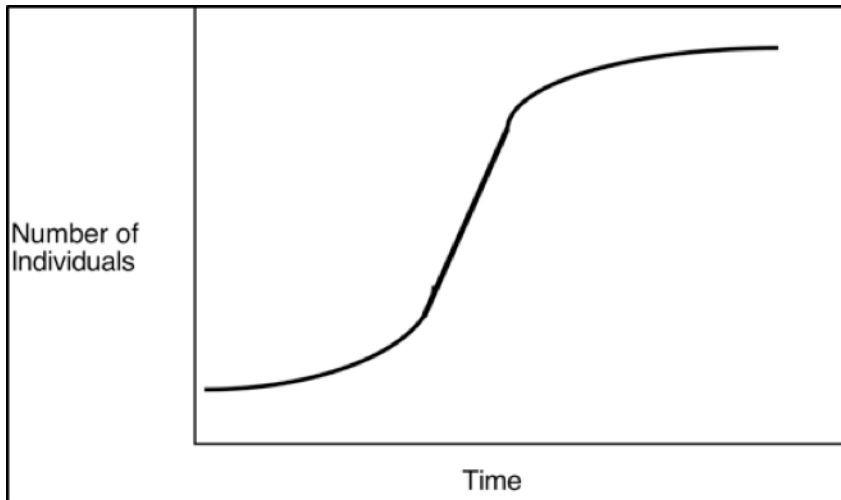
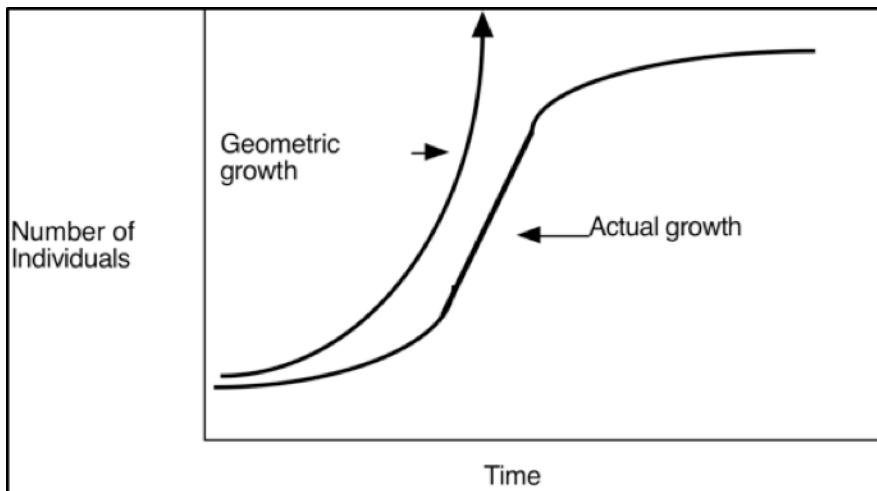Figure 10.1: Exponential and logistic population growth

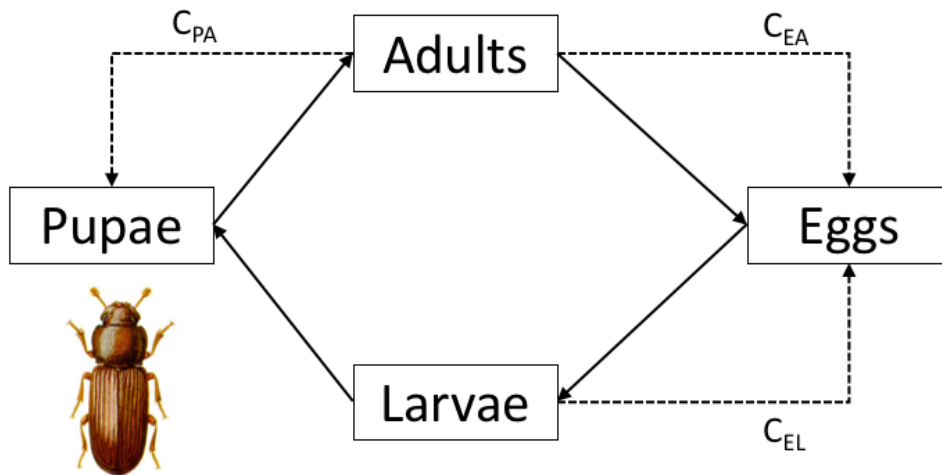Figure 10.2: Exponential and logistic population growth

Figure 10.3: Life cycle of the red flour beetle including the significant cannibalistic interactions.

Another way of looking at populations and population growth is from the point of view of the processes that result in changes of population size. There are four such processes: 1) birth, 2) death, 3) emigration and 4) immigration. Births and immigration represent gains in the population, while deaths and emigration represent losses. When:

`Birth Rate + Immigration Rate = Death Rate + Emigration Rate`

the population size will be stable, neither increasing nor decreasing. There are many factors that influence these four factors.

The nature of the factors that result in population growth and stabilization are central questions in ecology, and have been the subject of a great deal of research. In real life, populations of species generally interact not only with members of their population but with other species as well as their physical environment. This makes understanding and predicting population growth in natural populations very complex and difficult undertaking.

We are going to demonstrate the principles of population growth by studying it in a simplified system with only one species and a non-renewing environment. To do this we will use flour beetles. The flour beetles of the genus *Tribolium* are ideal subjects for this study. They are small, have short life cycles, require little care because they spend their entire life cycle in dry flour, can be easily counted at intervals, and can take the kind of abuse that you can dish out (*please don't test this theory*). The vial of flour is their universe - it both supports them and limits them.

The Red Flour Beetle (*Tribolium castaneum*) is an insect pest of flour and other stored grain products. Like many other insects, they go through a complete metamorphosis (Figure **??**). During complete metamorphosis, the immature stages do not resemble the adult stages (for example, caterpillars and butterflies). Adult female beetles can lay up to 400-500 eggs in stored grains. In 3-5 days the eggs hatch into the actively feeding stage called the larva. A larva grows by periodically shedding (molting) its skin (exoskeleton) until it reaches the size of the adult. It then molts into the pupa, which is the resting stage. This stage finally molts into the adult (Figure 10.4). The adult then matures and within days is able to reproduce by mating and laying eggs.

The flour beetle is a good insect for life cycle observations. All of its life stages are easy to rear and retrieve, and the life cycle is short. The life expectancy is approximately 6 months. The Red Flour Beetle is particularly ineresting because in addition to the intrinsic rate of increase, cannibalism at multiple levels deterines the population growth rate. These are depicted in Figure 10.3 (following Cushing et al. 2003). By careful observations you will be able to see a number of interesting phenomena for yourself. We will
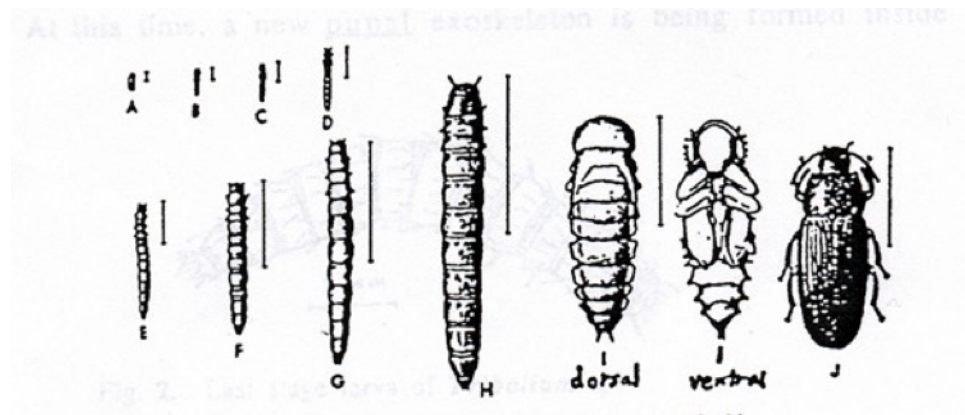
Figure 10.4: Life stages of flour beetles: A. Eggs, B-H. Larval instars, I. Pupa, J. Adult, from Lumsden et al. 2010.

manipulate the amount of resource to try to determine the impact of resource limited growth on the Red Flour Beetle population. We will also compare the effect of different type of food resources on their populations.

10.2   Objectives

- To understand and perform the elements of the scientific method by performing a population growth experiment with flour beetles
- To improve understanding of resouce limitation on population growth
- Practice developing and testing hypotheses regarding the effects of different environments on populations

10.3   Materials

- 4 glass vials (per group)
- Petri dish or tray
- Beetle growth medium (whole wheat flour)
- Tape (to label vials)
- 8 beetles (per vial)
- Marking pen
- Funnels
- Sifters
- Data table
- Data graph
- Calculator
- Paint brushes
- Petri dish with agar medium

10.4   Initial Set-Up

1. In groups of three, you will be assigned one of two type of food and will do four levels of that resource, requiring four vials.
2. Fill the vials with 2, 4, 8, or 16 g of food resource.

3. Mark each with a piece of tape with your group ID, date, lab section, and amount of the resource written on it.
4. Add 8 beetles to each vial if your instructor has enough, otherwise add 4 individuals.
5. Stopper the vials with cotton or a porous plug.
6. Make your first entry on your lab data sheet and in the laboratory computers.
7. The instructor will put the beetles in an incubator at a constant temperature and complete darkness.
8. Each week count the number of living adult beetles and number of dead adult beetles in the vial during your lab period or during another arranged time, recording the data on your data sheet and in the computer. Again, be careful not to leave flour on the tabletop. Depending on time, you may count the number of larvae and pupae in the vials.

In order to count the number of beetles, pour the contents of the vial into the sifter. Sift the flour into the tray. After counting the number of adult beetles, return the beetles and the medium to the vial using a funnel (*NOTE: Do not leave any flour on the table top. This flour may contain eggs*)

10.5   Assignment

Near the end of the semester, we will do final counts and organize and distribute all the data from both lab sections. You will then answer a set of questions relating the experiment to ecological and scientific concepts. A rough outline of the questions are listed below but will be provided in more detail in lab during the final beetle count day.

1. During the last week of observation, make a final population count of the adult and larval beetles in your vial. Enter the data into the class Google Doc.

2. Your instructor will organize a table of the compiled class data from the Google Doc and post it under "Course Materials" on Blackboard. From these data, plot week (on the x axis) versus mean adult population size (on the y axis) **for each food type**. Use the data on your graph to determine the slope during each time interval (REMEMBER: slope is the change in y over the change in x, or rise over run; i.e., $slope = \frac{\Delta y}{\Delta x}$). Record the slopes for each week in a table.

Between weeks 1 and 2

Between weeks 2 and 3

Between weeks 3 and 4

Between weeks 4 and 5

etc.

3. How do the slopes change? What does this tell you about the beetle population growth over the course of the semester? Does food type matter? What would happen to the population growth if all the slopes were the same?

4. Plot the abundance (y-axis) over time (x-axis) of adult beetles for **each food amount**. Do the same thing for larvae. How does the amount of food affect the pattern of population growth? Do the patterns look the same for larvae and adults?

5. If the beetle population reached a peak, why did it not stablize at that point? What could be done to maintain a stable population level?

Chapter 11

Competition and Allometry

Lab adapted from the University of New Mexico Biology 310L, Principles of Ecology Lab Manual

11.1 Lab activities

1. Collect data on survival, size, and mass of plants
2. Plan data entry
3. Discuss our findings
4. Discuss expectations for lab report

11.2 Objectives

You should get a feeling for how to think and work through a controlled experiment, with treatments, controls, and replicates. You should understand the concept of competition in the sense of what happens to individuals and in the sense of how it can contribute to the development of community structure. You should also be getting comfortable with how to bring real data and models together to produce deep insights into how nature works.

11.3 Introduction

The theory of natural selection assumes that living organisms compete for limited resources. Those individuals with phenotypes that allow them to more efficiently gather those limited resources and turn them into viable offspring are favored over time and are selected for. In the case of plants, competition between neighbors for sunlight, water, and nutrients influence patterns of growth and reproduction (Harper 1977). In other words, nearby competitors of the same or other species reduce the amount of resources available to an individual, which may then suffer reductions in growth, reproduction, germination, and survival. In addition, competition may affect how plants allocate resources to aboveground or belowground growth and reproductive structures (such as flowers) (Harper 1961).

Plants have developed mechanisms to deal with competition. Competition for light results from shading by the leaves and stems of neighboring plants. To compensate for the reduced light availability caused by their neighbors, plants may change leaf morphology to capture more of the available sunlight (recall performing an ANOVA using MS Excel or the `Anova` function in R during the Statistics Lab (Chapter 4) to test for differences in petal length among species of iris). Competition for water and nutrients occurs belowground.

Plants have evolved root structures to access water in different parts of the soil column (such as on the surface or deeper down), allowing some plants to grow a little closer together without experiencing quite as much competition. And some plants, such as creosote bush (*Larrea tridentata*), may even excrete chemicals into the soil that inhibit the growth of nearby plants (known as allelopathy), effectively reducing the competition experienced by the allelopathic plant (Mahall and Callaway 1992).

Competition also contributes to the development of plant communities. Have you ever noticed that mature forests tend to have widely spaced trees, whereas younger forests tend to have trees spaced more closely together? When a forest begins to regrow after a disturbance, many seeds may germinate, and many small young trees will begin to grow. As the trees get larger however, their demand for nutrients increases, causing increased competition among the trees. Ultimately, many of the young trees die out, leaving a maturing forest with more widely spaced trees. This decreasing density of stems as the stems get larger is called self-thinning.

The negative relationship between the number of plants and the size of the plants follows a power law. We can write:

$$M = kD^\theta$$

where M is plant mass, D is plant density, θ is the exponent characterizing the relationship, and k is the prefactor (intercept in a log-link regression).

Original estimates of θ were $-3/2$, fitting a simple geometric model of plant growth (Yoda et al. 1963). The geometric model is based on the idea that plants fill a three-dimensional space but cover ground in only two dimensions (thus 3 over 2). Recent evaluations of the rule suggest a value of $\theta = -4/3$, which can be accounted for by a fractal model of plant allometry (Weller 1987, Niklas 1994, Enquist et al. 1998). An allometric relation, again, is one where traits of various organisms can be linked to body mass via a power law. In this case, the fractal branching of a plant's roots and stems determines how much space is required by a plant of a given body size, which in turn determines how many individuals can fit in an area. Try to imagine how a tree's branches and roots fan out and begin to intermingle with the branches and roots of neighboring trees. Branching structure determines how much space a plant needs. The exponent is $-4/3$ because the plant is operating in three dimensions plus time (four dimensions) to move resources through the branching network, but they do it through space (thus 4 over 3).

In this exercise, we will perform a controlled greenhouse experiment with cultivated radish to measure competition in plants and test the theory that plant mass scales with density to the $-4/3$ power. We will plant seeds at a variety of densities, watch them grow, and measure the relationship between size and density at the end of the experiment. Because competition impacts survivorship, growth, and reproduction, we also will examine the effects of density on survivorship and on the tendency to store energy in tubers (the radish itself).

11.4   Hypotheses

1. There will be lower survivorship as densities increase,
2. The plants will grow larger at lower densities, creating a negative relationship between plant mass and density,
3. The mass of the plants will scale to density to the -4/3 power,
4. The plants will be less likely to store energy in tubers at higher densities.

11.5   Materials

- 12-cm plastic pots (1 per student)
- Marker stakes or label tape

- plastic starter trays
- Sand and potting soil thoroughly mixed at a 1:1 ratio
- ~850 radish seeds
- Rulers
- Electronic balance

11.6   Planting Methods

1. Set up the pots in the trays. We will decide on replicates and treatments in class, but we often have 4-8 replicates of four density treatment (2, 5, 15, or 30 plants). Each student will be randomly assigned an experimental treatment.
2. *Optional:* Tear (~15 cm by ~15 cm) squares of newspaper and crimp into the bottom of each pot.
3. Mix the potting soil.
4. Fill each pot with an equal amount of soil. The easiest way to do this is to fill the pots up to about 1.5 cm from the top of the pot, or to the point where the pot gets a little wider, if it does, or to a lip in the pot, if there is one. Try not to let the soil quantity vary from pot to pot.
5. Label pots with your name, date, and experimental treatment and which lab section you are in.
6. Lay the correct number of seeds out for each pot. Add extra seeds to make sure that if not all seeds germinate that we will still have the correct number of plants (we will decide as a class how many extra to add). After germination, we will randomly prune the seedlings down to the correct treatment level.
7. Push the seeds no more than ¼ inch into the soil and cover with a small amount of soil.
8. Lightly spray the top of the soil with water and fill the tray up to about 1 inch deep with water.
9. *If greenhouse technician is not available*: Sign up to water the plants, and note your watering days on your calendar. On every other day, we will rotate the flats so that they all get equal exposure to the light during the course of the experiment.
10. We will thin the pots after about two weeks.

11.7   Measurement Methods

1. We will do all of the measurements on the day the competition lab is scheduled. Bring all of the plant trays into the lab.
2. When we get started, always take care to note which treatment and replicate you have.
3. Count the number of surviving stems in each pot. You may have to decide what constitutes "surviving" because some plants will be yellowing and not dead yet. Assume that the original number of plants in a pot can be determined by the total number of living and dead shoots.
4. Measure the height of the plants from the soil surface to the extent of the tallest leaf. Grab the tallest leaf of all of the plants and estimate the highest extent for the plants as a group, and take your measurement there.
5. Dig up the plant and shake the soil loose from the roots if the soil is dry enough. If the soil does not all easily come off, you will need to rise them in water then gently pat them dry before weighing. Determine the mass of the plant by weighing it on the electronic balance. Cut off the radish itself and weigh that. Now we have the whole plant mass, the aboveground mass, and the belowground mass.
6. If the plants have sent up inflorescences (flowering stalks), we will want to quantify the number, height, and perhaps number of flowers, too.

11.8   Analysis Methods

1. Enter measurements into a spreadsheet, pool among sections, and distributet to whole class (try Google Form or Sheet).

2. Calculate the mean above-ground, below-ground, and total mass of the plants for each pot. Do this for separately for plants that flowered and for plants that flowered. That is, for each pot, there are going to be two sets of averages.

3. Take the log (base 10) of the masses and the density.

4. Plot all three types of log mass (whole plant, above ground, and below ground) against log density. There should be two plots: one for plants that flowered and one for plants that did not.

5. Add the linear regression trendlines and their equations to the graph along with the R^2 value (or report in the figure description). Make sure that the legend and/or figure description clearly states which set of data are plotted with each color or symbol.

6. Using the coefficients from the regression equation above, produce the power laws that relate each type of plant mass to density. You might consider putting all of the power laws in a table in the lab report.

7. Evaluate the scaling relation between flowering and density: do the same type of plot as above. This time however, plot the log(density) on the x-axis and the log(average # of flowers) on the y-axis.

8. Fit a linear trendline and add R^2 and equation to the graph (or figure description). Make sure to use only the set of data for plants that flowered.

11.9   Results and Discussion

These questions are just to stimulate your thought for the discussion section of your lab report. They shouldn't be answered in a numbered section but rather in paragraph form weaved into the discussion.

1. Did the plants get smaller as density increased?

2. Can you list the resources for which the plants competed that would cause this pattern?

3. Were there any results, perhaps a particular treatment, that came out other than expected? Was there a lot of within-treatment variation? What would cause the variation?

4. Did we find the expected power law between size and density? What was the scaling exponent? Was this close enough to -4/3 to believe that is really what we found? If not, why do you think it wasn't?

5. Did the experiment give an adequate test of the theory?

11.10   Literature Cited

Enquist, B. J., J. H. Brown, and G. B. West. 1998. Allometric scaling of plant energetics and population density. Nature 395:163-165.

Harper, J. L. 1961. Approaches to the study of plant competition. Pp 1-39 in Mechanisms in Biological Competition (F.L. Milthorpe, ed.), Symposium No. 15, Society for Experimental Biology. Cambridge University Press, Cambridge.

Harper, J. L. 1977. Population Biology of Plants. Academic Press, London. Mahall, B. E., and R. M. Callaway. 1992. Root communication mechanisms and intracommunity distributions of two Mojave desert shrubs. Ecology 73:2145-2151.

Niklas, K. J. 1994. Plant Allometry: The Scaling of Form and Process. University of Chicago Press, Chicago. Weller, D. E. 1987. A reevaluation of the -3/2 power rule of plant self-thinning. Ecological Monographs 57:23-43.

Yoda, K., T. Kira, H. Ogawa, and K. Hozumi. 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. Journal of Biology Osaka City University. 14:107-129.

11.11 Homework – Lab Report

You will write up a lab report covering this chapter's questions and analyses. The report is due on November 15 (Tuesday section) and 16 (Wednesday section). Write a short but complete report that tells what your question was, how you answered it, and what the answer was.

What needs to be in the report:

1. Introduction

Introduce the topic of intraspecific competition and how it influences access to resources and growth. In your own words describe the theory relating plant size to density. Describe how your study relates to that theory. What specific questions are you asking? Generally, how are you going to answer them? Specify what needs to be shown to support or refute your hypothesis. Strategically, you want to pose a compelling question that is answerable by the results, thereby creating a meaningful storyline for the reader to follow.

2. Methods

Describe what you did in just enough detail to allow someone else to repeat your study.

3. Results

Without any discussion our interpretation, describe what you found. You must include the figures discussed in 2 and 3 of the analytical methods above. The graphs must be produced in a spreadsheet program. Each graph must have clearly labeled x- and y-axes and a figure legend (below the figure) that orients the reader to the result. In the text, describe the results in words. For example, you could say, "Survival of plants declined with increasing density of plants (Figure 1)," or "Plants were taller in the low-density treatments (Figure 2)". Say what you found as simply and directly as possible. As an author, your task is to guide the reader's attention to the key information. Some specific style requirements are 1) use the past tense, as you have already conducted the study, and 2) do not add additional tables of data or printouts of your spreadsheet.

4. Discussion

What is/are the answer/s to your question? Is it what you expected? If not, why not? Were the methods insufficient? Were there enough data? How does this study relate to the major studies? Was there something we did that limits what we can say from our results? Do you have alternative interpretations that are consistent with your results?

5. Literature cited

Properly list the references cited in your text. The list should definitely include Enquist et al. (1998). It should also include at least two other peer-reviewed journal articles that you have found. Format references like the Literature Cited of this chapter.

11.12 Grading key to the lab report on competition and mass-density scaling

Use this key to help you include the necessary components of the paper (30 points total).

11.12.1 Introduction (6 points)

- General opening to paper (1)
- Defined competition (1)
- Described theory of size-density scaling (i.e., the power law that relates them) (1)
- Stated hypothesis/question (1)

- Errors and readability (2)

11.12.2   Methods (8 points)

- Explained our experimental setup (2)
- Explained our efforts at reducing bias and confounding variables (1)
- Explained how we determined flowering, density, and mass (1)
- Explained how we determined the power law in our study (2)
- Errors and readability (2)

11.12.3   Results (9 points)

- All three figures included with legends (3)
- Presented relationship between density and flowering (1)
- Presented relationship between density and mass (2)
- Errors and readability (2)

11.12.4   Discussion (7 points)

- Discussed relationship between density and flowering (1)
- Discussed relationship between density and mass (2)
- Two additional references (2)
- Critique of methods (1)
- Errors and readability (2)

Chapter 12

Turtle Ecology

Lab adapted from "Turtle Population Biology" by Greg Haenel at Elon University

12.1 Objectives

- Understand important demographic parameters to estimate
- Become familiar with various local pond turtle species
- Learn how to collect mark recapture data
- Learn how to mark turtles
- Learn how to measure and sex turtles
- Practice applying basic mark-recapture calculations

12.2 Lab activities

Goals of today: Catch turtles, see if they are marked, if not, mark them, and measure them. Take data and photos.

You will need to dress appropriately for being outdoors. You may want to bring water, a hat, sunscreen, long pants, and shoes that protect your feet. Flip flops and shorts will not be adequate for outdoor labs. If you have any allergies to bee stings (or similar issues) please inform your instructor at the beginning of class. Waders may be beneficial but are not required.

This week we will focus on mark recapture techniques using pond turtles as a model system. You have read a little background on some of the more common species found in ponds of the region. You will be taking part in an ongoing mark-recapture study of the turtles in the C&O Canal National Historic Park. One of the key questions in population biology is, "what are the current and future population sizes of a given organism?" Current population sizes can be estimated using mark-recapture methods. To predict future population size we need to also estimate survivorship, reproductive schedules (birth rates), death rates, immigration, and emigration rates. Some of these parameters are beyond the scope our lab but we can estimate some as we collect more data over more semesters. As you observe the pond ask yourself the following questions:

- What factors might impact survivorship of the turtles?
- Would survivorship of hatchling and adult turtles be similar?
- What may be impact growth rates of the turtles?
- What could be impacting birth rates?
- Is there a relationship between growth rates of turtle and fecundity (or birth rates)?

- These turtles lay eggs that they bury in the ground. What factors may be impacting the success of female nesting?

12.3   Mark Recapture (Capture Recapture)

For species that are difficult to capture or detect, mark-recapture can provide a much better estimate of population size (abundance) or density. The simplest form of mark-recapture is the Lincoln-Peterson estimator with a single marking (cohort marking) and single recapture effect. The estimator is calculated as

$$N = \frac{nM}{R}$$

where N is the esimate of the total population size, n is the number of animals captured in the sample (number caught on day 2), M is the number of marked individuals released back into the population (usually number of animals caught on day 1), and R is the number of marked recaptures in the sample (day 2).

12.4   Questions for Lab Assignment

1. What difference is there between the claws on the front feet of male and female painted turtles?

2. What is the average size of female painted turtles?

3. What is typical food of a painted turtle? Are adult painted turtles are carnivorous, omnivorous, or herbivorous? Define each term.

4. How do you sex snapping turtles?

5. Use the class data from the first two trapping days (posted on blackboard) to calculate the total abundance of each species.

6. What are the assumptions of the Lincoln-Peterson population estimator? Look up and describe at least one more robust mark-recapture population estimator and indicate why it might be better.

7. What are the sex ratios of each species?

8. Plot the size distribution (histogram) of each species using one of the measurements we took. Why did you choose this measurement? *Be sure to label your axes and any other symbols used*

Prior to the start of this lab we will continue activities related to ongoing experiments:

Chapter 13

Population Spatial Variation

- Go over literature cited 10 sources and topics
- Count flies and pupa
- Thin plants to treatment density, water, 1/4 turn

13.1   Lab activities

1. Learn salamander and invertebrate identification
2. Plan data entry
3. Collect natural cover object field data on replicate plots
4. Discuss expectations for lab report

13.2   Objectives

13.3   Introduction

13.4   Hypotheses

13.5   Materials

- Tape measures
- Pin flags
- Data sheets
- Clipboards
- Pen/Pencils

13.6   Methods

1. In groups of 3-4 students, establish a 4 x 25 m plot, ensuring that sides of the plot are parallel (rectangular plot). Use flags for the corners of the plot.
2. Flip all natural cover objects (rocks and logs) that you can move, which have a contact patch with the ground greater than 400 cm^2.

3. Tally the number of each salamander spp., beetles, centipedes, and millipedes found the plot.
4. Record the number of cover objects flipped in each plot.
5. Back in the lab: Enter measurements into a spreadsheet, pool among sections, and distribute to whole class.

13.7   Literature Cited

13.8   Homework – Lab Report

For next week, answer each of the following questions. Answers should be typed using 12 point font and 1 inch margins. Late homework will not be accepted.

1. Make a table with the mean and standard deviation for each taxa across all replicate plots.

2. Which species/taxa has the highest variability in counts? What species/taxa is most abundant?

3. Is there a significant difference in the counts among species? How do you know? Show your work/results (hint: this will require an ANOVA).

4. Does the number of cover objects flipped in a plot influence the number of salamanders found? (hint: this will require a linear regression). Plot the number of objects flipped vs the count of salamanders in each plot. Add the linear regression trendlines and their equations to the graph along with the R^2 value (or report in the figure desription).

5. What might be a better measure of search effort and available habitat rather than the number of cover objects flipped?

6. If this were a real observational field study, what are some other variables that you would want to record?

Chapter 14

Forest Stand Dynamics

14.1   Lab activities

1. Plan data entry
2. Collect data on forest stand characteristics
3. Discuss expectations for lab assignment

14.2   Objectives

- Become familiar with the stages of forest succession
- Gain experience with standard forest measurement techniques
- Be able to visually identify stands at different stages of succession
- Contextualize field observations with reading on stand development patterns
- Gain additional pratice in hypothesis testing

14.3   Introduction

Ecosystems are constantly in flux. Some changes are subtle and short-term while other changes alter the entire structure and function of an ecosystem. Even long-lived forests that may appear relatively stable change over time. Community ecologists are interested in understanding and predicting the changes in community structure including the different species present, relative abundance of different species, and the interactions among these species. Ecosystem ecologists are interested in how these changes alter the processes such as nitrogen and carbon cycling and exchange of materials into and out of the system. Fish and wildlife biologists are often interested in how the changes in the major plant communities affects populations of fish and wildlife through altered food resources and habitat structure. Finally, conservation biologists and land managers are frequently concerned with the protection of rare species, habitats, or communities. Today we will examine the process of change in forest communities. We will refer to the change in forests over time as forest stand dynamics. Below are definitions of a few important terms we will use in this lab.

A **stand** is a spatially continuous group of trees having similar structures, growing under similar conditions, and often started development following the same stand-replacing disturbance (Oliver and Larson 1996).

DBH is the diameter at breast height is the diameter of a tree at 1.35 m (4.5 ft) above ground. When on a slope this is measured from the upslope side of the tree. If the tree splits into multiple trunks below this height, each trunk is measured independently.

CWD stands for coarse woody debris and refers to dead fallen logs on the forest floor.

Species Richness refers to the number of species in a given area.

Common trees in the area (You should familiarize yourself with these before lab):

- Pin cherry
- Black cherry
- Witch hazel
- Red maple
- Sugar maple
- Red oak
- Chinkapin oak
- Pitch pine
- Tulip poplar
- Yellow birch
- Eastern hemlock
- Striped maple
- Black locus
- Sassafras
- Pignut hickory
- Shagbark hickory
- American chestnut (rare but at the site)
- Sumac (*Rhus spp.*)

14.4   Materials

- Tape measures
- Pin flags
- DBH tape
- Spherical densiometer
- Tree/CWD calipers
- Data sheets
- Clipboards
- Pen/Pencils

14.5   Methods

1. In groups of 3-4 students, establish a 5 x 5 m plot in the recent clearcut or a 10 x 10 m plot in the other forest stands. Use flags for the corners of the plot.
2. Count the number of stems above 2 m tall in the plot by species.
3. Measure the DBH of the 5 largest trees in the plot.
4. In each coner, measure the canopy cover using the spherical densiometer.
5. Measure the diameter of any CWD in the plot at the midpoint of the log.
6. Back in the lab: Enter measurements into a Google spreadsheet, pool among sections, and distribute to whole class.

14.6   Literature Cited

14.7   Homework – Lab Report

For next week, read Chapter 5 of Forest Stand Dynamics (Oliver and Larson 1996) posted under Readings on blackboard. Answer each of the following questions. Answers should be typed using 12 point font and 1 inch margins. Late homework will not be accepted.

1. What are the stages of stand development?

2. Species composition during stand initiation is often largely determined by the type of disturbance that initiated development. How might disturbance from a stand-replacing fire change the early species composition relative to logging (which we observed)? Don't focus on specific species bur rather general differences in the types of species or source of species that would first dominate.

3. Which strata did you observe in the second forest stand we visited and which stage of development do you think this stand is in? Why?

4. Make a null and alternative hypothesis regarding the species richness in the difference forst stands.

5. Test your hypothesis using the data. Did you reject or accept your null hypothesis? (hint: In which stand did you observe the most species, be sure to compare per unit area if you didn't use plots of the same size? Was the difference in species richness *significantly* (statistically) different among stands? Show your evidence).

Chapter 15

Phenology

Phenology is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life. It has been referred to as "nature's calendar". The root *phaner* originates from the Greek *phaneros* meaning visible, open, evident, or to show. This in turn relates to the Greek *phainomenon*, that which is seen. This is where we get our English term "phenomenon" and phenology being short for phenomenology. This basis in the root meaning "to show" is why phenology (birds show up in the spring, flowers appear and become evident) and phenotype (outward appearance or expression of the genotype). -From E.C. Jaeger. 1955. *A source-book of biological names and terms.* Third Edition.

15.1 Activity

Recording phenology data over broad spatial extents and long time periods is generally more than a single research can accomplish. As such, the USA National Phenology Network maintains data submitted by researcher and volunteer citizen scientists. They hae accumulated more than 10 million phenologic records. Your task today is to

1. go to their data portal https://www.usanpn.org/node/21094 and download phenology data for a place and species of interest.
2. Filter, sort, and summarize the data in MS Excel as necessary (*remember the magic of pivot tables*)
3. Make a Line plot of one or two phenologic traits (e.g. egg laying, fledging, flowering, arrival, etc.) for that species and a particular location or region.
4. Add a trendline to see if there is a change in the phenology over time.
5. Share with the class what species and location you picked, what the trend looked like, how variable the trait was, and any other interesting information you found.

If you get interested in this and want to contribute to science, you can contribute data to their Nature's Notebook Project at https://www.usanpn.org/natures_notebook.

Chapter 16

Lab 2: Population Setup and Statistics

16.1 Population Density Dependence

16.2 Review of Introductory Statistics

16.3 Introduction to Scientific Programming

16.4 Basic Statistics with R

We can use an Analysis of Variance (ANOVA) to test whether petal length differs among species of iris.

```r
# Conduct and save the analysis
length_anova <- aov(formula = Petal.Length ~ Species, data = iris)

# View the summary results
summary(length_anova)
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## Species        2  437.1  218.55    1180 <2e-16 ***
## Residuals    147   27.2    0.19
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Chapter 17

Migration

Prior to the start of this lab we will continue activities related to ongoing experiments:

- Go over literature cited 10 sources and topics
- Count flies and pupa
- Thin plants to treatment density, water, 1/4 turn

17.1 Lab activities

1. Learn diurnal raptor identification
2. Sign out binoculars
3. Review binocular use
4. Collect data on migrating hawks
5. Return binoculars
6. Discuss lab homework

17.2   Objectives

17.3   Introduction

17.4   Hypotheses

17.5   Materials

17.6   Planting Methods

17.7   Measurement Methods

17.8   Analysis Methods

17.9   Results and Discussion

17.10   Literature Cited

17.11   Homework – Lab Report

Chapter 18

Population Growth

Lab adapted from Heaps et al. (2016)

18.1   Initial Set-Up

Step 1: Obtain Supplies

You will be working in groups of four. You will need two vials and two jars for each group, a culture of fruit flies, FlyNap, and a wand. Prepare your culture medium in each container using 1 part dry flakes, 1 part water (20 ml of each; it should be the consistency of peanut butter), and a pinch of yeast (a few grains). You will prepare the following four set-ups within your group:

- Large jar, warm conditions (25 C)
- Small vial, warm conditions (25 C)
- Large jar, cold conditions (20 C)
- Small vial, cold conditions (20 C)

Step 2: Anesthetize Fruit Flies

1. Dip absorbent end of the wand into the FlyNap.
2. Tap the culture vial of flies on the table top to knock the flies to the bottom of the vial and with one finger push the plug very slightly to one side.
3. Remove wand from vial of FlyNap; quickly stick anesthetic end into culture vial just below plug. Be careful not to touch the wand to the foam cap!
4. Immediately replace the cap on the FlyNap vial.
5. Tip vial on its side and wait approximately 1 minute with wand in place—just until all but one or two flies are asleep (**too long will kill them!**). Do not touch the culture medium with the wand.
6. Remove wand and plug from culture vial and spill flies onto card for study.
7. Replace plug in culture vial; return wand to box.

Step 3: Determining the sex of your flies

You will need to obtain one male and one female fruit fly. This means you will have to determine their sex. You should have researched this at home. Discuss your findings with your group members and your instructor to be sure that you understand how to do this. After you have sexed them you will place one male and one female into your jar.

Place the fruit flies in your jar but keep them on their side. Be sure that they do not fall into the medium where they can drown. After you have your flies in the jar you will plug it with the provided foam and leave

it on its side (your instructor will place it upright once the flies wake up later in the day, or we will do it at the end of the lab period).

Predictions:

Discuss with your group your four different set-ups (two different jar types and two different fly types). Consider and answer the following questions together:

1. How do you think jar type will affect your population size over the next ten weeks? Why?

2. How do you think temperature will affect your population size over the next ten weeks? Why?

3. Do you expect that container size will interact with temperature to affect your population size over the next ten weeks? Why?

4. Make a prediction as to approximately how many flies you think you will get in each of the four set-ups.

Step 4: Your Assignment—Counting your fruit fly population

Each week you will count the new offspring in your jars/vials. In order to do this you will need a little background on the lifecycle of a fruit fly. Your assignment is to go home and research Drosophila. Specifically, investigate information regarding their life expectancy, breeding cycles, life stages, etc. You will need to come up with a feasible way to determine your population size each week. This research will also help you to more accurately predict how many flies you think you will have in each set-up at the end of ten weeks.

18.2 Assignment

For your lab, you will be looking at how fruit flies grow in an ideal environment. At the beginning of the semester, you placed two male and two female flies in a jar with food and closed the lid. These fruit flies then reproduced over the course of the semester.

1. Based on your background research, draw below the life cycle of a fruit fly including approximate timing below.

2. If we start with four fruit flies in a jar with an abundance of food, what do you think the population will be after reproducing for a week? a month? four months? Record the expected numbers based on

exponential growth ($N_t = N_0 e^{rt}$) assuming an intrinsic rate of growth of 0.18. What would you have to do in order to keep the population growing indefinitely?

3. Plot week (on the x axis) versus adult population size (on the y axis) for cold (20 C) and warm (25 C) vials. Just use the data from your group (unless you never had any reproduction, in which case you data from a different group). Use the data on your graph to determine the slope during each time interval (REMEMBER: slope is the change in y over the change in x, or rise over run; i.e., $slope = \frac{\Delta y}{\Delta x}$). Record the slopes for each week in a table.

Between weeks 1 and 2

Between weeks 2 and 3

Between weeks 3 and 4

Between weeks 4 and 5

etc.

4. How do the slopes change? What does this tell you about the fruit fly population growth over the course of the semester? What would happen to the population growth if all the slopes were the same? Are these curves better represented by an exponential or logistic growth curve? Why? If it looks logistic, what is the carrying capacity?

5. Repeat question 3 but using pupa rather than adult flies and do it for all four experimental treatments (temperature X small/large). How do they compare? Which flies did best (explain)? Which did worst (explain)? Can you hypothesize factors that might have caused differences between treatments?

6. If you were to repeat this experiment, what would you do differently?

7. If you were to design a population growth experiment for this class, what treatments would you use (i.e. what factors would you experimentally manipulate) and why?

Chapter 19

Cemetery Demographics and Life Tables0

Note: This handout is modified from the following lab activities 1) "Cemetery Demography" by Nancy Flood (U. Toronto) in the Ecological Society of America's Experiments to Teach Ecology, edited by Dr. Jane Beiswenger and 2) Human Population Ecology by Dr. Bruce W. Grant, Department of Biology, Widener University, Chester, PA.

19.1   Synopsis of Today's Lab.

Today we will travel to a local cemetery and record dates of birth and death etched on the headstones commemorating previous local residents. After lab, I will pool the class data and you will examine demographic parameters such as survivorship and mortality of males and females during two time intervals: pre-1950 and 1950 to the present.

19.2   Introduction

Demography is the study of the internal composition of populations and the effects of that composition on population growth. Patterns of survival vary a great deal from one species to another. Moreover, depending upon the environment, there may be substantial variation in survivorship within a species. Age is an important structuring component for many populations because fecundity and survivorship frequently vary with age.

Humans are one species whose fecundity and survivorship is affected by age and the environment. This includes occupation and the time period in which they live. One way that biologists attempt to discern patterns in survivorship rates is to use a bookkeeping system called a life table. Life tables were developed by the insurance industry because in essence, they are betting on how long you may live. Life tables permit them to keep track of how long different segments of the population have lived. From this, they try to predict how long the current population will survive. Ecologists have adopted this technique to help them study the population patterns of plants and animals.

The basic data in a life table are the number of individuals in each age class. There are two different approaches to constructing life tables; a cohort life table and a static life table. The most straightforward of the two is the cohort life table. It starts with a group of individuals born at the same time and tracks their mortality until the last one dies. Cohort data are difficult to obtain, so these data sets are not common. The other way to construct a life table is to record the age at death of a large number of individuals. This

information can be used to calculate mortality and survival and thus create a static life table. The table is called static because the method involves a snapshot of survival within a population during a short interval of time. Your sampling will create a static life table over a long period of time.

Local cemeteries are an excellent place to study human demography. Etched in the gravestones are the dates of birth and death of the person below, at least in most cases. From these data we can calculate death rates and draw survivorship curves. A survivorship curve is simply a graphical representation of the chance that an individual will survive from birth to any particular age. By comparing survivorship curves for different periods of time we may look for historical trends in demography over the decades. Also, different cemeteries may represent different socio-economic cross-sections of the population, and comparing data among cemeteries may reveal different patterns of mortality.

Over the last few centuries, advances in health care and large-scale global political conflict have left rather opposing marks on the demographics of our population. In this lab, you will investigate how three major time intervals in American history impact the survivorship of this local population. Pre-1900, the U.S. experienced its own Industrial Revolution, the Civil War, a 2nd Industrial Revolution following the Civil War, and a lot of changes in politics. The period between 1900 and 1950 includes periods of prosperity (the roaring 20's) WWI, the Great Depression and WWII. Following 1950, numerous vaccines and antibiotics were widely used and, with the exception of the Korean, Vietnam, and Gulf Wars (not to mention a few other incidents…), this has been an era of relative peace in North America (in the greater historic context). What are your predictions about how the demographics of the local human population have changed during these two time periods?

In order to study the demography of the entire human population that once lived in the area, we would have to study all of the local cemeteries and assume that no one emigrated from the area and was buried elsewhere. Neither is likely. We only have a few hours, and many deceased local residents were buried, or otherwise, elsewhere. Thus for now, we will assume that the cemeteries we will visit are representative of all humans in this area, although we should be aware of these sorts of biases in the data.

19.3   Methods

Location: Frostburg, MD.

Data Collection: The cemetery is typical of many of the local churches. Older headstones are close to the main church, and more recent ones are farther away as the cemetery expanded. We will collect data from headstones in a manner so that everyone can investigate both old and new headstones. You will work in pairs, first in the older portion, then in the newer one. One person from each pair will collect data on females and one will collect data on males. Collect data from as many headstones as possible without overlapping the progress of others. To help prevent overlap, each pair will start at the beginning of a row. When you are done, you collectively will have gathered data on;

- Group 1: FEMALES WHO DIED BEFORE 1900 Group 2: MALES WHO DIED BEFORE 1900
- Group 3: FEMALES WHO DIED AFTER 1900 BUT BEFORE 1950 Group 4: MALES WHO DIED AFTER 1900 BUT BEFORE 1950 Group 5: FEMALES WHO DIED AFTER 1950
- Group 6: MALES WHO DIED AFTER 1950

!!PLEASE CALCULATE THE AGE AT DEATH FOR ALL INDIVIDUALS!!

Back in the lab we will enter all the data into a google spreadsheet and I will check it over and post a final copy to blackboard for your use in answering the questions.

19.4   General Instructions

Record what group you are collecting data for at the top of the Data Sheet #1. Record your names. Enter the data from the headstones. There are spaces for the birth year, death year and age at death. The cells of the data sheet are designed so that you can calculate one bit of data from the other two.

Some guidelines for collecting data. If you are unable to tell from the name or other evidence whether an individual was male or female, omit him or her. If only initials are used rather than given names, the individual was probably male. Occasionally infants or stillborn children were recorded as simply "baby", "infant" or some other designation from which sex cannot be determined. Tally these and put half in one sex and half in the other of the 0 category.

Please exercise restraint when collecting these data. Do not run, shout, stomp on graves, etc. Be respectful of the dead and those who mourn the dead. If there are burials or mourners we will stay a minimum of two rows from them.

19.5   Data Analysis

To estimate demographic characteristics of the local population, we need to know the ages of people when they died for each sex and time interval. To get this, simply examine your field data sheets, and count the number of people who died in each age interval, 0-0.9; 1-9; 10-19; etc.

The life table parameters are defined in the table below. The data used to generate a life table is either the number of individuals (n_x) surviving from a chorot of individuals born at the same time (a cohort or horizontal table) or the proportion of individuals (l_x) surviving to each life stage as derived from the age structure of a population (static life table or vertical table). In our case, we will use the proportionate survivorship group data from our sampling.

x	Age class	Calculation
n_x	Number of surviving in cohort	Data or $1000 * l_x$
l_x	Survivorship for x to $x+1$	Data or $\frac{n_x}{n_0}$
d_x	Deaths for x to $x+1$	$|n_{x+1} - n_x|$
q_x	Mortality rate for x to $x+1$	$\frac{d_x}{n_x}$
L_x	Average number alive during age interval x to $x+1$	$\frac{n_x+n_{x+1}}{2}$
T_x	Total years lived into the future by individuals of age class x	$\sum_x^{X_{max}} L_x$
e_x	Life expectancy for age class x	$\frac{T_x}{n_x}$

Note that we have set the initial n_x value to 1000. This is the traditional cohort, although you can use any value and get the same results. For the expectation of further life, sum the L_x values from the target age class (x) to the bottom of the life table.

$$e_x = \frac{\sum_x^\infty L_x}{n_x}$$

In order to use life table information to estimate population growth, we must add an additional column to our life table, the age specific fertility or birth rate (b_x). This is the average number of offspring produced per female of age class x, so it is technically fertility, not fecundity, although you often hear it referred to as the age specific fecundity rate.

Since the calculations that follow use products of x, l_x, and b_x, we have added appropriate columns to the life table. Below is an example life table 6.3 including birth rate information.

We can now compute the average generation time, G, for our population. This is sometimes expressed as T so be careful not to get it confused with T_x.

$$G = \frac{\sum_0^\infty x l_x b_x}{R_0}$$

where R_0 is the net reproductive rate calculated as

$$R_0 = \sum_{i=0}^{i=\infty} l_x b_x$$

From this we can estimate the intrinsic growth rate of the population, r as

$$r = \frac{ln R_0}{G}$$

where ln is the base of the natural logrithm, also written as log_e. With this estimate, we can model population growth for a rice grain population with a stable age class distribution using the exponential growth equation

$$N_t = N_0 e^{rt}$$

where N_t is the population abundance at time t and N_0 is the starting population size.

1. Create a life table (clearly labeled) for each of the four demographic groups, e.g. MALES or FEMALES and BEFORE 1950 or AFTER 1950, that includes one column for each of the parameters listed in the table above. Use the age groups (0-0.9, 1-9, 10-19, 20-29, up to 100-109).

2. Make two separate graphs, one with survivorship curves, plotting them on an arithmetic basis and one plotting them on a logarithmic basis. Each graph should be large enough to clearly show the survivorship differences for each of the demographic groups. Which graph, arithmetic or log, permits you to accurately compare trends among the four curves? WHY?

3. What are the trends for infant & child (ages 0-19) mortality rates for males and for females in each time period? List and describe all factors that might account for any differences you see.

4. What are the trends for mortality rates for reproductive age adults (age 20-39) for males and for females in each time period? List and describe all factors that might account for any differences?

Note: Many of the men who died during WWI and WWII were not returned to the United States.

5. What are the trends for mortality rates for adults ages 80 and onward (upward) for males and for females in each time period? List all and describe all factors that might account for any differences you see.

6. What shifts in the survivorship curves would you expect if environmental problems worsen and pollution-related diseases increase? Explain why.

7. What shifts in the survivorship curves would you expect if cutbacks to social services such as prenatal and infant care are enacted? Explain why.

Age Class (x)	l_x	b_x	$l_x b_x$	$x l_x b_x$
0	1	0		
1		1		
2		4		
3		2		
4		0		
		$R_0 = \Sigma lxbx$		

Figure 19.1: Life Table Calculations

8. What was the initial life expectancy for a male born before 1950? After 1950?

9. Assume age specific birth rates (b_x) of 0.25, 1.0, and 0.75 for females of age classes 10-19, 20-29, 30-39 respectively and zero for all other age classes. Calculate R_0 and G from these in a fecundity table.

10. Calculate r for females post-1950 and assuming an initial population size of 2,000 females, how many are expected after 25 years ($N_{t=25}$)?

Chapter 20

Lab 3: Introduction of Scientific Writing

Course Information

Instructor

Dr. Daniel Hocking, Compton 309, djhocking@frostburg.edu, 301-687-4343

Meeting Times and Locations

Lecture: Tuesday/Thursday 8:00-8:50 am; Compton 327

Laboratory:

- Section 1: Tuesday 2:00-5:50 pm; Compton 321
- Section 2: Wednesday 2:00-5:50 pm; Compton 321

Office Hours: Compton 309; Monday 11:00 - 12:00; Tuesday & Thursday 9:00 - 10:30 AM, Wednesday 9:00 - 10:00 AM; or by appointment

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Description

Environmental relationships of plants and animals. Field laboratory experience. Measuring environmental variables in terrestrial and aquatic ecosystems. Two hrs. lecture, one 4-hr. lab. Every semester.

Prerequisites

BIOL 150, 160 or 161; CHEM 202 (or CHEM 201 and permission of the instructor); MATH 109/209.

Learning Outcomes

The primary objective of the lab section is to provide you with experience collecting real, relevant ecological data. Specifically you will:

1. become familiar with ecological data collection for various taxa and in a variety of ecosystems.
2. be able to analyze data and interpret results.
3. practice and improve written and oral communication skills.

Grades:

Task	Pct	Grade
Lecture Exams	45%	A $>= 90\%$
Homework, & In-class assignments	5%	B $= 80 - 89\%$
Final Exam, comprehensive	20%	C $= 70 - 79\%$
Lab Reports	10%	D $= 60 - 69\%$
Literature Review Paper	15%	F $< 60\%$
Literature Review Presentation	5%	

Total points, percentages, and assignments may change to accommodate teaching and learning parameters. Grades are still based on percentage of total points. Grades from individual assignments will be posted on blackboard; **however, the grade calculated by blackboard could be incorrect because of differences in weighting of assignments**. It is your responsibility to calculate your current grade based on the grading scheme described above.

Literature Review

The purpose of this exercise is two-fold. First, it is designed to illustrate the problems that a researcher in ecology has when he/she must submit a grant proposal or manuscript for publication. In both of these cases the author must demonstrate that he/she has found and considered many important references to previous work on the subject. Additionally, this assignment will force you to read some of the primary literature to see how actual research is done and presented before it is synthesized by textbooks. Specific instructions will be provided in class.

Extra Credit

Extra credit may total up to 5% of your grade.

- Species of the week (1 pt per approved submission - see below)
- Diving vans for field trips (1 pt for training/registration + 1 pt per trip driving)

Species of the Week

Over the course of the semester (no more than one submision per week), each student may upload to blackboard a description of the ecology and life history of a species observed in the wild. This can be any wild plant or animal but must be positively identified to species (non-native species and planted trees count but not planted flowers). The description and location of the sighting should be included. No animals should be disturbed or handled for this assignment. Additional instructions on uploading will be provided in lab. It is important to remember that Species of the Week is a competition! As such, once a species has been reported, another member of class may not receive credit for it. The description of the ecology and life history must be a minimum of 1 page, single-spaced with 12 pt font and 1 inch margins. Students will receive 1 pt for each approved submission up to a total maximum of five.

Expectation of Student Work

Student work is defined as assignments, homework, and other academic activities to be completed outside of instructional time, including reading, studying, writing, research etc. Students should expect to spend a minimum of two hours per week completing this work for each credit hour enrolled (thus 6 hours of work outside of class for a 3-credit course), although the time spent outside of class may increase based on the topic and level of the course.

Late Policy: Assignments turned in after the due date will lose 10% per day for a maximum of 3 days, after which they will not be accepted and will receive a zero. Assignments turned in at any point after the time due (even 1 minute late) will lose a minimum of 10%. This excludes quizzes, in-class assignments, in-lab activities, exams, and presentations, which can not be turned in late or made up without prior arrangement with the instructor for extremely extenuating circumstances.

General Laboratory Information

Labs are an opportunity to gain hands-on experience with ecological techniques and gain a greater appreciation of the scientific process. Lab assignments will help guide you through the development of ecological questions, formation of hypotheses, and design of ecological studies. Studies will be conducted in the field or via computer simulation. Students will learn and be expected to use appropriate statistical techniques along with data visualizations (e.g. figures/plots/graphs) to summarize the data and test the hypotheses. Some labs will require full reports (intro, methods, results, dicussion, literature cited) but most will just require answering a series of questions to help guide inference and understanding of the results.

Please note that many of our labs will be conducted at local field sites. These labs will be conducted outside so you are expected to use common sense in deciding what to wear and what to bring. You will get dirty and you will get wet during these labs. Be prepared to spend 4 hours in areas without restrooms, if you have questions about outdoor restroom etiquette please consult leave-no-trace (lnt) principles: http://www.lnt.org/training/educationaltraining.php, http://lnt.org/training/OnlineCourse/ or ask the instructor if you have specific questions. You must notify the instructor during the first week of class if you are allergic to bees or have never been stung by a bee. Refer to the safety 1 section for additional information.

Course Topics and Schedule

The laboratory schedule is flexible based on previous lab timing and weather. We will often go out in the field during inclement weather as long as it does not result in undue risk of injury. Thus, come to all labs prepared to go out in the field and get wet and dirty. More about the lab schedule will be provided during your lab section. Below is a tentative laboratory schedule.

Week	Activity	Assignment Due
1	No Lab	
2	Set up experiments, intro lit review	
3	Questions, Hypotheses, and Data Management	Literature review
4	Turtle Mark Recapture	Turtle pre lab
5	Turtle Population 2	Lit review outline
6	Invertebrate Diversity Field	Turtle Lab Qs
7	Invertebrate Diversity ID	Lit review draft
8	Forest Succession and Diversity	Diversity Lab Qs
9	Sampling Rice and Ant Mounts	Peer review
10	Life Tables and Demography	Forest Lab Qs
11	Writing Workshop	Ant Sampling Qs
12	Finish Beetle and Radish Labs	Final draft
13	THANKSGIVING BREAK NO LAB	
14	Presentations	Radish comp lab
15	Presentations	Writing reflection

Important dates and information

- November 3: last day to withdraw with a "W"
- November 22 - 26: no classes (Thanksgiving Break)
- December 11: last day of classes
- Email and Blackboard: access to your email and Blackboard is required for this class. Check your email daily.

Attendance

Attendance is required for all laboratory sessions. Each missed lab will result in a **5% reduction in your overall grade** and you will receive a zero for any work associated with that lab. Additionally, any assignments due in lab that day will be late. *If you show up late to lab and miss the van, it will be considered an absence. The van will not wait for anyone.* For indoor labs, arriving more than 15 minutes late will count as an absence (5% reduction in grade), but you will be able to participate for credit in any activities associated with the lab.

Documented excused absences are generally limited to the following examples: university sanctioned events (field trips, or events where the student is an athlete/performer), funerals (requires an obituary or other proof), or illness/medical emergencies (requires a doctor's note or other proof). For all of these, documentation must be provided. If a student is participating in extracurricular activities or has an excused absence, I must be notified within one week to arrange makeup assignments.

If you have an unexcused absence, you do not need to contact me. Common examples of unexcused absences are "family emergencies", "car trouble", and "my ride is leaving early this week." While you may deem these as legitimate excuses, accepting them as excusable absences and allowing students to make up work will only encourage widespread abuse. Makeups of any kind are not allowed for unexcused absences.

Class Policies

There will be no cell phones on the desk or in lab. There will be no use of laptops unless prior consent is obtained for special circumstances. You may not eat food or use tobacco products including electronic cigarettes in class or labs. Disruptive behavior (using phones, talking, etc.): I will kick you out if I think you are being disruptive.

"The University will not tolerate disorderly or disruptive conduct which substantially threatens, harms, or interferes with university personnel or orderly university processes and functions. A faculty member may require a student to leave the classroom when his/her behavior disrupts the learning environment of the class. A student found responsible for disruptive behavior in the classroom may be administratively withdrawn from the course."

Beacon Early Warning System: all students should have a network of people who will support them in their educational journey. For that reason, the University uses a system known as Beacon, whereby your instructors and coaches, if applicable, can post notices about your academic behavior. For instance, if you are absent repeatedly from a class or are not completing assignments, your instructor may post a notice on Beacon. That information may be shared with your other instructors and/or your athletic coach. I will be monitoring notices posted on Beacon so that you and I may address any issues before they become obstacles to your academic success.

Confidentiality and Mandatory Reporting

Frostburg State University and its faculty are committed to maintaining a safe learning environment and supporting survivors of violence. To meet this commitment and comply with federal and state law, FSU requires all faculty and staff (other than the confidential employees in CAPS and Brady Health) to report any instances of gender-based harassment, sexual misconduct, relationship violence, or stalking against students. This means if you share your or another FSU student's experience with gender-based harassment, sexual misconduct, relationship violence, or, stalking, I have a duty to report the information to the University's Title IX Coordinator. The only exception to my reporting obligation is when such incidents are communicated during class discussion, as part of an assignment for a class, or as part of a University-approved research project.

Faculty and staff are also obligated to report allegations of child abuse and neglect to University Police and to Child Protective Services. This obligation extends to disclosures of past abuse even if the victim is now an adult and the abuser is deceased. My duty to report suspected child abuse and neglect extends to disclosures that are made as part of classroom discussions and in writing assignments.

If you or someone you know has experienced an incident of harassment or violence, please go to www.frostburg.edu/titleix to find information on reporting options and the resources and services available for support.

Academic Honesty

Definition of Academic Dishonesty from your student handbook: "Academic dishonesty is defined to include any form of cheating and/or plagiarism. Cheating includes, but is not limited to, such acts as stealing or altering testing instruments; falsifying the identity of persons for any academic purpose; offering, giving or receiving unauthorized assistance on an examination, quiz or other written or oral material in a course; or falsifying information on any type of academic record. Plagiarism is the presentation of written or oral material in a manner which conceals the true source of documentary material; or the presentation of materials which uses hypotheses, conclusions, evidence, data or the like, in a way that the student appears to have done work which he/she did not, in fact, do. In cases involving academic dishonesty, a failing grade or a grade of zero (0) for either an assignment and/or a course may be administered. Students who are expelled or suspended for reasons of academic dishonesty are not admissible to other institutions within the University System of Maryland. Suspension or expulsion for academic dishonesty is noted on a student's academic transcript."

Any violation of academic honesty will result in a zero for that graded work, and a repeat violation will result in failure of the course. Cheating will be reported and further disciplinary action may be pursued by the University Judicial Board This includes plagiarism. I will check long answers, essays, and lab reports with plagiarism-checking software. When in doubt, just cite the source. There's nothing wrong with building on somone else's ideas, in fact it's the way progress in made in science. Just give that person credit.

Persons with Disabilities

Frostburg State University is committed to providing equal educational opportunities for students with documented disabilities. Students who require disability serves or reasonable accommodations must identify themselves as having a disability and provide current diagnostic documentation to Disability Support Services. All information is confidential. Please call 4483 or visit 150 Pullen Hall for more information.

Bibliography