WEEKS 2 & 3
EXERCISE 3. SEHOME HILL ECOLOGY STUDY: ASSESSING PRODUCTIVITY OF FOREST TREES

OBJECTIVES

1. Estimate the amount of land area necessary to sequester the CO_2 emissions of the U.S. population.
2. Test the relative contributions of existing populations of conifers and deciduous trees on Sehome Hill to overall tree abundance, biomass, and ecosystem productivity.
3. Estimate your personal carbon footprint.
4. Gain experience in using field methods to gather ecological data.
5. Analyze data and produce graphs and tables using Excel.
6. Become familiar with scientific writing by a) reading a scientific paper and discussing its contents, and b) preparing a Results section for a research paper, complete with formatted tables and figures and a paragraph of text describing the patterns observed.

TERMS TO KNOW

community	global warming	decomposition
ecosystem	density	consumption
abiotic factors	biomass	sample
biotic factors	respiration	plot
net primary productivity	pool of carbon	carbon sink
net ecosystem productivity	autotroph	heterotroph

TIMELINE

30 min. – General introduction and sampling techniques
90 min. – Field sampling
50 min. – Data entry

INTRODUCTION

Overview

Understanding plant growth is critical to our understanding of **ecosystem** functioning and the problem of global warming: can people plant enough trees to help soak up carbon dioxide (CO_2) released from the burning of fossil fuels? The current rise in average global temperature (**global warming**) has been linked to the increase in CO_2 in the atmosphere produced by human activity. Plants and other photosynthetic organisms use CO_2 from the atmosphere and sequester (remove from the atmospheric **pool**) the carbon into their **biomass**. We know that planting trees will help sequester CO_2 from the atmosphere; the question is, "How much?" How much forested land area would be needed to soak up a single person's yearly carbon emissions? Is there enough land in the United States to soak up the yearly emissions from the entire U.S. population were we to plant it all in trees? We will answer these questions in a couple of steps:

1) Measuring the average amount of carbon taken up by a nearby forest (Sehome Hill Arboretum);

2) Having each student calculate his/her own carbon footprint (the amount of fossil fuel CO_2 you release annually);

3) Based on our measurements, estimating the total amount of forest area necessary to sequester CO_2 from the population of the U.S. and comparing that to the available land area.

Where does the CO_2 go that humans put into the atmosphere?

Currently, humans world-wide release about 7.9 Pg (petagrams = 10^{15} g) of CO_2 into the atmosphere each year. Most of this (~ 6.3 Pg) is from fossil fuel burning, but about 20% (~1.6 Pg) is from the clearing and burning of tropical forests. Yet, measured CO_2 in the atmosphere is only increasing by ~3.2 Pg per year. Where does the rest go? Some CO_2 (~1.7 Pg) leaves the atmosphere by dissolving in ocean water. The remaining 3 Pg (that's 3 billion metric tons!) is unaccounted for. The best information so far indicates that regrowing temperate forests, such as large areas in the eastern United States that used to be farmland, are responsible for taking up that CO_2. Therefore, if we plant more trees, can we increase forest carbon sequestration sufficiently to offset our emissions?

Test yourself:
Put the numbers above into a global carbon budget – what are inputs to the atmosphere and what are sinks from the atmosphere? Do the numbers have to be equal?

6.3 Pg (f.f. burning) + 1.6 Pg (land clearing) = 3.2 Pg (atm. Accumulation) + 1.7 Pg (oceans) + 3 Pg (forests); inputs = outputs + accumulation.

How does carbon cycle?

The building of organic carbon compounds from inorganic CO_2 during photosynthesis is called **primary productivity.** Here is a simplified equation for this process:

$$\mathbf{CO_2 + H_2O + energy\ (light) \rightarrow O_2 + biomass}$$

Another term for **biomass** is "fixed" carbon – basically sugar and all compounds derived from it (e.g., cellulose and lignin in cell walls, etc.). Biomass is the quantity of organic matter present in an organism or at a site (such as an area of forest). It can be viewed as the total amount of organic matter present, both living (e.g., live plant matter) and dead (e.g., detritus). It can also be viewed as the amount of carbon present in organic matter (carbon typically makes up about ½ of the total plant biomass). Plants also burn some of the sugar that they photosynthesize for energy to run their cells and grow. This is known as **plant respiration**. It releases some (about half, on average) of the plants' fixed carbon back into the atmosphere.

As long as carbon stays in the biomass of plants, detritus, or other organisms that eat the plants, it won't contribute to warming of the atmosphere. Therefore, ecosystem ecologists try to keep track of how much carbon is stored in an ecosystem (biomass), as well as how much is coming and going (**productivity)**. Productivity is just the flux, or rate of change in size, of the biomass pool. Plants are known as **primary producers** or **autotrophs** – organisms that can make their own food. Biomass made by primary producers is also consumed or decomposed by other organisms (**heterotrophs** – those organisms that must consume other organisms to get food). Heterotrophs don't contribute at all to primary production; rather, they are ultimately dependent on the autotrophs for food. Most of the carbon compounds produced by photosynthesis are ultimately converted back into CO_2 in the energy-releasing reactions of **respiration** (and some other reactions), either by the producers themselves (plant respiration), or by **consumers** or **decomposers**, in the following process:

$$\textbf{biomass (fixed carbon)} + O_2 \rightarrow CO_2 + H_2O + \textbf{energy out (ATP)}.$$

That ATP energy is what all organisms use to power their cells. **Net primary production (NPP)** is the difference between plant photosynthesis (gross primary production, GPP) and plant respiration. If NPP is positive, that means that the total amount of plant biomass is increasing. **Net ecosystem production (NEP)** is the difference between plant photosynthesis and total ecosystem respiration (respiration of primary producers, consumers, and decomposers; that is, $R_{plants} + R_{heterotrophs}$). If NEP is positive, that means that the total amount of ecosystem biomass and the carbon it contains, is getting larger. That is, NEP > 0 means that the ecosystem is pulling more CO_2 out of the atmosphere than it is putting back in, so that ecosystem would be a net **carbon sink.** See Figures 54.1 and 54.14 in your text for diagrams of the carbon cycle that put all these pools and transfers into perspective. In this lab, we will focus on NPP. While NEP is number we need for the true “bottom-line” in our carbon budget to assess forest sequestration, it is much harder to measure than NPP. We can think of our experiment as a conservative estimate of forest carbon sequestration potential: because NPP is always greater than NEP, if there’s not enough land for trees to soak up human-released CO_2 with their NPP, then there certainly won’t be enough land once we account for additional CO_2 release via decomposition and heterotrophic respiration.

Test yourself:
Why is NPP > NEP? Can you write a simple equation for each?

NPP = GPP – Rplants; NEP = NPP – Rheterotrophs; NPP > NEP because heterotrophic respiration always puts some carbon fixed by plants back into the atmosphere.

What controls primary production? History matters

How much carbon forests store depends on a number of factors, including climate (temperature and precipitation), soil fertility, which species are present, and the time since disturbance. In general, the warmer and wetter the climate and the more fertile the soil, the higher the productivity of an ecosystem. The relationship with species and time is not quite as simple. In fact, the species present often change with time since disturbance, which is called **succession**. In about 1900, the last of the old-growth forest on Sehome Hill that had towered above the earliest settlers of Bellingham was logged. The earliest photographs of WWU’s Old Main show a bare hillside rising behind the building (Figure 3.1). Since that time the **community** of plants and other organisms on this land has slowly changed composition through the process of **secondary succession**. This occurs when a disturbance (such as logging in this case) removes existing vegetation but leaves an intact soil. As time proceeds, new plants and other organisms inhabit the soil and each community changes the environment so that it appeals to a different community. At present, Sehome Hill is in the middle stages of succession where the community composition is changing from an earlier hardwood stage, dominated by red alder (*Alnus rubra,* see illustrations of all species in Figure 3.2) and bigleaf maple (*Acer macrophyllum*) to a community dominated by the conifer, Douglas fir (*Pseudotsuga menziesii*). In addition, there are younger individuals of the conifer species western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) that will increase in numbers and importance later in succession. The early successional species tend to grow quickly, but not live very long.

Figure 3.1 Left. Bellingham Normal School, 1899 several years after construction and clear-cutting of Sehome Hill behind Photograph by Hermann Wahlstrand, courtesy of Whatcom Museum of History and Art. Right. Old Main, WWU, summer 2007.

Figure 3.2 *Alnus rubra* *Acer macrophyllum* *Pseudotsuga menziesii* *Tsuga heterophylla* *Thuja plicata*
(All photos from Wikipedia)

In addition to plant species composition, total biomass and productivity also change through the stages of secondary succession. The patterns of these changes have important implications for a number of practical and theoretical questions, including how soon one should re-harvest a forest for timber after it has been cut, and how different successional plant communities take up carbon that humans are releasing into the atmosphere by burning fossil fuels. As succession proceeds through early and middle stages, the amount of live plant biomass increases. Plant productivity typically is low initially as succession is just starting out (because the amount of plant biomass growing is less for small plants), peaks in mid-succession (when there is a moderate amount of biomass growing quickly), then decreases later in succession (the reasons for this decrease are debated). For the purposes of this lab, however, a key question is this: if carbon uptake slows down as succession proceeds in regrowing forests, will the rate at which forests sequester CO_2 from the atmosphere slow down? In the future, might regrowing forests only take up 1 or 2 Pg of CO_2, rather than 3? If this slowdown in uptake occurs as humanity increases its CO_2 output, eventually atmospheric CO_2 will increase even faster than it currently is.

MEASURING CARBON SEQUESTRATION

Study overview

People are suggesting planting trees as a way to offset burning fossil fuel. For example, if you release 20 tons of CO_2 a year driving your car, can you just pay someone to plant enough trees to soak up that extra CO_2? Can industries use this as a strategy to offset their emissions as part of the Kyoto Protocol on greenhouse gas emissions? How many trees would you have to plant? How much land would this take? A fuller understanding of the roles of forest trees in sequestering atmospheric carbon is of vital importance to knowing how much CO_2 forests can sequester and how long those sinks might last.

In the present lab exercise, we will investigate some basic community and ecosystem properties of the forest trees on Sehome Hill to help answer these big questions. We will address the following main question: **Is there sufficient land area for reforestation to sequester the CO_2 emissions of the population of the United States?**

Below, state your primary and alternative hypotheses regarding this specific question.

Primary Hypothesis:

Alternative Hypothesis:

First, we will describe the forest on Sehome Hill in terms of the density (stems per hectare) and existing biomass (megagrams per hectare – 1 megagram = 10^6 grams) of different tree species, grouping them into deciduous trees (predominantly red alder and bigleaf maple) and coniferous trees (Douglas fir, western hemlock, western red cedar). Second, by measuring radial growth over the last 10 years and calculating the difference between total plot biomass now and biomass ten years ago, we will calculate the average net primary productivity of the forest on Sehome Hill (Mg $C*ha^{-1}*yr^{-1}$). We will use that estimate, plus current estimates of the U.S. population and the carbon footprint of the average U.S. citizen, to estimate the total land area necessary to absorb U.S. carbon emissions.

Second, we will assess the relative contributions of each of the different species, and each of the two types of species (deciduous and conifer), to stem density, stand biomass, and annual productivity of this forest ecosystem. You will write up this aspect of the study as a Results Section. To prepare for that, state your hypotheses for the following specific questions:

1. Which type of tree, coniferous or deciduous, is most common (most individuals per hectare) on Sehome Hill?

2. Which type of tree, coniferous or deciduous, has the highest biomass on Sehome Hill?

3. Which type of tree, coniferous or deciduous, has the highest NPP on Sehome Hill?

Sampling basics

Obviously we can't measure every tree on Sehome hill. Ecologists devise schemes to sample vegetation to provide estimates of true values of the criteria they are interested in. Ideally, such sampling schemes should:

- Be unbiased – not produce estimates that are predetermined in any way;
- Be repeatable – give the same result (within statistical variation) no matter who does the sampling;
- Provide statistically reliable results for the estimates – allow the researchers to calculate error limits for the estimates;
- Be nondestructive – leave the existing vegetation intact and healthy;
- Allow the gathering of data to be as easy and safe as possible.

The procedures we will use have been devised to satisfy all these requirements, although we will not do any but the simplest statistical tests of the data obtained. In the first week, your team will determine the numbers and sizes of all trees in small plots of known size. To eliminate bias, the locations of these plots will be determined systematically, relative to a baseline we establish. A systematic sampling scheme is one that is laid out in a regular pattern from a base point chosen in an unbiased manner. Your team will measure the densities and diameters of all the trees in your plot and estimate the biomasses of those trees using equations that relate biomass to tree diameter. In the second week, you will measure radial growth rates for each tree species and use these to estimate productivity of all the individuals of each species. The results obtained by your team individually, and your lab class as a whole, will be used to answer our main question in an assignment (pp. 15-16) and you will each individually write a results section presenting the lab class's overall results as to the specific questions about tree productivity (pp. 17-18).

INVESTIGATIONS

WEEK 1 – FIELD SAMPLING

1. Meet in lab for background and overall outline of activities
2. Divide up into teams – ~4 students (1 lab table) on a team
    a. Each lab's teams will be gathering part of the data used by all teams in the lab
    b. Each lab will be assigned a region on Sehome Hill (see Sehome Hill map, Appendix 2)
    c. The first team's plot will be determined randomly along a baseline parallel to the trail in that region. All other plots will be positioned in a systematic manner relative to that first plot.
3. First the teams will locate & set up their individual plots (Fig 3.3):

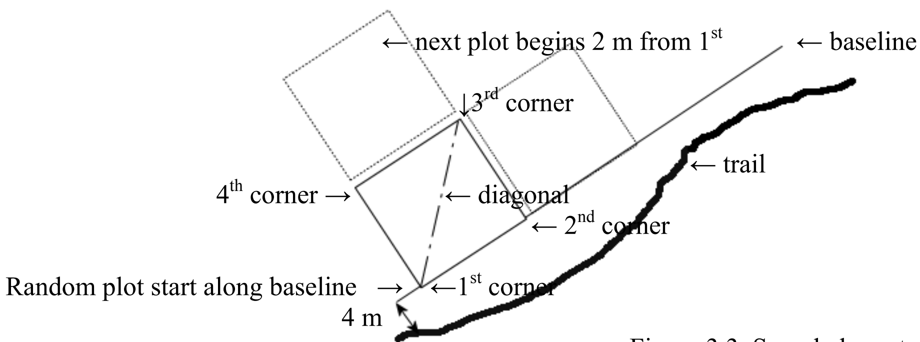

Figure 3.3 Sample layout of plots next to trail

    a. Your TA will describe the scheme for choosing plots and help establish the 1st corner of each plot. In general, the sampling plots will be oriented to a nearby trail. Plots will be arranged along a baseline parallel to the trail.
    b. Start of baseline will be off the trail approximately 4 meters
    c. The 1st corner of the 1st plot will be determined randomly. Once this corner is established, your team will lay out a 10 x 10 meter plot using steps 4-8 below.
    d. Remaining team plots will be established parallel to the first plot margins and 2 meters away
4. Flag the location of the 1st corner. With the first 30 meter tape lay down the 1st boundary along the baseline. Flag the location of the 2nd corner. Using a compass, turn the tape 90 degrees away from the trail and establish the 3rd corner at a distance of 10 meters from the 2nd. **Leave the first tape in place to delimit the boundary**.
5. Now, using the second 30 meter tape, measure the diagonal distance from the **1st** corner towards the **3rd** corner. This distance should be the length of the plot side times the square root of 2 ($10 \times \sqrt{2} = 14.14$ meters). How does this help make the plot square? Where does this distance come from?
6. Adjust the location of the 3rd flag so that it is both 10 meters from 2nd flag and 14.14 meters from the 1st.
7. With the second 30 meter tape, lay down the final two boundaries, each 10 meters in length. Flag the 4th corner. **Leave the second tape in place to delimit the boundary**
8. **Note on large trees that intersect a boundary**: Boundaries should be straight from flag to flag. A tree is inside the plot if more than 50% of its trunk basal area is inside a

boundary. As you lay out the plot boundaries, consider the effect of wrapping the tape around the tree to continue on towards the next corner. Add a bit to the length of the tape if it wraps around a tree.

9. Teams gather data
    a. On one "Data Collection Form" (Figure 3.4), record the following:
        i. Team members
        ii. Date of data collection
        iii. Description of location (in "notes")
        iv. Abiotic measures (use center of plot to record): aspect (true compass – on Sehome Hill, true north is 17 degrees west of magnetic north), slope, canopy cover. Measure these at the center of the plot. For rolling terrain, use the general trend of the slope.
        v. Notes: dominant vegetation, amount of downed and standing dead, other observations
    b. For each **<u>live,</u>** **<u>standing</u>** tree greater than 10 cm DBH fill out a separate row on the form as follows:
        i. Tree species
        ii. Tree DBH = the diameter to nearest cm from diameter tape at breast height. [DBH is officially defined as the outside bark diameter at 4.5 feet (1.37m) above the forest floor on the uphill side of the tree. For the purposes of determining breast height, the forest floor includes dead leaves and small branches (the duff layer) that may be present, but does not include unincorporated large woody debris that may rise above the ground line; for stump-sprouted maples, each stem is a separate tree as long as it is separate at breast height]
        iii. "Notes": indicate any unusual situation – stump sprout maple, species name if different from the five indicated, etc.
10. Finally the lab class will core two trees. These cores will be combined with others from other labs and used to estimate tree growth next week.
11. Return to lab to enter data.
12. **Data entry: Due at the end of class.**
    a. Obtain a copy of **PlotDataForm.xls** from your TA's Blackboard site. **Save this file on your local computer and rename it with your lab section and group number.** When renaming, use the first letter for your lab day (T, W, R, or F), the second letter for the starting time of your lab (11, 1, 2, or 5), then your group number (for example, W2Group1.xls). <u>Please follow this naming convention exactly, as it will greatly help your TAs keep all their files organized.</u> This will be the "team worksheet" described in the following discussion).
    b. NOTE: when you open this file in Excel, a message may tell you that there are links to other cells. Click the button saying "Don't Update".
    c. Step 1 (these steps are further explained on the worksheet): Fill in team member names and plot data above.
    d. Steps 2 & 3: Enter data from field forms into this copy of the team worksheet.
    e. Step 4: Enter the biomass-estimating equations from the table below to each row that you have recorded a DBH (use the correct species' equations).

f. Step 5: Adjust several formulas that calculate density and present biomass for each tree species, for each tree type and for all trees in the plot based on your team's data (see worksheet for specific instructions on how to do this)
g. Step 6: Rename the tab name in the team worksheet with your group number, save the worksheet, and make sure all team members have a copy
h. E-mail the completed worksheet to your TA as an attachment or copy it to their pen drive.

WEEK 2 - DATA ANALYSIS, DISCUSSION OF RESULTS, AND RESULTS SECTION ASSIGNMENT

During this week we will

A) Measure radial growth and answer our main question about potential for forest carbon sequestration in the U.S. (Exercise 3 assignment);

B) Prepare graphs and a table for writing a results section that addresses our additional hypotheses about different species' contributions to biomass and productivity on Sehome Hill;

C) Discuss a scientific research paper related to carbon sequestration to better understand the mechanics of scientific writing and interpreting the scientific literature (see Scientific Paper Reading Assignment, below).

Measurements and Calculations

1. You will be using an Excel "class spreadsheet" that includes all the team plot data from all the groups (each as a separate worksheet) and several other worksheets. Refer to the outline of instructions on the first sheet of that spreadsheet. **IT IS VERY IMPORTANT THAT NO DATA BE CHANGED ON THIS SPREADSHEET EXCEPT WHERE YOU ARE SPECIFICALLY INSTRUCTED. IF IN DOUBT, ASK BEFORE PROCEEDING.**
2. Individual students will obtain core or disk growth measurements
    a. Measure last ten years worth of growth from tree disks and cores. Each student in the lab will measure the radial growth rate of one sample provided in lab, a core obtained either the previous week or in previous years.
    b. Note the species and the overall diameter of the tree from which the core or disk was obtained (DBH's of cores are provided with the samples);
    c. Using a metric rule, measure the radial width of the last ten rings of growth (your TA will demonstrate this).
    d. If you are unable to get a record from 10 rings worth of growth, record how many rings of growth you were able to measure.
    e. Record all your data in your lab note book, and enter the DBH and radial growth increment in the class spreadsheet on the Ring Width Data worksheet (your TA will show you where).
    f. Once everyone has finished, each team will enter the ring data on their team copy of the class spreadsheet.
3. Once all the radial growth data are entered, formulas on the spreadsheet will calculate density, biomass and productivity measures of the different species, for conifers vs. deciduous trees, and for all trees in your plots.
    a. Make sure that your copy of the class spreadsheet agrees in all details with that shown by your TA. <u>All further work will be done with this spreadsheet. Each student should save a copy of this spreadsheet for future reference</u>.
    b. Examine the equations used to calculate tree biomass on the next page and make sure you understand how to enter these as formulas on the spreadsheet.
    c. Examine the results shown on the Summary worksheet. Using the formats of graphs on that worksheet, each team should produce and format similar figures from the tables of data on their team's plot data worksheet.

4. Individuals answer the In-class Assignment questions alone and then discuss your answers among your teammates. In about 30-45 minutes your TA will discuss your answers to these questions with the class as a whole.
5. Your final, <u>individual</u> assignment will be to write a Results section, presenting the class average results comparing different species and functional types (see instructions, p. 19). **This assignment is based on the class spreadsheet. Be sure you have a copy!**

EQUATIONS FOR ESTIMATING TREE BIOMASS

You will use the following equations in your spreadsheet to estimate total biomass of each individual tree. DBH values are in cm. Total biomass values given by the equation are in grams. You'll need to convert grams to megagrams (10^6 grams) in the spreadsheet. These equations are simplifications of the ones given in Harmon et al. (1996), which are shown in Appendix 1.

Total live biomass = bark + trunk wood + leaves + live branches + dead branches + roots

Note: we include dead branches here in the "live tree biomass" because those branches have not yet fallen off and become part of the forest floor detritus pool.

Equations to estimate **total biomass** (g) for individual trees using DBH (cm)	
red alder/black cottonwood	ln(total biomass) = -2.666 + 2.621*(ln(DBH))
Douglas fir	ln(total biomass) = -1.657 + 2.372*(ln(DBH))
bigleaf maple/vine maple	ln(total biomass) = -2.603 + 2.623*(ln(DBH))
western red cedar	ln(total biomass) = -2.096 + 2.385*(ln(DBH))
western hemlock	ln(total biomass) = -2.319 + 2.568*(ln(DBH))

Since these regressions were of ln(total) vs. ln(DBH), you will need to take the exponent of each side, remembering that exp(ln(X)) = X.

REFERENCE

Harmon, M.E., Garman, S.L., and Ferrel, W.K. 1996. Modeling historical patterns of tree utilization in the Pacific Northwest: carbon sequestration implications. Ecological Applications 6: 641-652.

DATA COLLECTION FORM

Team members:

Notes:

Plot data

Date:

Slope:

Aspect:

Canopy cover:

Acma – *Acer macrophyllum* bigleaf maple
Alru – *Alnus rubra* red alder
Other – indicate species in notes

Tshe – *Tsuga heterophylla* western hemlock
Psme – *Pseudotsuga menziesii* Douglas fir
Thpl – *Thuja plicata* western red cedar

Species	Diameter (cm)	Notes

Figure 3.4 Data Collection Form

SCIENTIFIC PAPER READING ASSIGNMENT. DUE IN LAB, 2ND WEEK OF STUDY

Read the assigned scientific paper (available on your lab or lecture Blackboard sites – your instructors will describe what you are to read and where to get it). **Include a reference to the paper here, using the format (Author. Date. Title. Source. Volume:pp.) used in the Literature Cited section of the paper.**

Refer to Ch. 6 in your Knisely text (pp. 99-107) while reading the paper and answering the following questions. The marginal comments in Knisely will be especially helpful. Other chapters of the text may also be useful, so don't forget to look around a bit.

1. In your own words, describe the objective(s) of the study in the assigned scientific paper.

2. What section (Results or Discussion) would the following statements belong in?

_______________ a. Stream habitat quality was significantly higher in forested watersheds than in agricultural or developed watersheds. The average percent shade differed among the stream-side vegetation types, being 49.2% in fully wooded streams, 25.0% in partially wooded streams, and 15.3% in non-wooded streams.
(adapted from Blann *et al.* 2001)

_______________ b. The prevalence of marine fish bones in the scat samples indicates that the seals that haul out at the Umpqua River do not feed exclusively in the river.
(adapted from Orr *et al*. 2004)

_______________ c. Abundance of the youngest coho salmon group (age-0) decreased by ~50% through the summer during 1988 and 1989 in each of the three small study streams. Two streams had higher abundances than the third throughout the entire study period (statistically significant at $p<0.05$).
(adapted from Keith *et al.* 1998)

3. Stated below are two hypotheses. Which one has the strongest support from the data in this paper? Be sure to state why, and where in the paper you found your answers.
H1: (Null hypothesis) Trees and soil store similar amounts of carbon in old growth Pacific Northwest forests.
Ha: Soils store more carbon than trees in old growth Pacific Northwest forests (based on studies in other regions of the U.S.)

3. a. Did Smithwick et al. measure pools of carbon or fluxes of carbon?

b. Which measurement of ours is most closely comparable to theirs?

c. What components of the ecosystem carbon budget did they measure that we didn't?

5. Focus on Table 3. Which component of Table 3 is most closely related to the measurements we made? How do our numbers compare with theirs? If there are differences, state at least one hypothesis about why those differences might occur.

6. With respect to their objective(s), and considering the overall context of the study described in the assigned paper, state two primary conclusions the authors drew from their study (write in your own words).

In-Lab Assignment, to be done 2nd week

1. Where (from the environment – soil, water, minerals, atmosphere) did the productivity (of carbon compounds) observed between trees now and trees 10 years ago come from? Explain all the factors (processes, organs, other needs) active in the tree that result in productivity.

2. Describe the overall differences you and your team saw when comparing the class-average results and the results based just on your team's data. Are your team's results or the lab-class average results likely to be closer to the actual value if you measured all trees on Sehome Hill? Why?

3. Go to the website: http://www.nature.org/initiatives/climatechange/calculator/ and calculate your own carbon footprint (note that this website calculates footprint in terms of tons of CO_2; multiply the result by 3/11 to get tons of carbon). What is your best estimate of how much area of a similar mix of trees to that observed on Sehome Hill in this study would be needed to take up your yearly emissions of carbon? (Note: a metric ton = 1000 kilograms = 1 megagram = 10^6 grams). Show your calculations below.

4. The average carbon footprint of a citizen of the United States is 7.5 megagrams of carbon per year and there are approximately 303 million people in the U.S. (http://www.census.gov/population/www/popclockus.html). What is your best estimate of how much area of these trees would be needed to take up the yearly carbon emissions of all U.S. citizens? Show your calculations below.

5. State at least two assumptions[1] that went into our calculations of U.S. carbon sequestration.

[1] Note: Assumptions are merely simplifications that make the calculations easier. It's ok to make assumptions, but it's also very important to be aware of what they are and how they influence your final answer. For example, one set of assumptions might mean that your answer gives "the best case scenario", and another set might give "the worst case scenario". A good scientist will know the difference!

ASSIGNMENT DUE IN ONE WEEK: WRITE A RESULTS SECTION

Your assignment (due in one week) is to produce a professional Results section for a scientific paper comparing the abundance, biomass, and productivity of different types of trees. **Use the "class spreadsheet" that we built and saved together in the second week of this lab.**

1. State your hypotheses about which types of trees, conifers or deciduous, have the greatest abundance, biomass, and productivity on Sehome Hill (see pp. 5-6). (While this isn't typical for a results section, normally a reader would be aware of these hypotheses from the introduction section of a paper. They should also help you focus what you say in your results section.)

2. Include the following (3) figures for deciduous trees (sum of all individual deciduous tree species), coniferous trees (sum of all individual conifer species), and total trees (sum of deciduous and conifer trees; same units as above):
   - Bar graph of density
   - Bar graph of current biomass
   - Bar graph of productivity per hectare

3. Include a single table that compares the following across all individual tree species:
   - density (# trees/ha)
   - current biomass (Mg $*ha^{-1}$)
   - productivity per hectare (Mg C $*ha^{-1} * yr^{-1}$)
   - productivity per tree (kg C $*tree^{-1} * yr^{-1}$)
   - This table will be useful in helping to understand your primary results in the graphs above. For example, if you get surprising results with your functional type comparison, you might find that they are caused primarily by the characteristics of a particular species.

4. You must follow the guidelines below and in Appendix 3 in writing your results section.
5. Make sure all tables and figures are properly formatted for a scientific paper and include appropriate numbers and captions (see grading rubric, page 21).
6. Describe the findings in your Results section, referring to the table and figures.
7. Consult below for tips about how to formulate your Results section. Also read the appropriate pages in Knisely.
8. Include a draft version, showing that it has been edited with the final version of your Results section (your TA will explain this requirement).
9. Include an annotated copy of the grading rubric, checked off to indicate that you have used it in revising your draft (your TA will explain this requirement).
10. This assignment is due in one week.

There are four main components to a scientific paper: Introduction, Materials and Methods, Results, and Discussion (see Knisely for a discussion of the content and format of scientific reports). In brief, the Results section just describes the patterns observed, while the Discussion section includes interpretation of the results. Comments about whether these results support your hypotheses can go either place, but such comments are a rough "dividing line" between results and discussion: you would want no more interpretation than that in you Results section, but that's where the interpretation in the Discussion section begins. After making the necessary changes to the table and figures generated in EXCEL, you will need to copy and paste them into a WORD document, and write a few paragraphs that describe the main findings. Your lab instructor or teaching assistant will go over how to generate appropriate tables and figures, as well as what information should and should not be included in the text.

Here are a few tips on writing Results sections. For more detailed requirements **see Appendix F** and the **Grading Rubric**, below.

1. You should have a minimum of one paragraph for each of the following topics:
   - trends in density
   - trends in biomass
   - trends in productivity (per hectare and per tree)

   Each paragraph should include comparisons between tree types (e.g., coniferous & deciduous) and tree species (e.g., Douglas fir, bigleaf maple, etc.).

2. Start with the big picture: talk about the major trends that you see in the overall data. Make this each paragraph's topic sentence.
3. The sentences that follow support the topic sentence with specific reference to data shown in either the table or figure [include a text reference to the table/figure – e.g. "Annual productivity of maples (as carbon) was 17% higher than productivity of alders (Figure 1)".]
4. Use quantitative comparisons to describe patterns in the data. Be clear if values are increasing, decreasing, greater than, etc. Using percentages to quantify differences is very effective. To calculate the percent change, use the general equation:

   $$\%\text{ increase } = \frac{\text{larger value - smaller value}}{\text{smaller value}} x\, 100$$ (% decrease would be slightly different)
5. Describe the direction of any changes; for example, don't just say that tree types differed, say which were greater than or less than which.
6. Lack of data can be results. We expect all 5 tree species will be present in the overall class data. If a tree species is missing in the part of Sehome Hill you examined, this should be noted.
7. Keep scale in mind: what constitutes a biologically significant difference versus a slight difference that could have resulted merely by chance? 1%, 5%, 50%? Since we have not done statistical tests on the significance of the data, you will just have to use your "gut feelings" as to what differences to point out.

RESULTS SECTION - Checklist and grading rubric

(You **MUST** hand in a copy of this page with your final Results section and rough draft)

TEXT (10 pts)

___ Paragraphs begin with a topic sentence that clearly states the main message of the whole paragraph
___ Paragraphs describe **all** main patterns and trends in the data
___ Big picture trends in the data are described first
___ Writing is clear; tone is formal
___ Does not present raw data
___ Measurements are used correctly (e.g. "density" ≠ "abundance")
___ Does not list values presented in table or figure
___ Uses quantitative comparisons to describe trends in data
___ Table and figures are properly referenced
___ Uses complete sentences & proper grammar; no typos or spelling errors
___ Capitalizes species names correctly
___ Times New Roman font type
___ 12 pt font size
___ Double-spaced throughout

FIGURE (5 pts)

___ Correct data are presented, as instructed by TA
___ Figure is large enough to read/interpret
___ Caption is included at bottom of figure
___ Caption is a statement that describes the data presented in the figure; does not describe trends or patterns
___ Caption begins with "Figure X. ..." and ends with ".", where "X" is appropriate figure number
___ Only first word and proper nouns are capitalized in caption (as in a sentence, not a title)
___ If necessary, the caption explains any other details needed to interpret the figure
___ Times New Roman font type
___ 12 pt font size
___ Regular style font (no bold)
___ No gridlines
___ White background
___ Axes are labeled correctly (including correct capitalization)
___ Axes are scaled appropriately
___ Colors/patterns are adjusted so figure can be easily interpreted when printed in black and white
___ Legend is included and labeled correctly (for biomass figure only)

TABLE (5 pts)

___ Correct data are presented, as instructed by TA
___ Table is large enough to read/interpret
___ Caption is included at top of table
___ Caption is a statement that describes the data presented in the table; does not describe trends or patterns
___ Caption begins with "Table X. ..." and ends with ".", where "X" is the appropriate table number
___ Only first word and proper nouns are capitalized in caption (as in a sentence, not a title)
___ Times New Roman font type
___ 12 pt font size
___ Regular style font (no bold)
___ Columns and rows are labeled correctly (including correct capitalization)
___ Units are included in the column/row headings and formatted correctly
___ Cells/lines are sized to fit headings and/or data
___ Headings and data are centered in columns
___ Line separates column or row headings from data; no gridlines within the data itself; a line above the column headings (to separate the table from the caption); and a line below the last row in the table.

___ Rough draft included **___ Rubric included**

APPENDIX 1. ORIGINAL EQUATIONS FOR ESTIMATING TREE BIOMASS

These equations come from Harmon et al. (1996). To get the simplified equations used in the spreadsheet, we simply calculated biomass for all the different tree parts below for individuals from a range of DBHs (5-100 cm for alder/cottonwood and maple, 5-280 cm for the conifers). We summed the biomasses of the parts for each individual to get a total, then did a regression of ln(DBH) vs. ln(total) for each species. This worked well - in all cases, $r^2 > 0.999$.

Equations to estimate **trunk bark** biomass for indiv. trees, using DBH (cm)

red alder/black cottonwood	$\ln(\text{trunkbark}) = 2.265355 + 2.461700(\ln(\text{DBH}))$
Douglas fir	$\ln(\text{trunkbark}) = 2.902625 + 2.481800(\ln(\text{DBH}))$
bigleaf maple/vine maple	$\ln(\text{trunkbark}) = 2.333800 + 2.574000(\ln(\text{DBH}))$
western red cedar	$\ln(\text{trunkbark}) = 2.385440 + 2.198700(\ln(\text{DBH}))$
western hemlock	$\ln(\text{trunkbark}) = 2.766209 + 2.347400(\ln(\text{DBH}))$

Equations to estimate **trunk wood** biomass for indiv. trees, using DBH (cm)

red alder/black cottonwood	$\ln(\text{trunkwood}) = 4.238755 + 2.461800(\ln(\text{DBH}))$
Douglas fir	$\ln(\text{trunkwood}) = 4.841987 + 2.332300(\ln(\text{DBH}))$
bigleaf maple/vine maple	$\ln(\text{trunkwood}) = 3.414800 + 2.723000(\ln(\text{DBH}))$
western red cedar	$\ln(\text{trunkwood}) = 3.862652 + 2.445400(\ln(\text{DBH}))$
western hemlock	$\ln(\text{trunkwood}) = 4.176308 + 2.535300(\ln(\text{DBH}))$

Equations to estimate **leaf** biomass for indiv. trees, using DBH (cm)

red alder/black cottonwood	$\ln(\text{leaf}) = -2.447300 + 3.243400(\ln(\text{DBH}))$
Douglas fir	$\ln(\text{leaf}) = 4.061600 + 1.700900(\ln(\text{DBH}))$
bigleaf maple/vine maple	$\ln(\text{leaf}) = 0.415955 + 2.503300(\ln(\text{DBH}))$
western red cedar	$\ln(\text{leaf}) = 4.290800 + 1.782400(\ln(\text{DBH}))$
western hemlock	$\ln(\text{leaf}) = 2.777800 + 2.128000(\ln(\text{DBH}))$

Equations to estimate **live branch** biomass for indiv. trees, using DBH (cm)

red alder/black cottonwood	$\ln(\text{livebranch}) = -0.911945 + 3.488600(\ln(\text{DBH}))$
Douglas fir	$\ln(\text{livebranch}) = 3.213700 + 2.138200(\ln(\text{DBH}))$
bigleaf maple/vine maple	$\ln(\text{livebranch}) = 2.671760 + 2.430000(\ln(\text{DBH}))$
western red cedar	$\ln(\text{livebranch}) = 3.641700 + 2.087700(\ln(\text{DBH}))$
western hemlock	$\ln(\text{livebranch}) = 1.758800 + 2.778000(\ln(\text{DBH}))$

Equations to estimate **dead branch** biomass[2] for indiv. trees, using DBH (cm)

red alder/black cottonwood	$\ln(\text{deadbranch}) = -0.707845 + 2.624300(\ln(\text{DBH}))$
Douglas fir	$\ln(\text{deadbranch}) = 3.378800 + 1.750300(\ln(\text{DBH}))$
bigleaf maple/vine maple	$\ln(\text{deadbranch}) = 4.791800 + 1.092000(\ln(\text{DBH}))$
western red cedar	$\ln(\text{deadbranch}) = 3.378800 + 1.750300(\ln(\text{DBH}))$
western hemlock	$\ln(\text{deadbranch}) = -0.177240 + 2.805000(\ln(\text{DBH}))$

Equations to estimate **root** biomass for indiv. trees, using DBH (cm)

All species	$\ln(\text{root}) = 2.2117 + 2.6929(\ln(\text{DBH}))$

[2] Note: we include dead branches here in the "live tree biomass" because those branches have not yet fallen off and become part of the forest floor detritus pool.

APPENDIX 2: SEHOME HILL TRAIL MAP

Numbered ovals are areas for Sehome Hill Ecology study.

Map from City of Bellingham Trail Guide

APPENDIX 3: GUIDELINES FOR WRITING A RESULTS SECTION

N

General

1. The entire paper should be written in past tense and double-spaced, EXCEPT where noted below.
2. You should ONLY use the data presented in the Summary page of the Excel spreadsheet. Inclusion of raw data (e.g., DBH values) is inappropriate for a Results section.

Audience, Tone, and Style

1. Academic dishonesty will not be tolerated. You are encouraged to work with your lab-mates as you prepare to write the Results section. But remember – this is an **individual** assignment, and everyone must turn in their own copy *in their own words*. Assignments with plagiarism problems can result in no credit, failing the class, or expulsion from Western. If you have any questions about what constitutes plagiarism, talk to your TA or class instructor, and/or see Western's web site: http://www.library.wwu.edu/ref/plagiarism.html and http://www.wwu.edu/depts/soc/plagiarism.PDF.
2. You are writing for your peers within the scientific community. Assume they have a knowledge base similar to your own. Therefore you do not need to explain simple terms nor describe standard, accepted procedures.
3. Style of writing should be formal. Avoid extreme terms. Do not use casual phrases. For example, the following sentence is too lazy and informal for science writing: "Moss coverage was *pretty much the same* for both substrates." Avoid writing the way you talk; we tend to speak informally, and use many more words than are necessary to get the point across. Reading your section aloud may help you catch run-on sentences. Remember: simplify, simplify, simplify! Example:

> Wordy: "In analyzing the data that we collected, I found that the transect invaded by ivy contained slightly less relative percent cover from native species than the uninvaded transect, not invaded by ivy."
> Revised: "Relative percent cover of native species in the invaded transect was lower than in the uninvaded transect (Table 1)."

4. Always profread to be be sure you're sentence is without errors and sense making. How many errors can you find in the previous sentence? Typos and grammatical errors are incredibly distracting when reading a paper and may prevent the reader/grader from understanding what you are trying to say, which will result in a lower grade. NEVER, EVER turn in your first draft! Proofread your work! Get rid of typos! Read sentences aloud to be certain they make sense! If you have problems with grammar, get help! Go to the writing center or ask a friend. Do not turn in a paper with poorly constructed sentences! It is VERY helpful to go back to the paper after you've had a break (a day, or at least a couple of hours) for proofreading.

Text

1. Just report the findings of your study.
2. That's it. Nothing more. This is a Results section, so do not include information that would typically go in an Introduction (e.g. background infc Map from City of Bellingham Trail Guide
and Methods (e.g. site location, site characterization

(interpretation of the results). Simply state the results using statements about trends and patterns. Refer to the "Good student lab report" in Knisely for additional help.

For example, if a plant has high relative cover, it is appropriate to state that it has high relative cover or that it is the dominant plant in the transect. However, do NOT interpret this as overcrowding, outcompeting, overpowering, overgrowing, pushing, strangling, killing, forcing, etc. Interpretation is done in a Discussion section.

3. State your results as plainly as possible.

-Begin your section with big picture trends (from your table). It provides context, so when you describe trends in relative cover of species, your audience understands how they fit into the study.

-Start a paragraph with a strong topic sentence that is supported by all other statements in the paragraph.

4. Be straightforward and thorough. Point out major trends and patterns within the data. For example, "As x increased, y decreased."

-Summarize trends using quantitative comparisons (e.g. 10% greater, 3 times less). If several plants exhibited similar trends, try to lump them together in a single statement rather than provide a list of values. Above all, do not **list** values that can be read or inferred from the figure and table. **See your lab manual for the equation for "percent difference".**

-When you calculate your quantitative comparisons, be sure to check your math! Do your values agree with your figure and table? Does one column really look 4 times bigger than another? Is that column about 30% shorter than the other?

-There are instances when quantitative comparisons are inappropriate. Specifically, when a plant has 0% relative cover (or 0% relative frequency) in one transect, you cannot say that it has 100% more relative cover in the other transect.

5. Avoid vague statements about your results. For example, "Moss coverage was consistent with canopy coverage." This sentence begs the following questions: What do you mean? *How* was it *consistent with* canopy coverage? Did it consistently decrease or increase as canopy cover increased? Does this mean that moss coverage was exactly the same as canopy coverage? Can you see how the example statement doesn't tell the reader **specifically** what the relationship was between moss and canopy coverage?

6. Formatting specifics.

-The entire paper should be double-spaced, EXCEPT where noted.

-Write in the past tense, e.g. "Percent cover was…", "The invaded transect had…"

-If you mention a trend or value from the figure or table, you need to remember to cite it. The easiest way to cite a figure or table is in parentheses at the end of a sentence: "Relative cover of ferns did not change between transects (Figure 1)." Avoid using phrases such as "Figure 1 shows" or "Table 1 says"; figures and tables are merely organized, visual presentations of your data, not animate objects.

-Simplify your vocabulary. Use the terms from your figures and tables:

-**relative** frequency, not frequency

-percent relative **cover**, not percent coverage

-**percent** relative cover, not percentage relative cover (or, worse, percentage relative coverage)

-use only the words Native, Non-native, Invaded, and Uninvaded to refer to plant or transect types

-when referring to transects, call them transects, NOT sites or plots or patches (you didn't conduct your study on a whole site/plot/patch, just a transect).
-avoid using "extreme" terms, such as really, very, obviously, totally, completely. They really make me totally want to completely stop grading....*obviously*.
-do not mention "significant" differences or changes in measurements. That term is reserved for statistical analyses.

-Citing numbers in the text. You will often want to include some actual numbers in your results text, but be careful not to clutter up the text with too many strings of numbers. Don't repeat data that is already shown in tables and figures. Just use numbers in the text to highlight the most important points or comparisons.

-Spell out the word versus (NOT vs.).

-Spell out the word percent (e.g. percent cover) UNLESS you are talking about a number (e.g. 25%).

Tables and Figures (within Results section)

1. Do Not Present Raw Data!

2. Figure titles/captions go BELOW the figure. There should be absolutely nothing above a figure. Each figure should be numbered.

3. Table titles/captions go ABOVE the table. As described above with figure captions.

4. Titles/captions must be in 10-12 pt font, Times New Roman, single-spaced, centered or flush left.

5. Captions should be brief and concise but contain enough detail that readers don't have to refer to the text of the paper to understand and approximately interpret your figures (and how the data were obtained). Your figure and table captions should include the details of your variables (what is on the x-axis? What is on the y-axis?) and the location of the study.

6. Eliminate grey background of figures.

7. Adjust colors and patterns for printing in black and white. Provide a legend when more than one data series is provided in a figure.

8. Label each axis accurately. Include any necessary units in parentheses.

9. Only include figures or tables that help you convey a point made within the text of the results section. In other words, only include the figures and tables we tell you to include. Within the results body, you must refer to each table and figure that is included in the section.

10. When reporting the results of your data, point the reader to any relevant figure or table by referring to it by number, within parenthesis at the end of the sentence. For example, "Moss coverage increased on tree trunks as the canopy coverage overhead increased (Figure 1)."