Math Applications in Life Science Courses

Chemeketa Community College
Salem, OR
Wynn W. Cudmore

most courses = for non-majors

1. Graph generation and interpretation
   - Scatter plots
   - Line graphs
   - Histograms
   - Pie charts
   - Identification of patterns/trend analysis
   - Determination of LD-50s
2. Correlation
   - By inspection
   - Calculation of correlation coefficients (e.g., tree growth vs. annual precipitation")
3. 2-D Geometry
   - Area calculations of regular shapes
   - Borders/edges
4. 3-D Geometry
   - Calculation of volumes/surface areas of cylinders
   - Density calculations
5. Calculation of rates of change
   - Population growth
   - Diffusion rates
   - Percent loss /gain
6. Descriptive statistics
   - Mean, range, standard deviation
7. Inferential statistics
   - Genetics/frequency data
   - Chi-square

Cudmore - Chemeketa

Bi 131 Environmental Science
W.W. Cudmore
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Log Decomposition Lab

Which is more alive - a standing live tree or a decaying log on the forest floor?

The answer seems so obvious that at first glance one would think it must be a trick question. Clearly a living organism must be more alive than a dead one! Upon closer examination, however, we find that by any measure, a decayed log is far more alive than a living tree! In cross-section the majority of a living tree is made up of dead cells that make up xylem tissue. Living tissue is restricted to a few tissues such as the leaves and a thin cambium layer that lies inside the bark. A decayed log on the other hand contains a myriad of living organisms. Termites, ants, beetles, mites, bacteria, nematodes, protozoans, fungi and small vertebrate animals such as voles and salamanders may all call the "formerly living tree" home.

As we attempt to manage our forests under the guiding philosophy of "ecosystem management", an understanding of short-term and, in particular, long-term ecological processes becomes essential. The processes that maintain and enhance soil fertility, for example, are long-term processes and are an important consideration as we manage on broader scales of both time and space. We have recently gained a greater understanding of the role of decomposing materials, particularly in forests. Today's laboratory is designed to explore the nature of log decomposition as one component of nutrient cycling in forest ecosystems.

I. BACKGROUND

A. How has the role of woody debris been viewed in the past?

In the past, woody debris (logs, branches, bark, standing dead trees, etc.) was viewed either as a wasted resource or an impediment to the management of forest resources. In streams, logs formed natural dams that impeded water travel by humans and anadromous fish. On the forest floor, woody debris was thought to contribute to disease and fuels that feed forest fires. Standing dead trees (snags) were seen as victims of disease or chance events like lightning strikes or wind storms - trees that "died before they could be harvested". Snags with dead limbs - "widow-makers" - were hazards to logging crews. Forests with an abundance of woody debris were considered "over-mature", suggesting that harvesting had been delayed too long. The removal of woody debris was seen as a priority in the proper management of forests and streams running through these forests. Until recently, the U.S. Forest Service spent hundreds of dollars per acre to remove logs from stands prior to replanting.

B. What do we know now about the role of woody debris in ecosystems?

Rotting logs and snags are a dominant feature in old growth forests of the Pacific Northwest. A 500-year stand may hold over 80 tons of logs per acre in various stages of decay. Recent research has dramatically changed our view of the role of dead trees in forested ecosystems. They form an important part of what is known as the "biological legacy" of the forested stand. As we will see in later labs, this legacy speeds up the recovery of a forest after a disturbance such as a fire or a harvest.

Woody debris is now known to serve the following ecological functions in forest ecosystems:

- Rotting logs serve as substrates for wood rotting fungi. These fungi are an important source of food for many wildlife species and they play an important role in nutrient cycling in forest soils.
- Rotting logs are an important substrate for tree seedlings and shrubs. By establishing on logs, these seedlings have a ready source of nutrients and water and gain a competitive advantage over plants on the forest floor in the competition for available sunlight. For this reason, these logs are sometimes referred to as "nurse logs".
- Woody debris holds soil in place and reduces erosion on slopes.
- Large logs retain moisture throughout the year and are important sources of moisture during drought conditions.
- Woody debris is an important habitat component for a number of wildlife species. Populations of some species of salamanders and small forest mammals, in particular, have been shown to be associated with the abundance of large woody debris on the forest floor.
- Decaying logs are important reservoirs of plant nutrients that are slowly released into the soil contributing to soil forming processes.
- The formation of pits and mounds due to wind throw of trees causes soil disturbance and an increase in plant and animal diversity in forests.
- In streams, large logs are important habitat components for aquatic organisms including anadromous fish (salmon and steelhead). They divert energy during high flows, reduce streambank erosion, create pools and serve to retain nutrients in streams.
- Standing dead trees (snags) are an important habitat component for cavity nesting birds, wood-boring insects and some forest mammals.

As a result of these new findings, there have been some changes in policies that include leaving woody debris (both logs and snags) in managed timber stands as well as in streams. Stream restoration efforts often even include the *addition* of woody debris to streams.

"No one had considered that, ecologically the logs might be doing a great deal. In retrospect, it's almost unbelievable that we could have been that stupid."

- Jerry Franklin, University of Washington College of Forest Resources

II. OVERVIEW OF THE STUDY

In today's lab we will contribute to a long-term study of woody debris decomposition that began in October 1997. Unlike most laboratories in *Environmental Science* where the results are known in a very short period of time (usually by the end of the lab period) the final results of this study may not be known for 10 or 20 years! We will examine logs that have been decomposing for different lengths of time and develop hypotheses that we will evaluate using information that has accumulated thus far in the study.

Decomposition rates might be expected to be influenced by a number of physical and biological characteristics of logs. Smaller logs, for example, since they have proportionally greater surface areas and smaller volumes, would be expected to decompose quicker than large logs. Species with high densities (mass per unit volume) would be expected to decay more slowly than those with low densities. Some species may be more resistant to decay due to chemical characteristics of the wood. Bark may be an effective barrier to entry by some insects and decomposing bacteria and fungi. Bark thickness and percent of a log covered by bark may, therefore, be important as well.

The logs you will examine today were prepared by previous students. A number of measurements were taken on new logs and each log was given a unique number and tag. Measurements were selected to be representative of the initial conditions of the logs. Once these measurements were taken, the logs were placed in a forested study area where decomposition has proceeded. Each year some logs have been retrieved from the study area and the measurements have been repeated and compared to the initial conditions. This will continue until the logs are completely decomposed. It is expected that as decomposition proceeds, values such as "mass" and "density" of the logs will decline, while evidence of insect and fungal activity will increase.

The importance of obtaining accurate information concerning the conditions of these logs cannot be overstated! The study is based on making comparisons between new and decomposed logs. Precise and accurate measurements are a must. Be sure that you are using the measuring instruments properly.

II. PROCEDURE

A. Original Collection of Logs

Log pieces of four tree species have been collected each fall beginning in 1997 from a location 3 miles NW of Dallas, Oregon. New logs were added to the study each year from 1997 to 2009 and each year since 1997 some logs have been pulled to examine in the laboratory. These partially decomposed logs are referred to as "1-year logs", "2-year logs", etc. depending on how long they have been decomposing on the forest floor.

In an effort to make all new logs as uniform as possible:

- Logs were taken only from bole (trunk) sections of live trees
- Only logs with a minimal number of lateral branches were selected
- Logs were selected to be approximately the same diameter - a target diameter of 8 cm was selected with log diameters of ± 25% (6 to 10 cm) allowed
- All logs were cut to approximately 37 cm in length.

B. Initial Measurements on New Logs

The following initial <u>measurements</u> were taken on each new log by students before it entered the study:

Diameter *Length* *Bark Thickness* *Percent Moisture*

From these measurements, the following values were <u>calculated</u> using simple algebra:

Total volume *Total surface area* *Bark surface area* *Density* *Dry weight*

The logs were also checked for the presence of fungal hyphae and any evidence of boring by insects.

The average values for all measurements taken on new logs can be found on the last page of this handout (see "*Initial Measurements of New Logs for Log Decomposition Study*").

C. Labeling Log Pieces

After initial measurements were taken on the new logs and recorded carefully on the data sheets, each piece was permanently labeled with an aluminum tag using a coded system. First, each log was given a four-letter code corresponding to its species name:

Douglas-fir (*Pseudotsuga menziesii*) = DOFI
Bigleaf maple (*Acer macrophyllum*) = BLMA
Black locust (*Robinea pseudoacacia*) = BLLO
Lodgepole pine (*Pinus contorta*) = LOPI

Then, unique numbers were assigned to each log. So, for example, a log with a tag that is "*DOFI-173*" indicates "Douglas-fir log number 173"

The ends of each log were sealed with paraffin before being placed at the study site.

D. Measurements on Decomposed Logs

Your lab group will be responsible for the measurement of one of several decomposed logs that have been extracted for today's lab. These logs have been lying in a 40-year old Douglas-fir plantation located 3 miles NW of Dallas at an elevation of about 830 feet above sea level. The logs are arranged in groups of eight logs each - 2 logs of each species (Lodgepole pine, Black locust, Douglas-fir and Bigleaf maple). All logs were placed in the horizontal position. **Odd numbered** logs were buried in the topsoil to a depth equal to the diameter of the log. The duff (litter) layer was then replaced over the log. **Even numbered** logs were laid directly on the duff. Log groups were separated from each other by one meter spacing.

These logs will be discarded after today's lab, so they can be carefully dissected, much like a post-mortem necropsy. Wet weights were obtained from these logs when they were removed from the study site two weeks ago. They were then placed in a drying oven at 55^0 C and have been drying for 14 days.

You will be given a data sheet entitled *Log Decomposition Data Sheet- Old Logs* for your decomposed log. The <u>initial</u> measurements for your log have been entered on the data sheet. Carefully measure or calculate the following parameters for your log. Record these measurements in the "pulled" row on the *Log Decomposition Data Sheet - Old Logs* and then fill in the "Change" row by subtracting the "initial" values from the "pulled" values. (NOTE: All measurements are metric.)

Dry Weight (g)	Dry weight of each piece measured in its entirety to nearest 0.1 g after oven drying at 55° C for 14 days
Moisture content (%)	**[(Wet weight - Dry weight)/Wet weight] x 100** Record to nearest 0.1%
Diameter	The average diameter of the log measured with digital calipers to nearest 0.1 mm. If your log is no longer intact (i.e., no longer cylindrical in shape or fragmented into many pieces) enter "NA" (= "not available")
Length	The average length of the log measured with a metric tape to the nearest 0.5 mm. If your log is no longer intact (i.e., no longer cylindrical in shape or fragmented into many pieces) enter "NA" (= "not available")
Volume	Calculate the volume of what is left of your log. Rather than have you calculate the volume by hand, I have created an *EXCEL* spreadsheet that performs this calculation for you. If your log is still intact, simply enter your <u>measured</u> values for "diameter" and "length" in the proper location on the spreadsheet and the volume will be <u>calculated</u> automatically. If your log is no longer intact (i.e., no longer cylindrical in shape or fragmented into many pieces). The volume can be estimated by water displacement using a graduate cylinder. This will be demonstrated in lab.
Percent volume bark, sapwood and heartwood	Visually estimate the percent volume for each of these tissue types for your decomposed log. These 3 values should <u>always</u> add up to 100%.
Density (g/cm^3)	Dry weight of the log divided by its volume

Evidence of boring by insects	Carefully examine outer bark, sapwood and heartwood for evidence of boring by insects. If openings or galleries are present, estimate the <u>number</u> of each for each tissue type (i.e. how many penetrate bark? sapwood? heartwood?) If insects are found, note their location and collect specimens If galleries are seen, sketch on data sheet
Presence of fungal hyphae	Carefully examine outer bark, sapwood and heartwood for fine white strands of fungal hyphae. If present, estimate percent of area occupied by fungal hyphae for each tissue type If absent, enter "0"
Notes	Record any other pertinent observations on data sheet. Examples might include: ▪ amount (%) of original bark remaining ▪ descriptions of insect activity ▪ evidence of discoloration or cracks in the log ▪ general condition of bark, sapwood and heartwood (sound, crumbling, absent, etc.)

Once you have entered all of your data onto the data sheet, fill in the "Change" row by subtracting the initial values form the pulled values. Be sure to indicate whether the resulting value is positive (indicating a gain) or negative (indicating a loss).

SUBMIT YOUR COMPLETED LOG DECOMPOSITION DATA SHEET(S) TO THE INSTRUCTOR
BEFORE YOU LEAVE LAB TODAY

E. Development of Hypotheses

A number of questions concerning the decomposition of woody debris can be answered using the approach we have selected. For example, each of the following questions could be explored:

How does the presence of bark influence the decomposition process?

How does the local environment (forest vs. open area) influence the decomposition process?

What insect and fungal species contribute to the decomposition process of these species and what are their roles?

We will, however, narrow our attention to the following:

1. Of the tree species under study, which species will decompose most rapidly? Least rapidly? In what order will these species decompose?

2. Is decomposition of these species a constant, linear process or a non-linear process? In other words, if a 1000 g log is completely decomposed in 10 years, does it lose 100 g per year (linear) or is there some other pattern?

3. How does position in the substrate (on substrate surface vs. buried in substrate) influence the decomposition process?

After we have completed the measurements on the decomposed logs, you will develop hypotheses that provide plausible answers to each of these questions. Your hypotheses should be based on:

- Initial measurements on new logs will provide some information on the physical characteristics of the different species (See, "*Data Summary - Initial Measurements on New Logs*" table).
- Comparisons between initial values and values after several years of decomposition should also be useful

You will be given a worksheet to document your hypotheses and to provide supporting evidence and rationale.

Initial Measurements of New Logs for Log Decomposition Study

The following pages contain student-collected data for the initial condition of each of the logs used for the current study. Measurements and calculations for each parameter are described in the procedure for the lab. Measurements were taken from 1997 to 2009.

Sample Code	Each log was assigned a unique code designation. This code was comprised of four-letter code designating the species and a number representing the log number for that species. Species codes were as follows: DOFI - Douglas fir BLMA - Bigleaf maple BLLO - Black locust LOPI - Lodgepole pine
Ave. Dia.	The average of diameters taken at three locations along the log (each end and middle of log) with digital calipers to nearest 0.1 mm. In logs that were not round in cross-section, multiple measurements were taken at each location and these were averaged.
Length	Log Length measured with a metric tape to the nearest 0.5 mm
Volume	Total Volume of log in cm^3 . Calculation assumes each log approximates a cylinder with a radius equal to 1/2 the average diameter and a height equal to the log length. Volumes of three tissue types (heartwood, sapwood and bark) were estimated and recorded as % of total volume.
TSA	Total Surface Area of log in cm^2. Calculated using diameter and length above.
BSA	Bark Surface Area in cm^2. Area of log covered with bark. If bark is intact on entire log, then BSA = TSA - area of ends. If some bark is removed on log, that area is measured with a metric tape and subtracted as well.
Density	Density of log in g/cm^3 and equal to dry weight of log divided by total volume.
Wet Weight	Wet weight of log measured directly on electronic balance to nearest 0.1 g
Dry Weight	Dry weight of log to nearest 0.1 g estimated by a sampling procedure
% Moisture	Initial percent moisture in log estimated by a sampling procedure
Bark Thickness	Average of four measurements taken with digital calipers and recorded to nearest 0.1 mm

Data Summary - Initial Measurements on New Logs
(average values for all new logs measured from 1997-2009)

	Douglas Fir	Bigleaf Maple	Black Locust	Lodgepole Pine
N	177	171	162	157
Ave. Diameter (mm)	77.7	75.3	72.9	78.2
Ave. Length (mm)	370.3	370.3	370.1	370.2
Volume (cm^3)	1794.6	1687.7	1578.6	1833.1
Total Surface Area (cm^2)	1000.7	966.6	932.6	1008.1
Bark Surface Area (cm^2)	903.7	875.4	847.3	909.1
Density (g/cm^3)	0.43	0.51	0.60	0.45
Wet Weight (g)	1241.7	1288.4	1366.8	1555.0
Dry Weight (g)	771.8	856.7	948.8	822.4
% Moisture	37.8	33.3	30.6	45.4
% Heartwood	0.2	0.6	29.0	0.4
% Sapwood	89.2	88.7	53.8	89.8
% Bark	10.6	10.6	17.2	9.7
Bark Thickness (mm)	2.09	2.05	3.33	1.92

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Bi 132 Environmental Science
Chemeketa Community College
W.W. Cudmore

Dendrochronology Laboratory

INTRODUCTION

You are probably aware that the annual rings of trees in temperate and boreal forests can be used to determine the age of a tree. Since growth rates change dramatically with season each annual ring is representative of a single year's growth and is followed by a period of relative inactivity. Each annual ring is composed of two, easily distinguished bands: **spring wood** is laid down early in the growing season and tends to be lighter and more porous than **summer wood** which is laid down later in the growing season and tends to be darker and more dense. The scientific study of the annual rings of trees is called **dendrochronology.**

Foresters routinely determine the approximate age of a stand by obtaining core samples from a representative sample of trees. An instrument called an **increment borer** is twisted into the bark of the tree and inserted to about half the diameter of the tree. A 1/8 inch core is removed and prepared for examination of the annual rings. Bristlecone pines in Arizona as old as 8255 years have been aged using this method!

In addition to aging, detailed study of annual rings can provide us with a wealth of information concerning the physical and biological conditions present during the lifetime of the tree. Catastrophic events such as fires, volcanic eruptions, hurricanes, earthquakes, glacial advances, lightning strikes, floods, insect infestations, injury and disease may all be recorded in the annual rings of a tree. For example, if a tree is tipped over by a storm but continues to grow, changes in the orientation of annual rings may occur.

Past climatic conditions can often be reconstructed from patterns in the growth of annual rings. Temperature and rainfall conditions that are optimum for the growth of that species result in particularly wide annual rings while years of poor growing conditions result in narrow annual rings. Competition from other trees may also result in narrow growth rings and various management treatments such as thinning, herbicide spraying or fertilizing would be expected to result in a corresponding change in the width of annual growth rings.

Dendrochronology can also be used to assess historic levels of some pollutants. Trace levels of lead and mercury, for example, can be measured in annual rings and thus provide a chronological record of the degree to which industrial pollution contributes to the natural level of these substances.

In today's lab you will be analyzing patterns of annual growth in a common western Oregon tree - Western Hemlock (*Tsuga heterophylla*). Climatic data will be provided and you will test the hypothesis that there is a correlation between annual growth, average annual temperature and annual precipitation.

BACKGROUND

Each group of students will be given a cross section from a Western Hemlock that was harvested on Bureau of Land Management (BLM) land in January 1996. Stand information was obtained from Salem District BLM records:

Site Location:

BLM Unit #170 Polk County, Oregon Township 7S Range 7W Section 4

Site Description:

This is a 25-acre unit dominated by large Douglas fir trees 21+ inches DBH (diameter at breast height). BLM categorizes stands of this age as "old growth". The stand has been judged by BLM as suitable for spotted owl nesting, roosting and foraging. It is considered to be "well-stocked", meaning that the density of trees on the site is considered adequate (70-100% of normal basal area or volume). The birth date for the stand is the year 1800 as determined by coring and aging a sample of dominant trees - 7 years were added to the ring count to account for time required to reach 4 1/2 feet. The assumption is that a stand replacement fire occurred at approximately this time. The stand condition is considered "GOOD" meaning that the stand is not decadent, with very few dead and dying overstory trees. Slopes in this area range from 35-59%. The site index is 120 (a 100-year old tree would be expected to grow 120 feet). No disease or insect damage has been documented for this site.

The stand is being managed as an "Adaptive Management Reserve" and silvicultural treatments are not needed at present. Regeneration since 1800 has been entirely natural on this site and there has been no treatment (thinning, planting, etc.) of any kind.

BIOLOGICAL CHARACTERISTICS OF WESTERN HEMLOCK

Forests of western Oregon and Washington are dominated by Western Hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*) and Western Redcedar (*Thuja plicata*). These species are adapted to moist, temperate conditions of the region. Summers are dry with only 6-9% of total precipitation falling during those months. Mean annual temperatures range from 46 to 48 °F and neither January nor July temperatures are extreme. The environment is mild and quite favorable for forest development. Unlike drier western forests such as those dominated by Ponderosa Pine, Garry Oak or Western Juniper, the forests of the Western Hemlock zone tend not to be responsive to small changes in soil moisture. In fact, neither moisture nor temperature are severely limiting for these species.

Western Hemlock is the climax species of the Western Hemlock Zone and is commonly found in association with Douglas-fir and Western Redcedar. It is very shade tolerant and reaches a maximum age of at least 400 years. It does not tolerate long periods of frozen soil in the root zone.

The following climatic data were taken from seven representative sites within the Western Hemlock Zone (Franklin and Dyrness, 1973). Use them to help define optimum growing conditions for the species and to interpret trends seen in your graphs. Ranges are given in parentheses.

Ave. Annual Temperature (°F)	48.8	(45.3-50.7)
Ave. January Temperature (°F)	33.9	(29.8-37.2)
Average January Minimum Temp (°F)	27.5	(25.3-31.6)
Average July Temperature (°F)	63.3	(60.4-66.0)
Average July Maximum Temp (°F)	79.4	(72.7-84.9)

Average Annual Precipitation (Inches)	81.2	(57.2-126.2)
Average June-August Precipitation (Inches)	5.0	(4.2-6.1)

PROCEDURE

Perform the following procedures for your cross section:

1. Estimate the age of the tree by counting the annual rings. Assume that the section was taken at "breast height" (4 1/2 feet above ground). Each annual ring is composed of two, easily distinguished bands: **spring wood** is laid down early in the growing season and tends to be lighter and more porous than **summer wood** which is laid down later in the growing season and tends to be darker and more dense. Be sure to add 7 years to account for the number of years required to reach 4 1/2 feet. (NOTE: This number is specific for western hemlock. Eight years would be added for Douglas-fir.)

2. Select a representative radius from the center to the perimeter of the cross section and carefully measure the <u>width</u> of each annual ring (spring wood and summer wood combined) beginning with the ring laid down in the Spring and Summer of 1995. Use vernier or digital calipers to measure annual ring width (**to the nearest 0.1 mm**) for each year and record on the attached data sheet. You may find it useful to mark every 10th year or so with a pin to keep track of your measurements.

3. Historical climatological data for this site were obtained from Oregon State University's Climatological Service Web Site. You will be given a copy of these data on a flash drive and asked to analyze them in the next section.

ANALYSIS

Using your observations and the background information above, answer the following questions for your cross section.

1. Measure the length (in mm) of 5 radii from the center of your cross section to inside the bark. Are the annual rings perfect circles? If not, what factor(s) may contribute to the irregularity?

2. How old is the tree? What factors could add error to this estimate?

3. What accounts for the fact that the age of this tree is less than the age of the stand? (See background information above)

4. Western hemlock is a shade-tolerant tree while Douglas-fir is less shade-tolerant. Would you expect a dominant Douglas-fir taken from this stand to be older or younger than this tree? Explain your answer.

5. Plot "Annual Rainfall" and "Annual Growth" against "Time" on the same graph. Enter your data into a spreadsheet program (*EXCEL*) and use that program to generate your graph.

   NOTE: Be sure the earliest dates appear on the left end of the X-axis.

6. On a second graph, plot "Average Annual Temperature" and "Annual Growth" against "Time", as above.

7. Using only the "annual growth" portion of your graphs as a source of information, write a brief narrative that describes the growth history of this tree. What explanations can you offer for the trends you have described? Consider the background information on this stand and the biological characteristics of western hemlock (given previously) in your answer.

8. How would the growth history of this tree be different if it grew for the first 40 years in a stand at very high density and then the stand was thinned? How would this be reflected in the annual rings?

9. Carefully examine the graphs you have generated. Use EXCEL to calculate the **correlation coefficients** for "Temperature" and "Annual Growth" vs. "Time" and "Precipitation" and "Annual Growth" vs. "Time". Does there appear to be any correlation between these climatic data and annual growth? If so, explain the relationship. If not, explain why there may not be a relationship between climatic data and annual growth in these samples. Consider the biological characteristics of western hemlock (given previously) in your answer.

10. What is the "Average Annual Growth" of this tree measured as increase in diameter? Describe how you calculated this value and give your answer in millimeters.

11. Western hemlock and Douglas-fir are adapted to the cool moist forests of the Pacific Northwest. If climatic conditions change to drier, warmer conditions as might be expected in a greenhouse scenario, growth patterns could change from what you have seen here. What changes would you expect in reproductive success? in growth rates of mature trees? Of these two species, which would you expect to be more affected by the "greenhouse effect"? Why?

12. Western hemlock now occupies elevations from approximately 500 to 3300 feet in the Oregon Cascades (see range map) How would you expect this to change in a greenhouse scenario that results in an increase in global average temperature of 4 - 7 °F by the year 2050?

13. Indicate by coloring **in red** on the attached range map the approximate range for Western hemlock under the greenhouse scenario described above.

14. Annual rings do not form in trees from tropical rainforests. Why not?

Western Hemlock Cross Section

Year	Annual Growth (in mm)	Year	Annual Growth (in mm)	Year	Annual Growth (in mm)	Year	Annual Growth (in mm)	Year	Annual Growth (in mm)
1995									